An Efficient Mobility Management Approach For IEEE 802.15.4/ZigBee Nodes

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***Abstract* - Mobility management in IEEE 802.15.4/ZigBee networks is not efficiently handled. This paper presents an enhanced approach for mobility management of end devices in IEEE 802.15.4/ZigBee cluster tree network related to a backbone network. This approach anticipates link disruption and does not require scanning neighbor cells. It is based on the link quality indicator (LQI) and uses a speculative algorithm. Using different mobility models and network parameters, it is demonstrated that the energy consumption as well as the latency of mobile devices can be significantly reduced.**

Keywords-IEEE 802.15.4/ZigBee; mobility; LQI; energy consumption; latency

I. INTRODUCTION

Mobility in wireless networks has become a necessity in many applications that also impose QoS requirements. An optimized mobility management strategy has to be defined in the most optimized way to avoid the decrease in the performance in energy and delay of the network nodes. In infrastructure networks, the first step of a handover is the cell reselection procedure. In many wireless networks such as GSM, IEEE 802.11 and WiMAX, the procedure of reselecting cell is a layer-2 procedure and is based on scanning periods. This supposes that a mobile node has to listen to neighbor attachment points periodically so that it updates its neighbor list. Of course, challenges are not the same when using IEEE 802.15.4 WPAN protocol [1]. In fact, the received signal strength range is much lower, which imposes that delay of cell change must be very short. Moreover, IEEE 802.15.4/ZigBee [1][2] nodes usually have less energy capacity, thus mobility management approach has to ensure low energy consumption during reselecting cell procedure. In [4], we presented an original approach that both anticipates link disruption and does not require scanning neighbor cells. This approach is based on a speculative algorithm that manages mobility in an IEEE 802.15.4 cluster tree network connected to a backbone network. Many research studied mobility in IEEE 802.15.4 sensor networks and different mobility use cases were evaluated. Evaluations concerned mainly the movement of nodes [9][10][11], nature of mobile nodes (whether they are routers or end devices) [7], [8] or network architecture [8]. For instance, in [7], authors are interested in ZigBee mesh network and precisely in the impact of the nature of mobile nodes (routers or end devices). They indicate that the ZigBee mesh routing algorithm exhibits significant performance difference when the number of reduced functional devices (RFD) is highly different from the number of full functional devices (FFD) in the network. Routing performance in ZigBee network does degrade when the network includes an increasing number of ZigBee end devices. In [10], the purpose of the study is the evaluation of deployment of path-constrained mobility of sinks. This paper presents one of the first published works to propose improvements to the current ZigBee standard in order to manage path-constrained sink mobility. The method consists in broadcasting the new address and location of the mobile sink at each new association. This method overcomes the shortcomings of ZigBee mobility management that is based on flooding the entire network by control messages. However, it implies that a mobile node has to inform the network (or a part of it) of its location at each new association, which may be energy consuming. Moreover, all static nodes are organized in mesh topology and have to operate on the same channel, which increases collisions.

It is demonstrated in [4][5] that mobility management in IEEE 802.15.4 standard protocol is not efficiently handled and has to be optimized. In addition to that, authors in [5] have shown that mobility evaluation have to take into consideration the network topology. As far as we know there is no previous research that dealt with the mobility management of end devices in a cluster tree topology. This paper focuses on optimizing energy consumption of ZigBee mobile end devices for this kind of topology. We propose an enhanced speculative algorithm, still based on Link Quality Indicator (LQI) like in [4], but handled more efficiently. Moreover, this approach has been validated using different mobility models such as Manhattan [15]. It is demonstrated that energy consumption and delay can be reduced up to 72% and 75% respectively, using the proposed approach compared to IEEE 802.15.4 protocol for mobile end devices in grid architecture.

The paper is organized as follows: Section II presents the enhanced mobility management approach. Section III introduces random waypoint, Gauss-Markov and Manhattan mobility models that are used in our simulations as well as the simulation setup. In Section IV, we evaluate network performance and we analyze the mobility behavior of end devices when some parameters such as the number of mobile nodes in the network, the probability that nodes changes streets are varied. Conclusion and perspectives are given in Section V.

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II. ENHANCED MOBILITY MANAGEMENTN APPROACH

The studied use case consists of static coordinators that form a grid. Coordinators are represented by their index in Fig. 1. As it is illustrated in Fig. 1, each vertical or horizontal segment can be assimilated to a road. Successive coordinators of the same road are separated by 25 meters. Each coordinator defines a cluster. The cluster is a star network and is initialized by its coordinator which defines a unique channel frequency on which all cluster nodes have to communicate. All end devices can only communicate through their coordinator. Coordinators are connected to a backbone network through a device named SuperCoordinator (SC). The SC has the list of all coordinator addresses, their positions and the channel on which they communicate.

