Node Mobility Scheme for IP and Non-IP Wireless Personal Area Network Nodes using 6LoWPAN

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***Abstract*—The rapid growth of technology has enabled more devices (IP and Non-IP, high powered and low powered) to be connected to the Internet and these devices are expected to be mobile. However, the existing IP mobility protocol is not suitable for devices that have low resources, such as Wireless Sensor Networks (WSNs). This paper proposes a mobility scheme using 6LoWPAN, targeted for any LoWPAN devices that may or may not have IP stack capability. It uses a combination of host-based and network-based mobility. In the scheme, the mobile device would be configured to store the home edge router IP address that would be given to new edge router to establish communication with the home edge router. The paper analyses the signaling messages in setting up communication once mobile node moves to a new network. The theoretical and analytical results show that the performance of the scheme is better than the existing methods.**

Keywords-Mobile IPv6; Network Mobility; Proxy based Mobile IPv6; Wireless Personal Area Network; 6LoWPAN

I. Introduction

The proliferation of devices in recent years has enabled people to expect services to be seamless even when they are moving from one network to another. Knowing this would be required, IETF has proposed MIPv6 [1] that provides IP layer handover. Since then, few more standards have emerged to cater for different solutions. Some of the mobility solutions that emerged after the introduction of MIPv6 are Fast MIPv6 [3], Network Mobility [2] and Proxy Mobility [4]. These different types of mobility solutions uses different network setup and for different use cases. It has been proven by some studies that implementations of these standards results in poor handover latency and excessive signaling [12]. This lead to a number of new schemes to improve handoff performance. It was expected that the original mobility standards could be used for wireless personal area network (WPAN) [1]; but due to its excessive signaling, new frameworks have been established.

WPAN usually consists of large number of end devices, which has very low processing, low memory and depends on battery for operation. Wireless Sensor Network (WSN) end devices, which is part of WPANs, have two components; one is the sensor used to sense some parameters and the other component is the communication interface. Once the parameter is sensed, the data is forwarded to a border router either in single hop transmission or using multihop. Single hop implementation is simple and doesn't require routing protocol as in multihop. In multihop implementation, the intermediate nodes would consume more power than end nodes because they need to route packets received from multiple end nodes. Hence, reducing the number of overhead messages would reduce some amount of power consumption.

IPv6 over low power personal area network (6LoWPAN) working group [5] was established so that these LoWPAN devices would be able to communicate with other Internet devices using IPv6 protocol. This breaks the traditional way of communication for LoWPAN that was thought incapable to connect to the Internet. Two initial proposed standards under the working group that uses adaptation layer between the MAC and Network layer have changed the way WPAN communicate with external networks. This was considered as one of the main standards to be used in the Internet of Things (IoT) technology. It is anticipated that devices in IoT would be highly mobile compared to most of the existing deployment. Thus a better mobility solution is required for both IP and non-IP devices in IoT.

Since the nodes in WPAN would have limited resources, the large code size of existing MIPv6 would be unjustifiable. Besides that, the traffic exchanges caused by MIPv6 would be very high and it would be too much for low-bandwidth wireless links. Hence, the existing methods have to be updated. There are various solutions proposed that uses either host-based or network-based mobility. This paper proposes a new way of communication for mobile WPAN devices that reduces the number of signaling in the system. The problems being tackled in this paper are:

- Existing mobility solution is not suitable to be used for LoWPAN devices hence a new approach has to be devised.
- Signaling overhead between the mobile node and the gateway is high and is not suitable for WSN nodes which depends on battery power and has low processing capability.

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The objectives of this paper are:

- To design a method for low power personal area network (LoWPAN) devices that will have mobility support.
- To define the communication mechanism between edge routers to enable mobility for the nodes that would reduce the number of signaling messages.

The paper is organised as follows. Section II provides an overview of mobility models. Section III discusses the existing solutions specifically focusing on mobility for WPAN. Section IV provides the proposed framework and method. Section V provides the theoretical and analytical analysis while Section VI gives the implementation scenarios. Finally, conclusion and future work is presented in Section VII.

II. IPv6 Mobility

Mobility protocol for IPv6 has been divided into two broad categories, based on the role of the Mobile Node (MN) and the Edge Router. There are host-based mobility and network-based mobility.

