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A survey on mobility management protocols in Wireless Sensor Networks based on 6LoWPAN technology

Maha Bouaziz [a], Abderrezak Rachedi [b,*]

[a] University of Manouba, Hana Research Laboratory, Manouba, Tunisia
[b] Université Paris-Est, LIGM (UMR8049), UPEM F-77454, Marne-la-Vallée, France

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ABSTRACT

Mobility has the advantage of enlarging the WSN applications of the Internet of Things. However, proposing a mobility support protocol in Wireless Sensor Networks (WSNs) represents a significant challenge. In this paper, we proposed a survey on mobility management protocols in WSNs based on 6LoWPAN technology. This technology enables to connect IP sensor devices to other IP networks without any need for gateways. We highlighted the advantages and drawbacks with performances issues of each studied solution. Then, in order to select a typical classification of mobility management protocols in WSNs, we provided some classification criteria and approaches on which these protocols are based. Finally, we presented a comparative study of the existing protocols in terms of the required performances for this network type.

1. Introduction

Traditional Wireless Sensor Networks (WSNs) are developed using static nodes (SNs) [1–4]. These networks can be applied in numerous applications such as healthcare [5,6], military, industry, monitoring, tracking based on multimedia sensor [7] among others [8–10]. Hence, a lot of researches and propositions are made for static scenarios. Nevertheless, the advanced technology in the Internet of Things [11,12] involves applying more complex applications, which require mobility of their nodes [13]. Mobility of nodes can enlarge WSN applications [14]. It can also prolong the nodes lifetime, since data transfer between two nodes does not usually use the same relayed nodes in the path route. In addition, it serves to increase connectivity between nodes, since mobile nodes (MNs) can help the communication between two isolated nodes [15]. It also helps to extend area of coverage interest [16,17]. However, mobility can cause some problems, like disconnection of nodes during the handover process, which causes data loss and a negative impact on the applications performances. Other issues related to mobility are resource management, topology control, routing protocol, quality of services and security.

In this paper, we focused on mobility management protocols in WSNs based on 6LowPAN technology [13,18,19]. This technology was proposed by IETF Working Group in order to introduce IPv6 over IEEE 802.15.4 [20–23], since IPv6 is considered as one of the candidate technologies for the Internet oh Things [24]. Using IPv6 packets instead of IPv4 packets offered a more important address space, that helps to deploy an important number of nodes and satisfy scalability performance. Hence, introducing IPv6 over IEEE 802.15.4 made data accessible at any-time and from anywhere through the Internet. Therefore, 6LoWPAN offers the possibility to establish a direct connectivity between devices based on the IP address. Unlike ZigBee technology [25], each external communication from a WSN requires a Zigbee coordinator (ZC) or a gateway (GW) as an intermediate node which centralizes this kind of communication [26].

The aim of mobility support protocols is to keep nodes reachable and connected during the handover process, without any connectivity interruption [13]. Thus, when a node moves away from its neighbor's coverage, the protocol must rapidly provide an alternative router and ensure the configuration of a new interface for the MN.

The contribution of this paper is summarized as follows:

–Review of the state-of-the-art of mobility management protocols in WSNs based on 6LoWPAN technology. The advantages and drawbacks with performance issues of each studied solution are highlighted.

* Corresponding author.
E-mail addresses: maha_bouaziz@yahoo.fr (M. Bouaziz), rachedi@univ-mlv.fr (A. Rachedi).

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–An attempt of mobility management protocols classification in WSN is proposed, after studying different criteria and approaches.
–A comparative study of existing mobility support protocols in WSN is proposed and analyzed.

The remainder of this paper was organized as follows: Section 2 discussed the challenges to provide and design a protocol of mobility management. Section 3 focused on the classification criteria of existing mobility support protocols proposed for wireless networks, to select the best criteria which might be applied in 6LoWPAN Networks. Then, in Section 4, we presented our comparative study considering the limited constraints of 6LoWPAN Networks. Section 5 discussed the future directions to be considered for the design of a mobility support protocol in the 6LoWPAN Networks. Finally, in Section 6, we drew our conclusions and suggested some perspectives.

2. Mobility management, challenges and design issues

Mobility is the act of a node changing its attachment point due to the topology change. Before studying solutions dealing with mobility, we should understand its causes to be able to point out the appropriate challenge. In WSN based on 6LoWPAN technology, a topology change is caused by some reasons such as physical movement, failure of some routers, using aggressive sleep, radio channel conditions since the radio propagation is affected by any environmental change. Other possible reasons can be the network performances like the delay, the packet loss and the low signal [13].

The change of the attachment point requires the disconnection of the MNs. This disconnection causes significant problems of data loss and affects the proper functioning of applications. For these reasons, it is crucial to elaborate a mobility support protocol that tackles the encountered problems with mobility. The principal operations of this protocol follow some steps as shown in Fig. 1. The first step is the detection of the movement of nodes (or network). In the second step, the Mobile Node (MN) performs a new address configuration called Care of Address (CoA), and then performs the Duplicate Address Detection (DAD). The third step is the registration in the Home Agent, which is carried out by sending a Binding Update (BU) with the new address to the Home Agent. The final step is performed by the Home Agent (HA), which maintains the bond between the two addresses (HoA and CoA) after receiving the binding update. Then, it buffers and forwards traffic between the mobile node and its correspondent.

However, each operation can be performed in different ways depending on the network type requirements. Thus, it is interesting to clarify the requirements and specifications of our networks. Indeed, as we previously noted, WSNs based on 6LoWPAN technology provide the possibility to introduce IPv6 packets over the IEEE 802.15.4 to offer more advantages for the internet of things applications. Thus a problem of disproportion of IPv6 packets size (1280 bytes) compared to IEEE 802.15.4 frames size (127 bytes) is

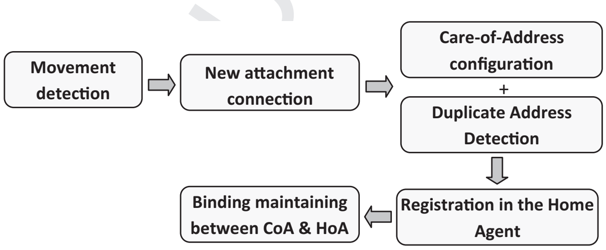

Fig. 1. Operations of mobility support protocol for mobile Networks.

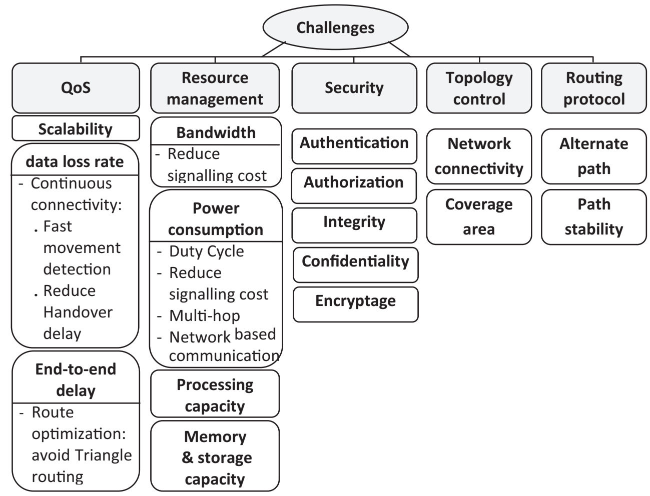

Fig. 2. Challenge of mobility management for WSNs based on 6LoWPAN.

present [27,28]. To tackle this problem, the 6LoWPAN technology proposed an adaptation layer between the MAC and network layers. The main aim of this layer is to carry out two main functions: packet fragmentation/reassembly and header compression/decompression. Moreover, 6LoWPAN technology is based on the Neighbor Discovery concept to provide some tasks -with the help of RS/RA messages- such as interfaces auto-configuration, IPv6 address resolution, router availability checking and mapping between IPv6 and MAC addresses. In addition, this technology supports a stronger density than traditional WSNs [29]. Furthermore, the overall application performed in the Internet of Things with 6LoWPAN technology involves a strong mobility of nodes, which need more resources, and thus increases the risk of attack in the network and impacts the connectivity and the routing path. Q3

On the one side, the concept of 6LoWPAN technology needs more overhead, memory and power consumption. And, on the other side, WSN devices are characterized by limited resources in terms of power, data rate, bandwidth, processing and storage capacities. The IEEE 802.15.4 standard enabled to reduce power consumption in WSNs using a periodic sleep/wake-up process [30]. Therefore, WSNs based on 6LoWPAN technology require more resources consumption than a traditional WSN or IPv6 Network.

Considering that the WSNs with 6LoWPAN technology imposes some delicate constraints and requirements [17], it has become urgent to discuss potential challenges to deal with these encountered problems as illustrated in Fig. 2.

In WSN with 6LoWPAN technology, the greatest challenge consists in providing a suitable "*Quality-of-Service*" (QoS) with different constraints consideration. For instance, mobility management must be efficient with an important density of nodes (i.e. ensure "*scalability*"). Moreover, mobility support protocol must mitigate the data loss rate. This problem occurs when the MN is disconnected during the handover process. Thus, it is important to reduce the handover delay in order to limit the disconnection time and ensure a continuous connectivity. Furthermore, after the handover process, mobility management must keep the same end-to-end delay as used before this process. Hence, in 6LoWPAN technology, protocol must avoid the triangle routing[1] (as illustrated in Fig. 3) which might enlarge the needed delay to communicate between the MN and its CN, as used in "*Hospital WSNs*" (HWSN6) [31–33], Inter-PAN [34,35] and "*Low Mobility*" (LoWMob) [36].

[1] Communication between a MN and its CN: Packet from a CN is forwarded to the HA, then, to the Foreign Agent and finishes at the MN.

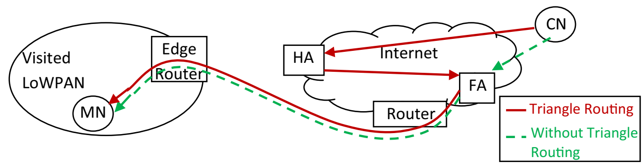

Fig. 3. Communication between MN & CN through triangle routing process.

