Soft Handover Method for Mobile Wireless Sensor Networks Based on 6LoWPAN

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***Abstract*—In many wireless sensor network applications the sensor nodes needs to be mobile. In order to support mobility, the management of several issues, such as routing, handover, security, addressing and auto-configuration of the network needs to be handled. In the past, the main focus of sensor network research has been on static sensor networks, therefore many mobility related problems remain unsolved. In this paper, the focus is on the management of handover and addressing in networks, where gateways and sensor nodes can be mobile. A novel approach, which eliminates unnecessary handovers in the case where multiple gateways are in the range of mobile sensor node, is introduced in this paper. The proposed soft handover method has been implemented and its functionality has been proven in a full-scale testbed. Furthermore, it has been evaluated that the soft handover method performs fairly well also in the sensor network, where gateways are static. The proposed solution is designed for IEEE 802.15.4 standard based sensor networks which use 6LoWPAN technique, but it can be easily adapted also to other type of networks.**

***Index Terms*—Handover, wireless sensor network (WSN), mobility.**

I. Introduction

Majority of the traditional wireless sensor network (WSN) applications are deployed using static nodes and therefore numerous protocols and algorithms have been proposed for static scenarios. Mobility of WSN nodes enables to deploy more versatile applications, but on the other hand, it creates many problems which must be handled. One important problem related to mobility is the required sensor node (SN) handover between different gateways (GW), which are connecting the sensor network to the backbone network. Handover is needed when either the SN(s) or GW(s) is mobile. There are many potential applications, e.g., for animal monitoring, medical, military and traffic scenarios where nodes (SN and/or GW) are mobile. For example, all the monitored animals, people or vehicles will carry mobile SNs and the data may be collected by mobile GWs which are installed only to fraction of the network nodes. In this paper, the focus is on the SN handover problem since it has not yet been addressed carefully in the previous works.

Also in the static WSNs, there may be similar problems which usually arise when devices are mobile. E.g., the topology of the network can change for numerous of reasons, which creates similar effect than mobile nodes. Topology may change, e.g., because the SN's battery runs out or nodes simply break down. Furthermore, wireless links are always prone to fading and interference, especially in the crowded 2.4 GHz band. Topology changes or poor quality links may create the need for handover in order to use a wireless link which can provide satisfactory communication performance. Even though the proposed handover method is designed for the mobile WSNs, it will also mitigate the above described problems.

There are a few proposed methods that can be used for handover in WSNs in the case when SNs are mobile [1, 2]. However, the problem with existing handover models is that they might handle handovers poorly in topologies where GWs are mobile. For example, if SN is on the range of multiple GWs, it might have problems to decide to which GW it should connect to. In the worst case, SN changes its connection between GWs constantly based on, e.g., received signal strength (RSS) or advertisement messages. Therefore, this paper proposes a novel approach how to do a handover in the mobile GW case without losing the connection. In the proposed method, the soft handover decision is based on the designed connection quality comparison algorithm. Soft Handover for WSNs based on 6LoWPAN (SH-WSN6) method avoids unnecessary handovers even when there are multiple GWs in the SN's range. Proposed method can be also generalized to networks which are not based on 6LoWPAN.

This paper is organized as follows. Section 2 gives an overview of related work on WSN handover methods. In Section 3, the network architecture [3], where SH-WSN6 is deployed, is introduced. Section 4 introduces the proposed soft handover method. In Section 5, a comparison of SH-WSN6 with existing methods is done. Section 6 concludes this paper with brief comments concerning future research.

II. Related work

There are not many existing methods designed for SN handover management. In this section will be introduced the relevant related works which can be considered for mobile WSN handover.

