Inter-MARIO: A Fast and Seamless Mobility Protocol to support Inter-PAN Handover in 6LoWPAN

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Abstract—Mobility management is one of the most important research issues in 6LoWPAN, which is a standardizing IP-based Wireless Sensor Networks(IP-WSN) protocol. Since the IP-WSN application domain is expanded to real-time applications such as healthcare and surveillance systems, a fast and seamless handover becomes an important criterion for mobility support in 6LoWPAN. Unfortunately, since existing mobility protocols for 6LoWPAN have not solved how to reduce handover delay, we propose a new fast and seamless mobility protocol to support inter-PAN handover in 6LoWPAN, named inter-MARIO. In our protocol, a partner node, which serves as an access point for a mobile node, preconfigures the future handover of the mobile node by sending mobile node’s information to candidate neighbor PANs and providing neighbor PAN information like channel information to the mobile node. Also, the preconfigured information enables the foreign agent to send a surrogate binding update message to a home agent instead of the mobile node. By the preconfiguration and surrogate binding update, inter-MARIO decreases channel scan delay and binding message exchange delay, which are elements of handover delay. Additionally, we define a compression method for binding messages, which achieves more compression than existing methods, by reducing redundant fields. We compare signaling cost and binding message exchange delay with existing mobility protocols analytically and we evaluate handover delay by simulation. Analysis and simulation results indicate that our approach has promising fast, seamless, and lightweight properties.

Keywords: Mobility protocol, 6LoWPAN, Fast handover, wireless sensor networks

I. INTRODUCTION

Mobility management is one of the most important research issues in 6LoWPAN, which is standardizing IP-based Wireless Sensor Networks(IP-WSN)[1,3,4,5,6,7] architecture. Currently, IP-WSN is popularly recognized as a global sensor network infrastructure by combining IPv6 protocol with WSN. Compared to traditional sensor networks, IP-WSN is applied to real-time network systems[16,17] such as healthcare and surveillance systems. In these applications, since patients to which a mobile node(MN) is attached to monitor their body status and patrol robots which detect enemies are moving, the handover may happen frequently. If the handover delay is high, the inaccessible time of the nodes will increase and the emergency reports can be missed out. Thus, a fast and seamless handover becomes an important criterion to support mobility in 6LoWPAN.

In most common IP-based mobility protocols such as MIPv6[10] and PMIPv6[12], during handover, there is an inaccessible time period because of link switching and IP protocol operations like Care-of Address(CoA) generation. These protocols handle mobility management by exchanging binding messages. Unfortunately, they have not solved how to minimize the handover delay. Even though HMIPv6[11] suggests Mobile Anchor Point(MAP) as a local Home Agent(HA) to reduce binding message exchange delay, it does not provide a solution to reduce handover delay for inter-network handover. Although mobility protocols[5,13] for 6LoWPAN were suggested, these protocols do not support fast and seamless handover, since these protocols only focus on adapting traditional mobility protocols lightweightly.

In this paper, we propose a new fast and seamless mobility protocol based on MIPv6 to support inter-PAN handover in 6LoWPAN, named inter-MARIO. When a MN moves out of its home Personal Area Networks(PAN) and joins a new PAN, the handover delay can be separated into movement detection delay, channel scan delay, L2 association delay, and binding message exchange delay. Since our objectives are to reduce the handover delay, inter-MARIO is designed with a make-before-break method. In our protocol, the partner node, which serves as an access point for the mobile node, preconfigures the future handover of the MN by sending MN’s information to candidate neighbor PANs and providing neighbor PAN information to the MN. Due to our preconfiguration scheme, the Foreign Agent(FA) can send a surrogate binding update message to HA for MN’s handover when MN associates with the new PAN simultaneously. Our preconfiguration makes a benefit to reduce channel scan delay. By using the neighbor PAN information which the MN receives, the MN can selectively scan the channel when previous link is disconnected instead of scanning all channels.