On the other hand, the resources management is regarded as a significant challenge to design a protocol dealing with mobility [37]. This challenge arises because of the limited resources of WSN with 6LoWPAN mainly in terms of power, bandwidth, memory and processing capacity. Hence, it is important to significantly reduce the cost of signaling messages, overhead communication and processing. Besides, the existing duty cycle used to reduce the energy consumption is not designed to support mobility constraints, thus, it must be adapted to this context.

The security issue is another challenge which must be considered in the mobility solution. In fact, the WSN nodes are exposed to attacks which disturb the mobility process by introducing false information. Thus, a trust model for a mobility scenario in WSN must be designed, and considered by the mobility management protocol to provide a secure network. The security services like authentication, authorization, integrity and confidentiality of data must be smartly introduced in mobile WSN [38]. The existing security mechanisms like intrusion detection systems must be adapted to support mobility in WSN [16].

The other challenges are the topology control and the routing protocol. The topology control is conceived to improve the network connectivity, increase the coverage of deployment area [39], and also reduce the energy consumption and increase the networks lifetime [40,41]. The performances of the routing protocol can directly affect the mobility management like re-activity to restore the link between two communicating nodes (time to find an alternative path when the intermediate nodes are not available), and the path stability [42].

3. Classification criteria of mobility support protocols

Considering the cited challenges, protocols dealing with mobility in WSNs based on 6LoWPAN technology should take into account not only the requirements of the application, but also WSN' characteristics. WSN has limited resources namely in terms of power, memory, processing capacity, bandwidth, short range, low data rate and small packet size.

The proposed protocols to deal with mobility perform the necessary operations in different ways, which generates diverse

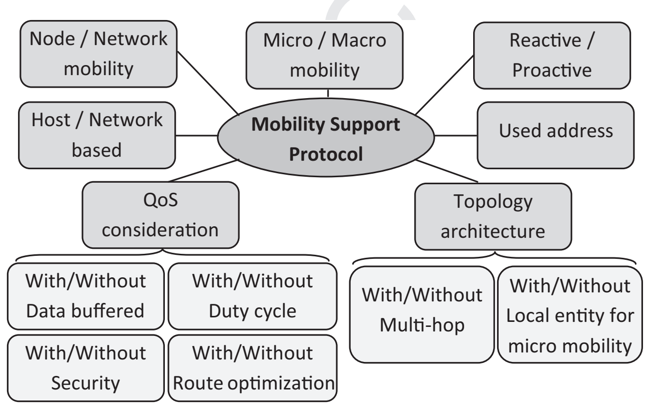

Fig. 4. Classification criteria of mobility support for 6LoWPAN Networks.

classifications. Hence, in the following parts of this section, we define and discuss the potential classification criteria of mobility support protocols illustrated in Fig. 4.

3.1. Node and network mobility

According to the application requirements, two classes of mobility can be considered: Node and network mobility. The "*node mobility*" refers to mobility of only one node either in the same PAN or between different PANs, regardless of other nodes. It occurs as a result of an attachment change of the node in an independent way. In contrast, the "*network mobility*" refers to mobility of the entire LoWPAN. In 6LoWPAN, such a network includes an edge router and member nodes, while only the edge router changes its attachment point on the Internet and the nodes remain attached to it [13]. This second class is a kind of the macro mobility type (explained in the next subsection).

3.2. Macro and micro mobility

According to the topology and application needs, two types of node mobility need to be taken into account. On the one hand, the "*micro mobility*", which refers to the node mobility within the same sensor network domain. In 6LoWPAN Networks, micro mobility is identified by the mobility of a node into the same LoWPAN domain, where the 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, the "*macro mobility*" refers to the node mobility between different sensor Networks. In 6LoWPAN Networks, macro mobility is identified by the mobility of a node between different LoWPANs, where the prefix is changed.

Hence, each protocol dealing with mobility for 6LoWPAN Networks has to consider these different mobility types, because of its impact on the prefix and then on the IPv6 address of the MNs.

3.3. Network and host based protocol

Two kinds of protocols are distinguished: the first is called the "*network based protocol*", and the second is the "*host based protocol*" [38]. In the "*network based protocol*", the signaling messages, related to the movement detection and Binding Update,[2] are sent by a SN in the network and not by the sensor MN. In literature, some existing solutions are based on this approach like Inter-PAN [34,35], Inter-Mario [43] and Cluster-Based Scheme [44]. In the "*host based protocol*", the MN is involved in the signaling messages process. Some existing solutions based on this approach are proposed in "*Mobile IPv6*" (MIPv6) [45] and "*Fast Handover for Mobile IPv6*" (FMIPv6) [46].

According to WSN constraints (limited resources: power, processing, memory, and throughput), it is recommended to perform the first kind (the network based protocol) in order to reduce the signaling cost and preserve the power of MNs [37,47].

3.4. Reactive and proactive detection protocol

Mobility support protocols can be classified into two categories:

–*Reactive protocol*: In this kind of protocol, dealing with mobility (such as movement detection, transfer of the Binding Update [48] and the configuration of the new Care of Address (CoA)) is

[2] Message transmitted to the HA to inform about the movement and the taken change.

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performed only after the movement of the MN and being in the visited network, as it is used by MIPv6 [45] and "*Proxy Mobile IPv6*" (PMIPv6) [49].

–*Proactive protocol*: This kind of protocol involves performing mobility support as soon as the MN moves and before being disconnected from its attachment point (MN pre-configuration before reaching the visited network), as it is used by Inter-PAN(2) [35], LoWMob, DLoWMob [36], Inter-Mario [43], Mobile IP-based [71], Cluster-Based Scheme [44], FMIPv6 [46] and Inter-Mobility [50].

The proactive protocol is the most suitable for WSN with 6LoWPAN, since, it helps to reduce the handover delay by reducing the configuration time. It also helps to avoid the disconnection of nodes, which reduces the data loss rate. However, it requires an important processing and memory to find and predict the new attachment point of the MN. These disadvantages represent an important challenge to handle.

To ensure a proactive process, the protocol has to provide a rapid detection of the movement considering the fact that the MN can move in a state of hibernation, and then predict the new attachment point of the MN [51,52].

3.4.1. Movement detection

Movement detection is a significant criterion to deal with the change in the attachment point of the MN. In WSN with 6LoWPAN, it has to be performed for the purpose of providing minimum signaling cost and reducing power consumption and handover delay. Hence, two main questions can be asked: Who is to perform the movement detection? and how to perform it? On the one hand, to ensure good performances in the signaling cost and the power consumption for the MN, it is not recommended that this entity execute the movement detection because of its limited resources. Hence, the movement can be detected by the edge router or other nodes in the network. On the other hand, to reduce the handover delay, this criterion of detection should be fast. In other words, the movement should be detected on time.

Just like the state-of-the art, the existing protocols use many ways to ensure the movement detection:

–A periodic sent of a Router Advertisement (RA) messages containing the prefix information [13]. The movement is detected in case this information changes.

–A periodic sent of a beacon having the PAN-ID information [53].

–A periodic sent of a Node Registration messages (NR) used by the Neighbor Discovery (ND) protocol [13,54,55] to check the existence of node address in the whiteboard table. The movement is detected when the source address of NR does not exist in this table.

–An estimation of the link quality based on Link Quality Index (LQI).

–The degradation of the Received Signal Strength Indicator (RSSI) value [56].

In WSN based on 6LoWPAN, sending messages periodically affects the signaling cost. In addition, RSSI cannot be well applied in an indoor environment, because of the reflection problem of the used signals [57]. Thus, another method is needed for the movement detection.

3.4.2. Mobility prediction

Mobility prediction consists in predicting the new attachment point of the MN after its disconnection. The idea behind this concept is to reduce the time of the handover process, and then to improve the performance of the protocol. In order to introduce this prediction, the position of the MN, its direction and the positions of its neighbors (from neighborhood map) are selected as parameters, and their assessment is based on some techniques such as the Received Signal Strength Indicator (RSSI) and the Angle of Arrival (AOA) [35,36,44,50,71].

3.5. QoS consideration

Ensuring a Quality-of-Service is important for most of the applications, such as: providing high transfer data rate, little power consumption, more security services and low end-to-end delay.

3.5.1. Data buffered

During the handover process, the data transferred to the MN must be buffered in the HA or the foreign agent, and be sent to the MN after confirming its new attachment point. This process allows to avoid data loss during the vulnerable handover period which is required to configure the new attachment [37].

3.5.2. Duty cycle consideration

Given the limited energy of sensors, nodes should alternate between active and inactive, called "*Duty cycle*" execution. This process is performed mainly when the node is in a state of hibernation to preserve its power and extend its lifetime [17], as it is used by the Inter-PAN(2) [35].

3.5.3. Security consideration

Many eavesdroppers and attackers can find the node location, send false node information or spoofed messages, steal traffic destined to a victim node and compromise its privacy and data confidentiality. To tackle these vulnerabilities, it is necessary to provide security by ensuring protection, integrity and confidentiality of resources [38,58]. Hence, the mobility support protocol should use authentication, cryptographic and confidentiality, as it is used by HWSN6 [31–33], "*Sensor Proxy Mobile IPv6*" (SPMIPv6) [59,60] and the secure solution for HIMALIS architecture (Heterogeneity Inclusion and Mobility Adaptation through Locator ID Separation) based on ID/Locator split [58]. However, in WSN based on 6LoWPAN, it's important to optimize the cost of security by taking into account the constrained resources [61–64].

3.5.4. Routing optimization after a handover process

After joining a visited network, when a CN from the IP network wants to communicate with the MN, data is sent to the HA. This one performs binding update between the two addresses of the MN (HoA and CoA). Then, it sends data to the Foreign Agent (FA), which transfers it to the MN. This is the case of the triangle routing [14], as used in HWSN6. However, this process increases the end-to-end delay of the communication between the source and the destination. Therefore, it is suitable to focus on the optimization of the route. Thus, data must be intercepted by the FA without passing through the HA, as performed by MIPv6 [45].

3.6. Kind of address

Macro mobility in WSN with 6LoWPAN causes a change in the IPv6 address. However, providing a new IPv6 address follows some steps: Configuration, Duplicate Address Detection (DAD) process and registration. These steps affect the handover delay. For these reasons, dealing with mobility should take into consideration the used kind of address.