Proxy Mobile IPv6 (PMIPv6) [4] is a network-based mobility management method for IPv6 devices. It is not designed specifically for WSNs, but it is suitable with WSNs based on 6LoWPAN. Typically each technology can have their own specific method for detecting lost devices, and therefore PMIPv6 does not describe how mobile device movement is detected. Nevertheless, PMIPv6 is important because it provides a handover solution that does not require any signaling from the mobile nodes [4]. The proxy mobility agents manage handovers and set up required routes in order to reach the node while it is moving. PMIPv6 has a multi-homing support, which allows mobile nodes to connect to a network through multiple interfaces. However, it does not allow mobile nodes to connect to multiple GWs simultaneously using the same interface.

Several improvements have been proposed for PMIPv6. PMIPv6 with bicasting [5] will transmit data packets to the previous and new gateway when mobile node is in the handover region. By bicasting, handover latency can be reduced. However, such a solution is not very suitable for WSNs with mobile GWs. If there are more than two GWs, deciding which two should be chosen can be problematic. Or if the solution would be to send packets to all, e.g., three GWs, bicasting would change into “tricasting”. Bicasting increases traffic in the network by duplicating packets.

Fast handovers for PMIPv6 (F-PMIPv6) [6] reduces handover latency and also packet loss ratio, when compared to PMIPv6, by notifying the previous GW about SN’s movements. Based on the IEEE Std. 802.21 development on handover and interoperability between heterogeneous networks, an attempt to apply Media Independent Handover (MIH) functions for PMIPv6 (MIH-PMIPv6) is also introduced in [6].

Handover management for WSNs suggested in [1] works as follows. SN transmits a probe message to its current access point and waits for an acknowledgement (ACK) message. After receiving ACK, SN decision about possible handover is based on RSS value and SN speed if available. If the decision is to do a handover, second phase of the algorithm will be executed. In the second phase, SN chooses a new access point based on several metrics: number of hops to sink, traffic load, energy level and link quality. If SN does not receive an ACK, handover is executed. This might cause extra handovers simply because either a probe or ACK message could be lost due other reasons than moving away from each other’s range.

III. Network architecture

This section introduces the used network architecture and its relevant interfaces and functionalities, which are needed for sensor resource interaction with the end user. The network architecture is based on the framework designed in the SENSEI project [7] and it is used here as an example architecture, where SH-WSN6 is deployed.

The network architecture is shown in Figure 1. In this architecture, the Resource Directory (RD) is a data base for Resource Descriptions published by the SNs [3]. Resource Description includes the information about the Resource and also about the interface(s) which need to be used in order to access to the Resource. The Resource can be data, actuation or management resource. The information about resource type is given in the meta-data included in the Resource Description. By using the SENSEI framework support functionalities [7], the user can discover the Resource Descriptions from the RD. Based on the information given in the Resource Description, the user can, e.g., send requests to a certain Resource. Requests are sent to SN trough the Resource Access Interface (RAI), which is implemented in the SN. In this architecture, the simplest role of a GW is to act as a router between SN’s and RD [8]. However, if SNs are not able to publish required Resource Descriptions, the GW needs do that on behalf of the SNs associated to it. In this work, the SN nodes are able to publish the Resource Description using the Resource Publication Interface (RPI). In the studied architecture, the GW and SNs can be mobile.

The described network architecture has been implemented in SENSEI Pan-European testbed [9]. In this work, the focus is on the sensor island part of the network but the rest of the architecture is used to support realistic study cases (detailed in Section V). The GW supports IPv4 and IPv6 towards RD and IPv6 towards SN’s. SNs are implemented on Contiki OS [10] environment for TelosB platform [11]. TelosB is equipped with Texas Instruments CC2420 radio transceiver [12] operating at 2.4 GHz band.

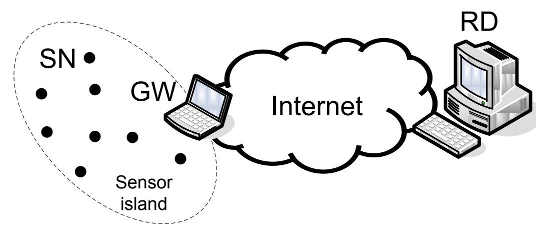

Fig. 1. Network architecture.

