A Survey on Mobility Management Protocols in Wireless Sensor Network-internet Protocol

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Abstract

This paper is intended to contribute towards diverse solutions of developing current issues in WSN-IP mobility management. A survey of mobility protocols, proposed by the Internet Engineering Task Force, and their corresponding derivations are presented. These protocols are classified based on host-based, net-based and NEMO. A qualitative comparison of protocols, in terms of macro-mobility, micro-mobility and hand-off approaches is provided. As WSNs are resource constrained, network-based mobility management schemes are more efficient for this network, because the network-based mobility decreases handoff latency and transmission cost by avoiding the participation of all nodes in mobility process separately.

Keywords: Host-based mobility, Mobility Management, Net-based, Wireless Sensor Network-Internet Protocol (WSN-IP)

1. Introduction

Wireless Sensor Network (WSN) is a collection of nodes, each of which has sensor functions1,2. The entry of WSN has made a remarkable development in the communication field3,4. By rapidly growing of the Internet of Things (IOT), the demand of Integration of Internet Protocol (IP) in WSNs has also been increasing. However, the static character of nodes in primitive WSNs is no more desirable in WSN-IP network as many critical applications such as healthcare, military and transportation systems appeal mobility. Because the current methods of conventional WSN are not suitable for WSN-IP, essential mechanisms are needed in order to keep communication continuity and to reduce the packet loss in this platform since high level of reliability and performance are demanded in critical applications. In Tunnel-based mobility standards which are common in WSNs, mobile nodes send and receive a large number of control information, carrying IPV6 header is transmitted in the network layer. This process however enforces extensive energy consumption in low power WSN5. Thus, significant designs and developments in WSNs-IP are needed to manage mobility by considering energy consumption.

The main objective of this research is to contribute towards the solutions of developing current issues in WSN-IP mobility management including handoff latency, Packet loss, load balancing, binding requests scheduling and energy dissipation. To substantiate the proposed research direction, next section reviews in details the pertinent works in this area. A comparison of protocols is then provided. Conclusion is extended in section IV.

2. Literature Review

In order to achieve a seamless connectivity, managing mobility is considered as a crucial issue6. This mobility can happen either on a single Mobile Node (MN) or a collection of MNs together. If a single MN moves, it is called terminal mobility7, but many application scenarios
demand group mobility when a collection of MNs moves together as a single unite. A group mobility of MNs is called Network Mobility (NEMO)\(^8,9\). This mobility can be managed by the MNs, called host-based. On the other hand, in the network-based mobility, this is the task of some entities to be responsible for detection and management of mobility in the network. It should be noted that the host-based mobility is not efficient for WSN, because of all MNs participating in the mobility signaling that result a higher level of energy consumption and long handoff latency. The network-based mobility relieves the MNs from participating in the hand off process which reduces mobility and signaling cost as well as handoff latency, subsequently reducing power consumption. The mentioned taxonomy and the protocols which overlap between these groups are shown in Figure 1 and Figure 2 respectively.

MIPv6 adaptation model for low PANs and mobile nodes soft handoff. The node discovery refers to detect whether the mote is within the network range. The soft handoff refers to a feature which a node simultaneously connected to more than two domains. The signal related to the best of all used channels can be used in the state of soft hand-off. The proposed mechanism for mobility detection is based on the RSSI value, which is the link metric\(^13\), provided by it connects to a foreign network. Nodes’ location information is sent to a home agent when they connect to a foreign network. The home agent then tunnels packet to their current location. MIPv6 leads to involve all MNs in mobility signaling including mobility messages (i.e. binding updates and binding acknowledgments). Thus, it is not efficient in low power WSN as it suffers from high signaling overhead, long handoff latency and high packet loss ratio\(^14\). Therefore, some extensions of MIPv6 such as LOW-MIPv6 and Fast Handovers for Mobile IPv6 (FMIPv6) have been introduced with the aim of addressing these issues.

LOW-MIPv6 has been proposed by Silva et al.\(^12\) in which a set of mechanisms has been presented in order to make sensor networks adaptable and flexible solutions for different applications. These mechanisms include alternative solutions for dynamic node and service discovery.

### 2.1 Host-based Mobility

The rapid growth of supporting mobile connections to the Internet has been developed by Mobile IPv6 (MIPv6)\(^10\) protocol updated by the IETF (Internet Engineering Task Force). This protocol is a host-based mobility which enables an MN to maintain its connections during moving. Although home address is used to identify each device, an MN has a Care-of-Address (CoA) for the time it connects to a foreign network. Nodes' location information is sent to a home agent when they connect to a foreign network. The home agent then tunnels packet to their current location. MIPv6 leads to involve all MNs in mobility signaling including mobility messages (i.e. binding updates and binding acknowledgments). Thus, it is not efficient in low power WSN as it suffers from high signaling overhead, long handoff latency and high packet loss ratio\(^14\). Therefore, some extensions of MIPv6 such as LOW-MIPv6 and Fast Handovers for Mobile IPv6 (FMIPv6) have been introduced with the aim of addressing these issues.

