JOURNAL OF SCIENCE
SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University | http://www.saujs.sakarya.edu.tr/

Title: CoAP and Its Performance Evaluation

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Recieved: 2019-08-30 00:24:50

Accepted: 2019-10-13 10:56:10

Article Type: Research Article
Volume: 24
Issue: 1
Month: February
Year: 2020
Pages: 78-85

How to cite
Ünal Çavuşoğlu, Mehmet Ali Ebleme, Cüneyt Bayılmış, Kerem Küçük; (2020), CoAP and Its Performance Evaluation . Sakarya University Journal of Science, 24(1), 78-85, DOI: 10.16984/saufenbilder.613202
Access link
http://www.saujs.sakarya.edu.tr/tr/issue/49430//613202

Sakarya University Journal of Science 24(1), 78-85, 2020

CoAP and Its Performance Evaluation

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Abstract

Constrained Application Protocol (CoAP) is one of the lightest IoT connectivity protocol. It has been developed for IoT devices that has constrained resources such as memory, processing power, battery etc. CoAP protocol is built on REST architecture. It provides connecting internet of IoT devices with UDP protocol. CoAP is a Client-Server request/response messaging protocol. CoAP provides two modes of operations: (i) non-confirmable, (ii) confirmable. In addition, it provides four methods to communicate for different application requirements. And it has two ways to response a request. This paper deals with CoAP IoT messaging protocol and presents its performance evaluation. In addition, performance evaluation of CoAP has been realized according to delay, throughput and energy consumption parameters.

Keywords: CoAP, performance evaluation, energy consumption, throughput, time delay

1. INTRODUCTION

Recently, the use of the Internet of Things (IoT) has increased rapidly due to developments in communication technologies and the increase in the number of devices connected to the Internet. An IoT device has detection, communication, addressing, networking and data processing capabilities. IoT objects communicate with each other using different messaging protocols. There are many communication and messaging protocols such as CoAP, MQTT, DDS, AMQP in the literature developed for IoT based applications. Many of these IoT protocols, IoT devices cosider limited features such as memory, battery, processing capacity, low bandwidth connections [1-2].Constrained Application Protocol (CoAP) is a web transfer protocol based on Representational State Transfer (REST), which uses http functions including GET, PUT, POST, and DELETE methods. Unlike REST, CoAP uses UDP as the communication layer. It is a lightweight messaging protocol due to the use of UDP. CoAP supports the client/server model that uses request /response communication. CoAP provides two modes of operation: non-confirmable and confirmable [3-5].

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There are many studies using CoAP protocol in the literature. Castellani et al. Proposed a web service for the safe and efficient communication of devices with limited resources using the CoAP protocol and the EXI library [6]. Kovatsch et al. proposed a CoAP protocol design with low power consumption for high energy efficiency operating on the Contiki operating system [7]. Colitti et al. performed performance evaluation of CoAP and HTTP protocols on different protocols in wireless sensor networks and it was shown that CoAP protocol has less energy consumption and shorter response time than HTTP [8]. Castellani et al. have implemented a new module design using HTTP and CoAP protocol [9]. Larmo et al. realized a comparison of CoAP and MQTT protocols in a Narrow Band (NB-IoT) network using cellular connectivity and examined the effect of different communication layers on NB-IoT performance [10]. Khattak et al. presented a research paper summarizing and evaluating medical studies using the CoAP protocol on wireless sensor networks. The comparison of CoAP and SNMP protocols is also given in the study [11]. Kovatsch et al. proposed a scalable cloud service using the CoAP protocol called Californium, for use on IoT devices. The proposed 3-tier protocol architecture has been shown to be highly efficient than the normal CoAP protocol and web-based services [12].

In this study, working principle of CoAP messaging protocol, message format structure, operating modes and return types are explained in detail. In addition, performance evaluation based on parameters such as message delay time, throughput rate and energy consumption is presented in the IoT application realized using CoAP protocol. The CoAP protocol is explained in the Section 2, the performance evaluation is given in the Section 3 and in the last part the results are examined.

2. Constrained Application Protocol (CoAP)

CoAP (Constrained Application Protocol) is an application layer protocol designed by IETF (Internet Engineering Task Force). CoAP works on UDP to keep design simple, with a primary goal of working on devices with limited resources and on networks with limited bandwidth. CoAP provides an interactive request / response model between application terminals; has built-in support for the discovery of services and resources; Uses key web concepts such as URL.