IV. Proposed Handover method

In this section, the proposed soft handover method is introduced, which is designed for WSNs using 6LoWPAN. SH-WSN6 method is based on H-WSN6 method, which will be therefore introduced at first in Section IV.A. Then the SH-WSN6 method is introduced in Section IV.B.

A. Handover for WSNs based on 6LoWPAN

Handover for WSNs based on 6LoWPAN (H-WSN6) was developed as a part of the SENSEI project [7]. H-WSN6 functionalities were needed in the WS&AN island to support mobility in the SENSEI architecture. Relevant parts related to this work were shortly introduced in Section III.

In WSNs, the transmitted data is rarely continuous, e.g., video or voice. Therefore, the handover procedure is different than in cellular networks for example. In many WSN applications, messaging pattern is request/response type in which requestor sends a message to a replier that returns a message in response with a content asked in the request message. In these applications, it does not matter from the user perspective by which route the data came.

H-WSN6 takes advantage of router advertisement (RA) message defined in the Internet control message protocol

(ICMP) [13]. GWs transmit RA messages periodically to advertise their presence. At first, SN can register to only one GW. When the SN receives RA message from a GW, it checks whether it has already registered to that GW. If not, SN transmits registration message to the GW. Registration message describes what Resources the SN has available for publication. The expected maximum speed of the mobile SN must be taken into account when defining the interval value between RA messages. If the interval is too large in relation to the speed of SN, there might a long delay before the SN receives RA message from any of the GWs. During that time, SN might not be registered to any of the GWs. On the other hand, too frequent RA distribution increases the redundant traffic and processing in the network, therefore decreasing networks lifetime. The RA interval value optimization is out of scope of this work.

GW replies with an URL address which includes unique identifier for the newly registered SN. URL address can, e.g., look as follows: http://GW-A.net:8000/0212-7400-10c5-42f3/, where GW-A.net is GW's address, 8000 is the port number and 0212-7400-10c5-42f3 is SN's extended unique identifier (EUI). After sending the URL, GW sends SN's Resource Description to the RD with SN's URL address. Now the SN's address can be seen in the RD.

To access SN's resources, a request can be done by simple searching for a resource from the RD, e.g., humidity or light. Sensor nodes' Resource Description will include information about the resources it offers and therefore the RD look up can be done easily. RD displays full address to SN as links providing easy access. Full address is, e.g., http://GW-A.net:8000/0212-7400-10c5-42f3/s/light. Letter "s" in the address describes that the resource is sensor value. Other possibilities are "a" for actuation, e.g., switch on a led, and "p" for parameter value, e.g., remaining battery level. Parameter value is used for management purposes.

If the SN receives RA messages from another GW whose address is http://GW-B.net, it registers with it as described above. But in this time, SN replies to the message by transmitting a delete message to GW-A through GW-B. GW-A then deletes registration with the SN and transmits a delete message to RD. Now, SN is registered only to GW-B. SN resources can be accessed using the same method described above. The only difference is that SN address in the RD, and the route between SN and RD, has changed.

B. Soft Handover for WSNs based on 6LoWPAN

The weakness of H-WSN6 method is that if there are multiple GWs in the SN range, SN would register to a new GW and delete its previous registration every time it receives the RA message from a new GW. That will create unnecessary handovers and also increases the risk of losing the connection. Here we introduce an improvement to H-WSN6 method. The new method is based on designed connection quality comparison algorithm and can be used to mitigate unnecessary handovers and connection losses.

By utilizing comparison algorithm and object oriented programming with C language in the SN, the SN can be registered to multiple GWs at the same time. By using this improvement, H-WSN6 method can now be called Soft Handover for WSNs based on 6LoWPAN (SH-WSN6).

Comparison algorithm can be integrated into different kind of sensor networks and is not dependent on the technology used in this work. The GW advertisement message is the only required feature. In 6LoWPAN networks, it is the RA message.

