The advent of the Internet of Things where billions of devices are able to exchange their data to give a better control to users on their environment has led to the expansion of Wireless Sensor Networks (WSN). To address the specificities of WSN, standards on networking protocols for low power sensors such as 6LoWPAN have been developed. While 6LoWPAN is well suited to fixed-sensor WSN, it must be extended to better address mobile sensors. However, so far little effort has been devoted to the handling of mobile sensor node peculiarities. In this article, generic mobility scenarios are highlighted, existing mobility solutions based in Mobile IPv6 are reviewed and remaining challenges to handle mobile sensors properly are identified.

© 2015 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Conference Program Chairs

Keywords: Mobility Management, WSN, 6LOWPAN, RPL, Mobile IP
The objective of this paper is to present a state of the art of existing mobility management solutions in wireless sensor networks, considering particularly IPv6 ones. The paper reviews and identifies what challenges are left to address mobility in sensor networks properly.

This paper is organised as follows. Section 2 presents general mobility scenarios. Section 3 presents existing protocols for addressing mobility, focusing on Mobile IP (MIP) and its extensions. Section 4 explores the remaining challenges in supporting mobility in the context of low-power wireless sensor network focusing on the standard 6LoWPAN. Section 5 analyses how the current mobility situation in WSNs should be improved and what challenges must be solved to propose appropriate mobility solutions, and finally, section 6 concludes and projects on our future work.

2. Mobility scenarios

According to topology and application needs, classically two main types of node mobility need to be taken into account, micro and macro mobility. On the one hand, micro mobility, refers to node mobility within the same sensor network domain, as shown on Fig. 1(c). In 6LoWPAN Networks, micro mobility is identified by the mobility of a node into the same 6LoWPAN domain, where the address prefix remains unchanged. Thus, the mobility of such a node, changing its attachment point from an edge router to another within the same extended 6LoWPAN, is considered as a micro mobility. On the other hand, macro mobility refers to node mobility between different WSN domains, as shown on Fig. 1(a). In 6LoWPAN Networks, macro mobility is identified by the mobility of a node between different 6LoWPANs, where the domain address prefix changes. Hence, protocol dealing with mobility for 6LoWPAN networks must take into account these different mobility types, because of its impact on the prefix and then on the IPv6 address of the mobile nodes.

As we will detail more later in this paper, hybrid scenario must also be addressed where several WSN domains are under the control of the same operator, as shown on Fig. 2. Although a solution adapted to the macro scenario would work to address this hybrid scenario, a specific solution for WSN domains under the control of the same administrator can provide a more appropriate solution. In particular, when domains are adjacent to each other and mobile sensors frequently roam across these domains.

In addition to these main categories, mobility solutions should consider the state of the sensor in motion, i.e., if the mobility happens when the sensor is active or not. In the second case, represented on Fig. 1(b), the sensor wake in a new network and it should be able to connect to this new network and communicate.

Finally, it is worth mentioning that a scenario on the mobility of a whole WSN, e.g. a sensor network on a vehicle, is outside the scope of the solution presented in this article since it actually addresses the mobility of network border routers, which are continuously turned on and in most cases, have not energy supply problem. Solution for router mobility can already be addressed based on the standard mobile IP protocol described later.

3. Mobility protocol overview

There is no specific Mobility Support in IPv6, so, packets destined to a Mobile Node (MN) would not be able to be sent when it moves out of its original network. Indeed, the correspondent mobile node transmits packets to the former address which has become obsolete. To continue a communication despite its movements, a mobile node will get a new IPv6 address in the network. However this will not be enough to maintain level 3 communication continuity. On the other hand, the correspondent node receives packets from an unknown address, then the Correspondent Nodes
(CNs) will reset their session with the mobile node thinking that the packets have been transmitted by another node. To solve this problem, the Mobile IPv6 has been proposed.

In this paper we focus on Mobile IP for IPv6 (MIPv6)\(^2\,5\) and its extensions to deal with Mobility in 6LowPan networks, since MIPv6 is compatible with 6LoWPAN design. Mobile IPv6\(^2\) is an IETF standard that aims to manage IPv6 mobility at level 3. The purpose of this Protocol is to maintain the connectivity between MN and CN using an intermediate station known as the Home Agent (HA). When MN is in its home network, it uses its original address, known as MN home address, and communicate with peers using standard IPv6.

