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Distributed CoAP Handover Using Distributed Mobility Agents in Internet-of-Things Networks

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Abstract

The constrained application protocol (CoAP) can be used for remotely controlling various sensor devices in Internet of Things (IoT) networks. In CoAP, to support the handover of a mobile sensor device, service discovery and message transmission needs to be repeated, although doing so would increase the handover delay significantly. To address this limitation of CoAP, a centralized CoAP scheme has been proposed. However, it tends to result in performance degradation for an inter-domain handover case. In this letter, we propose a distributed CoAP handover scheme to support the inter-domain handover. In the proposed scheme, a distributed mobility agent (DMA) is used for managing the location of mobile sensors in a domain and performing handover control operations with its neighboring DMAs in a distributed manner. A performance comparison reveals that the proposed scheme offers a performance improvement of up to 29.5% in terms of the handover delay.

Index Terms: CoAP, Distributed mobility agent, Handover, Internet of Things, Mobile sensor

I. INTRODUCTION

The Internet of Things (IoT) is a network of things embedded with various devices and provides a collection and exchange of measured data [1-3]. Moreover, many smart services can be provided using direct communication with a variety of sensor devices [4, 5]. However, if an IoT network is deployed in the current Internet environment, some problems can occur because of the limitation of the battery power of small sensor devices or constrained devices [6, 7].

In the meantime, to address the power-efficiency problem of constrained devices, the constrained application protocol (CoAP) has recently been standardized by the Internet Engineering Task Force (IETF) [8, 9]. However, CoAP does not consider the mobility of sensor devices. Accordingly, if a handover occurs, the device discovery operation needs be performed again. To reduce the handover delay by movement, a centralized CoAP mobility scheme has been proposed [9]. However, this scheme focuses only on an intra-domain handover, which may result in performance degradation in the inter-domain handover. For effective support of the inter-domain handover, we propose a distributed handover scheme for CoAP, which is based on the distributed mobility agents (DMAs) deployed in each network domain. The proposed scheme can further reduce the handover delay for the inter-domain handover in a CoAP-based network.

The rest of this paper is organized as follows: Section II reviews the two existing handover schemes for CoAP.

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Section III presents the proposed distributed mobility scheme. Section IV discusses the numerical analysis and comparisons. Section V concludes this paper.

II. EXISTING COAP HANDOVER SCHEME

A. CoAP Handover

In the existing CoAP handover [8], when a client wants to send some request/response messages to mobile sensors, it performs the service discovery operations again to find the location of the sensor. First, the client sends a discovery request message to the client gateway. Upon the receipt of this discovery request message, the client gateway forwards the request message to the other gateways by a multicast. Each gateway will also forward the service discovery message to the sensors in its domain by a multicast. If a sensor device receives the discovery request message, it will check the information of the target device contained in the discovery request message. Then, if the target device is its own, it will respond with a discovery response message to the client by a unicast. This will complete the service discovery. Then, the client and the sensor devices will be able to exchange the request/response messages by a unicast.

If the handover of a mobile sensor device occurs, messages cannot be forwarded to the sensor through the previous gateway, and the client receives a destination unreachable message as an Internet Control Message Protocol (ICMP) error. Then, the client performs the service discovery operation again by sending another discovery request message to the client gateway. The client gateway forwards the discovery request message to each gateway by a multicast so as to find the new location of the mobile device. This scheme tends to generate many additional control messages and to induce large handover delays.

B. Centralized CoAP Handover

In the centralized CoAP scheme [10], a centralized mobility agent (CMA) is used for storing and managing the location information of all sensor devices in the network. In addition, for mobility management, some new messages are defined and used, such as the request/response messages for registration, location query, and handover.

In this scheme, if a sensor is connected to the network, it sends a registration message to CMA so as to register its location information. It then receives a response message from CMA. When the client wants to exchange some messages with a sensor device, it sends a discovery request message to the client gateway so as to obtain the location of the sensor device. On receiving this discovery request message, the client gateway performs the location query process with CMA by using the location query and location query ACK messages. CMA then informs the location of the sensor device by sending the discovery response message to the client. Now, the client can exchange messages directly with the sensor device.

If a handover of a sensor device occurs, the sensor performs the handover operation between the two gateways concerned with the client and the sensor. First, the sensor sends a handover message to the client through both its old gateway and the client gateway so as to maintain the communication path during the handover. On receiving the handover message, the client responds with a handover ACK message to the sensor so as to inform it of the successful handover operation. Now, the sensor can continue the handover procedure with CMA by updating the associated cache table through the new sensor gateway. Then, CMA responds with the handover ACK message so as to complete the handover operation with the mobile sensor.