In SH-WSN6 method's registration process to a new GW, a SN does not reply to the GW message containing URL address with a delete message but it just replies with an ACK, if required. Now the SN is registered to two (or multiple) GWs, and it has more than one globally unique addresses. Each address is stored into SN's memory. Each time a request comes from a GW, SN checks is the GW is registered or not. Node replies only to requests coming from a registered GW.

Every time a SN registers with a new GW, it gains a new route to RD. This improves connectivity by having route diversity. If there is an unreliable link, comparison algorithm makes a decision to remove that link and therefore improves the Quality of Service (QoS) because poor links will not be used anymore. Comparison algorithm makes independently the decision when a handover should be made. Decision is made based on the comparison of the ratio of RA messages coming from GWs in the range. SN also notices when a GW moves away from SN's range by comparing the ratio of RA messages. Comparison algorithm assumes that GW's send RA messages at the same rate, which is a reasonable assumption.

Figure 2 shows a state machine that runs inside every SN and it explains the functionality of the comparison algorithm. Comparison algorithm is executed every time after RA message is received. Operation of comparison algorithm can be presented most clearly with an example. Let's assume that SN is in range of two GWs: GW-A and GW-B. When SN receives RA message from GW-B, SN first checks was the received RA message from a registered GW. Assume that SN is already registered to GW-B and as well as also to GW-A. Therefore there are two GWs registered, thus GW B_{hit} value is increased by one. In Figure 2, X_{hit} value is mapped with the GW that transmitted the RA message. Now, X_{hit} is mapped with B_{hit}. Next, X_{hit} value is compared with $Y_{i,\,hit}$ with formula presented as:

$$X_{hit} - Y_{i,hit} > \zeta \,, \qquad (1)$$

where $Y_{i,hit}$ value represents number of RA messages received from other registered GWs. In this example, there is only GW-A. If there are more GWs, all of them are compared against X_{hit} value by increasing i value, which changes $Y_{i,hit}$ mapping to another registered GW. ζ is application specific threshold value. E.g., in applications where packet lost should be kept small, value of the ζ should also be small in order to delete a registration with a GW that is no longer in the range of SN or the channel conditions are poor. Finding the optimal value for threshold ζ is out of the scope of this work.

If Eq. (1) is true, comparison algorithm makes the decision to delete an existing registration with the GW that is mapped