Additionally, in this paper, we define a compression
method for binding messages, which compresses more than existing methods, by reducing redundant fields of the standard binding message format. In order to analyze and evaluate inter-MARIO, we compare signaling cost and binding message exchange delay with existing mobility protocols for 6LoWPAN and we evaluate handover delay by simulation. Analysis and simulation results indicate that our approach has promising fast, seamless, and lightweight properties.

The outline of the paper is the following: Section II introduces two possible mobility scenarios. In Section III, we give an overview of our mobility protocol. Then, in Section IV, we show how our protocol performs inter-PAN handover in detail. Section V reports our analysis and simulation results. Section VI concludes the paper.

II. Possible Mobility Scenario

IP-WSN is being applied to healthcare systems in hospitals [17]. Sensor nodes which monitor patients’ body temperature and heartbeats are attached to the patients and each floor hosts a PAN which is comprised of static nodes which sense environmental data such as temperature and humidity of the building. The body sensor nodes notify the patients’ status to doctors through the static nodes when the patients’ status is in the emergency. Thus, whenever the patients are in the hospital, a link between body sensor nodes and the Internet should be maintained regardless of their whereabouts.

The surveillance systems to guard military bases and major facilities are one of the IP-WSN application domains. In these systems, the static surveillance nodes may be attached to a fence and they detect enemy infringement. Sentries and mobile patrol robots comb the vicinity of their main base and they are equipped with the MNs. They should report the searching situation to the situation room wherever they are.

In these two scenarios, the handovers may take place frequently and the seamless connectivity of MNs and fast handover should be guaranteed.

III. Inter-MARIO Mobility Protocol

We propose a new mobility protocol to support inter-PAN in 6LoWPAN. When a MN moves out of its PAN and moves into a new PAN, the MN should perform handover. In order to provide fast and seamless characteristics, we design the mobility protocol by following a make-before-break method. Moreover, we define a compress method for binding messages to adapt inter-MARIO protocol to 6LoWPAN lightweightly.

6LoWPAN consist of a gateway(GW), a PAN coordinator, and sensor nodes. The GW provides a connection between the 6LoWPAN networks and the Internet, and it plays a role as a HA for MNs and a FA for visiting nodes. Moreover, the GW[7] compresses incoming packets from the Internet to the inside of a 6LoWPAN network and it decompresses outgoing packets from the inside of a 6LoWPAN network to the Internet. The PAN coordinator is a representative of a PAN, which is responsible for starting the formation of a 6LoWPAN network. The sensor nodes can be separated into two types. One is a static node and another is a MN. A static node is a general sensor node which cannot move. It provides an access point to MNs and a router function to the other nodes. A MN is a sensor node which has an ability to move individually.

When a MN moves out of its PAN and it is attached to a new PAN, the MN should perform handover procedure. This movement of the MN called inter-mobility. Figure 1 shows the inter-PAN handover procedure of inter-MARIO when a mobile node moves from one PAN to another. In inter-MARIO, if a MN is MIPv6 enabled node, the MN does not need to implement additional mechanism in its stack to support a fast and seamless inter-PAN handover since the inter-PAN handover mechanism is handled by infrastructure nodes. In this section, the inter-MARIO protocol is described in detail. This section can be divided into two parts. The first part introduces the procedure of fast and seamless inter-PAN handover. The second part explains lightweight packet formats for handling handover.

A. Inter-PAN Handover

Our mobility protocol preconfigures inter-PAN handover by sending MN’s information to candidate neighbor PANs and providing neighbor PAN information to the MN. This preconfiguration is performed by the partner node, which serves as an access point for the MN. The partner node knows which neighbor PANs exist nearby itself, called neighbor PAN information. A parent node in HiLoW[20] and a mesh router in

Figure 1. The inter-PAN handover of mobile node.
mesh networks which keep the last remaining link connection with the moving MN become a partner node of the MN. In this paper, we assume that the partner node can detect the movement of MNs by using existing movement detection algorithms such as signal strength indicator, periodic hello packets, and link quality estimation.