III. PROPOSED DISTRIBUTED COAP HANDOVER

In the centralized CoAP handover scheme, the number of completely generated control messages can be reduced by using the unicast-based service discovery and location query procedures. In addition, it provides lower handover latency than the existing CoAP handover by using CMA as a mobility agent in the intra-domain handover where the gateway of a sensor device is not changed. However, in the inter-domain handover where the gateway of a sensor device is changed by the handover movement, the centralized CoAP handover may suffer from performance degradation. This is because the inter-domain handover in a large network may induce frequent changes of gateways by the handover and a relatively large distance between CMA and sensors, as compared to the intra-domain handover in a relatively small network.

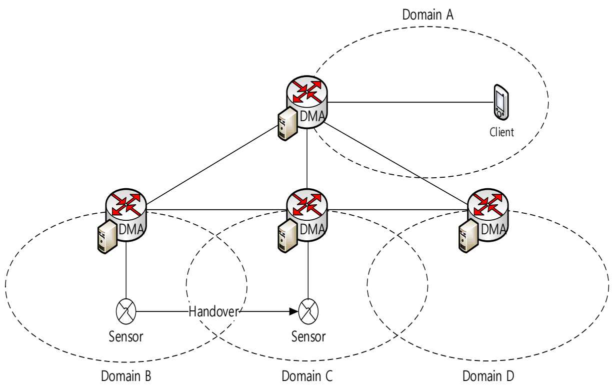

Fig. 1. Network model for distributed CoAP handover.

To reduce the handover delay in the inter-domain handover case, we propose a distributed CoAP handover scheme by using a DMA, as shown in Fig. 1.

We assume that the network consists of several domains and a gateway is assigned to each domain. In the proposed scheme, each gateway has its own DMA that is used for storing and managing the location information of mobile sensors within its domain. For mobility management, the proposed handover scheme uses the control messages for registration, location query, and handover, as done in the centralized CoAP handover scheme. However, unlike the centralized CoAP handover, the proposed scheme completes the registration operation within a domain. Moreover, the location query and handover operations are performed between the concerned gateways, not depending on the client and the sensors. These features will be helpful to reduce the handover delay in the inter-domain handover.

Fig. 2 shows the operational flow diagram of the proposed distributed CoAP handover scheme, in which a mobile sensor moves from the DMA_A region to the DMA_B region by a handover.

With initial network attachment, the sensor exchanges the registration and registration ACK messages with DMA_A (Steps 1 and 2). If a client wants to send some messages to the sensor, it first sends a discovery request message to DMA_D of the client in order to obtain the location information of the sensor (Step 3). On receiving the discovery request message, DMA_D sends a location query message to the other DMAs by a multicast. Then, DMA_A responds with a location query ACK (Steps 4 and 5). The forwarding of this location information to the client (Step 6) completes the location query phase (Step 7).

Now, the sensor moves from DMA_A to DMA_B. With handover detection, the sensor sends the handover messages to DMA_B, which is the new DMA of the sensor. Then, DMA_B updates the location cache table and exchanges the

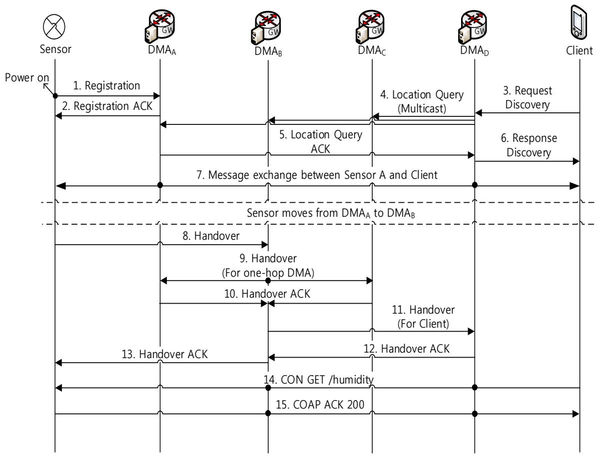

Fig. 2. Distributed CoAP handover procedures.

