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Design of a High Performance IoT QoS Transmission Mechanism and Middleware

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Abstract - *The rapid development of Internet of Things (IoT) services requires a huge number and variety of sensor devices. However, the power consumption of sensor devices, which adopt different transmission protocols to communicate with each other and the data servers, is a critical issue when deploying sensors in heterogeneous environments. A stable and efficient IoT application service, e.g., environmental surveillance in fields, urgently requires a flexible IoT middleware platform with efficient power consumption control. This study proposes an Efficient Power-Consumption (EPC) IoT middleware based on the open oneM2M communication standard. The proposed EPC IoT middleware provides the Dynamic Power Adaptation (DPA) mechanism, which is based on the quality of information, battery power level, conflict factor, and variation coefficient to dynamically adjust the power consumption and sleep intervals of sensor devices. The performance evaluation model of the DPA mechanism is proposed to achieve efficient power consumption while maintaining the trade-off between the quality of information and the battery life cycle of sensors. The Dynamic Duplication Avoidance Transmission Control (D2ATC) mechanism, which is based on the built-in sensor frequency table combined with the ETag of sensors, is proposed to solve the problem of repeated service requests, and to decrease the network transmission cost. Performance evaluation results reveal that the proposed DPA mechanism and D2ATC mechanism could provide good performance efficiency.*

Key Words: **Internet of Things (IoT), Middleware, Dynamic power adaptation control, Dynamic duplication avoidance transmission control, OneM2M standard.**

1. INTRODUCTION

As the rapid progress of Internet of Things (IoT) technology, the manufacturers develop unique IoT sensing devices for various application services [1]. Therefore, it results in a wide range technology specification of sensing devices and services. The different sensing devices usually adopt different communication protocols. The commercial companies design and implement the IoT communication servers and the application services also uses different communication specification, which lacks of the unified standards. Many international organizations develop IoT communication specifications and middleware for the markets [2-3]. OneM2M standard is one of the popular IoT communication specifications [4-5]. OneM2M specification provides a common service platform to support mobile applications, which are conveniently developed by embedding the various industries APIs [6].

Furthermore, it is also a critical problem for power consumption of IoT sensing devices [7-8]. Most of the sensing devices rely on the batteries for power supply. It often results in the quick power consumption due to the massive transmission of sensing data and IoT messages. It is inconvenient for users to often recharge the batteries to maintain the IoT application services. M. Taneja proposed a service architecture based on oneM2M specification, which was composed of IoT end devices, gateway, and data server, to achieve a power saving communication [9]. The basic principle of the proposed power saving control was to adapt the sleep interval of the sensor devices according to the characteristics of sensors and applications. Emergent situation needs more communication messages than the normal situation needs. N. Kuar proposed a power evaluation model based on the quality of information, overlapping conflict factor, battery level, and coefficients of variation sensors to adapt the sleep interval to achieve an efficient power consumption for the end sensor devices [10].

This study proposes an Efficient Power-Consumption (EPC) IoT middleware, which adopts the oneM2M standard to transfer the messages packages. The users subscribe in the EPC middleware, which provides the standard data and message format. The networking servers actively push information to the users. When users utilize the mobile appliances, the users could access the environment data and service message via the heterogeneous sensing devices. Since there are a large number of IoT connections and data transmission, this paper proposes the Dynamic Duplication Avoidance Transmission Control Mechanism (D^2ATC), which could efficient reduce the volume of sensing data and the computing burden of servers. The EPC middleware provides the Dynamic Power Adaptation (DPA) mechanism, which is based on the quality of information, battery power level, conflict factor, and variation coefficient to dynamically adjust the power consumption and sleep intervals of sensor devices. DPA mechanism could achieve the efficient power consumption of sensing devices.

The remainder of this paper is organized as follows. Section 2 presents the system architecture of the proposed EPC middleware. Section 3 describes the performance evaluation of the proposed control mechanism. Finally, Section 4 concludes this study.

2. SYSTEM ARCHITECTURE

Figure (1) depicts the system architecture the proposed Efficient Power-Consumption (EPC) IoT middleware. According to the oneM2M communication standard, the sensing devices are the application service nodes (ASNs), which are deployed in the experimental area to collect the environmental data, including the temperature, humidity, luminosity, images, and videos. IoT gateway is a mediate node (MN) and is responsible for the sensing data collection, filtering, and conversion. IoT server is an infrastructure node (IN), which stores the sensing data and provides the communication, computation and analysis for the end users.

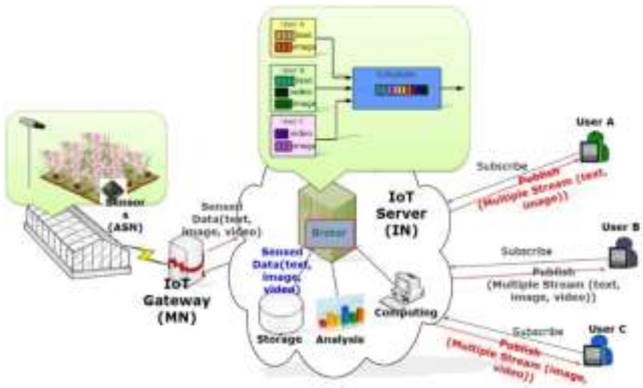

Fig – 1: The system architecture of the Efficient Power-Consumption (EPC) IoT middleware.