![Fig. 3. Mobile IP Principle](Image)

When MN moves from its home network to a visited network, as shown on Fig. 3, it gets a new temporary IPv6 address within that network. Then, that MN will notify its HA that its location has changed, and transmits its temporary address. A bidirectional tunnel IPv6 is established between MN and its Home Agent (represented with the red line on Fig. 3). So, the HA will redirect the traffic between MN (using its new temporary address) and its corresponding node, and vice versa. The Home Agent will intercept all arriving MN packets and redirect them via the tunnel, while MN is away from its home network.

From the CN point of view, there is no change, since the transmission of packets remains identical regardless of the MN new location. The reverse operation is carried out during the packets transmission to MN. Therefore, the mobility is completely seamless between MN and CN. The HA uses an association table to associate the home address of MN to its temporary address. Note that, to keep up to date the location of each MNs, MN and its home agent exchange Binding Update and Binding Acknowledgment messages. When MN leaves its home network to a new network (i.e. visited network), that MN obtains a new temporary address in the visited network, then it triggers the binding actions with its Home Agent.

Although MIP is the most popular Mobile protocol and also easy to deploy, it suffers from some limitations. We can notice a connection or a packets loss caused by the handover delay, mainly due to the time required for:

- Detecting the arrival of MN in a new network, based on receiving a router advertisement
- Acquiring a temporary address and verifying its uniqueness using the address duplication mechanism of the Neighbor Discovery Protocol
- Storing this temporary address in the home agent, which mainly depends on the Round Trip Time (RTT) between the MN and its HA.

In the following we present MIPv6 extensions which try to face these limitations.

### 3.1. The Fast handover for MIPv6

The Fast Handovers protocol for MIPv6 (FMIPv6) is a host based solution. The objective of FMIPv6\(^3\) is to reduce the handover latency at the Level 3 of MN. For this, MN can request information about surrounding access points. From this information, MN can anticipate the handover and thus transmit and receive packets when it reconnects to a network.

### 3.2. The Hierarchical MIPv6

The Hierarchical Mobile IPv6 (HMIPv6)\(^4\) is also a host based solution. HMIPv6\(^4\) also has the objective to reduce the handover latency using a new entity called "localized" in each domain. This entity acts as a local home agent, and thus, mask the signalling traffic during mobility within its domain. In addition, to reduce the registration latency,
HMIPv6 includes a mechanism to keep valid the temporary IPv6 address throughout the internal mobility of the MN inside a domain.

3.3. The Proxy MIPv6

Proxy Mobile IPv6 (PMIPv6)\textsuperscript{5,6} is a network based mobility support protocol. PMIPv6 uses a different approach than MIPv6 to support the mobility. Unlike Mobile IPv6, the movement of MN is totally transparent to its CN. Proxy MIPv6 uses a different architecture with a new equipment. This equipment, named ”mobile access gateway” will manage all signalling traffic (based on the Mobile IPv6) instead of MN. For this purpose, MN mobility is limited to a set of networks belonging to the same Proxy MIPv6 domain.

3.4. The Network mobility basic support

The Network mobility (NEMO) basic support\textsuperscript{7} is an IETF protocol that considers the mobility of an entire network. This protocol uses the same concept and architecture as MIPv6 but focuses the mobility management on the router’s wireless network, called mobile router. The mobile router transmits the different signalling messages on behalf of the network. The mobile router sends through the router advertisement messages a prefix that is the same while the network remains attached to the home agent. In order to reduce the signalling overhead, the Lightweight NEMO\textsuperscript{8} protocol uses a compressed mobility header. In the case where MN moves to another fixed or mobile networks, Nested NEMO is proposed\textsuperscript{9}.

3.5. Mobility Support issues in 6LoWPAN networks

To better understand the mobility support issues in WSN, we should first understand what could cause this mobility. A generic definition of the mobility corresponds to the change of the attachment point whatever the cause is. In WSN many reasons can cause this change, such as, physical movement, environment change which impact the radio channel, routers failure, and network performances (delay, packet loss, low signal) that may impact the topology\textsuperscript{5}.