Table 1. Parameters used for the performance analysis

Parameter	Description
$H_{a\text{-}b}$	Hop count between nodes a and b in the network
L_w	Wired link delay (s)
L_{wl}	Wireless link delay (s)
S_c	Size of control packet (bytes)
S_d	Size of data packet (bytes)
B_w	Wired link bandwidth (bps)
B_{wl}	Wireless link bandwidth (bps)
$T_{timeout}$	Timeout period for ICMP error message (s)
T_{lookup}	Table lookup time (s)
N_a	Number of instances of node a in each AR

handover control messages with its neighboring DMAs so as to update the location information of the sensor (Steps 9 and 10). These handover messages are also delivered to DMA_D so as to update the routing path between the client and the sensor (Steps 11–13). Now, the handover operation is completed, and then, the client and the sensor can continue its communication.

IV. DISCUSSION AND CONCLUSIONS

For the performance analysis, we compared the total handover delay (THD) of the three candidate schemes: existing CoAP handover, centralized CoAP handover, and proposed CoAP handover. THD consists of registration time (RT), initial transmission time (ITT), and handover time (HT). In this letter, we focus on the analysis of the inter-domain handover.

Table 1 presents the notations used in the analysis.

Here, $T_{x\text{-}y}(S_c)$ denotes the time of a control message with size S sent from x to y through a wireless link [11]. Then, $T_{x\text{-}y}(S_c)$ is expressed as $[(S_c/B_{wl}) + L_{wl}]$. Further, $T_{x\text{-}y}(S_d, H_{x\text{-}y})$ denotes the time of a data message with size S sent from x to y via a wired link. In this case, the hop count between node x and node y is considered. Therefore, $T_{x\text{-}y}(S_d, H_{x\text{-}y})$ is expressed as $H_{x\text{-}y} \times [(S_d/B_w) + L_w]$.

A. Analysis of Total Handover Delay

1) Existing CoAP Handover

In the existing CoAP handover, there is no registration phase. Therefore, this operation takes $RT_{CoAP}(S_c) = 0$. The client performs a discovery operation to find the target sensor device by using a discovery request message through a multicast. After the discovery phase, the client can exchange data messages with the sensor device. This operation takes $ITT_{CoAP} = 2 \times (T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(Sc) + T_{GW\text{-}sensor}(Sc) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d) + T_{GW\text{-}sensor}(S_d))$.

Upon the handover, the client may receive an ICMP error message from the old gateway. Then, it performs the discovery operation again. After the re-discovery, the client can obtain the changed location of the sensor. Now, the client and the mobile sensor can continue their communication. This operation takes $HT_{CoAP} = T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}CN}(S_c) + 2 \times (T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_c) + T_{GW\text{-}sensor}(S_c) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d) + T_{GW\text{-}sensor}(S_d)) + T_{timeout}$.

Thus, we can calculate the THD of the existing CoAP as follows:

$$THD_{CoAP} = RT_{CoAP} + ITT_{CoAP} + HT_{CoAP}$$
$$= 5 \times (T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW})) + 4 \times (T_{GW\text{-}GW}(S_c) + T_{GW\text{-}sensor}(S_c) + T_{GW\text{-}GW}(S_d) + T_{GW\text{-}sensor}(S_d)) + T_{timeout}.$$

2) Centralized CoAP Handover

In the centralized CoAP handover, a mobile sensor performs the initial registration with CMA. This operation takes $RT_{Centralized} = 2 \times (T_{CMA\text{-}GW}(S_c, H_{CMA\text{-}GW}) + T_{GW\text{-}GW}(S_c, H_{GW\text{-}GW}) + T_{GW\text{-}sensor}(S_c))$. The client performs the discovery operation to find the target sensor device with its gateway and CMA. Then, the client can exchange data messages with the sensor device. This operation takes $ITT_{Centralized} = 2 \times ((T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{GW\text{-}CMA}(S_c, H_{GW\text{-}CMA}) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d, H_{GW\text{-}GW}) + T_{GW\text{-}sensor}(S_d))$.

With handover detection, the sensor device performs the handover operations. First, the mobile sensor sends a handover message to the client through its old gateway and to CMA through its new gateway. Then, each client and CMA respond with a handover ACK message. In this phase, an additional processing overhead is required for location table lookup and update. With the handover operation, the cache table of CMA is updated, and the routing path between the client and the mobile sensor is modified. This operation takes $HT_{Centralized} = 2 \times (T_{CMA\text{-}GW}(S_c, H_{CMA\text{-}GW}) + 2T_{GW\text{-}sensor}(S_c) + T_{GW\text{-}GW}(S_c, H_{GW\text{-}GW}) + T_{GW\text{-}CN}(S_c, H_{GW\text{-}CN}) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d, H_{GW\text{-}GW}) + T_{GW\text{-}sensor}(S_d)) + T_{lookup}$.

