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A Comparative Study of IPv6-Based Protocols for Mobile Wireless Sensor Networks

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Abstract

Advances in wireless communications and embedded electronics have led to the emergence of new wireless sensor network (WSN) applications. Accordingly, in many recent WSN applications nodes involve internet connection for remote monitoring and control purposes. Moreover, in these applications the use of mobile nodes is strongly required in order to achieve their specific tasks. Consequently, specific communication protocols are needed to accomplish these requirements. In this paper, we study IPv6-based protocols designed to manage node mobility and take into consideration WSN constraints. Our study aims to classify these protocols, and then compare their energy and temporal costs in order to help users to choose the suitable protocol for their WSN applications.

Keywords: Wireless Sensor Networks, Internet of Things, Mobility, Handover, IPv6, 6LoWPAN, MIPv6, Inter-MARIO, SNEMO, SPMIPv6, CSPMIPv6

1. Introduction

The use of mobile nodes has become a necessary requirement in many modern WSN applications in which nodes can be embedded in vehicles, robots, or worn by people or animals. In addition, the current trend encourages connecting the WSN to outside networks in order to allow remote data collection and control, which involves the use of the IPv6 protocol. In this context, the paper is interested in IPv6-based protocols supporting node mobility in mobile wireless sensor networks (MWSN).

The use of IPv6 in WSNs poses many problems: (i) In WSNs, the bandwidth is too small (the maximum allowable data rate is 250 Kbps and the maximum transmission unit for data transmission is up to 128 bytes when using the IEEE802.15.4 standard [9]). Consequently, IPv6 packets over IEEE802.15.4 is more challenging and require special attention. (ii) The Neighbour Discovery (ND) [4] protocol sends control messages in multicast mode when IPv6 stateless address auto-configuration, which consumes more energy. In addition, the ND protocol does not take into consideration that nodes in WSNs alternate between listening and sleep periods.

Concerning the first point, by taking into consideration sizes of all the frame headers, the IEEE802.15.4 standard leaves a minor space for data. Because the frame is composed at least of MAC, IPv6 and UDP headers, which leave only 54 bytes for data (Figure.1).

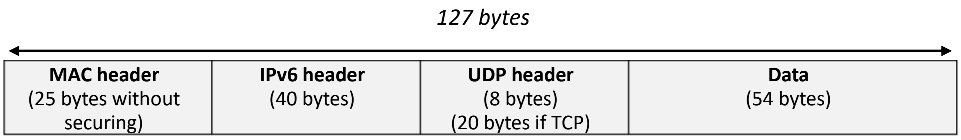

Figure 1. The IEEE 802.15 frame.

To overcome these constraints and allow the use of IPv6 protocol over WSNs, the IETF group has designed an additional layer, called 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks) [12] (Figure.2). This layer aims to reduce the size of IPv6 headers by using specific compression algorithms in order to extend the data part.

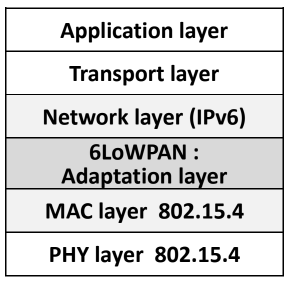

Figure 2. The position of 6LoWPAN in the protocol stack.

Concerning the second point, and in order to minimize the energy consumption caused by numerous control messages, WSNs employ an adapted version of the ND protocol which uses fewer control messages and takes into consideration that nodes are not accessible all the time. These adjustments allow simple communication with reduced costs [13].

The remainder of this paper is organized as follows: section 2 discusses various mobility scenarios, and then it presents our classification of IPv6-based protocols designed for MWSNs. In sections 3 and 4, we study these protocols. Then, in section 5, we compare the temporal and energy costs of mobility support in the studded protocols, and finally we will define for each one of them the suitable type of targeted applications.

2. Classification of IPv6-based protocols supporting mobility

From the viewpoint of network, there are two types of mobility: node mobility and network mobility. The node mobility is when a node (robot, vehicle, animal, etc.) changes its attachment point. While the network mobility occurs when a router, with all devices attached to it, changes its attachment point and all of these nodes appear as a single entity. This case of mobility can be found in many applications, such as military applications, etc.