As shown in Figure 2, if a partner node detects MN’s movement and has neighbor PAN information, it is possible that inter-PAN handover occurs. Thus, the partner node regards that the MN will perform inter-PAN handover. Then, the partner node starts preconfiguration procedure by sending Handover-Preconfigure message, which includes MN identifier, HoA, and the address of the HA, to the GW of the neighbor PAN. This GW will act as the FA of the MN. After MN’s physical movement, when the MN performs L2 layer association with a new PAN, the new PAN coordinator notifies it to the FA with identifier of the new comer. The FA checks whether or not the new comer is a preconfigured MN by comparing the identifier with preconfigured MN identifiers obtained from Handover-Preconfigure message. If the new comer is a preconfigured MN, the FA performs surrogate binding update with a binding [MN’s Home-of Address(HoA) -> FA] to the HA of the MN. After IP protocol operations like CoA generation, the MN follows MIPv6 operations: it sends binding update message with a binding [MN’s HoA -> MN’s CoA] to its HA. However, since the surrogate binding update for the MN is already done by FA, it is not necessary to deliver binding message to HA. In inter-MARIO, the FA which is a current gateway of MN’s new PAN checks whether or not a source of the binding message is already updated. If preconfigured, the FA intercepts it and creates the binding in its binding cache. Then, the FA responds to the MN by sending binding acknowledge message to the MN. Otherwise, the FA just forwards it to the HA without any operation. By these operations the inter-PAN handover of the MN is completed.

However, this procedure does not provide an optimal route from the corresponding node to the MN, since packets destined to the MN may be delivered to the HA and then is forwarded to the new location of MN. This is a triangle routing problem of MIPv6. To solve this problem, the MIPv6 standard proposes a route optimization method which is the Return Routability (RR)[10] procedure. In [10], to support the RR procedure, IPSec is mandatorily required. However, IPSec is not defined to support in 6LoWPAN[1, 4, 5] and it is not guaranteed to be supported later because of processing power, key management, and expensive computation. Thus, RR procedure cannot be achieved securely by the MN in 6LoWPAN. In our protocol, instead of the MN, the FA performs surrogate RR procedure. When the FA receives a packet of which destination address indicates a visiting MN in its network, the FA performs surrogate RR procedure to the source node instead of the MN. Thus, the MN can communicate with its corresponding node through optimal route. Also, for the secure binding update, GW which has relatively abundant resource can communicate with corresponding nodes outside of 6LoWPAN by using IPSec, and the sensor nodes can forward binding messages to the others inside of 6LoWPAN by using lightweight security protocols which is designed for sensor networks.

In case of network mobility, a standard network mobility protocol, NEMO Basic Support Protocol[21], has a route optimization problem when mobile network is nested. However, this problem can be easily solved by applying inter-MARIO, thereby performing RR procedure to the PAN coordinator of upper level mobile PAN when a PAN coordinator of each nested mobile PAN receives a packet destined to the MN. In this paper, we will not explain route optimization problem of network mobility in detail since the problem is out-of-scope.

Even though the preconfiguration is failed due to no neighbor PAN information or other reasons, since inter-MARIO is designed based on standard MIPv6, the MN can complete inter-PAN handover, but it is finished without benefits of preconfiguration. However, since our protocol defines a new header compression for binding messages, inter-PAN handover can decrease binding message exchange delay. This will be addressed in detail later on.

In order to succeed the preconfiguration, an important issue is how the partner node obtains neighbor PAN information. In our protocol, the partner nodes obtain this information at its startup time and periodically: When a static node powers up, it starts to scan all radio channels, and receives beacon signals from the PANs. Then, the node associates with a PAN. In general, the node discards received beacon information after its association. In inter-MARIO, however, the received beacon information is stored in order to support future MNs’ handover. We name the information the neighbor PAN information. With this information, when a MN moves out of its home PAN, the partner node gives neighbor PAN information to the MN. With this neighbor PAN information, the MN can selectively scan the channel to join the new PAN, not all channels. Due to this information sharing, our protocol can achieve briefer channel scan delay.

B. Packet Formats and Compression method

In this section, we define mobility packet formats: Handover-Preconfigure message and binding messages, which is illustrated in Figure 3. Inter-MARIO uses the same binding packets of MIPv6. However, these binding packets are significantly large size to use in 6LoWPAN, so we propose a compression method for binding messages.