2.1. The Working Principle of CoAP

The CoAP is a client-server request / response messaging protocol. CoAP communication consists of two main components: client and server. The client is the source of the generated data and its purpose is to send the generated data to the server. The client sends this data to the server using Get, Post, Put or Delete CoAP methods, which are similar to REST methods. And the server sends an appropriate response to the client if the messaging type is feedback [1-2].

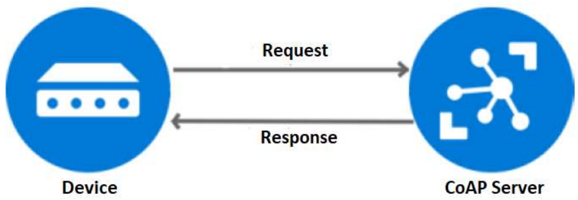

Figure 1. The basic architecture of CoAP

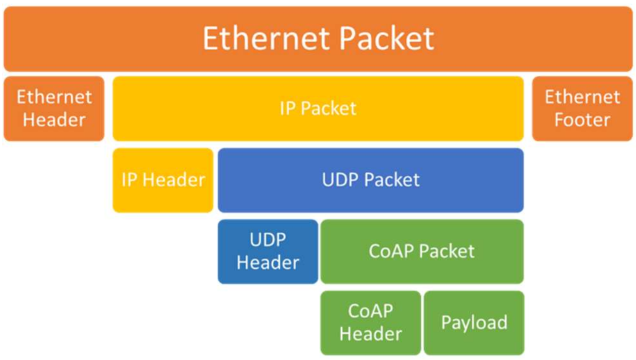

Figure 2. The packaging hierarchy of a CoAP message

The CoAP protocol is built on the UDP protocol to enable IoT devices to connect to the cloud (Internet). In CoAP communication, data is sent as datagrams over the UDP protocol. UDP packet headers are added to the message to be sent (load) and the message becomes UDP packet. Then the message is sent to the receiver by adding IP and Ethernet headers respectively. A message sent by CoAP is sent to the receiving computer as the last Ethernet Packet through the layers shown in

Figure 2. The following operations are under the control of the operating system.

2.2. The Message Format of CoAP

Figure 3 shows the CoAP package format. The first part is the header part that is fixed for each message. The following parts are optional. The Token field is used to associate requests and responses and can be from 0 to 8 bits. The Version field indicates the currently used version of CoAP. The 2-bit T (Type) field indicates the type of message. These can be confirmable (0), non-confirmable (1), acknowledgement (2) or reset (3) types. The TKL field is a 4-bit token length. The Code field is a field that expresses the result code of 8-bit response messages. This field is designed for easy expression of HTTP response codes. In the implementation part, it is used to express the class of the 3-bit response and the detail of the 5-bit response. (for example: 2.02) The 16-bit Message ID field is used in the duplication control and in matching responses.

Figure 3. The structure of CoAP message.

2.3. CoAP Operating Modes

The CoAP protocol has two basic transmission modes. These are non-confirmable and confirmable messaging modes. In non-confirmable mode, one-way and acknowledgment is transmitted without waiting. Therefore, successful transmission is not guaranteed in this mode. In Confirmable mode, it is assumed that the message is transmitted at least once when confirmation is received [3].

- Non-Confirmable Operating Modes

Non-confirmable data transmission follows a stream as in Figure 4.a. It can realize between server-client or client-server. The message is sent once and the transmission is not monitored to be successful.

- Confirmable Operating Modes

Confirmable data transmission is shown in figure 4.b. Firstly the message is sent, if no response is received within a predetermined timeout, it is considered not transmitted and resent. When an Ack (acknowledgement) packet with the same message ID arrives, it is verified that the message has been transmitted.

2.4. The Response Types (Synchronous-Asynchronous)

CoAP can respond to incoming requests in several ways. The synchronous-asynchronous transmission mechanisms have been described by CoAP as piggybacked and separate response [4]. In most cases, the response is carried directly within the acknowledgement message (the request message type must be confirmable). This is called Piggybacked Response. A piggybacked response is a response carried directly in the acknowledgment message [4]. The separate response consists of two CoAP messages. The first is an ACK message that is sent to prevent the client from deciding that the message has not been transmitted and sending it repeatedly. The second is a Confirmable (CON) message containing the response to the client [4]. Figure 5 shows responses to an optional piggybacked (a) and separate response (b).