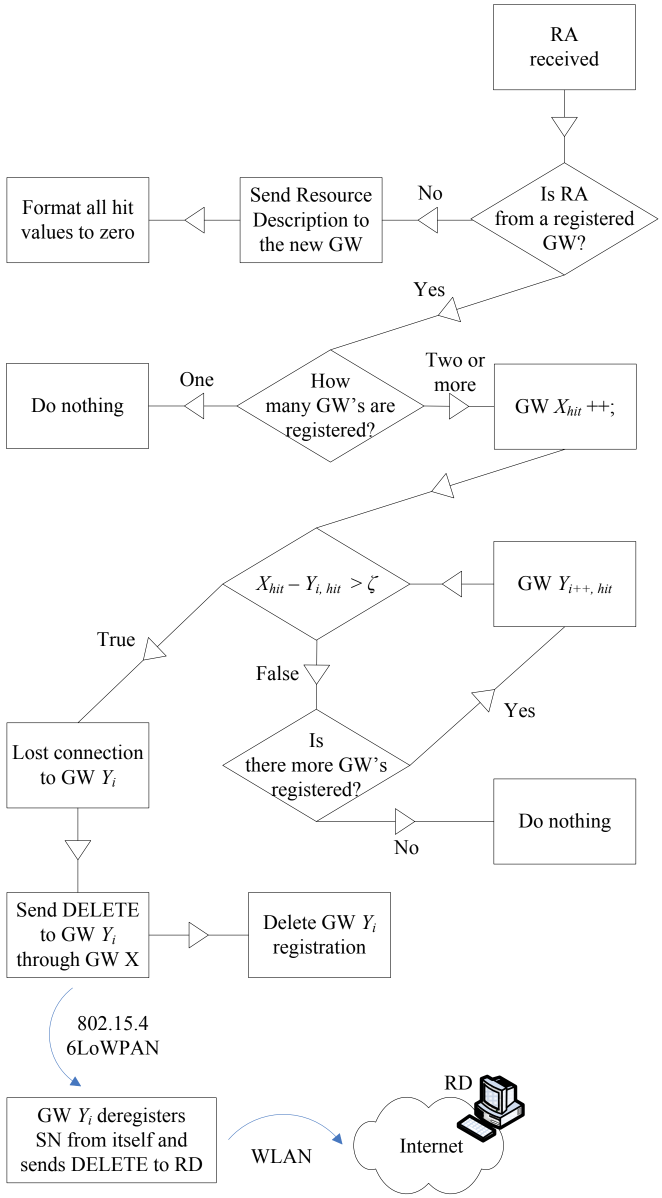

Fig. 2. Connection quality comparison algorithm state machine.

with $Y_{i,\ hit}$, which in this example is GW-A. SN transmits a delete message to GW-B. Delete message payload is the full SN address, http://GW-A.net:8000/0212-7400-10c5-42f3/. GW-B routes the packet based on the prefix of the payload to GW-A. GW-A deletes SN registration from itself and it transmits delete message to the RD.

It is important to delete the registration, if the connection is lost. Otherwise, a resource would be visible in the RD and queries could be made without any hope of a response, if any other mechanisms are not used to remove the outdated resources from RD.

One possible solution is such that if the resource is not updated before RD timer triggers, then resource will be deleted. However, the method proposed here improves the resource deletion mechanism because SN can do the decision based on the link quality (rate of RA messaged) it experiences. That will decrease the delay of the resource deletion mechanism. The objective of this paper is not to study which method is the best, instead to introduce a method that works very well.

V. Comparison of Handover Methods

SH-WSN6 is made part of the SENSEI Pan-European testbed and it needs GW(s) and RD entities in order to work as designed. Therefore, SH-WSN6 is compared against PMIPv6, F-PMIPv6 and MIH-PMIPv6 that are run in similar network architectures.

It is not straightforward to compare handover methods in WSNs, because there are usually two or more entities involved in the mobility management. Distances between entities in different proposals can vary significantly and connection media outside the WSN can be, e.g., WLAN, 3G, etc. Moreover, entities that can be mobile vary in different proposals. Usually the simplest entity is made mobile, but mobility of the GW is at least restricted.

In order to evaluate method performance in different situations, two scenarios are addressed here: with mobile GWs and with static GWs. In [6], an analytical study of PMIPv6, F-PMIPv6 and MIH-PMIPv6 handover performance has been done. The study evaluates performance of handover methods in terms of delay which is an important performance measure in this aspect. In order to compare fairly different handover methods in the case of static GWs, the parameters and assumptions from [6] are used also in this paper.

A. Mobile gateways

If GW movements are not restricted at all, there can be a situation where two or more GWs are in the vicinity of a SN. Similar situation can also occur if a SN moves into a range of multiple GWs. In those situations comparison between methods cannot be made, because [4] and [6] have not proposed a solution or results for this problem. It is understandable, since PMIPv6 is designed for different technologies that use IPv6. Designing a general method to detect the loss of a mobile node can be very difficult and maybe unnecessary. Therefore, the comparison to other methods cannot be made in the mobile GW case. Instead, we just verify that SH-WSN6 is a suitable solution for mobile GW scenario.

In SH-WSN6, the SN is connected to every GW in its range and it will be given a new address every time it discovers a new GW. Therefore, there is no need to do handover as long as the Eq. (1) is not true. Multiple addresses per SN are not a concern for the end user, e.g., in the SENSEI architecture. End user discovers Resource Description from the RD, which included description for all the registered resources offered by SNs. There can be same node twice or they can be mapped and shown as one.

Therefore, we can conclude that SH-WSN6 is a reliable method for mobile GW case. SH-WSN6 method delay for mobile GW case is same that for static GW case, which will be addressed in the next section.