2.1 Dynamic Duplication Avoidance Transmission Control Mechanism (D²ATC)

The main purpose of D²ATC is responsible for reducing the transmission traffic by avoiding unnecessary and duplicated transmission of information packets. Figure (2) and Figure (3) depict the proposed two data transmission schemes, which are the Active scheme and the Passive scheme, respectively.

For the Active scheme, as depicting in Figure (2), the IoT server actively deliveries the sensing data to the end users. Whenever the IoT server receives the sensing data transmitted form the sensor, IoT server compares the received data with the previous data stored in the database. Then, the IoT server actively transfers the different part of the received data to the end users to reduce the transmission traffic.

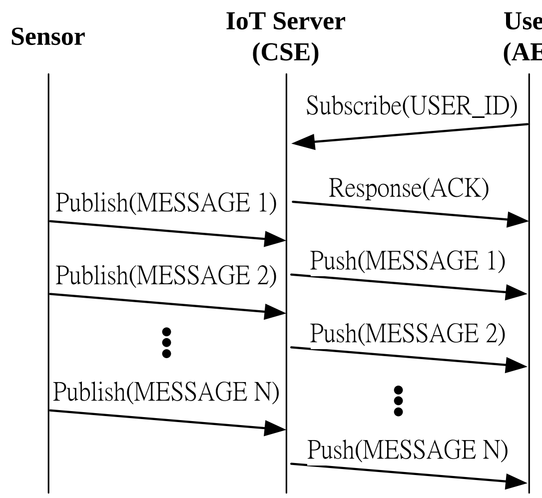

Fig – 2: The Active scheme of D²ATC mechanism.

For the Passive scheme, as depicting in Figure (3), the IoT server passively waits for the data delivery requirements of the end users. The end user sends the data requirement in the fixed time period or the update necessary. When the IoT server receives the data transmission requirement from the end user, the IoT server firstly check whether there are updated sensing data stored in the database, which are different to the previous data transmitted to the end user, or not. If there are updated sensing data, the IoT server transmit the data to the end data. Thus, the Passive scheme effectively reduce the unnecessary data transmission.

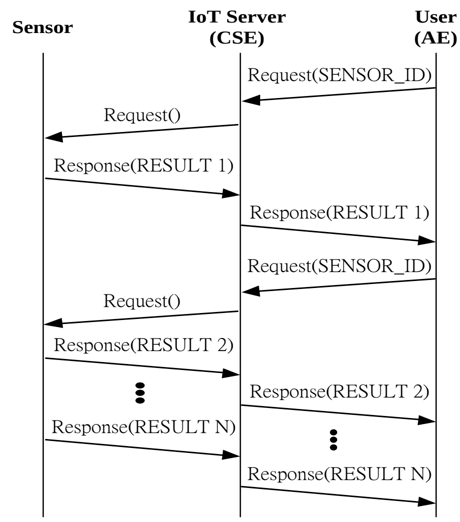

Fig – 3: The Passive scheme of D2ATC mechanism.

2.2 Dynamic Power Adjustment Mechanism (DPA)

The purpose of the proposed DPA mechanism is to dynamically adjust the power consumption and sleep intervals of sensor devices based on the quality of information, battery power level, conflict factor, and variation coefficients. The proposed evaluation equations (1) and (2) are used to predict the suitable sleep time interval of the sensor devices [10].

Equation (1) is used to calculate the next sleep time prediction (T_{n+1}^{i}), which is the actual sleep time t_n^i multiplied by the weight parameter (α) and pluses the historical sleep time T_n^i multiplied by the weight parameter (1-α). Equation (2) uses the predicted sleep time (T_{n+1}^{i}) to plus the sleep variation time (Δt^i) to predict the actual sleep time for the next sleep time prediction (t_{n+1}^{i}).

$$T_{n+1}^{i} = \alpha t_n^i + (1-\alpha)\, T_n^i\, ;\ 0 \le \alpha \le 1 \qquad (1)$$

$$t_{n+1}^{i} = T_{n+1}^{i} + \Delta t^i \qquad (2)$$

The Equation (3) shows the evaluation of the sleep variation time (Δt^i). The denominator is the summation of Quality information (ϕ) and the overlapping ranges (ξ_i) of two sensor devices. The numerator is the the remaining battery power level (E_i) of the sensor *i* multiplied by the coefficient of variation (CoV), which is the difference between the current value and the previous value of sensor *i*.

$$\Delta t^i = \frac{\phi + \xi_i}{E^i \cdot Cov} \qquad (3)$$

Figure (4) depicts the communication overlapping situation between two sensors. Equation (4) evaluates the overlap factor (ξ_i). Equation (5) evaluates the coefficient of variation (CoV).

$$\xi_i = r_1^2 \cos^{-1}\left(\frac{d^2+r_1^2-r_2^2}{2dr_1}\right) + r_2^2 \cos^{-1}\left(\frac{d^2+r_1^2-r_2^2}{2dr_2}\right) - \frac{1}{2}\sqrt{4d^2r_1^2 - (d^2+r_1^2-r_2^2)^2} \qquad (4)$$

$$CoV = \frac{\sqrt{\Sigma(x_i-\mu)^2}}{\mu} \qquad (5)$$

x_i = *sensing value of sensor i* , $\mu = \sum_{i=1}^{n} x_i / n$ = *The average value of the sensor*s.