Thus, we can calculate the THD of the centralized CoAP handover scheme as follows:

$$THD_{Centralized} = RT_{Centralized} + ITT_{Centralized} + HT_{Centralized}$$
$$= 6 \times (T_{CMA\text{-}GW}(S_c, H_{CMA\text{-}GW}) + T_{GW\text{-}sensor}(S_c)) + 4 \times (T_{GW\text{-}GW}(S_c, H_{GW\text{-}GW}) + T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d, H_{GW\text{-}GW}) + T_{GW\text{-}sensor}(S_d)) + T_{lookup}.$$

3) Proposed Distributed CoAP Handover

In the proposed handover scheme, a sensor device performs the registration with the DMA in its domain. This operation takes $RT_{proposed} = 2T_{GW\text{-}sensor}(S_c)$. In the discovery phase, the client gateway obtains the location information of the sensor devices from the other DMAs and then, responds to the client. This operation takes $ITT_{proposed} = 2 \times (T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_c, H_{GW\text{-}GW}) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d, H_{GW\text{-}GW}) + T_{GW\text{-}sensor}(S_d))$.

In the handover, the mobile sensor sends a handover message to its new DMA. Then, the DMA updates its location table and communicates with its neighboring DMAs. With these handover operations, the tables of the DMAs are updated, and the routing path between the client and the mobile sensor is modified. This operation takes $HT_{proposed} = 4T_{GW\text{-}GW}(S_c, H_{GW\text{-}GW}) + 2 \times (T_{GW\text{-}sensor}(S_c) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}GW}(S_d, H_{GW\text{-}GW}) + T_{GW\text{-}sensor}(S_d)) + T_{lookup}$.

Thus, we can calculate the THD of the proposed CoAP handover scheme as follows:

$$THD_{proposed} = RT_{proposed} + ITT_{proposed} + HT_{proposed}$$
$$= 6 \times (T_{GW\text{-}GW}(S_c, H_{GW\text{-}GW})) + 4 \times (T_{CN\text{-}GW}(S_c, H_{CN\text{-}GW}) + T_{GW\text{-}sensor}(S_c) + T_{CN\text{-}GW}(S_d, H_{CN\text{-}GW}) + T_{GW\text{-}sensor}(S_d) + T_{GW\text{-}GW}(S_d, H_{GW\text{-}GW})) + T_{lookup}.$$

B. Numerical Results

For the numerical analysis, we set the parameter values, as shown in Table 2, by referring to [11]. Note that the number of sensors in gateway (GW) has an impact on the table lookup time of CMA and DMA.

Fig. 3 shows the effect of the number of sensors on the handover delay. In the figure, the handover delay of the existing CoAP handover is not changed, since the number of sensors affects only the number of generated control packets. On the other hand, as the number of sensors increases, the handover delays of the centralized and the proposed schemes increase slightly. However, such increased values are very small and insignificant. The results reveal that the handover delay of the proposed CoAP handover scheme is considerably shorter than that of the existing two schemes.

Table 2. Parameter values used for the analysis

Parameter	Minimum	Default	Maximum
$H_{CN\text{-}GW}$		2	
$H_{GW\text{-}CMA}$	1	5	10
$H_{GW\text{-}GW}$		2	
$H_{GW\text{-}sensor}$		1	
L_w	0.0001 s	0.002 s	0.0055 s
L_{wl}	0.001 s	0.01 s	0.055 s
S_c		80 bytes	
S_d		128 bytes	
B_w		100 Mbps	
B_{wl}		11 Mbps	
$T_{timeout}$		0.04 s	
T_{lookup}		20	
N_{sensor}	2	20	40

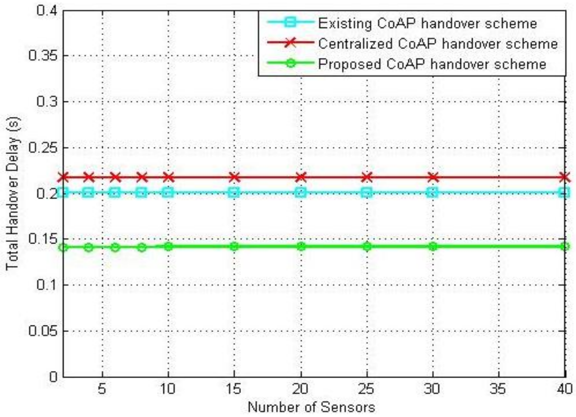

Fig. 3. Effect of the number of sensors on the handover delay.