B. Static gateways

Figure 3 depicts the considered scenario for static GW case. In order to enable fair comparison, the scenario is similar to the one considered in [6]. The scenario is extended with the components used in the SENSEI architecture. This does not affect the analytical comparison even though SENSEI components have different functionalities than PMIPv6 and its modifications have, because the link delays are assumed to be the same. It should be noticed, that different handover approaches have different names for components in hierarchical layers. In this paper the original names are used, which are introduced by corresponding authors, when discussing about certain handover method.

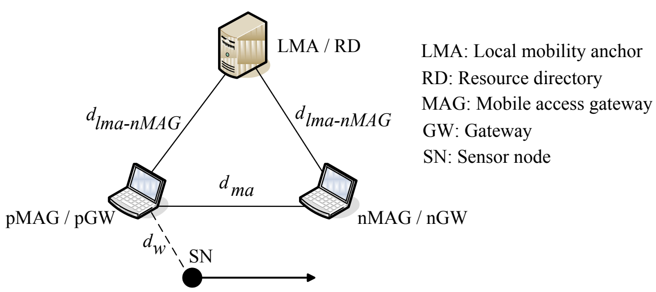

Fig. 3. Considered scenario for static GW case.

1) Handover latency study

Let's assume the following scenario where at the starting point, mobile SN is located at the previous GW (pGW) range and then SN moves to a new GW (nGW) range (Fig. 3.). Now the SN is no longer accessible from the RD by using the route through pGW. The time it takes to forward a packet, which was already sent to the pGW, to the SN by using nGW is defined in this study as handover latency.

Handover latency study of PMIPv6, F-PMIPv6 and MIH-PMIPv6 in [6] does not take into account how mobile access gateway (MAG) is discovered and determined. SH-WSN6 has a method to do that, but in order to compare handover methods fairly, it is not included into this study.

It is assumed that processing delays are negligible when compared to time used for accessing the channel and transmitting packets. Performance evaluation is done using the following parameters:

- d_w is the transmission delay between SN and nMAG.
- $d_{lma\text{-}nMAG}$ is the transmission delay between local mobility anchor (LMA) and MAG.
- d_{ma} is the transmission delay between two neighboring MAG's. It is assumed that they are in the same local network. Therefore, d_{ma} is a quite small value if compared to $d_{lma\text{-}nMAG}$.

Handover latency for PMIPv6, F-PMIPv6 and MIH-PMIPv6 are studied in [6] and formulas are shown in Table I. For SH-WSN6, the latency is composed of: 1) the time required to transmit a delete message from nGW to the pGW; plus 2) the time required to transmit a delete message from pGW to the RD; plus 3) the time required to forward a packet from RD to nGW; plus 4) the delay caused by the wireless part to transmit the packet to the SN. Therefore, the handover latency for SH-WSN6 can be calculated as:

$$l_{sh\text{-}wsn6} = d_{ma} + 2d_{lma\text{-}nMAG} + d_w. \qquad (2)$$

TABLE I
HANDOVER LATENCY

Method	Handover latency
PMIPv6	$d_w + 3d_{lma\text{-}nMAG}$
F-PMIPv6	$d_w + 3d_{ma}$
MIH-PMIPv6	$2d_w + 3d_{ma}$
SH-WSN6	$d_w + 2d_{lma\text{-}nMAG} + d_{ma}$

In [6], varying link delays and anticipation timing has been used in order to have results for different realistic conditions. The same parameters are used also in this work. In [6], the following assumptions are made based on discussions in [14] and [15]:

- *Wireless link delay*: 18 millisecond (ms), deviation: 8 ms.
- *Router distance delay*: 10 ms, deviation: 5 ms.
- *Delay between LMA and nMAG*: 15 ms, deviation: 5 ms.

Comparison between PMIPv6, F-PMIPv6 and MIH-PMIPv6 methods is done extensively in [6]. Therefore, this paper focuses mostly on analyzing performance of SH-WSN6 when compared to them.