In order to reduce the handover delay, many proposed protocols discuss the used node address. For instance, PMIPv6 uses a fixed IPv6 address in its domain, since it uses a multi-homing process. So, it reduces the handover delay by avoiding the time needed for a new address reconfiguration and for the DAD process. On the other hand, the protocols [43,46] are based on the address pre-configuration process where the MN configures its Care-of-Address before reaching the visited network.

In WSN with 6LoWPAN standard, the node uses an IPv6 address in the outside of the network, which combines the prefix (64 bits) received from the edge router and the Interface Identifier IID (64 bit) configured by the node. In 6LoWPAN, the node uses a 16 bit short address generated by the edge router when the node joins the 6LoWPAN network in order to use less bits reserved for the address.

3.7. Topology architecture

The functioning of the mobility support protocol depends on the topology architecture of the network, built according to some applications need.

WSN based on 6LoWPAN can be created following different topology architectures such as star topology, hierarchical topology based on tree configuration, mesh topology, grid topology and linear topology among others. Nevertheless, considering the limited resources of this network type and to ensure a suitable mobility protocol support, some requirements have to be fulfilled in the chosen topology, as follows:

3.7.1. Multi-hop consideration between the MN and the edge router

In order to reduce power consumption, the mobility support protocol should take into account the multi-hop communication from a MN to the edge router, because the MN requires an important power consumption when it is too far from its communicating node.

3.7.2. Local entity to deal with micro mobility

This requirement was used in order to reduce the handover delay. According to research studies, some protocols such as "*Distributed LoWMob*" (DLoWMob) [36] and "*Hierarchical Mobile IPv6*" (HMIPv6) [65] use a special entity within the 6LoWPAN networks, which acts as a local GW and manages mobility for a set of nodes, so as to reduce traffic control messages towards the global GW (which preserve power for the nodes in its vicinity) and reduce the handover delay for the micro mobility. Cluster-Based Scheme also performs this concept without using a special entity, but the ancestor parent node can be used as the responsible to deal with mobility in its sub-tree (without involving the GW).

3.7.3. Node deployment strategy

To satisfy the functioning and role of applications, some nodes are deployed within the 6LoWPAN Network to monitor and track the MN. So, they must be deployed in such a way to provide coverage and connectivity in the entire area of interest, in order to avoid data loss. Besides, a minimum number of active nodes should be deployed, to reduce power consumption of nodes, just like the process used in "*Mobility-assisted minimum connected sensor cover*" (MCSC) [66].

4. Comparative study of existing mobility support protocols

The work on mobility management was started in the 1990s. The first propositions were based on routing protocol such as Cellular IP [67] and HAWAII [68]. These are host based protocols, which require an active participation from the MN. Thus, the MN must periodically send control messages to achieve dealing with mobility. Therefore, this type requires a great signaling cost and power consumption for the MN, which it is not suitable with the constraint of WSN based on 6LoWPAN.

A suitable protocol dealing with mobility in WSN based on 6LoWPAN technology is delicate, because of its great number of nodes and its constrained resources in terms of power, bandwidth, memory, data rate and range. Hence, the protocol must provide a satisfactory quality of services considering the requirements of 6LoWPAN [17,69], namely less power consumption (longer lifetime), less signaling cost, less handover delay, less end-to-end delay, avoid or reduce data loss, security and scalability. There are many mobility support protocols proposed to enhance some performances, however, each of them still has some drawbacks.

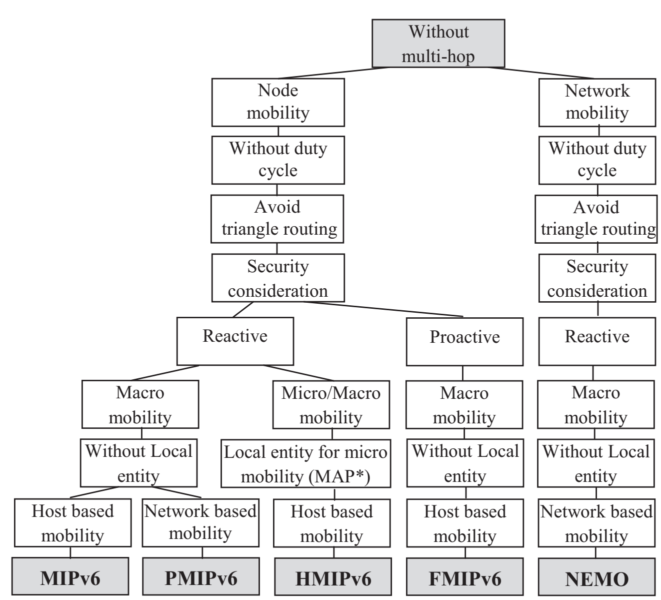
4.1. Mobility support protocols for mobile IPv6 Networks

In the early 2000s, some protocols were proposed for node mobility and macro mobility type, which attempted to improve some performances, such as "*Mobile IPv6*" (MIPv6) [13,45], "*Fast Handover for Mobile IPv6*" (FMIPv6) [46], "*Proxy Mobile IPv6*" (PMIPv6) [13,49], "*Hierarchical Mobile IPv6*" (HMIPv6) [65] and "Network Mobility" (NEMO) [70]. The used criteria for these protocols is represented in Fig. 5, and their impact on the network performances is discussed in the following sections. A brief summary of these protocols is shown in Table 1.

4.1.1. Signaling cost and its impact on power consumption

PMIPv6 [49] is a network based protocol whose entity called Mobile Anchor Gateway (MAG) is the responsible for sending and exchanging messages related to the mobility support, instead of performing it by the MN as in MIPv6, FMIPv6 and HMIPv6. Therefore, PMIPv6 helps the MN to reduce its signaling cost, which reduces its power consumption [13]. Moreover, NEtwork MObility (NEMO) [70] is a network based protocol which introduces a new logical entity called the mobile router (MR). This entity is responsible for handling MIPv6 functions for the entire mobile network. Thus, it may reduce the signaling cost in the MNs, when a set of nodes moves and only one node (MR) executes the messages exchange to support the mobility of all nodes.

Nevertheless, some problems appear when applying these protocols in the WSN based on 6LoWPAN, due to its strict constraints. First, these protocols use the prefix change to detect the movement by the MN. Thus, there is a periodic broadcast diffusion of Router



*MAP: Mobile Anchor Point

Fig. 5. Classification of mobility support protocols for mobile IPv6 Networks.

Table 1
Comparative study between different mobility support protocols for mobile IPv6 Networks.

	Address	Movement detection	Data buffered	Topology architecture
MIPv6 [13,45]	IPv6	RS/RA	HA	Star
PMIPv6 [13,49]	Fixed IPv6	RS/RA	LMA	Star
HMIPv6 [65]	RCoA/LCoA	RS/RA	HA or MAP	Star
FMIPv6 [46]	IPv6	RS/RA	HA	Star
NEMO [70]	IPv6	RS/RA	HA	Star

Advertisement (RA) messages within the network, which increases the signaling cost and power consumption. Second, they do not consider the multi-hop communication between the MN and its edge router. Hence, the MN needs a lot power to communicate with its edge router when it is too far. Third, they use tunneling to buffer data and send it through the new attachment point. However, tunneling requires using a lot of control information by the MN, which increases signaling cost and power consumption. Fourth, they do not perform a duty cycle to save power when nodes are in a hibernation state.

4.1.2. Handover delay

PMIPv6 is based on the multi-homing concept that the Local Mobility Anchor (LMA) entity acts as a HA for all the PAN Networks, which allows the MN to use a fixed IPv6 address in its domain, since the prefix remains the same. Hence, when the MN moves away from its home network, it does not need to configure a new care of address. Therefore, the handover delay is reduced because, it does not need any time to configure an address and perform the Duplicate Address Detection (DAD) [13].

Moreover, FMIPv6 and HMIPv6 concepts help to improve the handover delay [71]. FMIPv6 uses a proactive process, that can anticipate the new care of address configuration of the MN before being disconnected from its home network. HMIPv6 also reduces the handover delay for the micro-mobility using a local entity within the network, to manage mobility for a set of nodes without involving the GW. This entity, called Mobile Anchor Point (MAP), which acts as a local HA to reduce the delay that occurs during the message exchange.

4.1.3. End-to-end delay

The end-to-end delay is the necessary time to transmit packet across the Network from the source node to the destination node. After a handover process, packets may need more time for the end-to-end delay (as explained above in Section 3.5.4). Here, MIPv6, HMIPv6, FMIPv6 and NEMO use the triangle routing only for the first packet between communicating nodes. Then, they can avoid it for the rest of packets, to ensure the same end-to-end delay before and after the handover process. Also, PMIPv6 can keep the same end-to-end delay, since it is based on a multi-homing concept, which avoids using the triangle routing after each movement.

4.1.4. Security

Security is considered by these Protocols. On the one side, MIPv6, HMIPv6, FMIPv6 and NEMO are based on the IPSec protocol to secure messages related to mobility (the binding update and the binding advertisement). However, IPSec requires more power since it requires a significant number of cycles CPU and memory. So, it presents a big challenge to be applied with constrained devices in WSN based on the 6LoWPAN technology. In [61], the authors propose a lightweight MIPv6, which combines MIPv6 and IPSec following improvements in the messages related to mobility support. This proposition is feasible with the constrained resources of devices in this network type, mainly in terms of signaling and memory requirements. Nonetheless, this solution adds a brief delay needed for the encryption and the headed packet sent. On the other side, the PMIPv6 uses a security architecture called "AAA" [59,60], which is responsible for Authentication, Authorization and Accounting of the MN.

Ultimately, PMIPv6 appears the most appropriate to be applied in 6LoWPAN networks. However, it cannot be directly applied and it requires an important adaptation.