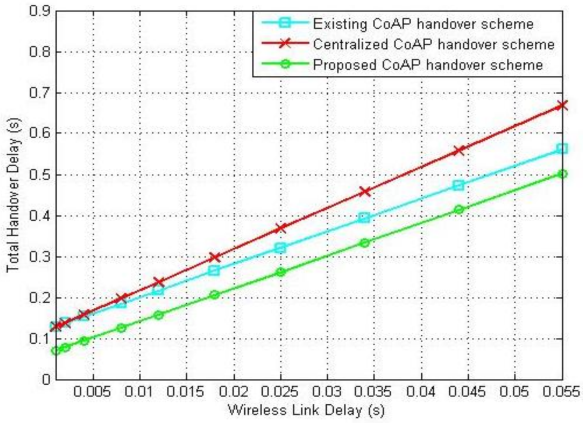

Fig. 5. Effect of the wireless link delay on the handover delay.

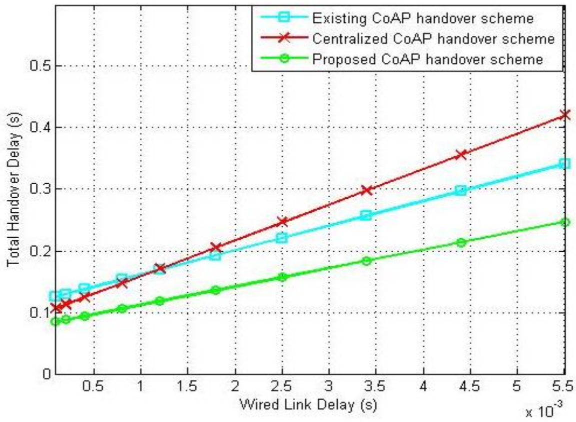

Fig. 4. Effect of the wired link delay on the handover delay.

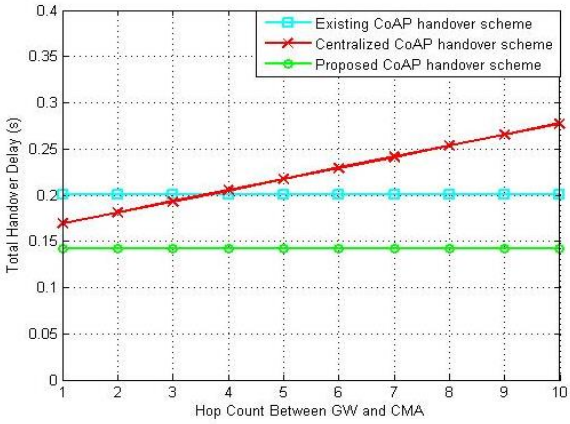

Fig. 6. Effect of the hop count between GW and CMA.

This is because the proposed scheme simplifies the handover operations by using the distributed mobility agents, as compared to the existing schemes.

Fig. 4 shows the effect of wired link delays on the handover delay. The figure shows that the centralized scheme depends considerably on the wired link delay. This is because this scheme frequently transmits the location query and handover messages over wired links between GWs and CMA during the handover. Thus, the handover delays increase with an increase in the wired link delay. The existing CoAP scheme also provides large handover delays, since the discovery operations should be performed again by the handover. Overall, the distributed scheme provides the best performance by simplifying the location query and handover operations.

Fig. 5 shows the effect of the wireless link delay. The centralized scheme shows the worst performance, since it uses the host-based handover control, and thus, many control messages will be delivered over the wireless links. However, the proposed scheme is a network-based handover control scheme, and the dependence of the wireless links is low.

Fig. 6 shows the effect of the hop count between GW and CMA for the analysis of the centralized handover scheme. In Fig. 6, we can see that the centralized scheme tends to result in good performance when the hop count is small, but provides the worst performance for a large hop count (4 or more in this analysis).

In this section, we compared the performance of three candidate schemes on the basis of the number of sensors, link delay, and the distance between GW and CMA. To summarize, the proposed scheme shows good performance in all the cases; in particular, it offers a performance improvement of up to 29.5% in the analysis based on the wireless link delay.

V. CONCLUSION

In this paper, we proposed a distributed CoAP handover scheme to reduce the handover delays in IoT networks. The proposed scheme uses DMAs for managing the location of mobile sensors and performing the handover operations with the neighboring DMAs.

The numerical analysis revealed that the proposed distributed scheme provides the best performance for the inter-domain handover. This is because the proposed scheme can simplify the location query and handover operations by using the DMAs.

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