LOW-MIPv6 has been proposed by Silva et al.\(^12\) in which a set of mechanisms has been presented in order to make sensor networks adaptable and flexible solutions for different applications. These mechanisms include alternative solutions for dynamic node and service discovery,
IEEE802.15.4. This value is used with the objective to detect when the mote is moving by comparing the RSSI of the exchanged messages. This point is defined as a rupture, or R-point. However, there is a critical point in which motes must connect to new Sink before reaching to R-point, called C-point. This is the area between C and R called critical area, in which motes must start hand-off process. The rest of the process are supported with the MIPv6 including the return route ability. However, some adaptations were deployed by the proposed protocol in order to address some part of MIPv6 issues. These adaptations refer to compressing, suppressing and coding fields of the original packets, in order to decrease each message size. Realistic test-bed is used to implement and evaluate all the proposed mechanisms and approaches. The proposed mechanisms aim to improve and optimize the handoff time and control latencies and packet losses.

Fast Handovers for Mobile IPv6 (FMIPv6) is another extension of MIPv6 which aims to improve handover latency. This protocol enables an MN to discover available access points and to request their subnet information, while it is still connected to current subnet. The Router Solicitation for Proxy Advertisement (RtSolPr) message is sent by the MN to Previous Access Router (PAR) after gaining one or more nearby access points. The RtSolPr message contains one or more Layer 2 identifier(s) to resolve the New Access Router (NAR)’s Layer 3 information. Then, the PAR replies Proxy Router Advertisement (PrRtAdv) message which contains one or more Access Point-ID (AP-ID) and ARInfo. With the provided information by the PrRtAdv message, the MN formulates a New Care-of Address (NCoA) for when it attaches to the NAR. The MN sends a Fast Binding Update (FBU) message after the Address Auto configuration procedure with the aim of binding the Previous CoA (PCoA) with the NCoA. Therefore, the destined packets to the PCoA will be tunneled to the NCoA during MN’s hand over. This tunnel helps to reduce the Binding Update latency. There are two operation modes regarding unpredictability of MN’s mobility. If a Fast Binding Acknowledgment (FBack) message is received through the PAR’s link, it is predictive mode, but if it is received through the NAR’s link, it is in the reactive mode. The predictive FMIPv6 shows better handoff performance against the MIPv6, however, it still suffers from the long end to-end delay and the handover disruption period due to the IEEE 802.11 MAC layer handover.

2.2 Net-based Mobility
Proxy mobility IPV6 (PMIPv6) is another extension of MIPv6. This network-based mobility added two functional entities including Local Mobility Anchor (LMA) and Mobility Access Gateway (MAG) in order to address host-based associated problems. While MAG detects MNs movement and registers the MN with LMA, LMA is responsible to maintain MNs’ reachability during their moves within local PMIPv6. MAG sets up the required signals with the Authentication, Authorization and Accounting (AAA) server for obtaining secure mobility, however, this protocol still suffers from some issues such as single-hop communication due to the constraints of each node to communicate with its point of attachment. Additionally, the control information between LMA and MAG are in the network layer which increase power consumption.

In MIPv6, all MNs participate in signaling messages that involve extensive processing and resources. This protocol also updates external nodes from domain with local and global mobility, even though, it is not essential for an external MN to be updated by local mobility. This update leads to energy waste in low power WSN. Therefore, an extension of the MIPv6 called Hierarchical Mobile IPv6 (HMIPv6) proposed by IETF, has been designed with the aim of reducing the required signaling and improving handoff speed for mobile node. This protocol added a new node called the Mobility Anchor Point (MAP) in order to manage local mobility and address MIPv6 issue. Since updates in local MAP occur faster that remote home agent, this approach tends to reduce handoff-latency by separating local and global mobility. This tree structure provides a scalable service, but it leads to additional packet processing overhead that are required to be addressed.