4.2. Mobility support protocols for sensor Networks

In the recent years, many efforts have been made for sensor Networks to support both mobility and routing, since most of the applications requiring the mobility of their nodes affect the routing path and cause data losses."*Zone Routing Mobile Sensor Networks*" (ZoroMSN) [72] is a hybrid distance based (proactive and reactive) routing protocol supporting nodes mobility within the network (micro mobility). It is performed in an area divided into some equal zones with a zone head, which acts as a router to forward data generated from its members towards the sink node through other zone heads. All the zone heads are organized in a tree topology. In addition, a new proposed protocol called "*Mobility-assisted minimum connected sensor cover*" (MCSC) [66] ensures data collection and their routing to the sink node, using minimum number of active nodes which cover the entire area of interest. This area is divided into some grids representing clusters including nodes organized in a tree topology and containing a cluster head, which is the responsible for forwarding data collected from the cluster members toward the sink node through other cluster heads. The MCSC supports the micro mobility of a node to replace a failure node and maintain the area coverage. The used criteria of these two protocols is represented in Fig. 6, and their impact on network

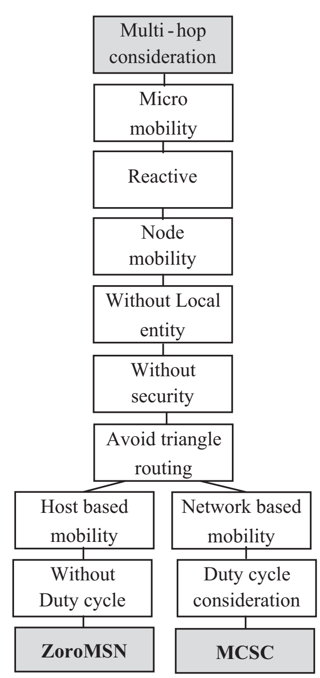


Fig. 6. Classification of mobility support protocols for sensor Networks.

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Table 2
Comparative study between different mobility support protocols for sensor Networks.

	Address	Data buffered	Topology architecture	Mobility model	Deployment of static nodes
ZoroMSN [72]	IPv6	Zone Head	Cluster tree	Random walk [73]	Random in square zones
MCSC [66]	IPv6	Not considered	Hybrid: tree-mesh	To failure node place	

performances is discussed in the following sections. A Brief summary of these protocols is shown on Table 2.

4.2.1. Signalling cost and its impact on power consumption

ZoroMSN and MCSC follow a hierarchical routing within the network, which helps them to reduce the signaling cost and power consumption. In fact, the hierarchical routing avoids exchanging route request (RREQ) and route reply (RREP) messages between neighboring zone heads to discover a route path, and avoid a routing loop. In addition, these two protocols can preserve power of nodes through the multi-hop consideration to forward data. This can be achieved relying on the distribution of consumption among different zone heads.

Moreover, the power consumption for ZoroMSN was reduced and this was proved following the energy model, which depends on the transmitted bits and the hop number [72]. In fact, reducing these two parameters through choosing the shortest path and the minimum signaling messages, the power consumption is decreased. Furthermore, the MCSC considers some parameters to choose the appropriate path with the minimum power consumption. The path is chosen following the highest benefit parameter, which is based on the remaining energy of the source node, the number of hops and the distance between the source node and its parents. When compared to other routing protocols, simulation results show that the ZoroMSN outperforms the others in term of energy consumption and node lifetime [72]. Also, the same results are found for the node lifetime even when the number of nodes in the networks is increased, which proves that this protocol ensures scalability. In addition, the same results of power consumption are found for the MCSC compared to ZoroMSN [72].

Nevertheless, ZoroMSN wastes power because of the periodic process of the reconfiguration of neighbor discovery, to create a list of zone heads used to the next hop in the data routing (time-based). This process needs a high signaling cost because of some messages exchange between neighbors. Furthermore, the MCSC wastes power during some processing steps such as computing a combination measurement to select active nodes, computing a benefit parameter to choose the appropriate path, and the periodic remaining energy computation performed by each node to check its level and detect its failure [66].

4.2.2. Handover delay

Neither the ZoroMSN nor the MCSC evaluates the handover delay. However, the inaccessibility time during the handover process is not reduced, since there is no proactive concept to predict the new attachment of the MN with the zone head of the visited zone. Hence, the MN needs some delay to perform its configuration and join the zone as a member when reaching it.

4.2.3. End-to-end delay

The end-to-end delay for the communication between each node and the sink node is well maintained by both the ZoroMSN and the MCSC protocols in case of a static network, since it performs a route optimization through choosing the lowest path and ensuring the free loop. Nevertheless, by introducing the mobility of some nodes, the link may break up and the data transmission will be affected. For instance, in the ZoroMSN, all zone heads in the Zone head list, which are used for the next hop, can move to other positions to be a member in another zone. In this case, the transmitter node will be unable to find the next hop to send its data, and thus it will buffer data and wait for the next neighbor discovery process to find another head which represents the next hop for the sink. This process increases the end-to-end delay. Even though the MCSC reacts to solve this problem using a redundant node to recover a failure node, this process requires an extra time which affects the transmission delay.

4.2.4. Data loss rate

Mobility of nodes affects the route path and causes data loss. The ZoroMSN concept helps to reduce the data loss rate, through the route maintenance method and data buffering. In fact, when the zone head does not find any zone head on its list of neighbors for the next hop, it buffers data and waits for the next neighbor discovery process. In case of the mobility of a zone head which has data to send, this one changes its state becoming a member in the visited zone, then forwards the data buffered to its new zone head. Simulation results prove the decrease of the data loss rate compared to other routing protocols supporting mobility. In addition, we noted that using large zones or high speed increases the data loss, which proves that this protocol is more adaptable to small zones with low mobility speed.

Furthermore, the failure of a node in the network causes an uncovered hole, which causes the partitioning of the network, disconnects the data transmission path and disturbs the functioning of the application used in the network. The MCSC deals with this problem to avoid the loss of the collected data. Hence, its concept consists in using redundant inactive nodes activated in case of active nodes failure. In fact, each node periodically checks its remaining energy level to detect its failure. This concept helps to avoid the uncovered holes, and then to ensure collecting and sending all the data.

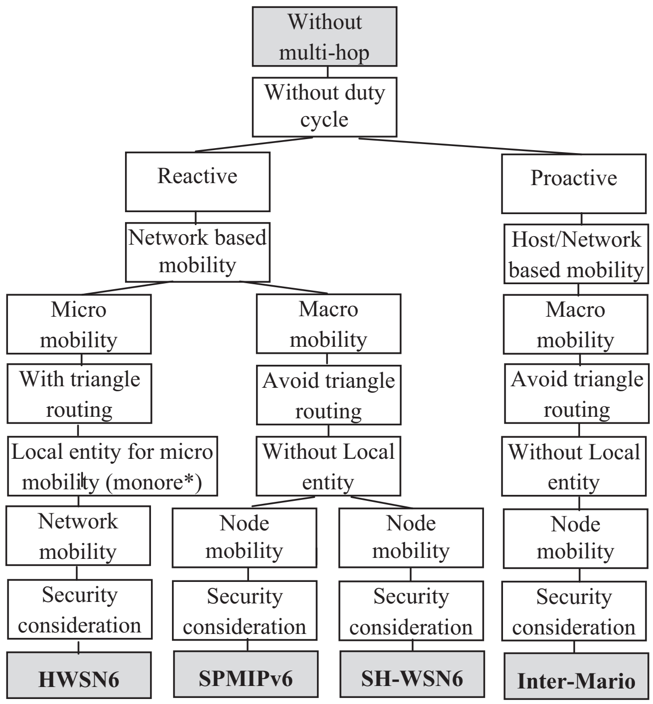
4.3. Mobility support protocols for 6LoWPAN networks without multi-hop consideration

The "*Hospital Wireless Sensor Networks*" (HWSN6) [31–33] and the "*Sensor Proxy Mobile IPv6*" (SPMIPv6) [59,60] are two proposed protocols that deal with network mobility and micro/macro mobility for a healthcare application based on the 6LoWPAN networks. The main goal consists in tracking the patient, who can move freely with some sensors node put in his clothes. Inter-Mario [43] and "*Soft Handover for Mobile WSNs*" (SH-WSN6) [74] are protocols dealing with node mobility and macro mobility for the 6LoWPAN networks with some improvements. The used criteria of these two protocols are represented in Fig. 7, and their impact on the network performances is discussed in the following sections. Brief descriptions of these protocols are shown in Table 3.

4.3.1. Signaling cost and its impact on power consumption

SPMIPv6 can be applied in a hospital or at the patient's home. It is based on PMIPv6 by combining Authentication entity with the LMA (HA) and authentication messages with the Binding Update, which reduces the number of messages in the network, thus reducing the signaling cost.

In addition, HWSN6 and SPMIPv6 are network based protocols in which the foreign agent for HWSN6 and the MAG for the



*monore: a local gateway

Fig. 7. Classification of mobility support protocols for 6LoWPAN Networks without multi-hop consideration.

SPMIPv6 are responsible for sending the mobility signaling. This reduces the involvement of the MN, and thus its signaling cost and power consumption.

The evaluation and simulation results of SPMIPv6 prove that the signaling cost (number of bits of messages RS, RA and BU) increases as the number of hops and the number of nodes increase, as it uses more signaling messages. Thus, the power consumption increases when the node density and data payload increase. In contrast, they are still lower when compared to MIPv6 and PMIPv6. So, using 500 nodes, the signaling cost is equal to 1000 bits for SPMIPv6 compared to 1240 bits for PMIPv6 and 1500 bits for MIPv6 at the same time [59,60].

Nonetheless, these protocols still face some problems to conserve power. First, since they do not solve the multi-hop communication problem within the 6LoWPAN networks, the MN consumes more power to communicate with the GW when it is too far. Second, SPMIPv6 and SH-WSN6 still use the periodic broadcast of the RA messages to detect movement; and HWSN6 uses the change of the PAN-ID received periodically in a beacon, or by the periodically sent of NR (Node Registration) message by the MN to the GW. These concepts require the involvement of the MN, which causes the overload of the bandwidth and increases the signaling cost and the power consumption in the network. Third, Inter-Mario increases the signaling cost through the double sending of the binding updates by the MN (host based protocol) and by the foreign agent in the pre-configuration process (network based protocol). Simulation results show that using 15 hops between the MN and the GW, the signaling cost is equal to 2250 bits with MIPv6 and 2750 bits with Inter Mario. Ultimately, they do not consider the duty cycle for nodes to conserve power.