Mobility in WSN is a natural evolution, the most basic networks do not support any kind of mobility, nodes must always be within range of their local access point. With larger deployments, the mobility has been included in networking protocols. For pure data collection protocols, the mobility is relatively trivial to implement, only the upward routes need to be updated. On the other hand, when bidirectional connectivity is required, more elaborated mobility support is needed, as broken downward routes could exist in the network if messaging packets are lost or missed.

As already mentioned in the introduction, we can classify the mobility of nodes in WSN into two main categories. The first one is micro-mobility, in which MNs stay within a given WSN domain. The second one is macro-mobility, in which MNs switch from one WSN domain to another. It should be stressed again that mobility often does not mean that the node is actually physically moving. Most of the time, a node need to update its communication path due to changes in the radio medium.

In WSNs based on 6LoWPAN, the micro-mobility is already handled intrinsically, all the modifications are handled within the 6LoWPAN layer and the IP layer is not impacted. In 6LoWPAN with ”mesh-under” routing protocol, the micro-mobility issues are hidden by the mesh routing protocol. In 6LoWPAN with ”route-over” routing protocol, the micro-mobility issues are handled explicitly by dynamically updating routing information. Depending on the actual routing protocol (RPL, LOADng, RIPng, ...), the update is done on routing tables of different intermediate nodes, or in the routing vector, or in the global routing table of the Edge Router.

When MN changes its attachment point, it is disconnected and is no more able to send or receive packets, which causes data loss and impacts seriously the functioning of applications. In addition, WSN based on 6LoWPAN technology imposes some particular constraints and requirements that should be considered to deal with mobility\textsuperscript{10}. The existing macro-mobility protocols can not be used blindly on 6LoWPAN network. Contrary to vanilla IPv6 networks, 6LoWPAN nodes can be in deep sleep and unreachable for long period of time. Since their resources are constrained and can not support complex protocols, the network is not reliable and easily congested. Also, the additional overhead on the data packet can lead to fragmentation. Taking all these parameters into account makes many existing mobility protocols ill-adapted to WSN in general, and 6LoWPAN networks in particular. More specifically, host-based mobility protocol, such as basic MIPv6, should be rejected, as the main burden of managing the mobility is taken in charge by the host and tunnelling is mandatory.

Reduce the handover delay and the packet loss are common challenges to mobility management. The resources management is a significant additional challenge to design a protocol dealing with mobility for WSN\textsuperscript{11}. The latter is closely associated to constraints such as limited resources of WSN with 6LoWPAN in terms of power, bandwidth, memory and processing capacity. So, it is important to significantly reduce the cost of signalling messages, overhead
communications and processing. Besides that, existing mechanisms used to reduce the energy consumption are not designed to support mobility constraints, thus, they must be adapted to this context.

The change of the attachment point of MN uses a movement detection mechanism which is a significant criterion to deal with for an efficient mobility management. In WSN with 6LoWPAN, it is necessary to perform the movement detection with a minimum signalling cost, power consumption and handover delay. Thus, to be efficient, we have to answer these two questions: Who performs the movement detection? and how?

Because of its limited resources and its possible deep sleep state, it is not recommended that an MN executes the movement detection to ensure good performances in signaling cost and power consumption. Hence, the movement should be instead detected by the edge router or other nodes in the network. On the other hand, to reduce the handover delay, the detection should be fast, so the movement will be detected on time.

For example, at first sight the mechanisms used by MIPv6 seem to fit perfectly in 6LoWPAN networks. MIPv6 defines two new types of messages (binding update and binding acknowledgment) that are contained in an 802.15.4 frame. The header mobility type binding update or a binding acknowledgment have a size of 12 bytes. Additionally, a binding update message contains a destination option that includes the node’s home address (20 bytes). Similarly, a binding post acknowledgment includes a routing header with a size of 12 bytes. These small messages can be contained in an 802.15.4 frame without any fragmentation need. However, the IPv6 in IPv6 encapsulation used for a bidirectional tunnel uses native functions of IPv6 that are always available in the adaptation layer 6LoWPAN. This encapsulation will leave less space for the transmitted data. Also, the signalling mechanism is performed by the host itself, increasing the resources needed.