From the viewpoint of mobility, there are also two types of mobility, micro and macro mobility (Figure.3): (i) the micro-mobility is when nodes move within the same field (e.g. nodes move within the same network or to another network that uses the same IPv6 prefix). Within this area, a Mobile Node (MN) can change its access point without changing the IPv6 prefix. (ii) In contrast, the Macro-mobility is when nodes move between different areas (e.g. from a network to another that uses a different IPv6 prefix).

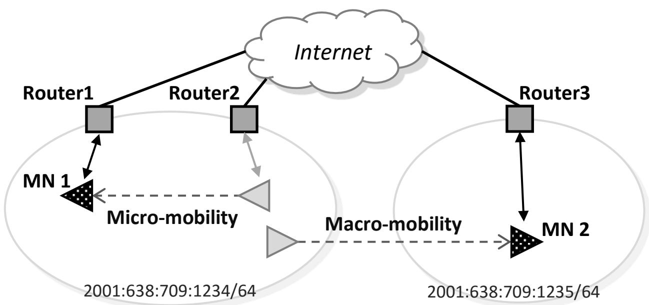

Figure 3. Types of mobility in IPv6-based WSN.

In order to manage mobility at the network layer, a set of protocols are designed and which are based on MIPv6 protocol. When using these protocols in WSNs, it is assumed that nodes understand each other at the MAC level and integrate adaptations seen above (the 6LoWPAN layer and the adapted ND protocol).

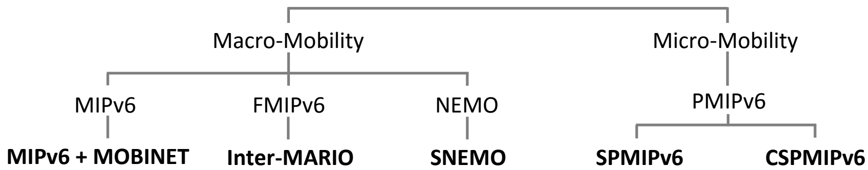

Figure 4. Classification of IPv6-based protocols supporting mobility in WSN.

Figure.4 presents the classification of IPv6-based protocols supporting mobility according to the type of mobility they manage (micro or macro mobility). So, this figure presents parent protocols and their specific extensions for MWSNs. The description of these protocols will be presented thereafter. We note that, even if it is intended for macro-mobility, MIPv6 is also able to manage micro-mobility considering it as macro-mobility.

3. IPv6-based protocols supporting mobility

3.1 MIPv6 & MOBINET

MIPv6 protocol (Mobile IPv6) [10] allows mobile nodes (MN) to maintain an active connection to the internet even when macro-mobility while keeping the same IPv6 address in all communications with its correspondent nodes (CN).

For a MN that uses MIPv6, networks are either (i) the Home Network (HN) which is managed by a router called Home Agent (HA) and in which the MN obtains a permanent IPv6 address (HoA: Home Address) when starting up for the first time, or (ii) Foreign Networks (FN) to which the MN may move and where it can obtain temporary IPv6 addresses (CoA: Care-of-Address). To support mobility, MIPv6 requires that: each MN records addresses of CNs with which it communicates, and that the MN's HA and CNs have to record the correspondence between the HoA and CoA of this MN.

When a CN wants to communicate with a MN that is away from its HN, it sends the first packet to the MN's HA which will forward it to the current MN's network using the MN's CoA. Then, the MN records the CN's address and sends to the CN its current CoA. Thus, only the first packet of this CN is sent through the MN's HA (Figure.5). Next communications with this MN will be directly sent to the MN since the CN will receive an update each time the MN changes its network.