4.3.2. Handover delay

HWSN6 proposes new architecture dedicated to be used in a hospital. Its concept consists in reducing the handover delay by using a local GW in each room called "*monore system*", which is responsible for dealing with the corresponding patient mobility.

Besides, HWSN6 and SPMIPv6 help to reduce the handover delay using a fixed IPv6 address, so they do not need an additional time whether to configure a new care of address, or to perform a duplicate address detection during the movement process.

Moreover, Inter-Mario is interested in reducing to reduce the handover delay based on MIPv6. To this end, it uses a proactive process performed with the help of a SN called "*Partner Node*" (PN) in the simple 6LoWPAN architecture. This process consists in carrying out monitoring and movement detection of nodes by computing the Received Signal Strength Indicator (RSSI), and in executing a pre-configuration of the future handover (before disconnection of the MN from its current attachment) through the exchange of information between the MN and the PANs in the vicinity with the help of the PNs. This process helps the MN to reduce the handover delay by scanning selectively the frequency of the PANs when it moves away from its home network, instead of scanning all the frequencies in the vicinity. Simulation results show that using 5 hops between the MN and the GW, the handover delay is equal to 35 ms with MIPv6, and 22 ms with Inter Mario [43].

Then, according to the state-of-the art, as noted previously, the MN is attached only to one GW and changes its attachment each time it receives a Router Advertisement message from a different GW, which causes an unnecessary handover with the risk of losing connection. The solution concept of SH-WSN6 is based on the idea to have more routes for the MN in order to ensure a continuous connectivity and to avoid handover process. It suggests allowing the MN to connect with more than one GW and having more IPv6 addresses, when there are more GWs in its range. This concept provides gain of a new route and improves connectivity. It also proposes to remove unreliable links using a comparing algorithm of the receiving Router Advertisement messages ratio, in order to improve Quality of Services (QoS) and ensure an acceptable end-to-end delay. According to the evaluation in [74], the handover delay of SH-WSN6 provides acceptable results, but it is not the best solution to have the fastest handover.

Nonetheless, Inter-Mario cannot succeed in achieving its goal in every movement of the MN, mainly with a rapid movement. In this case, it will perform a MIPv6 operation. In addition, there is a tradeoff between the fast handover and the great signaling cost for the MN and the network. This tradeoff is proved by simulation of Inter-Mario [43]. When compared with PMIPv6, the handover delay (the sum of the forwarding delay) is noticeably lower with an increased number of hops, but its signaling cost (including

Table 3
Comparative study between different mobility support protocols for 6LoWPAN Networks without multi-hop consideration.

	Address	Movement detection	Data buffered	Topology architecture	Mobility model
HWSN6(1) [31]	Fixed IPv6	PAN-ID	Not considered	Star	Unspecified
HWSN6(2) [32,33]	Fixed IPv6	NR/NC & NS/NA	Not considered	Star	Unspecified
SPMIPv6 [59,60]	Fixed IPv6	RS/RA	SLMA	Star	Probabilistic Random walk based on Markov chain [75]
Inter-Mario [43]	IPv6	RSSI/link quality	FA	Star	Unspecified
SH-WSN6 [74]	IPv6	RS/RA	LMA	Star	Unspecified

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routing cost, signaling cost of pre-configuration and binding updates) is higher. Furthermore, the reactive process of HWSN6 and SPMIPv6 (that they deal with mobility only after the MN reaches the visited network) increases the handover delay.

4.3.3. End-to-end delay

To reduce the end-to-end delay, SPMIPv6 and SH-WSN6 use the multi-homing concept to avoid the triangle routing after the handover process. Besides, Inter-Mario carries out the surrogate RR procedure to optimize route and keep an end-to-end delay almost identical to the latency before performing the handover process, which is proved by simulation in [43]. However, HWSN6 does not optimize the triangle routing process, because all data detected from the mobile patient must be transferred to its home GW, which overloads this GW, and then increases the end-to-end delay.

4.3.4. Security

Since HWSN6 and SPMIPv6 are designed to monitor vital constants and dependent on the patient's life applications [76], they introduce the security services such as confidentiality, and authentication of the MN. However, the cost of these security services is not taken into account to improve the network performance.

4.4. Mobility support protocols for 6LoWPAN networks with multi-hop consideration

Since the major power consumption is caused by the deficit of the multi-hop communication within the 6LoWPAN networks, some protocols are proposed to solve this problem and improve performances in the Networks. For instance, in [77], this issue is dealt with the combination of the proper concept of MIPv6 and the routing protocol OLSR (MIPv6 + OLSR). And in [78,79], the problem is tackled by the combination between NEMO and HWSN protocols. NEMO-HWSN is created for the healthcare applications to avoid the bottleneck problem encountered with NEMO protocol in the MR entity. Thus, its concept consists in sharing the functionality of the MR with other FFD-type MNs. Other proposed protocols ensure the multi-hop communication with the help of some SNs deployed within the 6LoWPAN. These are responsible for tracking the MN and routing packets from/to it. Among these protocols, we cite Inter-PAN [34,35], "*LoW Mobility*" (LoWMob) [36], "*Distributed LoWMob*" (DLoWMob) [36], Inter-Mobility [50], "*Mobile IP-Based*" [71] and RPL-Weight [80] for node mobility and Cluster-Based Scheme [44] for network mobility. The used criteria of these protocols are represented in Fig. 8, and its impact on the network performances is discussed in the following sections. A Brief summary of these protocols is shown in Table 4.

4.4.1. Signaling cost and its impact on power consumption

Power consumption is noticeably reduced for the MN for almost all the protocols cited above, since they consider the multi-hop communication between the MN and the GW of its 6LoWPAN network. In addition, they are classified as network based protocols, for which another entity acts as the responsible to perform the messages exchange and to manage mobility instead of the MN itself. This criterion decreases the power consumption and the signaling cost for the MN.

The simulation results of LoWMob and DLoWMob show that the signaling cost is not impacted by the speed of the MN, because it associates with the same number of SNs and it requires the same number of mobility messages. In addition, this performance parameter is better for DLoWMob (1.750 bits) than LoWMob (4.000 bits), because the number of hops from the MN to the GW is less important. Moreover, compared to HMIPv6 (13.000 bits), the signaling cost is lower, because it uses an optimized packet size [36].

The simulation results of Inter-PAN(1) [34] show that the signaling cost does not change when the speed of the MN increases, because the MN associates with the same number of parent nodes, which provides the same number of messages. Contrary to Inter-PAN(2) [35], the signaling cost is reduced by the increasing speed. Because when the node is slower, the MN performs more handover due to sleep-active state transition of the SN [35]. This parameter is relatively reduced compared to the HMIPv6, given that this one performs more handover, which significantly affects more messages related to mobility (200 bits with Inter-PAN compared to 2.500 bits with HMIPv6, using a MN speed 10 m/s [35]). The simulation results of NEMO-HWSN show that its signaling cost is smaller than that of NEMO and HWSN6 protocols, because of the decrease in the amount of signaling messages. Thereby, after 100 movements, the total signaling cost is around 50.000 Bytes with NEMO-HWSN6 protocol, however, it reaches 60.000 Bytes and 130.000 Bytes respectively with NEMO and HWSN6 protocols.

Besides, the Cluster-Based Scheme protocol helps in the routing of the mobility control message by an automatic routing through the tree topology. Hence, there is no need to transmit control information to establish a routing path, which decreases the signaling cost. Simulation results of Cluster-Based Scheme [44] illustrate that the mobility handoff cost remains unchanged with an increasing speed, since there is the same number of associate nodes. In addition, it proves that this performance does not exceeds 20.000 bytes with Cluster-Based scheme, using a packet arrival rate equal to 10 pkt/s. In contrast, it reaches 225.000 bytes with HMIPv6 [44].

Unlike the previous protocols, the Routing Protocol for Low power and lossy networks-Weight (RPL-Weight) is based on

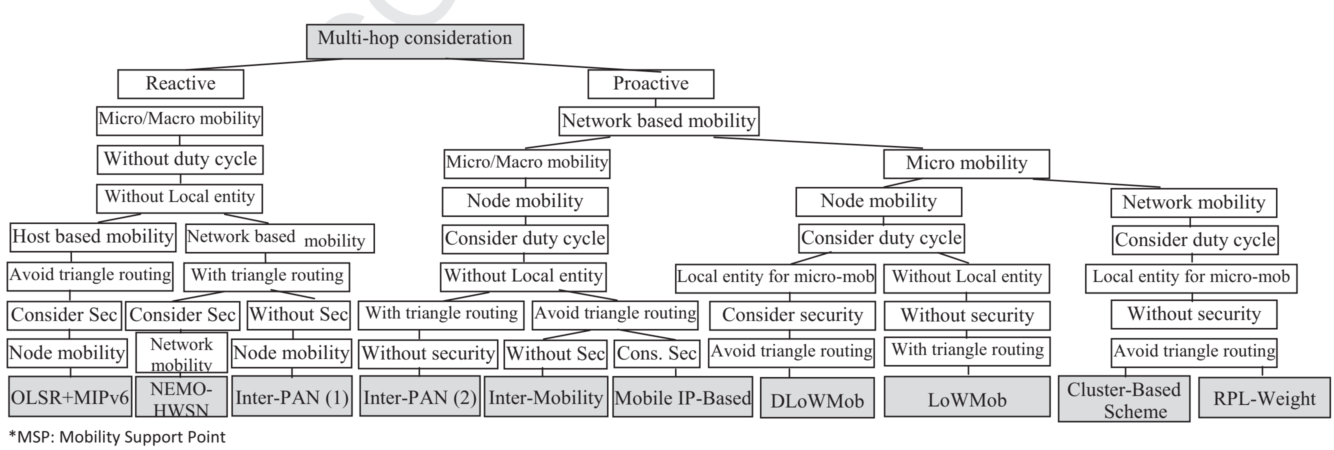

Fig. 8. Classification of mobility support protocols for 6LoWPAN Networks with multi-hop consideration.

Table 4
Comparative study between different mobility support protocols for 6LoWPAN Networks with multi-hop consideration.