3.6 Mobility Management Challenges

In this section we summarise the main challenges that a mobile protocol designed for WSN based on 6LoWPAN have to deal with. These networks have a great number of nodes and high resource constraints (limited power, bandwidth, memory ...). In addition, efficient solutions should provide a satisfactory Quality of Service (QoS) taking into account the 6LoWPAN requirements.9,12

Then, an efficient solution must ensure: less power consumption, less signalling cost, less handover, less end-to-end delay, reduce the data loss, handle security constraints, and scalability. It should be noted that to cope with these issues, macro-mobility support for mesh-under network are already drafted, like for example, MANEMO, which combines NEMO intra-domain mobility support and PMIPv6 support of inter-domain mobility.18 19 However, this evaluation has not been drafted yet for route-over protocols, like RPL.

4. Analyses

6LoWPAN standard has tight limits such as limited frame size, small power consumption, limited bandwidth. Although it would be feasible to solve mobility using MIPv6, notably, by installing MIPv6 on each LowPAN node, as explained in the previous section, many of the challenges would not be properly addressed such as low power or mobility detection of external to sensors.

To maintain connectivity while moving, a MN must have multiple protocols. At Level 2, the use of a standard is highly recommended to be used with many networks. A level 3 connectivity is required to allow a MN to communicate outside its network. For this, the adaptation layer 6LoWPAN is used. This layer provides an end-to-end connection without the need of any translation mechanism. However, to maintain this level 3 connectivity during the movement, the use of a mobility support protocol, such as MIPv6, is required. Thus, hybrid solution at level 2 and 3 will likely provide the most adequate approach. Several research works mentioned below studied the possible application of actual mobility protocols in WSN networks and highlight the limitations and main challenges with these solutions.

13 compared the performance of a MN using MIPv6 to a MN using standard IPv6. During the experiment, a MN moves between two IPv6 networks: its home network and a visited network. CN located in a third network sends 100 ICMPv6 packets to an MN that moves from the home network to the visited one at the 50th packet. The authors measure the ratio delivery, RTT, the energy consumed and the impact of fragmentation. The experiment showed that the use of MIPv6 increase significantly the energy consumption of MN. In addition, the packet fragmentation increases the packet loss, which rate reaches 80%. So the conclusion was that MIPv6 is not a suitable solution for the level 3 mobility in WSNs. However, the lack of information about the implementation and the mobility detection mechanism used, makes the experiment non-reproducible. In14, the authors also analyses MIPv6 in 6LoWPAN networks. They focus on the data packets overload and the large size of signalling messages in IPv6. The authors notice that the size of the binding update and binding acknowledgment messages are similar to the data packet size, which is respectively
address, thanks to the use of the Local Mobility anchor. In 15, the 6LBR play the role of a mobile access bridge and contributes to reduce the handover delay when a MN moves, since a MN does not need to configure a new care-of address, thanks to the use of the Local Mobility anchor. In 15, the 6LBR play the role of a mobile access bridge and transmits the signalling traffic instead of the MN. However, the authors have not considered any header compression mechanism in their evaluation. We are convinced that 6LBRs, responsible for the entirety of the 6LoWPAN network (routing, IPv6 prefixes management), are not able to support the management of nodes mobility, in addition to the bridge function between adapted IPv6 and classic IPv6, without impacting their performances. In the second paper16, the authors compare, using simulation process, the handover delay of MIPv6 and Proxy MIPv6. The MNs implement the HC1 compression mechanism and a standard version of the Neighbor Discovery Protocol. The results of their experience concern the handover delay. As a conclusion, one of the disadvantages of Proxy MIPv6 is the limitation of MN in the Proxy MIPv6 domain to which it belongs. The equipment of the Internet Of Things use diverse applications and this limitation may be problematic. The major problem using actual mobile protocol within WSN is that they don't take into account the strict constraints of WSN. These protocols use the Router Advertisement messages diffusion to detect the movement of MNs. To be efficient, these messages are sent periodically, which increase the signalling cost and thus the power consumption of MN. To avoid data loss, MIPv6 and its extensions use tunnelling to buffer data during a MN movement and sent it when that MN gets its new attachment. This mechanism also increases the signaling cost and thus, power consumption of MNs, since it requires the use of a lot of control information. Even if the mechanisms of these protocols (MIPv6 and its extensions) seem to be appropriate to handle mobility, they require an important adaptation to handle WSN characteristics.