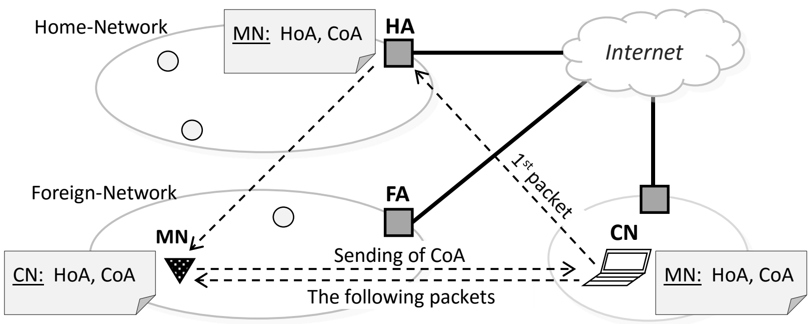

Figure 5. A communication scenario between a CN and a MN using MIPv6.

In MIPv6, MNs use the default router's lifetime for detecting their movements and triggering the handover process. The lifetime value is previously defined, which makes difficult to have an optimized mobility detection time: If the lifetime value is too short, it will consume a lot of energy due to several unnecessarily triggering the handover process, otherwise, MNs may not detect their mobility at the right time. To overcome this problem, MOBINET [11] protocol is used to count the number of the MN's neighbourhood changes in order to trigger a verification process each time it suspects network changing. In this way, the MN can detect its movement without waiting for the expiration of the default router's lifetime.

Analytical study:
The MIPv6 protocol meets the needs of macro-mobility management. It aims to ensure continuity of MN communications while travelling between different networks. But the use of the host-based mobility management is not too efficient because:

- The mobility signalling process is the responsibility of the MN. This affects its energy, generates handover delays and significant packet losses [1].
- Despite the use of MOBINET, mobility detection is not always reliable because the verification process is unnecessarily triggered or delayed in most cases.
- The IPv6-in-IPv6 tunnel used to encapsulate and forward packets addressed to the MN when it is away from its HN overloads the packet header.
- Sometimes, several MNs may perform handovers simultaneously. This leads to a high handover signalling load and increases the energy consumption [6].

3.2 FMIPv6 / Inter-MARIO

To optimize the handover time in MIPv6 protocol, The IETF has designed the Fast MIP [8] protocol. This protocol is designed for in classical mobile networks and aims to reduce the disconnection time of MN when changing network. With this protocol, a MN is able to request information concerning the surrounding access points. From this information, it can prepare its handover and thus transmit and receive packets once it is connected again to a new network. The concept of this protocol has been adopted by the Inter-MARIO [3] protocol which is designed for WSN contexts. Inter-MARIO reduces handover time by introducing a new entity (called partner node) which has extensive knowledge concerning neighbourhood and can detect MN mobility by regularly exchanging control messages and calculating their RSSI (Radio Signal Strength Indicator).

When a MN is approaching to leave the coverage area of the partner node to which it is attached, the partner node shares with the MN some information about the surrounding networks. Then, the partner node informs the next network's router of the arrival of the MN. Once the MN is connected to the new network, the MN can communicate without delay because the handover process is already executed.

Analytical study:
Inter-MARION is designed to provide fast handovers by introducing a new entity which performs some tasks of mobility signalling on behalf of the MN. This speeds up the handover process and reduces MN loads and energy consumption.

However, to guarantee these performances, Inter-MARIO requires a regular exchange of messages between the MN and the partner node for localization purposes, which represents additional control and energy costs.

3.3 NEMO / SNEMO

NEMO [12] protocol aims to manage network mobility. It is a MIPv6 extension designed so that network mobility is transparent to the nodes inside the mobile network by allowing them to be accessible even if their mobile network has changed the access point. The mobile router (MR), which connects the mobile network to other networks, performs the NEMO protocol with the HA.

SNEMO (Sensor-NEMO) [7] is an adaptation of the classical NEMO protocol to take into account WSN constraints. Therefore, the LOAD routing protocol is improved in SNEMO in order to optimize mobility management in MR.

Analytical study:

As advantages, the SNEMO protocol enables a seamless mobility for all nodes within the mobile network since only the MR is required to perform the handover process. It reduces the total mobility signalling and the handover latency compared to MIPv6 which requires that each MN executes its own handover process.