	Address	Movement detection	Data buffered	Topology architecture	Mobility model	Deployment of static nodes
OLSR + MIPv6 [77]/NEMO-HWSN6 [78,79]	IPv6	RS/RA	HA	Hybrid: Mesh-Star	Unspecified	Random
LoWMob [36]	Out: IPv6 In: 16-bit short	RSSI	PSN	Hybrid: Mesh-Bus	Random waypoint [81]/ Fluid flow [82]	Grid
D-LoWMob [36]	Out: IPv6 In: 16-bit short	RSSI	PSN	Hybrid: Mesh-Star-Bus		Random in square zones
Inter-PAN(1) [34]	Out: IPv6 In: 16-bit short	RSSI	GW	Hybrid: Mesh-Star-Bus	Fluid flow based on Marcov chain	Grid
Inter-PAN(2) [35]	Out: IPv6 In: 16-bit short	RSSI	NPSN	Hybrid: Mesh-Star-Bus	Fluid flow [82]	Grid
Inter-Mobility [50]	Out: IPv6 In: 16-bit short	RSSI/PAN-ID	Intra: NPA Inter: FA	Hybrid: Mesh-Star	Unspecified	Random
Mobile IP-Based [71]	Out: IPv6 In: 16-bit short	RSSI	Unspecified	Hybrid: Tree-star	Random Waypoint	Random
Cluster-Based Scheme [44]	Hierarchical	RSSI	Previous associated node	Hybrid: Cluster tree-Bus	Random walk [83]	Grid
RPL-Weight [80]	IEEE 802.15.4	Intended movement	Sink node	Hybrid: DoDAG-Mesh	To computed position place	Grid

routing protocol RPL which is able to manage micro mobility [80]. RPL is a hierarchical routing based on Directed Acyclic Graph (DAG) to define the network topology, and it uses Destination Oriented DAG (DODAG) algorithm. RPL-Weight is designed to track a MN with taking into account the sink node mobility. The sink node mobility contributes to reduce power consumption and to increase the network lifetime. Indeed, nodes closer to the sink are more frequently asked to forward packets of other nodes addressed to the sink node. Therefore, the power consumption at these nodes is more important compared to other far nodes from the sink. Consequently, these nodes become rapidly unavailable which affects the network lifetime. In order to mitigate this impact, and to increase network lifetime the load balancing policy can be introduced. In addition, RPL-Weight is a distributed based protocol which is not the case of other protocols based on the same concept.

Simulation results of RPL-Weight show that the network lifetime is increased compared to the static sink. It also improves the network lifetime when the network size increases. Furthermore, RPL-Weight helps to reduce the signaling cost.

Nonetheless, MIPv6 + OLSR increases the signaling cost and the power consumption within the networks, since it is a host based protocol and has the same concept as MIPv6. In addition, it does not maintain the duty cycle to preserve power for the nodes.

4.4.2. Handover delay

LoWMob, DLoWMob, Inter-PAN(2), Inter-Mobility, Mobile IP-Based and Cluster-Based Scheme help to reduce the handover delay using the proactive process. This process is achieved by employing a parent SN for the MN, which acts as an anchor point. This entity concept consists in:

–Monitoring and detecting the movement of the MN by a periodic computation of the RSSI value.
–Predicting the next localization of the MN based on RSSI computation and AOA techniques.

Following this process, the scan and join times is removed for Mobile IP-Based, then, the handoff delay is close to zero. However, in the case of a false prediction, the handover delay is similar to that of MIPv6 protocol [71]. Simulation results show that the Handoff delay is around 37.426 ms with 0 ms offline time when the movement prediction is correct. However, it is around 68.291 ms with 41.322 ms offline time, in the other case. Moreover, simulation results show that the accuracy reaches 95.4% [71].

Furthermore, DLoWMob and Cluster-Based Scheme can help to reduce the handover delay for the micro mobility by avoiding the required delay to send signaling messages toward the GW. Thus, DLoWMob uses an entity within the 6LoWPAN Networks called Mobility Support Point (MSP), which acts as a local GW to deal with mobility within a set of nodes. In opposition, the Cluster-Based Scheme delegates to the common ancestor node to receive messages to deal with the node mobility within its sub-tree (without the involvement of the GW). Moreover, RPL-Weight does not waste a handover delay since mobility is performed only during the global repair of its topology.

According to the simulation of the Cluster-Based Scheme [44], the handover delay relative to the increase in the number of hops is noticeably reduced compared to LoWMob, because this scheme performs mobility signaling only to the common ancestor node and it uses an automatic routing, which decreases delay to establish routing path. Finally, unlike the Cluster-Based Scheme, micro mobility in a tree topology with Mobile-IP Based protocol needs to send the Binding Update message to the coordinator, which requires more time for the handover delay.

4.4.3. End-to-end delay

Most of these protocols consider the route optimization after the handover process, which reduces the end-to-end delay of the communication data between the MN and its CN. Regarding NEMO-HWSN protocol, the end-to-end delay is reduced since each node directly sends its sensing data to the Border Router, instead of sending it through the MR. However, it is already increased, because, this protocol does not avoid the triangle routing in order to collect all sensing data of the patient in the same Border Router to detect illnesses. The simulation results show the decrease in the end-to-end delay for NEMO-HWSN compared to HWSN6 [78,79]. Thus, the end-to-end delay related to 1000 arrival packet is around 14s with NEMO-HWSN6, compared to 20 s with NEMO.

Moreover, according to the simulation results of LoWMob and DLoWMob [36], the end-to-end delay increases as the speed of the MN increases, because at a high speed, there are many interruptions of the association between the MNs and their parents. In addition, simulation results show that the end-to-end delay for DLoWMob is reduced up to twice compared to LoWMob.

4.4.4. Security

Only DLoWMob, NEMO-HWSN, Mobile IP-Based and MIP-v6 + OLSR introduce security services like confidentiality to secure the networks against eavesdroppers and attackers. DLoWMob and NEMO-HWSN use data encryption and authentication of the MN at the visited network. However, Mobile IP-Based performs authentication of nodes through communication with the AAA server, using security features (credential of authentication) from the neighborhood map. Ultimately, MIPv6 + OLSR uses IPSec to secure messages related to mobility.

4.4.5. Data loss rate

For LoWMob, DLoWMob, Inter-PAN, Inter-Mobility and Cluster-Based Scheme, when a parent SN detects a movement of the MN away from its range, it helps to buffer packets. Then, after the new attachment confirmation, it sends the buffered data toward the next parent node to avoid data loss.

Simulation results of LoWMob and DLoWMob illustrate that at a high speed, the number of the handoffs increases, which causes data loss [36], so the packet success ratio is reduced when the MN increases its speed. In addition, the packet success ratio is better for DLoWMob, since the number of hops is lower. Moreover, evaluation of the packet loss for Inter-PAN is less than HMIPv6, because ofHMIPv6 performs more handover with much delay, which causes data loss [34,35]. Then, compared to the LoWMob, the Cluster-Based Scheme simulation results show less data loss [44], because reducing the handover delay saves the number of the lost packets (it does not reach 20% compared to 60% with HMIPv6, using 10 hops between [44]). The GW and the associate node.

Ultimately, the Cluster-Based Scheme appears to be more suitable to the requirement of 6LoWPAN networks. Nevertheless, this scheme uses a hierarchical address depending on its topology organized in a tree architecture, that does not follow the 6LoWPAN standard and does not consider dealing with macro mobility. Thus, more work is needed for the mobility management on this kind of network.

5. Mobility in WSNs based on 6lowPAN: future directions

Dealing with mobility in WSN based on 6LoWPAN technology is a challenging issue, because of the strict constraints and the needed requirements of this network. Some important challenges (noted in Section 2) must be taken into consideration to provide appropriate solutions for the 6LoWPAN Networks. In order to meet these challenges, and according to our analysis in the study made for the existing mobility support protocols, it is important to consider some directions and recommendations.

First, to be able to avoid data loss and increase the packet delivery ratio (PDR), mobility management protocols must reduce the bandwidth occupation which might be overloaded by the signaling messages. Besides, it must avoid the disconnection span time by performing the prediction process to anticipate problems and reduce the handover delay. The needed delay for the handover can be decreased by providing a continuous connectivity. Hence, it is crucial to perform a fast mobility detection with more accuracy [51,84], in order to rapidly find a new attachment point. Moreover, it is important to perform a fast handover, for instance by using a pre-configuration process of the MN address in the visited network, as it is used by Inter-Mario [43].

Second, to keep the same end-to-end delay as before and after the handover process and to reduce the jitter impact on the applications. It is necessary to optimize the triangle routing process. In addition, in WSN based on 6LoWPAN technology, it is important to shorten the frame fragmentation, so as to reduce the needed time to perform buffering and verifying of headers [31]. Hence, mobility management should optimize the payload size, and use signaling messages encapsulated in IEEE 802.15.4 frames.

Third, to preserve the power of nodes and extend the network lifetime, which is considered as a key constraint of the WSN based on 6loWPAN technology, it is necessary to take into account some directions. For instance, performing duty cycle and topology control with consideration of multi-hop communication between nodes, since communication needs more power when the communicating nodes are too far away from each other. Since the MN consumes more power then the other nodes, it is preferable to apply a network based protocol. So, sending control messages should be performed by an entity other than the MN [47]. In addition, It is important to reduce treatments, since they require more power and this network type has limited resources in memory and processing. For these reasons, in WSN with 6LoWPAN, the protocol has to reduce fragmentation and signaling messages [37,47] and use compression mechanisms.

Fourth, security in WSN based on 6LoWPAN is already a challenging issue. In order to design a mobility management protocol, it is suitable to select the adapted cryptography algorithms to ensure security services with low cost from the link layer (IEEE 802.15.4) to the application layer. This point is recommended because performing a supplementary security mechanism requires more processing, memory and bandwidth, which are limited in this network type [31]. For this reason, it is recommended that the mobility support protocol should optimize the security cost according to the available resources (power, transmission rate, etc) [62–64]. In contrast, for the outside of the LoWPAN, the protocol may perform a mechanism [32] such as "*IPSec*" [85].