- **Host-based mobility**: There are three components in host-based mobility; the MN, gateway (edge router) and Home Agent (HA). In this approach, the MN must have mobility stack that informs the gateway of its presence as specified in RFC6275 [1]. MN is configured to have global IPv6 address and whenever it moves to a new network, it would be configured with new address (care-of-address (CoA)) based on the prefix advertised in the network. This new address is registered at the HA so that packets destined to MN would be forwarded appropriately. HA, which resides in the home network of the MN, will intercepts packets that are destined to MN and forwards it to the new CoA of MN. MN would then directly communicates with the CN. The signaling for this host-based mobility is given in Figure 1. Since WPAN devices are resource constraint, this solution would not be appropriate as it involve lots of signaling between MN and the gateway.
- **Network-based mobility**: In this approach, the MN is not required to have mobility stack. Instead, an agent would help to inform the other components about MN's movement. This agent usually placed together with the gateway, so that whenever a new node registers, the gateway can immediately process the required information. One of the standard in this category is Proxy-based MIPv6 [4]. Few components are involved in PMIPv6; Mobile Access Gateway (MAG) that is the gateway that provide all the signaling on behalf of the MN, Local Mobility Anchor (LMA) maintains the movements of MN. When MN moves to a new network, MAG would forward MN's information to the LMA. LMA acts like the HA, which intercepts packets and forwards to the appropriate MAG using a tunnel, which was created earlier. The MAG would then sends the packet to the MN.

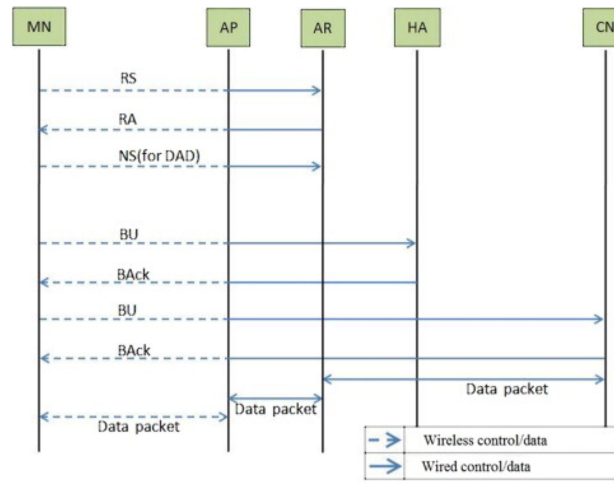

Figure 1. Signaling flow of inter-domain handover using MIPv6 [6]

Mobility of MN can also be categorized as micro mobility or Intra Personal Area Network (PAN) mobility and macro mobility or referred as Inter PAN Mobility in WPAN. In micro mobility, there is no change in the network layer address of the MN while in macro, the MN would have a new address.

Currently, there are many issues in Mobility solutions, such as high percentage of packet loss, excessive signaling, long handoff latency, high power consumption and topology issues [10]. In wireless personal area network, the issues maybe different for various types of implementations and have to be tackled on a case by case basis.

III. Existing Mobility Solutions

Due to the characteristics of WPAN nodes, the existing host-based mobility solutions are not suitable to be used. These protocols requires excessive control signals from MN to the edge router and also to the home agent. Since communication uses large amount of energy, these host-based mobility protocols are not used as it is in 6LoWPAN. To reduce the role of MN in mobility, PMIPv6 [4] was created. The mobile anchor gateway (MAG) process the control messages on behalf of the MN. When a MN moves to a new network, MAG sends the MN information to the local mobility anchor (LMA). This is achieved by using the network layer and an additional tunnel between LMA and MAG has to be established. In this way, MN does not involve in the mobility process. Each LMA would serve multiple MAGs and the same prefix can be used by MN while roaming under the same LMA. It was stated that the design of a new protocol for mobility remained an open issue and further research is required to provide mobility support for resource constrained devices in WPAN [7].

Under the IETF 6LoWPAN working group, there was a proposal that provides the mobility scenarios, the main challenges and security issues [8]. There was another proposed IETF draft that provides mobility support in 6LoWPAN [9].