SNEMO is suitable for 6LoWAPN networks where nodes move together, but it does not allow individual mobility of nodes (nodes have a valid identifier only within their mobile network). On the other hand, the selected node to work as MR consumes more energy as a result of taking care of the mobility signalling on behalf of other nodes which are at the mercy of their MR's performances.

3.4 PMIPv6

PMIPv6 (Proxy MIPv6) [2] uses a local hierarchical structure of routers to handle mobility on behalf of MNs in mobile ad-hoc networks. Its aim is to enable MNs to change the access point without changing their IPv6 addresses or even implementing a mobility protocol by making the PMIPv6 domain appear as the HN. This architecture (Figure.6) manages node mobility in a localized domain which is controlled by a local mobility anchor (LMA) router which acts as a HA for this domain and maintains accessibility to MN addresses. Each network belonging to that domain is managed by a mobile access gateway (MAG) which is connected with the LMA router through a tunnel. The role of MAGs is to detect MN movements and initiate the mobility signalling process with the LMA router.

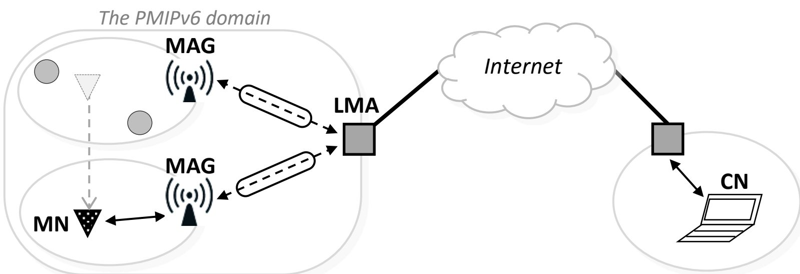

Figure 6. The PMIPv6 architecture.

Analytical study:

In PMIPv6, MNs does not have to implement complex mobility protocols nor to have a CoA or to execute DAD (Duplicate Address Detection). All these have become optional. Generally, PMIPv6 enables low traffic delays and reduces packet losses compared to MIPv6. In return:

- PMIPv6 depends on a single central LMA, so it is vulnerable to overload problems considering that each time a MN moves, the LMA must maintain update the corresponding entry of the binding cache. In addition, mobility signalling messages, as well as data packets, are sent to and through the LMA.
- MAGs are responsible for performing the mobility signalling process with the LMA on behalf of MNs. However, these MAGs may be overloaded when a large number of MNs are attached to them because of lack of mechanisms for balancing charges.
- The used routing paths in this protocol are not optimized since mobility signalling and communication messages exchanged between a MN and its CN pass through the LMA, even if both nodes are located in the same PMIPv6 domain. This needlessly increases communications delays.
- Mobility signalling, authentication, and registration messages exchanged between the LMA, the AAA server (Authentication, Authorization, and Accounting) and MAGs affect the handover latency and the packet loss rate when mobility occurs.

For WSN contexts, some PMIPv6 adjustments have been proposed such as SPMIPv6 (Sensor PMIPv6) [5] and CSPMIPv6 (Clustered SPMIPv6) [6]. Both protocols aim to manage mobility in WSN by giving a special attention to the energy efficiency.

3.4.1 SPMIPv6

In the SPMlPv6 architecture, LMA and MAGs have the same roles as those in PMIPv6 except authentication functions which are merged with LMA instead of performing these two tasks separately. So, the PBU (Proxy Binding Update) message, and the query of the AAA service are combined together and designated as BU&AQ (binding update & authentication query). Also, the Acknowledgement of AAA and the PBA (Proxy Binding Acknowledge) message are merged and named as BA&AR (binding acknowledge & authentication reply).

Analytical study:

The main SPMIPv6 feature is the network-based mobility management. Thus, the network is responsible for detecting node mobility and triggers the mobility signalling process. In addition, SPMIPv6 has significantly reduced messages of the mobility signalling. Hence, the energy consumption is reduced compared to the conventional PMIPv6. Despite these, SPMIPv6 suffers from other drawbacks inherited from PMIPv6.