An energy efficient mobility management protocol based on PMIPv6 called Sensor Proxy Mobile IPv6 (SPMIPv6) was proposed by Islam and Huh for WSN-IP. The proposed architecture for SPMIPv6 includes a Sensor Network-based Localized Mobility Anchor (SLMA), a Sensor Network-based Mobile Access Gateway (SMAG) and many fully functional IPv6 header stack enabled IP sensor nodes. Maintaining accessibility to a sensor node during node movement either within or outside of the SPMIPv6 domain is the main role of the SLMA. The SLMA contains a binding cache entry for each sensor node which is used to hold
mobile sensor node's information. The SMAG acts like an access gateway router which detects node movement and sets up related signals with node's SLMA. In SPMIPv6, AAA service has been integrated within SLMA called sensor network based authentication, authorization, and accounting (SAAA) schemes. Each fully functional node authentication is facilitated with the SAAA scheme services. The simulation results indicate that the proposed scheme reduces the signaling cost as well as the mobility cost against MIPv6 and PMIPv6, showing that the level of energy consumption has been reduced significantly. However, since this method still depends on a central entity such as LMA, it can suffer from some inherited problems form PMIPv6 such as bottleneck problem, handoff latency and load balancing and binding requests scheduling. These issues have been addressed by Clustered SPMIPv6 (CSPMIPv6) protocol.

In the proposed CSPMIPv6 architecture by Jabir et al., the MAGs are classified into clusters with one Head MAG (HMAG). The HMGA is one of the MAGs, functioning as a Cluster Head (CH). The main role of the HMAG is to perform intra-cluster handoff signaling and to provide an optimized path for data communications with the aim of reducing load on LMA. In addition, the HMAG could provide buffering schemes for MNs during the handoff process, which also deploy strategies to make balance between the MAGs’ load, as well as scheduling the MAG’s binding requests. The LMA and MAGs in CSPMIPv6 have similar roles to those in SPMIPv6. The numerical and analysis results show that the proposed CSPMIPv6 have better performance against the PMIPv6 and the SPMIPv6 in terms of local handoff latency, the LMA load, and transmission cost.

2.3 Sensor-group Mobility

Network Mobility Basic Support Protocol (NEMO-BSP) is an extension of MIPV6 that manage mobility for entire network. This protocol enables mobile networks to be attached to different points in the Internet. It also makes Mobile Network Nodes (MNNs) reachable during moving, with one or more mobile router(s) connecting network to the Internet. This way, traffic is not transited by MNNs, because these nodes are not aware of the network's mobility. There are different types of nodes inside the mobile network including (i) Local Fixed Node (LFN), which is always in a same mobile network, (ii) Local Mobile Node (LMN), which usually resides in the mobile network and is not able to move to other networks, (iii) Visiting Mobile Node (VMN), which moves and are attached to the mobile network from another network, and (iv) MR, which can be an MNN to form a nested mobile network. The LFNs do not need to perform binding update because of the transparency of the network mobility. This reduces the handoff signaling overhead. Moreover, the handoff for the VMNs has a better performance due to its simplified binding update procedure. However, NEMO-BSP inherits all drawbacks of MIPV6 such as inefficient routing path, increased packet overhead, high packet loss and high handover latency. Packets routing through the home agent of the mobile router, encapsulating packet twice and the single point of failure are the reasons for inefficient routing path, increased packet overhead and high packet loss respectively. NEMO-BSP also shows the large handover latency when the signaling messages are lost due to instability of the wireless link. Therefore, different derivations are released to overcome these disadvantages.

Proxy Network Mobility Protocol (PNEMO) is an extension of NEMO protocol established on network-based Localized mobility management. In PNEMO, wired network handles mobility management; therefore, when handover occurs, the signaling messages are not carried on the wireless link. This leads to make handover stable even during instability of wireless. PNEMO is implemented in Linux and the tested network shows that the handover latency is almost constant even if the wireless link is unstable. It also indicates that the overhead of PNEMO is negligible against NEMO-BSP. In PNEMO, it is not essential to establish a tunnel for data packet forwarding as the tunneling only uses between the LMA and the MAG and is not used on the wireless link. Subsequently, tunneling overhead is reduced.

An IP diversity-based network mobility management scheme named Seamless IP-diversity-based Network Mobility (SINEMO) was proposed by Chowdhury et al. This protocol is an extension of Seamless IP diversity based Mobility Management Architecture (SIGMA), which handle the mobility of a single mobile host in IP networks mobility, While the mobility of entire network is supported by SINEMO. Seamless handover between nearby Access Points (Aps) by exploiting IP diversity is likewise handled by this procedure. The definition of “IP diversity” is keeping old path alive, while new path
is being set up. In this concept, each node has multiple IP addresses. Because the mobility is transparent for nodes in SINEMO protocol, diverse advantages against NEMO-BSP is also provided. Due to the absence of tunneling, this protocol utilized bandwidth and reduces latency and packet loss during handover. Despite of the NEMO-BSP which is a network layer solution, SINEMO is an end-to-end solution \(^6\).