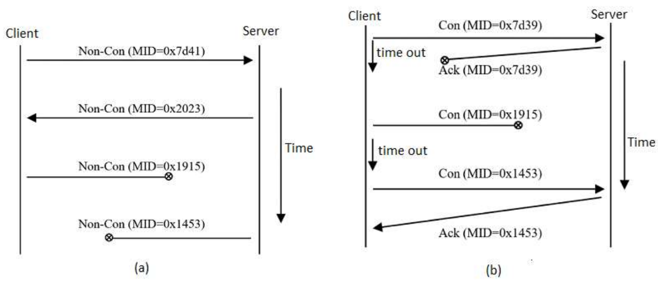

Figure 4. a. Non-Confirmable Operating Modes
b. Confirmable Operating Modes

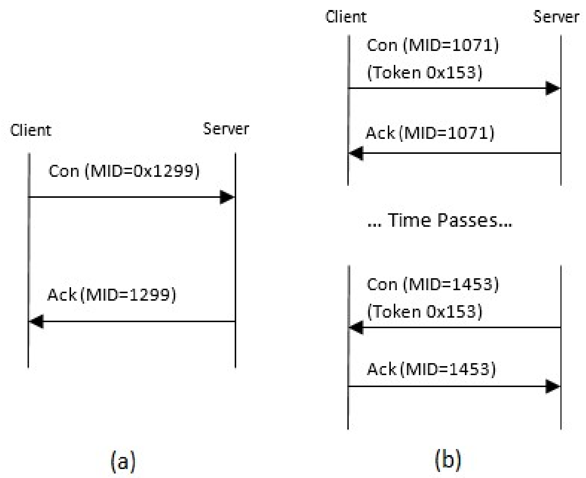

Figure 5.a. Piggybacked Response b. Seperate Response

3. THE COAP PERFROMANCE EVALUATION

In this study, a test platform consisting of server and client is established for performance evaluation of CoAP protocol. Figure 6 shows the test platform. In the test platform, the Wemos D1 device with 80/160 MHz operating frequency, 4 Mbyte memory and ESP8266EX WiFi module is used as IoT device. As for the server, i7 processor, 2.4 GHz processor speed, 8 GB. memory and a Windows 10 operating system installed. Table 1 presents the features of the test platform.

Performance evaluation was carried out on different parameters such as message delay time, throughput rate and energy consumption. To prevent connection problems and message repetition, the delay time is set as 10 msec. GET, POST and PUT methods are used in CoAP protocol. To test the GET method, the client sends a CON packet that is not installed and receives an installed ACK message from the server in response. For testing of the POST and PUT method, only the client sends a loaded CON packet.

Figure 6. The test platform for CoAP performance evaluation

Table 1. The Perforamance Metrics

Metrics	Expalanation
The number of message	10000
The waiting time between messages	10 ms.
The size of message	8, 16, 32, 64, 128, 256, 512, 1024 byte
IoT Device	WeMOS D1
Server	I7, 2.4 GHz, 8 GB. Ram
Network analysis program	Wireshark
The energy measuring dev.	UNI-T UT658 USB

3.1. The Time Delay Values of CoAP

Figure 7 shows the message delay evaluation results of different message sizes according to different methods of CoAP. The message delay value indicates the time between each successful message transmission. As the message size increases the delay time increases in CoAP. This is due to the fact that although the GET method sends a non-loaded CON packet, in response it receives a steadily increasing ACK packet from the server and the workload on the limited client device is low.

3.2. The throughput values of CoAP

Figure 8 shows the throughput values of the CoAP according to different methods. The performed tests compare the average byte sizes transmitted per second in the CoAP according to the message load size. As the message size increases in CoAP protocol, it is seen that the throughput rate increases. As shown in Figure 8, similar results are obtained in all the different methods studied. Because CoAP wraps the load into frame sizes with very low dimensions, the throughput rate increases in direct proportion to the load.

3.3. The energy consumption values of CoAP

UNI-T UT 658 USB tester is used for measuring energy consumption values. As a result of the measurement made with this device, the values of energy consumed during the transmission is calculated as milliamps. The total electrical charge (C) is calculated in Equation 1.