3.4.2 CSPMIPv6

CSPMIPv6 has been proposed to address some drawbacks of SPMIPv6 by dividing the proxy domain into local subdomains. Each subdomain is seen as a cluster that consists of a set of MAGs including one that functions as a cluster head (HMAG) and which is selected when network configuration.

Analytical study:

The CSPMIPv6 advantage is that HMAGs provide a local mobility management for each cluster by integrating the functions of the AAA, which reduces the signalling cost. They also offer a routing optimization strategy for communications within and between clusters. Therefore, they reduce handover latencies of MNs performing intra-cluster movements. In addition, HMAGs balance the load of connection requests between MAGs.

Even if CSPMIPv6 has some improvements compared to SPMIPv6, its complex structure of proxies (organized as a static tree) makes this solution difficult to deploy in large-scale WSNs. Moreover, as SPMIPv6, the LMA in CSPMIPv6 deals all alone of establishing the tunnel to the CN, which overloads the LMA and increases latencies.

4. Synthesis

Table.1 presents a summary of the studied protocols. Thus, the characteristics of mobility management in these protocols are highlighted (the type of the managed mobility, the mobile entity, the mobility management approach, additional infrastructures, etc.).

Table 1. Summary of characteristics of IPv6-based protocols supporting mobility in WSN.

		MIPv6 + MOBINET	Inter-MARIO	SNEMO	SPMIPv6	CSPMIPv6
Type of mobility supported	**Micro-mobility**	Yes (considers micro-mobility as macro-mobility)	No	Yes (considers micro-mobility as macro-mobility)	Yes	Yes
	Macro-mobility	Yes	Yes	Yes	No	No
Mobile entity		Node	Node	Network	Node	Node
Approach of mobility management	**Node based** (Mobile entities are responsible for managing their motilities)	Yes	Hybrid : (The partner node and the MN participate together in managing mobility)	No	Optional	Optional
	Network based (The network manages mobile entities' mobility)	No	Hybrid : (The partner node and the MN participate together in managing mobility)	Yes	Yes	Yes

Table 1. (Continued): Summary of characteristics of IPv6-based protocols supporting mobility in WSN.

Requires a CoA	Yes	Yes	No: for MNs. Yes: for MR.	Optional	Optional
Requires updating CNs	Yes	Yes	Yes	No	No
Additional infrastructure	No	Partner node	MR	LMA MAGs	LAMA MAGs HMAGs
Changes in the mobile entity (implementation of protocols managing mobility)	Yes	Yes	Just in MR	Optional	Optional

5. Comparison of mobility costs

In order to evaluate the temporal cost of mobility in the studied protocols, we are interested in analysing the disconnected phase (DP). Indeed, when a MN changes its network while communicating with a CN, a DP is generated. During this period, the MN tries to resume transmission of the remaining packets. For this purpose, it will spend time on performing the following two processes: (i) time to predict or to detect the network change (TDNC) and then (ii) a latency (HL) is required for performing the handover process and establishing a new link so that it is able to resume the communication. In Figure.7 we present the tow possible communication scenarios for a given MN: (s1) communication without mobility, and (s2) changing network while communicating.

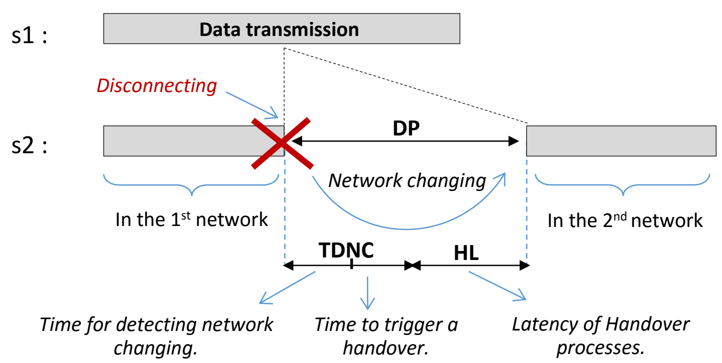

Figure 7. Communication with and without changing network.