The mobility management can also be divided into two categories including macro mobility and micro mobility\(^{18,26}\). Macro mobility is a term that refers to the procedure in which an MN or MR moves between different domains. In the other hand, micro mobility explains local mobility in a domain. Micro mobility concept was proposed with the aim of improving performance for mobile Internet users because of its ability in reducing the number of Binding Updates (BUs) to the distant HAs and handoff latency. Therefore, the main idea of Micro-NEMO scheme proposed by Hu et al.\(^{27}\) is to bring the concept of micro-mobility into NEMO protocol. This protocol maintains characteristics of both micro-mobility and NEMO protocols. The Micro-NEMO protocol is an extension of HMIPv6, which consequently suffers from single point failure issue. In that sense, Micro-NEMO++ was proposed in order to address this problem\(^6\). A single micro domain in micro-NEMO++ is composed of two micro domain of micro-NEMO. In the proposed scheme, each Access Router (AR) is indirectly connected to two MAPs. This approach guarantees supplying of requests, until the failed MAP is replaced. Results show that micro-NEMO++ has the same cost of deployment as Micro-NEMO. Additionally, numerical results indicate that micro-NEMO++ has low signaling overhead and achieves low average handoff latency against the NEMO-BSP and micro-NEMO protocol.

### 3. A Comparison of Protocols

Different protocols have been studied in the field of mobility management, each of which meets diverse demands by applications. The purpose of proposing host-based mobility as standardized by IETF, has been to maintain connectivity during movement, however, host-based protocols are yet not suitable for WSN with limited resources, due to the participation of all mobile node in the signaling process. The IETF has standardized an extension of MIPV6 called PMIPv6 with the aim of address host-based mobility issues. In this net-based mobility and other related derivations, it is the responsibility of the network to implement mobility processes which avoid all nodes to participate in processing. NEMO is another extension of MIPV6 proposed by IETF in order to cover group mobility such as train or vehicles’ movement. It also could reduce handoff signaling against MIPV6, however, this still inherits the weakness from MIPV6 such as long signaling delay and movement detection time\(^{29}\). Different derivations for this protocol have been proposed to

![Figure 2. Comparison of mobility management protocols.](image-url)
address its associated issues as discussed in previous section in details.

Another classification for Mobility management based on MNs movement between or within domains is Micro-mobility and Macro-Mobility, also known as Intra-domain and Inter-domain mobility respectively. Proposed protocols for Macro-mobility solutions are not suitable for Micro-mobility. These protocols can degrade performance by increasing the number of BUs to the distant HAs and handoff latency. Therefore, other protocols, such as Micro-NEMO and Micro-NEMO++ have been proposed to address the related issues.

Mobility handoff is performed in two ways: soft and hard handoff. Soft handoff refers to when the MNs keep the previous connection while it is setting up a new connection. In hard handoff, the MNs have to break up the previous connection and then establish a new connection. In soft handoff, delay can be increased but minimizing packet loss is decreased. Despite of the soft handoff, the delay and signaling decreases in hard handoff but the packet loss is increased. A comparison of studied mobility management protocols are proposed based on the above mentioned characterizes in Table 1.

### Table 1. A comparison of mobility management protocols

| Protocols | Host-based | Net-based | NEMO | Soft-Handoff | Hard-handoff | Micro mobility | Macro mobility |
|-----------|------------|-----------|------|--------------|--------------|----------------|----------------|
| MIPV6     | ✓          |           |      | ✓            | ✓            |                |                |
| Low-MIPV6 | ✓          |           |      | ✓            | ✓            |                |                |
| FMIPv6    | ✓          |           |      | ✓            |              |                |                |
| HMIPv6    | ✓          | ✓         |      | ✓            |              |                |                |
| PMIPv6    | ✓          |           |      |              | ✓            |                |                |
| SPMIPv6   | ✓          |           |      |              | ✓            |                |                |
| CSMPV6    | ✓          |           |      |              | ✓            | ✓              |                |
| NEMO      | ✓          |           |      |              | ✓            |                |                |
| PNEMO     | ✓          | ✓         |      |              |              |                |                |
| SINEMO    | ✓          |           |      | ✓            |              |                |                |
| Micro-NEMO| ✓          | ✓         |      | ✓            |              |                |                |
| Micro-NEMO++ | ✓    | ✓         |      | ✓            |              |                |                |

### 4. Conclusion

Effectively deploying IP in WSNs has demanded some adaptations such as mobility support and mobility management. In order to investigate the possible challenges in WSN-IP mobility management, this paper provided a qualitative comparison of mobility management protocols proposed by IETF and its derivations. The current issues and solutions were also discussed. The reviewed protocols of the mobility management were classified in this survey based on host-based, net-based and network mobility (NEMO). Additionally, analysis of the protocols regarding macro-mobility, micro-mobility and how they hand-off were provided. Considering limited resource nodes in WSN, network-based mobility management schemes are more efficient for this platform. The network-based mobility reduces signaling cost by relieving all nodes from participation in mobility process separately, resulting decreasing handoff latency and transmission cost. With respect to the proposed approaches for mobility management in WSN-IP, this field is still open for more discussion.
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