There are few solutions proposed for WSN based on the existing mobility stacks. In Sensor Proxy Mobile IPv6 (SPMIPv6) [12], few new components has been added to the existing PMIPv6, which are sensor LMA (SLMA) and sensor MAG (SMAG). SLMA is a powerful device that acts as topological anchor for its entire groups of SMAGs and sensor nodes, which reports to LMA. SLMA keeps binding cache entry for each sensor node in its domain and information of SMAGs table. SMAGs acts like a sink node and responsible to detect the movement of sensor nodes and handle mobility related signaling with the SLMA on behalf of the nodes. In this solution, extra devices have to be configured and added into the architecture. Another solution, based on PMIPv6 and an enhanced architecture for SPMIPv6, is cluster-based proxy mobile IPv6 for IP-WSNs [13]. In the proposed solution, the MAGs are grouped into clusters, each with a distinguished cluster Head MAG (HMAG). The new layer in the existing PMIPv6 is to reduce the load on LMA by performing intra-cluster handoff signaling and providing an optimized path for data communications.

Inter-MARIO [11], designed with a make-before-break method, is another solution that requires many static nodes in the network. In the solution, the partner node, which serves as an access point for the MN, pre-configures the future handover of the MN by sending MN's information to candidate neighbor PANs and providing neighbor PAN information to the MN. In this schemes, MN movement has to be predicted so that information pertaining to the MN can be send to the appropriate access points.

A network-based mobility that was proposed for WSN is LoWMob [15]. Similar to Inter-MARIO setup, LoWMob also uses static nodes to relay MN movement information to the gateway. Another solution that uses cluster tree that only uses the node ID to communicate with the head cluster is given in [14]. The control information interaction for both the mobility handoff and the tunnel establishment is performed at the link layer, hence it is claimed that the control information is smaller and the delay time taken to transmit this information is shorter.

IV. System Design of Node Mobility

The proposed system uses less devices to make it easier for implementation and would have lesser signaling. Design of the new proposed system is based on the combination of host-based mobility and network-based mobility. It is because both the mobile node (MN) and the Edge Router (ER) or border router has to work together to provide mobility support but the mobile node would have reduced functionality compared to system in pure host-based mobility, but unlike PMIPv6 in which MN doesn't involve in signaling. Because of this, signaling from the MN to ER would be reduced and this results in lesser power usage by the MN compared to MIPv6.

Our solution consists of MN and ERs and involves both link layer and network layer communication. Network diagram for the proposed solution is given in Figure 2.

In our solution, it is assumed that the first connected network is the home network and nodes information is stored in the Home Edge Router (HER). When a mobile node discovers its HER and associates to it, the HER will send its IP address to the MN. The HER will update its PAN table and record the details of the node. MN would also keep HER address to be used when it moves to new network.

Both HER and visited ER keep all the information of MNs in a table, which consists of the followings:

- Node ID: ID of the MN within the PAN related to the Edge Router. Since the solution is for various types of standards, the node ID has to be unique and a method for node identification and naming is being researched separately. We may combine this field and MAC field in the future as both can be used for identification and addressing.
- MAC: MAC address of the mobile node within the PAN related to the Edge Router. Since the solution is for IP and non-IP devices, some other identification system would be used such as RFID identification for RFID devices. For non-IP devices, the MAC address or unique identification would be mapped to the global IPv6 address that was given to it by the HER.
- Edge Router IP: The visited/home Edge Router's IPv4/IPv6 address.
- Home Edge Router IP: The Home Edge Router's IPv4 / IPv6 address, which the mobile node has recorded.
- Corresponded Node: A node address that communicates with the MN through HER or ER.
- MN IP: MN IP is generated by attaching the MAC address to the prefix used for LoWPAN network. The process of registering of creating this is explained 6LoWPAN Gateway given in [16].

An example of updated table at HER is given in Table I.

HER also acts as the home agent as in MIPv6, that is to capture packets from corresponding node and tunnel it to the new edge router the MN connected.

Table I
Home Edge Router Initial Table

Node ID	MAC	ER IPv6	HER IPv6	MN IP	CR
MN 1	a:a:a:a	b:b:b:b	b:b:b:b	z:z:z:z	x:x:x:x

When the MN moves to a new PAN (visited PAN) and associate to the ER, the ER of the visited PAN will record