We define a new dispatch header pattern, LOWPAN_MCP,
TABLE I. THE COMPARISON OF COMPRESSION PERFORMANCE

<table>
<thead>
<tr>
<th></th>
<th>Standard MIPv6</th>
<th>Adapted Model</th>
<th>Inter-MARIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binding Update</td>
<td>32 bytes</td>
<td>21 bytes</td>
<td>13 bytes</td>
</tr>
<tr>
<td>Binding Ack.</td>
<td>12 bytes</td>
<td>3 bytes</td>
<td>3 bytes</td>
</tr>
<tr>
<td>Route Optimization</td>
<td>Support</td>
<td>Support</td>
<td>Support</td>
</tr>
</tbody>
</table>

TABLE II. PARAMETERS AND TYPICAL VALUES

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{int} )</td>
<td>Signaling cost of inter-mobility.</td>
</tr>
<tr>
<td>( t_{avg} )</td>
<td>Average residual time of the link.</td>
</tr>
<tr>
<td>( H_{from} )</td>
<td>The number of hops from ( from ) to ( to ).</td>
</tr>
<tr>
<td>( P_{x} )</td>
<td>Packet size of ( x ).</td>
</tr>
<tr>
<td>( \tau ), ( \kappa )</td>
<td>Transmission costs in wired and wireless link, respectively. (wired=1, wireless=2 [19])</td>
</tr>
<tr>
<td>( c )</td>
<td>Processing costs for routing and binding procedures (30 [18]).</td>
</tr>
</tbody>
</table>

which presents that the packet is mobility related one. This dispatch header is followed by a LOWPAN MH header, which includes an identifier to distinguish Handover-Preconfigure and binding message and which indicates how the packet is compressed. It also contains some fields of binding message format of MIPv6 such as A, H, status, etc. In our compression method, we omit a checksum field from binding messages, since the mobility message is included in IEEE 802.15.4 MAC payload and the checksum is calculated in MAC layer. Our method also compresses a lifetime field to its half the size and doubles the unit of lifetime compared to MIPv6.

In our compression method, to make the binding message lightweight, compressed binding update message does not include an IPv6 full address. Instead, 64 bits interface identifier and SLA ID are included except the first 48 bits network prefix. This reason can be shown in IPv6 address architecture[2,8,9]. IPv6 address consists of fixed bits which are assigned by ISP. Site-Level Aggregation Identifier(SLA ID) to distinguish sub-networks, and interface identifier. Thus, the first 48 bits of HoA can be obtained from the destination address of binding update message, which is the HA’s address. By compressing this redundant field, as described in Table I, inter-MARIO compresses 32 bytes BU message of MIPv6 into 13 bytes and 12 bytes BA message of MIPv6 into 3 bytes. This is the result that our protocol compresses 8 bytes more than existing compression method. The performance improvement due to our compression method is analyzed in next section.

IV. ANALYSIS AND EVALUATION

A. Analysis of Signaling cost

To analyze the performance of inter-MARIO, we calculate the total signaling cost when a MN performs handovers. Signaling in our protocol takes place when a MN moves from the coverage of one PAN to another. The MN has to update its location by exchanging binding messages. To calculate signaling cost, we follow the calculation method of signaling cost in [13] and modified the method to reflect our protocol in signaling cost. In case of inter-MARIO, the signaling cost can be calculated as

\[
C_{\text{int}} = C_{\text{inter-pref}} + C_{\text{inter-routing}} + C_{\text{binding by proxy}}
\]

where \( \tau \) and \( \kappa \) are the unit transmission costs in wired and wireless link and \( c \) is the processing cost for routing and binding procedure. The notations used in our analysis are described in Table II. The signaling cost, \( C_{\text{int}} \), includes all signaling cost generated by each hop to forward mobility packets from the MN to the destination such as routing costs, signaling costs of preconfiguration and signaling costs of binding update. For the calculation, we assume that \( \tau \) is 10. The signaling costs for standard MIPv6[10] and an Adaptation Model for MIPv6 support in lowPAN(Adapted Model)[5] are calculated except the signaling cost for preconfiguration in above equations, since they do not perform preconfiguration. Figure 4 shows variation in the total signaling costs, with various average residual times which illustrate the frequency of the movement. Since the preconfiguration which is an additional signaling is performed before handover, the signaling cost of inter-MARIO with preconfiguration is larger than others. However, the signaling cost for binding message...
exchange is lowest. This result shows the signaling overhead of the preconfiguration which is a tradeoff between signaling cost and fast handover.