Macro mobility is not ignored by WSN management protocols. For example, the Routing Protocol for Lossy Networks (RPL), defines an entity called the Virtual DODAG Root, which aim is to synchronize several smaller RPL domains into one large virtual domain. The node mobility between theses smaller domains uses the existing mechanisms of RPL, and the Virtual DODAG Root takes care of the synchronization of the Roots of the smaller domains 21.

Furthermore, 6LoWPAN-ND, the standard management protocol of 6LoWPAN, supports synchronization of multiple 6LoWPAN Border Routers (6LBRs) 23. But in both cases, the synchronization protocol is not defined, only the requirements for such a protocol are laid down. Proposals for such synchronization protocol exist 23, 24, but not standardization has yet been achieved. We believe that this hybrid mobility can improve the mobility of WSN hosts as, if designed properly, it could combine the lightweight and fast switchover provided by the micro-mobility provided by existing WSN management protocols and the support of a large number of hosts. This also provides a scalable mobility architecture where every domain can be tailored to manage only the right number of hosts and delegates some management aspects to the higher level. For example, the security registration could be done at the "hybrid" level instead of the smaller domain level. So when a host moves from one smaller domain to another, it does not need to initiate again a security registration handshake, which is costly in term of energy and time. This also has the advantage of providing a fast handover between two smaller domains, and therefore there is no need to store delayed messages.

Regarding the remaining challenges on how RPL synchronisation protocol may need to be adapted for the micro and hybrid mobility scenarios, a reflection on whether or not mobile nodes should be given a special status is needed. In particular, the solution explored in 24 assumed fixed nodes. It is not currently clear if the current routing decision would need to be augmented to more efficiently address certain node mobility scenarios. For instance, maintaining node mobility history and discovering node mobility patterns might help to discover more dependable routing in highly mobile situation in which most nodes are mobile with fairly predictable mobility schedule. Alternatively, in situation with few mobile nodes and very unpredictable mobility patterns, the routing decision could try to segregate
mobile nodes so they never become relay nodes in a WSN. Furthermore, other node characteristics such as energy autonomy or ease of access for recharging could also be used to yet improve the routing decisions. In particular, some mobile nodes whose accessibility for recharging is predictable based on their mobility schedule could be more quickly promoted to become relay node in a WSN. As demonstrated by these few examples, interesting challenges are still open requiring appropriate solution suited to a node mobility context in WSN. Finally, self-management with dynamic/adaptive context-aware RPL synchronization protocol is still to be investigated.

5. Conclusion and Future Work

Mobility management in 6LOWPAN-based WSNs enhances the actual applications and services offered by these networks. The fact that these networks were not designed to support macro mobility represents a major challenge to cope with especially due to real-time constraints on WSN nodes such as low processing and power capabilities.

In this paper we focus on Mobile IPv6 and its extensions, We highlight the advantages and remaining challenges for each one. An efficient solution should optimize the handover delay, the movement detection and the signalling cost to reduce the power consumption and preserve the nodes performances. Furthermore, a hybrid scenario where an MN moves in WSN administered by the same operator is also identified with its associated challenges. A few pointers based RPL suggests initial ideas on how these challenges could be addressed.

A project dedicated to designing and implementing mobility effectively in wireless sensor networks is planned to start at CETIC in the second quarter of 2015. In the context of this project, alternative designs will be explored and the most promising one will be prototyped.

References
1. C. William, D. Huo "Mobility Considerations for 6LoWPAN" - draft williams-6lowpan-mob-02.txt, March 8, 2010
23. Z. Shelby, S. Chakrabarati, E. Nordmark, and C. Bormann, Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs), RFC6775, 2012