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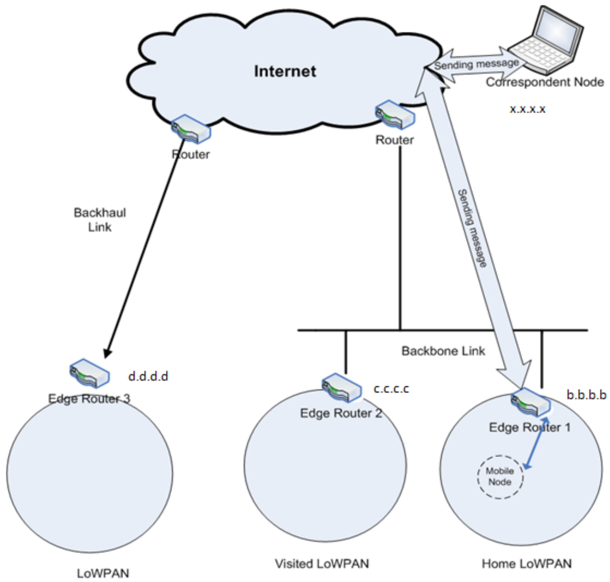

Figure 2. Overall Network consists of MN, HER, ER and CN

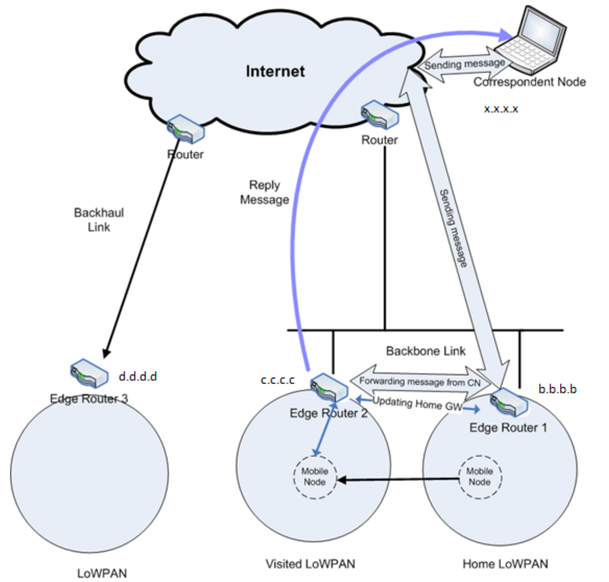

Figure 3. MN moves to new PAN

the details of the mobile node. This is executed using the methods available now, which is using layer two node association and neighbor discovery messages. Once the MN associated to the new ER, it will send the IP address of its HER to the visited ER. The ER will update its table and at the same time send an update to the HER informing that MN is now attached to the new ER. The HER will update its PAN table with the updated information. Table II shows the new information updated in new ER, while Table III shows the updated information in HER. The network diagram is represented in Figure 3 and the proposed new message flow is given in Figure 4. As shown in Figure 4, the MN attaches to new ER using the same registration as in when the MN attaches to HN. Once the link layer attachment is completed, MN would registers its HER address to the new ER. New ER, which has the HER address, would then send the location of MN and get it updated in the HER database. If there is a packet destined for MN from a CN, the HER would intercept, encapsulate the packet and then forwards it to the new ER. New ER would then decapsulate and forwards the packet to MN. This new flow of messages eliminates the binding update from AR to HA as in MIPv6.

When the MN moves to another new ER, the same process is executed. Since HER already has the ER entry in the table, HER would first inform the previous ER to remove the MN entry and then update the table with the new ER address information.

The CN will send the request messages destined for the mobile node to the HER. HER will encapsulate the request message and forward the request message to the visited PAN ER based on the details in the PAN table. The ER of the visited PAN will send all the messages from the mobile node

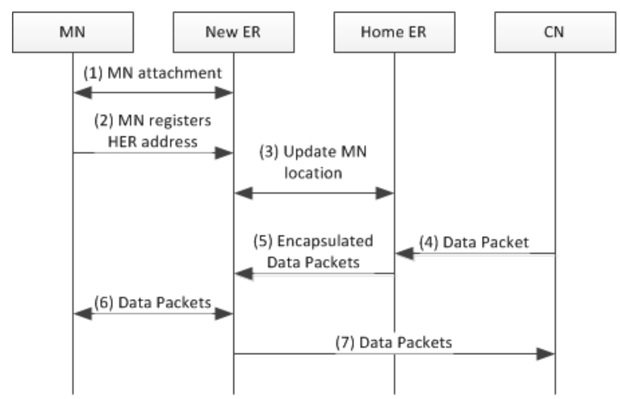

Figure 4. New Mobility Message Flow

Table II
EDGE ROUTER 2 TABLE AFTER NODE MOVED

Node ID	MAC	ER IPv6	HER IPv6	MN IP	CR
MN 1	a:a:a:a	c:c:c:c	b:b:b:b	p:p:p:p	x:x:x:x

Table III
HOME EDGE ROUTER TABLE AFTER NODE MOVED

Node ID	MAC	ER IPv6	HER IPv6	MN IP	CR
MN 1	a:a:a:a:a	c:c:c:c	b:b:b:b	p:p:p:p	x:x:x:x

to the correspondent node of the mobile node based on the PAN table.