In [58], the authors propose a security solution based on the ID/Location split concept which tackles mobility and multi-homing problems by the mapping and binding systems [86]and taking into account the constrained resources. This proposition considers the advantages from the existing security solution such as LISP [87] and HIP-DEX [88]. Thus, it provides authentication based on Return Rout-ability (RR), cryptographic based on ECC technique [89] and extends the trust domain to ensure scalability based on the Diffie–Helman key exchange and kerberos technique [90]. These used techniques are considered in this paper as the most adequate to reduce costs.

Fifth, it worth noting that the mobility management protocol must reduce complexity in terms of time, memory, and messages. In addition, the scalability is an important parameter which must be ensured.

Finally, it is recommended to have a glance at the IEEE 802.15.4 g standard [91], since it has been used over the last few years to ease a large scale process control application (such as the smart grid). This standard can use multiple data rate in variable frequency bands, following different modes. For instance, the MR-OFDM "*Multi-rate Orthogonal Frequency Division Multiplexing*" was used to provide a higher data rate with a higher spectral efficiency, "*Multi-rate and multi-regional Offset Quadrature Phase Shift Keying*"

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(MR-OQPSK) was applied to create a multi-mode simple in design at a low cost, and "*Multi-rate and multi-regional Frequency Shift Keying*" (MR-FSK) was used to provide better transmission power efficiency. It's important to consider the contribution of this standard in the conception and the evaluation of the mobility management protocol.

6. Conclusion and perspectives

Mobility of nodes in WSN with 6LoWPAN technology involves many advantages and functionalities for the needed applications. However, it represents a major challenge to face, because of its impacts and changes on this kind of network. In this paper, the state-of-art of mobility support protocols was surveyed. We began our work by introducing the challenges required to design a mobility management. Then, the classification criteria of mobility support protocols were proposed. The choice of such criteria depends on the used application and the needed performances. Based on these criteria, a comparative study of the existing protocols was presented to discuss the effect of each used criterion on the performances of the 6LoWPAN networks.

After our study and analysis of the existing protocols, the major conclusion to be drawn is that there is no efficient solution to meet all the requirements and constraints of WSN with 6LoWPAN Technology. Thus, some improvements are still required. Moreover, the micro mobility was observed to affect the routing path within the LoWPAN. Hence, the micro mobility cannot be treated without considering the routing protocol. IETF ROLL working group proposed a routing protocol for LoW Power and Lossy Networks called "*RPL*". This protocol might be considered in our future work to support mobility over the routing protocol in WSN with 6LoWPAN technology.

References

[1] Jennifer Yick, Biswanath Mukherjee, Dipak Ghosal, Wireless sensor network survey, Int. J. Comput. Telecommun. Networking 52 (12) (2008) 2292–2330.
[2] I.F. Akyildiz, W. Su, Y.S. ubramaniam, E. Cayirci, Wireless sensor networks: a survey, J. Com. Net. 38 (2002) 393–422.
[3] D. Culler, D. Estrin, M. Srivastava, Overview of sensor networks, IEEE J. Comput. Soc. 37 (8) (2004) 41–49.
[4] K. Römer, F. Mattern, The design space of wireless sensor networks, IEEE Wireless Commun. 11 (6) (2004) 54–61.
[5] M. Welsh, D. Malan, B. Duncan, T. Fulford-Jones, S. Moulton, Wireless sensor networks for emergency Medical Care, Harvard and Boston Universities, A Talk Presented at GE Global Research, March 2004.
[6] Stanislava Stanković, Medical applications based on Wireless Sensor Networks, Trans. J. Int. Res. 5 (2) (2009) 19–23.
[7] I. Boulanouar, A. Rachedi, Stéphane Lohier, Gilles Roussel, Energy-aware object tracking algorithm using heterogeneous Wireless Sensor Networks, in: 4th IFIP/IEEE WD'2011, Ontario, Canada, October 2011.
[8] S. Prasanna, S.Rao, An Overview of Wireless Sensor Networks Applications and Security, IJSCE, vol-2(2), May 2012, ISSN: 2231–2307.
[9] J.A. Stankovic, A.D. Wood, T. He, Realistic applications for wireless sensor networks, Theoretical Comput. Sci. (2011) 835–863.
[10] Antoine Bagula, Application of Wireless Sensor Networks, A Talk Presented at WSN Applications, UCT, February 2012.
[11] Antonio J. Jara, Socrates Varakliotis, Antonio F. Gmez-Skarmeta, Peter T. Kirstein, Extending the internet of things to the future internet through IPv6 support, J. Mobile Inf. Syst. 10 (1) (2014) 3–17.
[12] P. Lopez, D. Fernndez, A.J. Jara, A.F. Skarmeta, Survey of Internet of Things Technologies for Clinical Environments, AINA Workshops, 2013, pp. 1349–1354.
[13] Zach Shelby, Carsten Bormann, 6LoWPAN: The Wireless Embedded Internet, Book, IETF (6LoWPAN-WG), 2009.
[14] Luís M.L. Oliveira, Amaro F. de Sousa, Joel J.P.C. Rodrigues, Routing and mobility approaches in IPv6 over LoWPAN mesh networks, IJCS 24 (11) (2011) 1445–1466.
[15] A. Ghosha, S.K. Dasb, Coverage and connectivity issues in wireless sensor networks: a survey, J. PMC 4 (3) (2008) 303–334.
[16] B. Liu, P. Brass, O. Dousse, P. Nain, D. Towsley, Mobility Improves Coverage of Sensor Networks, ACM(MobiHoc'05), Illinois, USA, May 2005.
[17] R. Nuno, M. da Silva, Mobility support in Low Power Wireless Personal Area Networks (MLoWPAN), Coimbra University, Portugal, 2010.
[18] G. Montenegro, N. Kushalnagar, J. Hui, D. Culler, Transmission of IPv6 Packets over IEEE 802.15.4 Networks, IETF RFC 4944, September 2007.
[19] Jonathan Hui, David Culler, Samita Chakrabarti, 6LoWPAN: Incorporating IEEE 802.15.4 into the IP architecture, (IPSO) Alliance, January 2009.
[20] Md.S. Hossen, A.F.M.S. Kabir, R.H. (Khan), A. Azfar, Interconnection between 802.15.4 devices and IPv6: implications and existing approaches, IJCSI 7 (1) (2010).
[21] IEEE Computer Society, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), IEEE Std 802.15.4, October 2003.
[22] Luca De Nardis, Maria-Gabriella Di Benedetto, Overview of the IEEE 802.15.4/4a Standards for Low Data Rate Wireless Personal Data Networks, WPNC'2007, Hannover, Germany, 2007.
[23] J.W. Hui, D.E. Culler, Extending IP to low-power, wireless personal area networks, IEEE JIC 12 (4) (2008).
[24] A.J. Jara, L. Ladid, A. Skarmeta, The internet of everything through IPv6: an analysis of challenges, solutions and opportunities, J. Wireless Mobile Networks (UCDA) 4 (3) (2013) 97–118.
[25] ZigBee Alliance, ZigBee Specification, October 2007.
[26] P. Baronti, P. Pillai, V.W.C. Chook, S. Chessa, A. Gotta, Y. Fun Hu, WSNs: a survey on the state of the art and the 802.15.4 and ZigBee standards, J. ComCom 30 (7) (2007) 1655–1695.
[27] IEEE Computer Society, Part 15.4: wireless medium access control (MAC) and physical layer (PHY) specifications for low-rate wireless personal area networks (WPANs), IEEE Standard 802.15.4. August, 2007.
[28] K.D. Korte, I. Tumar, J. Schonwalder, Evaluation of IPv6 over low-power wireless personal area networks implementations, in: 4th IEEE SenseApp'09, Zurich, Switzerland, 20–23 October 2009.
[29] A.d.P. Escola, Development of a Wireless Sensor Network with 6LoWPAN Support, Master, Polytechnique University, Catalunya, July 2009.
[30] Nazim Abdeddaim, Analyse des performances d'un r–seau de capteurs exploitant le standard IEEE 802.15.4, thesis report, Grenoble, August 2006.
[31] A.J. Jara, M.A. Zamora, A.F.G. Skarmeta, HWSN6: hospital wireless sensor networks based on 6LoWPAN technology: mobility and fault tolerance management, CSE'09, vol. 2, Vancouver, BC, 2009, pp. 879–884.
[32] A.J. Jara, M.A. Zamora, A.F.G. Skarmeta, An initial approach to support mobility in hospital wireless sensor networks based on 6LoWPAN (HWSN6), J. WMN (UCDA) 1 (2/3) (2010) 107–122.
[33] Antonio J. Jara, Miguel A. Zamora, Antonio F.G. Skarmeta, Intra-mobility for Hospital Wireless Sensor Networks based on 6LoWPAN, in: 6th IEEE (ICWMC), Valencia, 20–25 September 2010, pp 389–394.
[34] G. Bag, H. Mukhtar, S.M.S. Shams, K.H. Kim, S. Yoo, Inter-PAN mobility support for 6LoWPAN, Int. Conf on CHIT, Busan, Korea, 2008.
[35] G. Bag, S.M.S. Shams, A.H. Akhbar, M.T. Raza, K.H. Kim, S.W. Yoo, Network assisted mobility support for 6LoWPAN, in: 6th IEEE CCN, Las Vegas, USA, January 2009.
[36] G. Bag, M.T. Raza, K.H. Kim, S.W. Yoo, LoWMob: Intra-PAN Mobility Support Schemes for 6LoWPAN, Sensors'09, vol. 9(I7), July 09, pp. 5844–5877.
[37] N. Kushalnagar, G. Montenegro, C. Schumacher, IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals, IETF RFC 4919, August 2007.
[38] J. Kempf, B. DoCoMo Problem Statement for Network-Based Localized Mobility Management (NETLMM), IETF RFC 4830, April 2007.
[39] Benyuan Liu, Peter Brass, Olivier Dousse, Philippe Nain, Don Towsley, Mobility Improves Coverage of Sensor Networks, ACM (Mobi-Hoc'05), Illinois, USA, May, 2005.
[40] Silvia De Lucia, Optimization of Handover Algorithms forWireless Networks, Master's Degree Project, Stockholm, Sweden, 2010.
[41] Y.C. Wang, F.J. Wu, Y.C. Tseng, Mobility Management Algorithms and Applications for Mobile Sensor Networks, in: WILEY WCMC in Special Issue of Recent Advancement in Wireless Ad Hoc and Sensor Networks, vol. 12(1), January 2012, pp. 7–21.
[42] M. Pascoe, J. Gomez, V. Rangel, M. Lopez-Guerrero, F. Mendoza, A mobility-based upper bound on route length in MANETs, J. Telecommun. Syst. 52 (1) (2013) 105–119.
[43] Minkeun Ha, Daeyoung Kim, Seong Hoon Kim, Sungmin Hong, Inter-MARIO: a fast and seamless mobility protocol to support Inter-PAN handover in 6LoWPAN, in: IEEE GLOBECOM'10, Miami, FL, December 2010, pp. 1–6.
[44] W. Xiaonan, Z. Shan, Z. Rong, A mobility support scheme for 6LoWPAN, J. ComCom 35 (3) (2012) 392–404.
[45] D. Johnson, C. Perkins, J. Arkko, Mobility Support in IPv6, in: IETF RFC 3775, June 2004.
[46] R. Koodli, Mobile IPv6 Fast Handovers, in: IETF RFC 5568, June 2008.
[47] Myung-Ki Shin, Hyoung-Jun Kim, L3 Mobility Support in Large-scale IP-based Sensor Networks (6LoWPAN), in: 11th IEEE ICACT 2009, vol. 2, Phoenix Park, February 2009, pp. 941–945.
[48] R. Silva, J. Sa Silva, An Adaptation Model for Mobile IPv6 support in LoWPANs, IETF, draft-silva-6lowpan-mipv6-00, May 2009.
[49] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, B. Patil, Proxy Mobile IPv6, IETF, RFC 5213, August 2008.
[50] Z. Zinonos, V. Vassiliou, Inter-Mobility Support in Controlled 6LoWPAN Networks, in: Globecom 2010, Miami, FL, December 2010, pp. 1718–1723.
[51] G. Bag, M.T. Raza, H. Mukhtar, A.H. Akbar, S.M.S. Shams, K.H. Kim, S.w. Yoo, D. Kim, Energy-aware and bandwidth-efficient mobility architecture for 6LoWPAN, in: MILCOM, San Diego, USA, November 2008, pp 1–7.