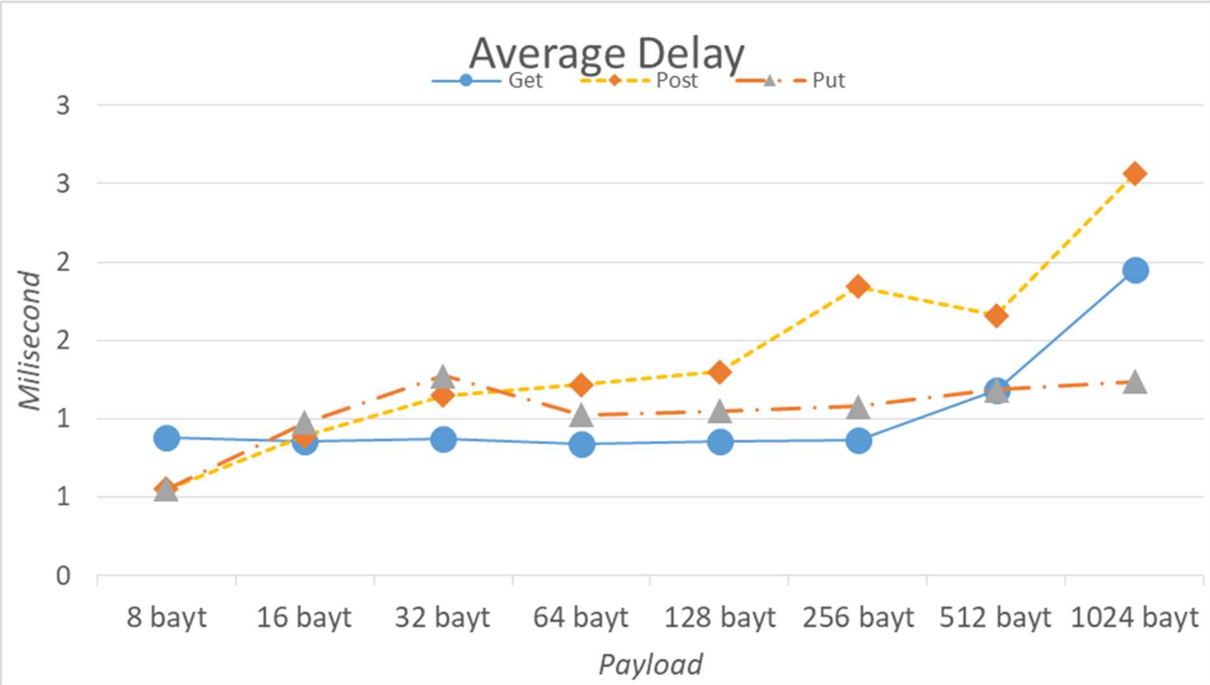

Figure 7. The Message delay values of CoAP in different methods

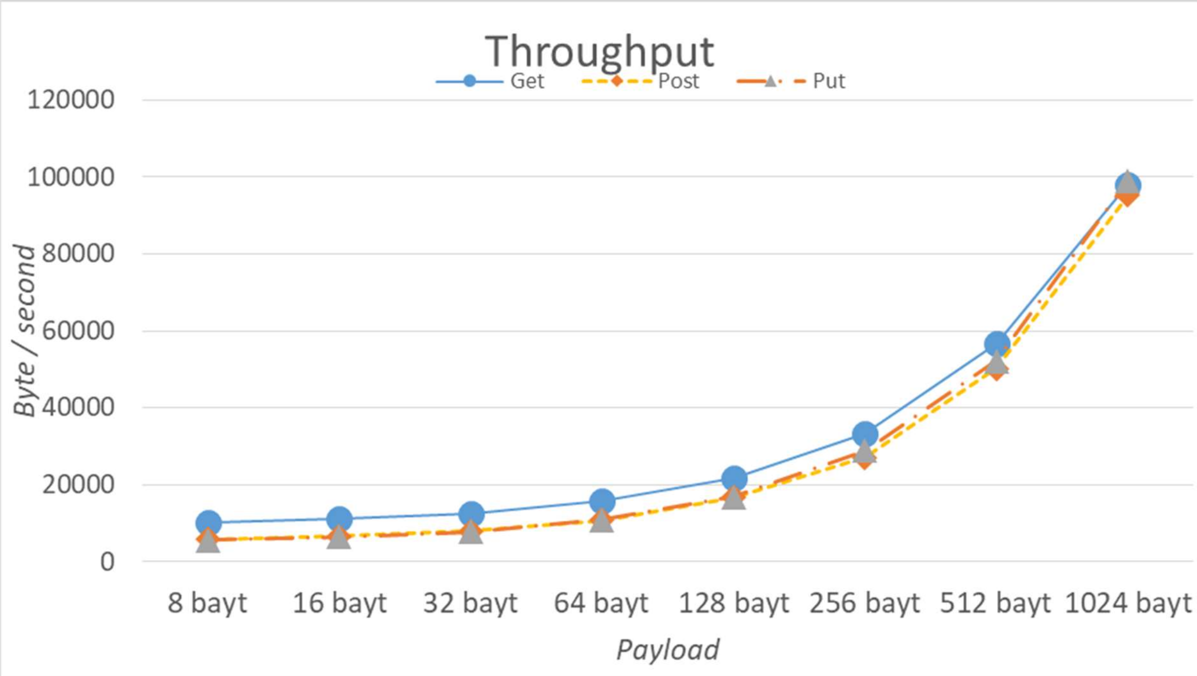

Figure 8. The throughput values of CoAP in different methods

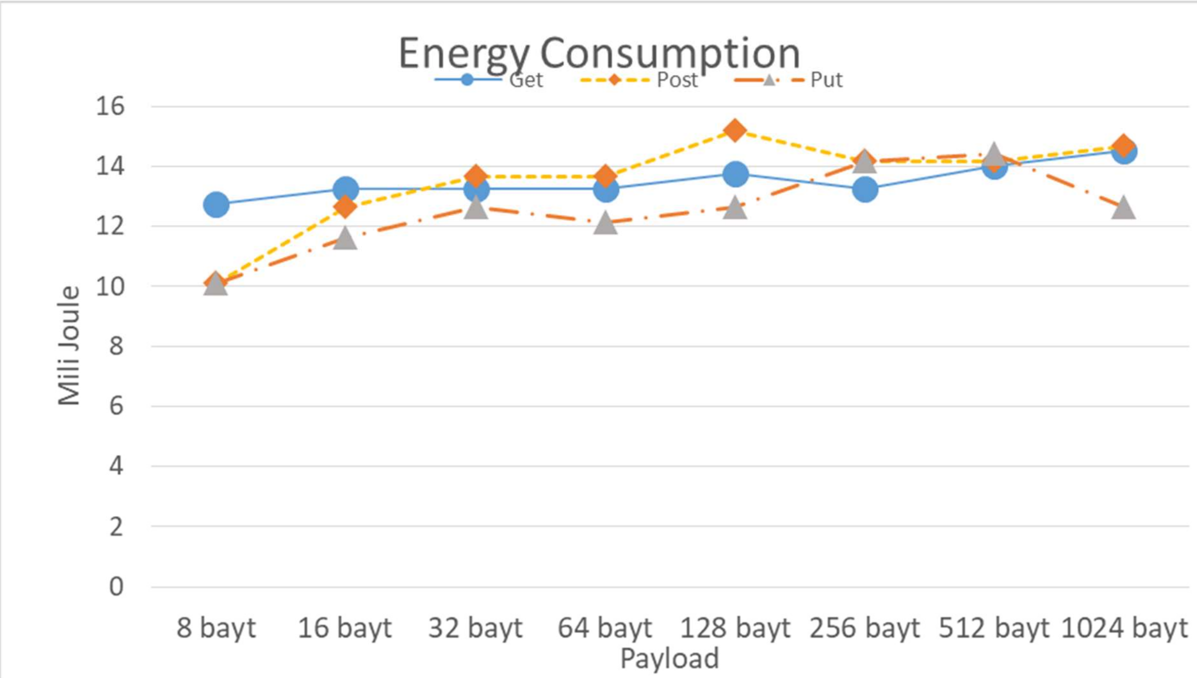

Figure. 9. The energy consumption values of different methods of CoAP

In this equation, Current (A) is multiplied by time. Since the energy meter counts the amount of current drawn by the IoT device at varying intervals, it delivers the total electrical charge (C) directly. In Equation 2, the energy consumption of the Joule type is calculated by multiplying the charge and voltage. In Equation 3, since the energy consumption data shows very low values, we converted from Joule type to milli-Joule type [13].

$$\text{Charge(C)=Current(A)xTime(seconds)} \quad (1)$$

$$\text{Energy(J)=Charge(C)xVoltage(V)} \quad (2)$$

$$\text{Energy(mJ) = En(C (mAh)) X Voltage (V)} \quad (3)$$

Figure 9 shows the energy consumption values of the IoT application using the CoAP. In the Figure 9, energy consumption values of different message size values of CoAP are given for GET, POST and PUT methods. As shown in the figüre, the CoAP has different energy consumption values for different methods and message sizes. It can be said that this difference is caused by message repetitions, network usage and efficiency of used IoT device. For all methods, it is seen that when the message size increases in general, energy consumption increases.

4. CONCLUSION

In this study, CoAP protocol which is one of the most widely used IoT messaging protocols has been experimentally tested and the results are presented. In addition to this the method performance evaluation of the CoAP protocol is performed. In these evaluations, message delay time, throughput rate and energy consumption values which are generally the most desirable features in IoT applications, are compared according to different method types and load sizes. As a result, the CoAP protocol is a highly suitable IoT communication protocol for use in restricted devices with low frame sizes and efficient throughput rates. It is thought that the obtained results will provide the IoT application developers with an idea about the communication protocol they prefer.

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