The MN address will change every time it moves to new network, however the permanent address to outside world would be the one registered at HER. The network diagram with the address for each is given in Figure 5.

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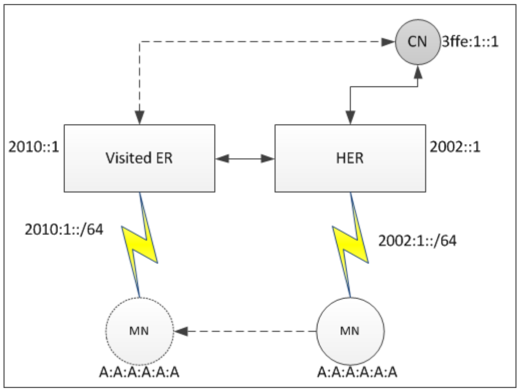

Figure 5. Network Diagram with Addressing configuration

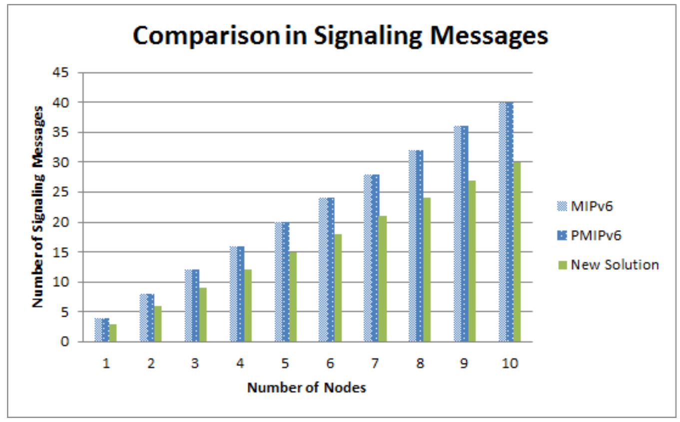

Figure 6. Comparison of Signaling Messages

V. Theoretical and Analytical measurement

The solution that we propose is analysed in terms of signaling and scalability and compared with MIPv6 and PMIPv6.

Comparison between our solution with MIPv6:

- In MIPv6, all the signaling is from the MN starting from registration in the new network until binding to the HA as shown in Figure 1, whereas in our solution, MN only registers to the new network and all other signaling is executed by the ER on behalf of the MN. This reduces the involvement of MN in exchanging messages, which further reduces the power comsumption.

Comparison between our solution with PMIPv6:

- In PMIPv6, MN's movement is registered to the MAG, which then informs the LMA. Packets are intercepted at the LMA before being tunneled to MAG. In our solution, the ER would directly informs the HER of the MN attachment, so it can be deployed in any network and easily scalable. PMIPv6 cannot support inter-domain handover, but in our solution, new ER directly communicates with the HER in any domain it operates.

We use a simple analytical model to analyze the signaling. The following notations and assumptions are used:

t_a = the signal message from MN to ER or MAG

t_b = signal from ER to HER or HA or LMA

With the assumption that the signaling weight is the same and there is no authentication involved, the total signaling cost (sc) from the time the MN attached to new edge router until acknowledgment received from the HA or LMA or HER for MIPv6, PMIPv6 and our solution are given below. Some of the signaling cost has been combined as one unit such as for MN association.

$MIPv6_{sc}$ = signal from MN to AR (Association) + signal from AR to HA (Binding Update)+ signal from HA to AR (Binding Acknowledgement)+ signal from AR to MN (Binding Acknowledgement)

$$MIPv6_{sc} = 2t_a + 2t_b \quad (1)$$

PMIPv6$_(sc)$ = signal from MN to MAG (Association) + signal from MAG to LMA (Node update) + signal from LMA to MAG (Acknowledgement) + signal from LMA to MAG (Tunnel creation)

$$PMIPv6_{sc} = t_a + 3t_b \quad (2)$$

Our solution$_{sc}$ = signal from MN to ER (Association) + signal from ER to HER (Node update) + signal from HER to ER (Acknowledgement)

$$Oursolution_{sc} = t_a + 2t_b \quad (3)$$

Based on the signaling messages given, the total number of signaling messages is lesser in our proposed solution compared to the MIPv6 and PMIPv6. This is shown in Figure 6 with the value of t_a and t_b as 1 each.