[52] Q. Dong, W. Dargie, A survey on mobility and mobility-aware MAC protocols in Wireless Sensor Networks, IEEE JCST 15 (1) (2013).
[53] L. Toutain, K. Perros, J. Lee, Supprimer le protocole Neighbor Discovery dans les réseaux de capteurs, CFIP, les Arcs:France, 2008.
[54] Z. Shelby, P. Thubert, J. Hui, S. Chakrabarti, C. Bormann, E. Nordmark, 6LoWPAN Neighbor Discovery, in: Draft-6lowpan-nd-06, September 2009.
[55] Wikipedia-6LoWPAN. <http://fr.wikipedia.org/wiki/6LoWPAN>.
[56] A. Attwood, M. Merabti, O. Abuelmaatti, Network mobility and fragmentation in wireless mesh internetworks: issues and challenges, in: The 11th PGNet, June 2010.
[57] H. Miura, K. Hirano, N. Matsuda, H. Taki, N. Abe, S. Hori, Indoor localization for mobile node based on RSSI, In: Knowledge-Based Intelligent Information and Engineering Systems, 2007, pp 1065–1072.
[58] A.J. Jara, V.P. Kafle, A. Skarmeta, Secure and scalable mobility management scheme for the Internet of Things integration in the future internet architecture, J. Ad Hoc Ubi Com 13 (3/4) (2013) 228–242.
[59] Md.M. Islam, M.M. Hassan, E.N. Huh, Sensor proxy mobile IPv6 (SPMIPv6)-a framework of mobility supported IP-WSN, in: 13th ICCIT 2010, Dhaka, Bangladesh, December 2010.
[60] Md. Motaharul Islam, Eui-Nam Huh, Sensor proxy mobile IPv6 (SPMIPv6)-a novel scheme for mobility supported IP-WSNs Sensors, in: Sensor 2011, vol. 11(2), 2011, pp. 1865–1887.
[61] Antonio J. Jara, David Fernandez, Pablo Lopez, Miguel A. Zamora, Antonio F. Skarmeta, Lightweight MIPv6 with IPSec support, J. Mobile Inf. Syst. 10 (1) (2014) 37–77.
[62] A. Rachedi, A. Hasnaoui, Security with quality-of-services optimization in wireless sensor networks, in: IWCMC'2013, Cagliari, Italy, July 2013.
[63] A. Rachedi, L. Kaddar, A. Mehaoua, EDES- Efficient Dynamic Selective Encryption Framework to Secure Multimedia Traffic in Wireless Sensor Networks, in: IEEE ICC'2012, Ottawa, Canada, June 2012, pp. 1026–1030.
[64] A. Rachedi, H.Baklouti, muDog: Smart Monitoring Mechanism for Wireless Sensor Networks based on IEEE 802.15.4 MAC, in: IEEE ICC'2011, Kyoto, Japan, June 2011.
[65] H. Soliman, C. Castelluccia, K. ElMalki, L. Bellier, Hierarchical mobile IPv6 (HMIPv6) mobility management, in: IETF, RFC 5380, October 2008.
[66] A.M. Khedr, W. Osamy, Mobility-assisted minimum connected cover in a WSN, J. Par. Dist. Comput. 72 (I7) (2012) 827–837.
[67] D. Saha, A. Mukherjee, I.S. Misra, M. Chakraborty, Mobility support in IP: a survey of related protocols, IEEE Network 18 (I6) (2004) 34–40.
[68] R. Ramjee, T. La Porta, S. Thuel, K. Varadhan, S. Wang, HAWAII: a domain based approach for supporting mobility in wide area wireless area networks, in: Network Protocols, Toronto, Canada, 1999, pp. 283–292.
[69] R. Silva, J.S. Silva, F. Boavida, Towards Mobility Support in Wireless Sensor Networks, CRC'10, Braga, Portugal, October 2010.
[70] V. Devarapalli, R. Wakikawa, A. Petrescu, P. Thubert, Network Mobility (NEMO) basic support protocol, in: IETF, RFC 3963, January 2005.
[71] A.J. Jara, R.M. Silva, J.S. Silva, M.A. Zamora, A.F.G. Skarmeta, Mobile IP-based protocol for wireless personal area networks in critical environments, J. WPC 61 (I4) (2011) 711–737.
[72] N. Nasser, A.Al. Yatama, K. Saleh, Zone-based routing protocol with mobility consideration for wireless sensor networks, J. Telecommun. Syst. 52 (I4) (2013) 2541–2560.
[73] Navid Hassanzadeh, Scalable Data Collection for MobileWireless Sensor Networks, Thesis Report, Stockholm, Sweden, November 2011.
[74] J. Petäjäjärvi, H. Karvonen, Soft Handover method for mobile wireless sensor networks based on 6LoWPAN, in: IEEE Int. Conf on DCOSS, Barcelona, 27–29 June 2011, pp. 1–6.
[75] T. Camp, J. Boleng, V. Davies, A survey of mobility models for Ad Hoc Network Research, WCMC: special issue on mobile ad hoc networking: research, Trends Appl. 2 (I5) (2002) 483–502.
[76] J.H. Kim, R. Haw, C.S. Hong, Development of a framework to support network-based mobility of 6LoWPAN sensor device for mobile healthcare system, in: ICCE, Las Vegas, NV, January 2010, pp. 359–360.
[77] V. Köster, D. Dorn, A. Lewandowski, C. Wietfeld, A novel approach for combining Micro and Macro Mobility in 6LoWPAN enabled Networks, in: IEEE VTC, San Francisco, CA, September 2011, pp. 1–5.
[78] M.S. Shahamabadi, B.B.M. Ali, N.K. Noordin, M.b.A. Rasid, P. Varahram, A.J. Jara, A network mobility solution based on 6LoWPAN hospital WSN (NEMO-HWSN), in: IEEE IMIS, Taichung, July 2013, pp. 433–438.
[79] M.S. Shahamabadi, B.B.M. Ali, P. Varahram, A.J. Jara, A NEMO-HWSN solution to support 6LoWPAN network mobility in hospital wireless sensor network, Comput. Sci. Inf. Syst.
[80] L.B. Saad, B. Tourancheau, Sinks mobility strategy in IPv6-based WSNs for network lifetime improvement, in: NTMS 2011, Paris, France, February 2011.
[81] Alexander Pelov, Mobility Models for Wireless Networks, Thesis Report of Computer Science, University of Strasbourg, 2009.
[82] C. Schindelhaue, Mobility in Wireless Networks, in: 32nd Springer SOFSEM, Merin, Czech Republic, January 2006, pp. 100–116.
[83] Cholatip Yawut, Adaptation la mobilit dans les rseaux ad hoc, thesis report of computer science, University of Toulouse, 2009.
[84] D. Roth, J. Montavont, T. Nol, gestion de la mobilité à travers différents réseaux de capteurs sans fil, AlgoTel, Belle Dune-Cote d'Opale, June 2010.
[85] S. Kent, K. Seo, Security Architecture for the Internet Protocol, in: IETF, RFC 4301, December 2005.
[86] EC FIArch Gr, Fundamental Limitations of Current Internet and the path to Future Internet, European Commission, FIArch Group, vol. 1.9, 2010.
[87] D. Farinacci, V. Fuller, D. Meyer, D. Lewis, Locator/ID Separation Protocol (LISP), in: IETF, 2010.
[88] R. Moskowitz, HIP Diet EXchange (DEX), draftmoskowitz-hip-rg-dex (work in progress), in: IETF, 2011.
[89] L. Marin, A.J. Jara, A.F.G. Skarmeta, Shifting primes: extension of pseudo-mersenne primes to optimize ECC for MSP430-based future internet of things devices, in: IFIP, Springer, 2011, pp. 205–219.
[90] J. Kohl, C. Neuman, The Kerberos Network Authentication Service (V5), IETF, 1993.
[91] K.S. Panchal, Implementing Phy Layer of IEEE 802.15.4G Standard with Direct Sequence Spread Spectrum (DSSS) Using Offset Quadrature Phase Shift Keying (O-QPSK), Master, San Diego State University, 2012.

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