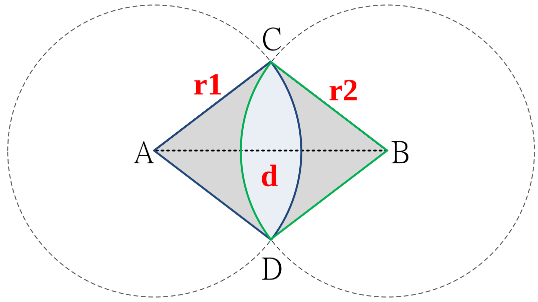

Fig – 4: The communication overlapping situation between two sensors A and B.

3. PERFORMANCE EVALUATION

This Section describes the performance evaluation of the proposed D²ATC mechanism and DPA mechanism. The purpose of the D²ATC mechanism is to effectively reduce the amount of network packets. Table (1) depicts the comparison of the data amount with or without using D²ATC mechanism.

Table – 1: The Comparison of the Data Amount with or without Using D²ATC Mechanism.

Control Scheme / Amount (Bytes)	Dynamic sleep interval with *D²ATC* (active mode)	Dynamic sleep interval without *D²ATC* (active mode)	Fixed 30 minutes sleep interval with *D²ATC* (passive mode)	Fixed 30 minutes sleep interval without *D²ATC* (passive mode)
The total amount of packets	271,690	678,068	196,140	490,307
The amount of repeated packets	8,224	414,602	3,056	297,223
The ratio of the repeated packets	3.027%	61.14%	1.558%	60.62%

The total amount of data transmission is 271,690 bytes and 678,068 bytes with or without using D²ATC mechanism, respectively. Furthermore, the amount of repeated packets is 414,602 bytes and the ratio of the repeated packets is 61.14% without using D²ATC mechanism. Under the condition of the sleep interval of fixed 30 minutes, the total amount of data transmission is 196,140 bytes and 490,307 bytes with or without using D²ATC mechanism, respectively. The amount of repeated packets is 297,223 bytes and the ratio of the repeated packets is 60.62% without using D²ATC mechanism. Both of the amount and ratio of repeated data packets using D²ATC mechanism are much less than the values without using D²ATC mechanism.

Figure (5) depicts the comparison of battery power consumption among the proposed DPA mechanism, N. Kaur scheme [10], and a fixed 30 minutes method. The evaluation results show that the proposed DPA mechanism achieves the most effective power-saving. The N. Kuar method has the second performance and the fixed interval scheme has the worst performance. The power consumption efficiency improvement of the DPA mechanism is 25.37% and 37.67% than the N. Kuar scheme and the fixed interval scheme, respectively.

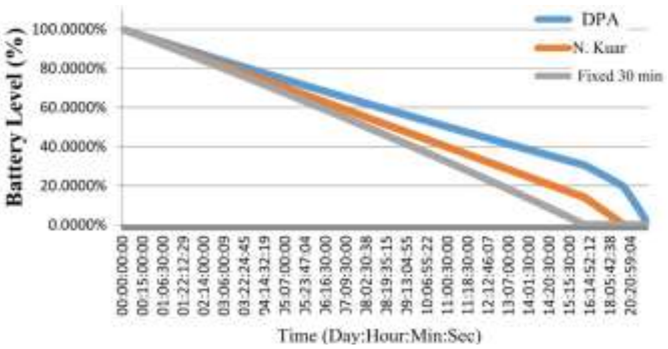

Fig – 5: Comparison of battery power consumption.

4. CONCLUSION

This study proposes an Efficient Power-Consumption (EPC) IoT middleware based on the open oneM2M communication standard to achieve flexible communication in a heterogeneous IoT environment. The proposed EPC IoT middleware provides the Dynamic Duplication Avoidance Transmission Control (D^2ATC) mechanism, which is based on the built-in sensor frequency table combined with the ETag of sensors, is proposed to solve the problem of repeated service requests, and to decrease the network transmission cost. The proposed Dynamic Power Adaptation (DPA) mechanism, which is based on the quality of information, battery power level, conflict factor, and variation coefficient to dynamically adjust the power consumption and sleep intervals of sensor devices. The performance evaluation model of the DPA mechanism achieves the efficient power consumption while maintaining the trade-off between the quality of information and the battery life cycle of sensors. Performance evaluation results reveal that (1) the D^2ATC mechanism reduces the volume of data transmission packets by about 60%, and (2) the proposed DPA mechanism extends the battery life to 25.37%.

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BIOGRAPHIES

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