In Figure 4 is shown the handover delay as a function of wireless link delay. From the figure can be observed that SH-WSN6 handover latency is 5ms less than for PMIPv6 and 10ms more than F-PMIPv6, for whole range of different wireless link delay values. The difference in delay remains constant due to fact that these methods require same amount of wireless transmissions in the handover procedure. SH-WSN6 delay is more than for F-PMIPv6 due to fact that SH-WSN6 sends one additional packet to the LMA.

Figure 5 shows how handover latency changes when router distance delay is increased from 5ms to 15ms with 1ms intervals. With small router distance delay values, F-PMIPv6 is evidently better than the other methods. Also MIH-PMIPv6 performance is slightly better than SH-WSN6 performance. But with larger router distance delay values, the performance of F-PMIPv6, PMIPv6 and SH-WSN6 are close to each other, and MIH-PMIPv6 handover delay is more than 15 ms worse.

When delay between LMA and nMAG is 10 ms, the handover latency of F-PMIPv6, PMIPv6 and SH-WSN6 is 48 ms, as shown in Figure 6. When delay increases, the handover latency between SH-WSN6 and F-PMIPv6 increases as well. From Figure 6 can be observed that the most critical factor in the handover delay is the delay between LMA and nMAG for the SH-WSN6 and PMIPv6 methods. However, the delay between LMA and nMAG should not be more than 20ms in practical applications.

Results show in Figure 4 to Figure 6 that also in the static GW case, the SH-WSN6 delay performance is at desirable level when compared to the other proposed methods.

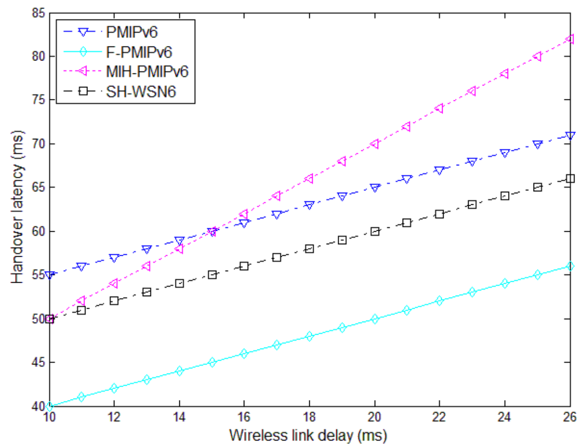

Fig. 4. Handover latency vs. wireless link delay.

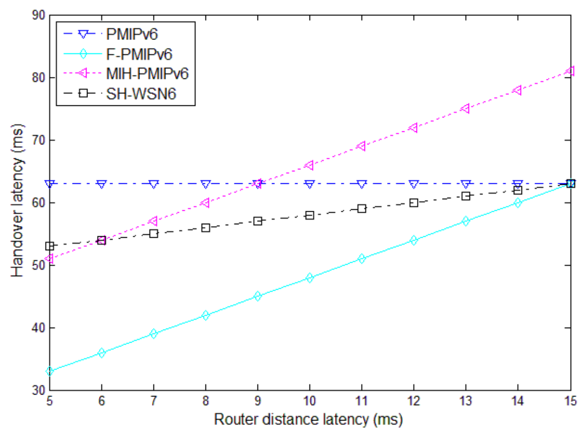

Fig. 5. Handover latency vs. router distance latency.

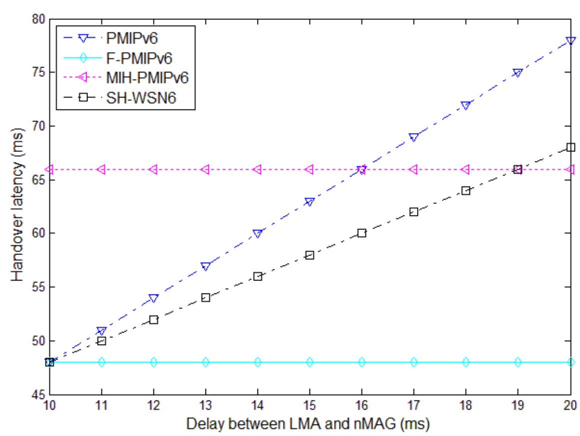

Fig. 6. Handover latency vs. delay between LMA and nMAG.