TDNC characterizes the time required to predict/detect network changing as well as the waiting time to trigger a handover. The TDNC in a protocol is qualified as:

- **AAA**: The protocol allows the MN to predict the network changing and triggers the handover quickly
- **AA**: The handover is triggered just after the network changing.
- **A**: The handover is triggered after an average time of the network changing.

- **BBB**: The time required to detect the network changing and to trigger a handover is penalizing.

HL indicates the time required to perform a handover, which consists of all processes that allow MNs to re-establish the connection after predicting or detecting the network changing. Thus, we qualify a protocol as "**AAA**" if the HL is optimal, "**AA**" if it is average and "**A**" if it is penalizing.

After qualifying the TDNC and HL latencies, we are able to qualify the DP. In this point, we are interested at the moment when the MN's handover process is completed according to the moment when it changed its network. To understand the method used to qualify the DP we have represented all ratings of TDNC and HL latencies in Figure.8. Thus, the moment when changing network is considered as a reference in order to define the qualification intervals and each of these represents a DP qualification class. The summary of the DP's qualification results according to TDNC and HL qualifications is presented in Table.2.

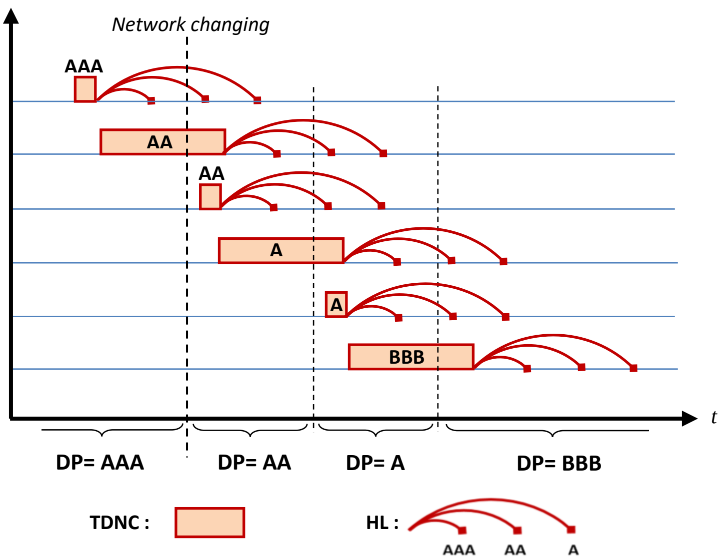

Figure 8. Qualifications of DP according to TDNC and HL.

Table 2. Qualifications of DP according to TDNC and HL.

TDCN	HL	DP
AAA	AAA	AAA
AAA	AA	AA
AAA	A	
AA	AAA	
AA	AA	A
AA	A	
A	AAA	
A	AA	BBB
A	A	
BBB	AAA	
BBB	AA	
BBB	A	

In addition to the protocols comparison in term of temporal costs, Table.3 compares also these protocols according to their energy costs in all nodes when a MN (or mobile network) changes its network. The energy cost depends on the type and number of additional tasks performed by a node to deal with the mobility. Thus, we qualify the energy cost as follow:

- **AAA**: The protocol prefers the node in term of energy by exempting it from performing mobility signalling.
- **AA**: Mobility signalling requires a moderate additional energy consumption.
- **A**: Mobility signalling requires a high energy consumption (e.g., the node participates in most tasks related to the mobility's signalling process).

Table 3. Comparison of IPv6-based protocols supporting mobility in WSN.