B. Analysis of Binding Exchange delay

In this section, we analyze how much our protocol reduces Binding Message Exchange (BME) delay, which is a summation of forwarding delays. In order to estimate the delay, equation (5) proposed in [13] is used. This equation (5) consists of \( t_s \) which means time to configure/process a signaling message (1ms [14]), \( P_x \) which indicates a packet size of \( x \), \( t_r \) which signifies routing and processing time for a packet in every hop (0.001ms [15]), and \( L \) which represents the summation of propagation delay in wired line and wireless and link layer delay (\( L_{wireless} \): 0.5ms, \( L_{wired} \): 2ms). In (5), \( H \) indicates hop counts (\( H_{pan} \): from MN to GW, \( H_{GW_HA} \): from GW to HA).

\[
\text{BME} = t_s + \sum_{H_{pan}} \left( \frac{P_{\text{Compressable}} + P_{\text{Incompressable}}}{BW_{\text{wireless}}} \right) + 2t_r + 2L_{\text{wireless}}
\]

Figure 5 shows the comparison between BME delay of standard MIPv6, adapted model for MIPv6, and inter-MARIO according to the change of HPAN when \( H_{GW_HA} \) is 10. In this comparison, BW of wired is assumed as 100Mbps and BW of wireless is assumed as 250kbps. When hop counts from MN to GW are 10, BME delay of standard MIPv6 takes 55.8044ms, BME delay of Adapted Model takes 55.0044ms, inter-MARIO without preconfiguration(preconfigure fail) takes 54.6844ms, and inter-MARIO with preconfiguration(preconfigure success) takes 42.66ms. This result shows that inter-MARIO decreases 23.55% of BME delay of standard MIPv6 and 22.44% of BME delay of Adapted Model.

C. Simulation

To allow evaluation of inter-MARIO, we have implemented our solution in Qualnet 4.5 simulator. In this simulation, the terrain area is set to 1,500x1,500m² and two PANs are deployed. The simulation setup is illustrated in Figure 6. In this scenario, a MN moves at speed 10m/s. We manually triggered handovers of the MN to obtain the handover delays without the performance effect of movement detection algorithm. The simulation is run for 90s with 20s setup time. In our simulation, corresponding node periodically sends 32 bytes CBR packets to the MN at rate 50packets/s.

Our simulation is allowed to measure the inter-PAN handover delay and the end-to-end delays for CBR packets before and after inter-PAN handover. In Figure 7 and 8, the empty space shows the disconnected link time. In our simulation, the last packet received time before handover is 55.00585s and the first packet received time after handover is 58.06586s. These received times indicate that the inter-PAN handover takes about 3s. This is the reason that the handover delay includes the time period when MN is out of the communication range. Also, since Qualnet simulator has limitation to implement additional layer between two layers, the 6LoWPAN adaptation layer is implemented in IP layer. This limitation means that our protocol has dependency on IP layer operations, and it increases the handover delay.
Figure 8 shows a benefit of route optimization. Since more extra routes lead to larger end-to-end delivery delay, if route optimization is not supported, CBR packets will de-tour 10 more routers and the end-to-end delay after handover increases. However, since inter-MARIO provides a route optimization solution by using surrogate RR procedure, the end-to-end delay can be almost same with the latency before handover.

V. CONCLUSION

In this paper, we proposed a new mobility protocol to support inter-PAN handover in 6LoWPAN. We showed how inter-MARIO can support inter-PAN handover based on a make-before-break method. We also defined an efficient compression method for binding messages. Analysis and simulation results indicate that our approach has promising fast, seamless, and lightweight properties. To support mobility management completely in 6LoWPAN, efficient movement detection, addressing, and security remain as our future works.

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