VI. Implementation

The system has been implemented as proof of concept for patient movement monitoring. For that, a testbed was created. We used the WSN node as the MN for patients. The nodes that are used are Sensinode WSN node which is loaded with Nanostack OS. The nodes are configured with the signaling format that was detailed earlier. Three laptops were used as the home router and edge routers. These laptops are configured to run on Ubuntu OS with Nano Router. Nano Router is an USB device that is attached to one of the available USB port in the laptop. The testbed for this implementation is given in Figure 7 .

The out patient treatment room could be the MN's home network. Edge routers can be placed in each room and whenever the patient moved out to another room, the MN

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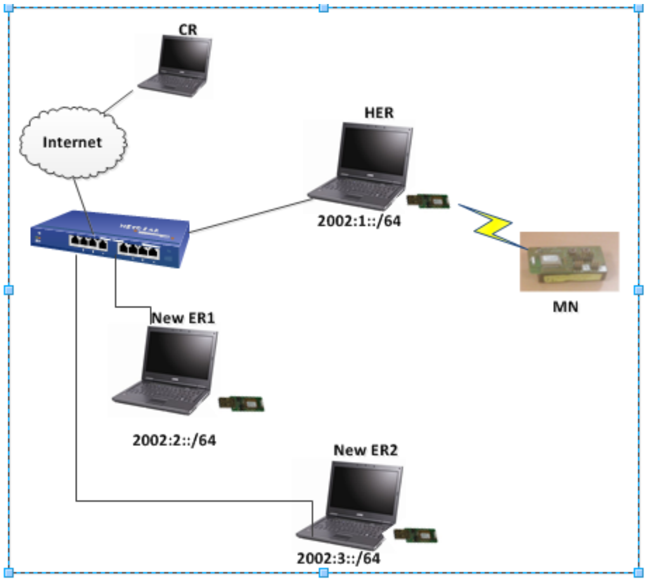

Figure 7. Testbed for validating the mobility scheme

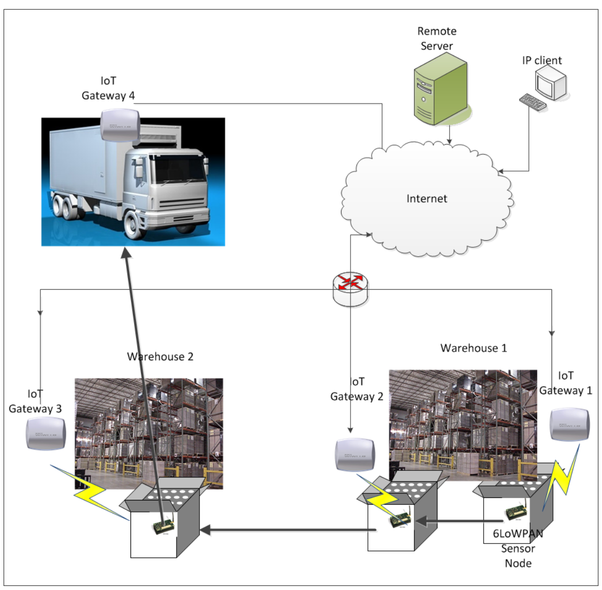

Figure 8. Implementation of Mobility solution in Logistics

would attach to the new ER, which would then inform the HER.

The mobile node successfully communicated with the correspondent node even when the MN attaches to New ER1 and New ER2. Measurements are not discussed in this paper.

Another use case that this system can be used for is for tracking goods in a warehouse until it is transported as shown in Figure 8.

VII. Conclusion and Future Work

In this paper, the new method of handling WPAN nodes mobility was introduced. The solution proposed is for both IP and non-IP devices and this would be suitable to be used in IoT scenarios, which comprises of multiple standards. The non-IP devices such as RFID, are given unique IP addresses at the gateway.

Based on the theoretical and analytical studies, the signal messages is lesser compared to MIPv6 and PMIPv6. The differences of these signaling messages is same as the total number of nodes in the network if the value for t_a and t_b are 1 each.

Future work consists of implementation of authentication between the MN and the edge router and QoS of packets. Besides that, the node ID and MAC address would be combined and used as one field with the inclusion of identification and naming method. Handover delay need to be measured as well to determine if it is better than other solutions.

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