VI. Conclusion and Future Work

In this paper, a new soft handover (SH-WSN6) approach for WSNs was proposed. SH-WSN6 method is developed because there are no existing solutions that enable 6LoWPAN based WSN GWs to be mobile without complications. In current and future applications the mobility of nodes is increasing and therefore that problem need to be addressed. SH-WSN6 handover latency performance evaluation model and results were introduced in this paper. In the mobile GW study, SH-WSN6 is the only method that can handle multiple GWs in the range of SN properly. The comparison between SH-WSN6, PMIPv6, F-PMIPv6 and MIH-PMIPv6, in the static GW case, showed that SH-WSN6 performance was second best of the group. The static case is analyzed only to show that SH-WSN6 operates well also in this case. SH-WSN6 is implemented and its functionality has been proved by running it as a part of the network.

SH-WSN6 does not support multiple hops between SN and GW. Future research will be made to solve this clear deficiency. Furthermore, research to find optimal value for threshold ζ will be done.

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References

[1] H. Fotouhi, M. Alves, A. Koubâa and N. Baccour, "On a Reliable Handoff Procedure for Supporting Mobility in Wireless Sensor Networks", the 9th International Workshop on Real-Time Networks RTN'2010 in conjunction with the 22nd Euromicro International Conference on Real-Time Systems (ECRTS 2010), Brussels, Belgium, July 2010.

[2] R. Silva, J. Sa Silva, M.Simek and F. Boavida, "A New Approach for Multi-Sink Environments in WSNs", 11th IFIP/IEEE international conference on Symposium on Integrated Network Management, New York, USA, June 2009.

[3] SENSEI: D3.6: Final Architecture. Technical deliverable, FP7 Contract 215923, 2010.

[4] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy Mobile IPv6", RFC 5213, Internet Engineering Task Force, August 2008.

[5] J.I. Kim, S.J. Koh, N.S. Ko and S.B. Hong,"PMIPv6 with Bicasting for IP Handover", Third International Conference on Convergence and Hybrid Information Technology, November 2008.

[6] J. Lei and X. Fu, "Evaluating the benefits of introducing PMIPv6 for localized mobility management", International Wireless Communications and Mobile Computing Conference 2008 (IWCMC 2008), Crete, Greece, Pages 74-80, IEEE, August 2008.

[7] SENSEI (Integrating the Physical with the Digital World of the Network of the Future) – an Integrated Project in the EU's Seventh Framework Programme. URL: http://www.sensei-project.eu/

[8] SENSEI: D5.1: Implementation & Evaluation Plans for Pan European Test Platform and Field Trials. Technical report, FP7 Contract 215923, 2010.

[9] SENSEI Cookbook, D.5.3, Technical deliverable, FP7 Contract 215923, URL: https://ncit-cluster.grid.pub.ro/trac/Sensei-WP5-Public

[10] Contiki operating system. URL: http://www.sics.se/contiki/

[11] TelosB sensor node platform. URL: http://www.xbow.com/

[12] The CC2420, IEEE 802.15.4 compliant RF transceiver. Datasheet URL: http://focus.ti.com/lit/ds/symlink/cc2420.pdf

[13] T. Narten, E. Nordmark. and W. Simpson, "Neighbor Discovery for IP Version 6 (IPv6)", RFC 2461, Internet Engineering Task Force, December 1998.

[14] D. Su and S.-J. Yoo, Handover Failure-Case Analysis in Hierarchical Mobile IPv6 Networks, IEICE Trans. Communications., Vol E89-B, No.6, 2006.

[15] L. Jun Seob and M. Jae Hong and K. Sang Ha, "Considerations for designing fast handoff mechanisms in Mobile IPv6," The 6th International Conference on Advanced Communication Technology, Vol. 21-24, 2004.