		MIPv6 + MOBINET	Inter-MARIO	SNEMO	SPMIPv6	CSPMIPv6
Temporal costs of mobility	TDNC	**A**: by using MOBINET which counts the number of neighborhood changes.	**AAA**: the MN and the partner node regularly exchange control messages and calculate their RSSI.	**BBB**: by sending periodic Gateway Discovery messages.	**AA**: the MAG is responsible for tracking the location of MNs.	**AA**: the MAG is responsible for tracking the location of MNs.
	HL	**A**: the handover is not anticipated and a significant latency is required.	**AA**: the handover is anticipated by the partner node, but the MN has to announce its presence in the new network.	**A**: the handover is not anticipated and a significant latency is required.	**AAA**: the handover (ensured by the MAG and LMA) is transparent to the MN.	**AAA**: the handover (ensured by the MAG and LMA) is transparent to the MN.
	TD	**BBB**	**AA**	**BBB**	**AA**	**AA**
Energy costs of mobility	In MNs	**A**: the MN executes all mobility signaling processes.	**AA**: the MN needs to announce its presence in the new network.	**A**: for the MR which executes all mobility signaling processes. **AAA**: for MNs inside the mobile network.	**AAA**: mobility is transparent to the MN.	**AAA**: mobility is transparent to the MN.
	In static nodes	**AA**: for the HA which keeps update {HoA, CoA} and forwards packets to the MN when is it outside the HN. **AAA**: other nodes.	**AA**: for the HA which keep update {HoA, CoA} and forwards packets to the MN when is it outside the HN. **A**: for the partner node which tracks the MN position and anticipates the handover. **AAA**: other nodes.	**AA**: for the HA which keep update {HoA, CoA} and forwards packets to the MN when is it outside the HN. **AAA**: other nodes.	**A**: for MAGs and the LMA which are responsible for tracking the MN location and execute the mobility signalling process. **AAA**: other nodes.	**A**: for MAGs and the LMA which are responsible for tracking the MN location and execute the mobility signalling process. **AAA**: other nodes.

The studied protocols can be used in various WSN applications. Accordingly, by using the information presented in Table.3 as well as the operating characteristics of these protocols, we find useful to define for each one the type of targeted applications. This will help application designers to choose the protocols adapted to the requirements of their applications.

Thus, MIPv6 and SNEMO are suitable for environmental applications like monitoring wild animals. The aim of this application is to collect information (health, behaviour, movements, etc.) on wild animals. Since the studied area is very wide and the network deployment is necessarily composed of several internet access points (networks). Each network consists of strategically distributed static nodes, and MNs (the nodes carried by animals that are the subject of study) move from one network to another. Also:

- The information that we are interested in this application is that of MNs (animals) which are always in motion and move with average speeds, so a TD qualified as (A to BBB) is enough.
- In term of energy, batteries of nodes can be renewed after a few months.
- In this application, sometimes it is useful to use the SNEMO protocol instead of MIPv6 when animals that are the study subject move in groups.

Inter-MARIO can be used in road traffic management applications. The role of WSN in this application is to manage vehicle priorities and direct them (especially ambulances and police vehicles) towards optimal routes for road system effectiveness purposes. Indeed, the network should detect the number of vehicles and their types, and then communicate information containing the decisions taken. This application requires a WSN installed in every crossroad of the city, and MNs (nodes embedded in vehicles) move between these networks. Thus, in this scenario:

- The network is characterized as very dynamic, which requires a TD qualified as (AAA to AA).
- The application don't care about energy consumption since it is possible to renew batteries of all network entities.
- The application collects information and communicates decisions concerning vehicle directions, so it is possible to introduce "partner node" entities that are able to anticipate vehicles' handovers in their next crossroads.

Proxies-based protocols can be used in medical applications for monitoring and tracking patients in a hospital. In this application, each patient carries on his body sensors measuring some values concerning his health. As a MN, each patient must then communicate these information to his doctor via a WSN composed of several static nodes placed everywhere in the hospital. This latter usually consists of many floors or services (each of which may be considered as a network). Moreover:

- All the patient's information must be delivered in real-time because they are very critical. So a TD qualified as (AAA to AA) is required.
- In term of energy, we consider the worst case scenario where sensors are deployed on patient's body, which requires that the mobility energy cost of MNs is qualified as (AAA).
- Since it is possible to group all these networks in a single domain and centralize mobility management, SPMIPv6 and CSPMIPv6 are the appropriate protocols.

6. Conclusion

In many Internet of Things applications the use of WSNs has become indispensable.

However, specific constraints of WSN-based applications involve to give special attention when adopting a protocol. In this context, our work aims to help application designers to choose the most appropriate protocols in terms of temporal and energy costs of mobility for their targeted applications.

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