Mobility management strategy has to keep mobile nodes connected to the network when they move from one cluster to another. This is ensured thanks to the anticipation of change of cells. In fact, the procedure is triggered by a mobile node when the LQI of a received packet is less than a threshold value ($LQI_{threshold}$). Fig. 2 summarizes our optimized procedure of change of cell and shows control packets exchanged during it. If a mobile node M has to begin a cell change procedure, it has to send an LQI notification packet (lqiNot) to its current coordinator (e.g. C1). Then C1 has to transmit a handover request (HRqt packet) to the supercoordinator SC which determines the next coordinator of association (here C2) based on a speculative algorithm. After that, the SC communicates via HRsp packet information about the new coordinator C2 to the old coordinator C1. M begins an association procedure as defined in the IEEE 802.15.4 standard [1] after receiving the response packet (lqiRsp). After the end of the association procedure, C2 sends to SC a handover notification (HNot) to notify the success of the association. If this procedure fails at any step, the mobile node has to begin an active scan in order to discover neighbor coordinators. More detailed description of reselection cell procedure is given in [4].

A. An $LQI_{threshold}$ based on network caracteristics

1) $LQI_{threshold}$ computation

In this paper, we consider that only the IEEE 802.15.4 beacon-enabled mode is used [1]. Thus, end devices are periodically receiving beacon messages. Cases where LQI decreases due to interferences are ignored since all associated nodes are not allowed to transmit during the beacon time slot. Thus, for a defined level of noise, the LQI of a beacon packet depends only on the distance between the sender and the receiver. However, during the contention access period (CAP) the LQI may depend on interferences caused by communicating nodes. In [4], we evaluated the impact of different $LQI_{threshold}$ on the success of the procedure of cell change, as well as on the energy consumption and the latency for mobile end devices. However, the $LQI_{threshold}$ was a constant value identical for all nodes. In this paper, the $LQI_{threshold}$ is handled more efficiently. As it can be observed in Fig. 3, when a node is moving through a coordinator (C) coverage area, it can be associated to C after a scan period and/or an association procedure. As soon as M receives an association response from C, an LQI_{init} based on the first received beacon frame is stored. A handover procedure is started as soon as the LQI of a received packet is less than an $LQI_{threshold}$.

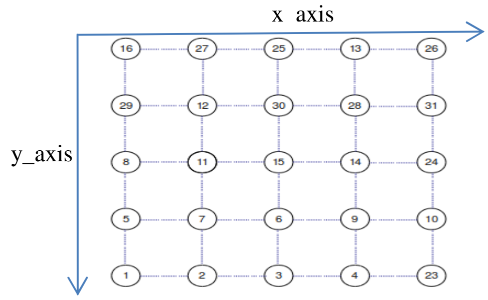

Figure1. Coordinators in the grid architecture

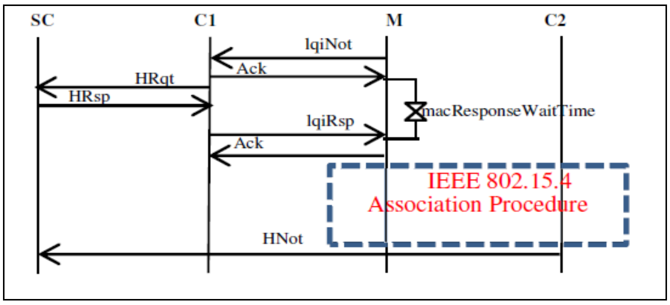

Figure 2. Timing in the reselection cell procedure

The instant when the handover procedure must be started, i.e. the $LQI_{threshold}$ choice, has to be determined carefully, neither too early nor too late.

As illustrated in Fig. 3, during the association procedure, packets can be exchanged between a mobile node and its coordinator. During this interval, these packets have an LQI lower than LQI_{init} and higher than LQI_{min} in all cases. It can be concluded that the $LQI_{threshold}$ has to be within this interval and it must also take into consideration some network parameters that can have an impact on LQI. Parameters that can be also included to determine $LQI_{threshold}$ value are the number of end devices in the cluster, the number of transmitting nodes, the distance from the coordinator, the node velocity, etc.

So far, only the distance and the velocity of mobile nodes have been taken into account. The proposed formula to compute the $LQI_{threshold}$ is as follows:

$$LQI_{threshold} = LQI_{init} - (LQI_{init} - LQI_{min}) / \beta \quad (1)$$

Where LQI_{min} is a constant and $\beta \geq 1$. Note that LQI_{min} depends on the RF transceiver LQI calculation. It can be noticed from (1) that the higher β is, the earlier the handover procedure is started (and vice-versa). In Fig. 3 only a straight trajectory is represented for M. Actually, a mobile node may have any other trajectory.

1) Impact of β parameter

The average of total energy consumed during procedures of cell reselection, when the mobile end devices' number and β parameter value vary, is calculated. Results are given in Fig. 3. So far, this average energy has only corresponded to the power required by the RF transceiver.

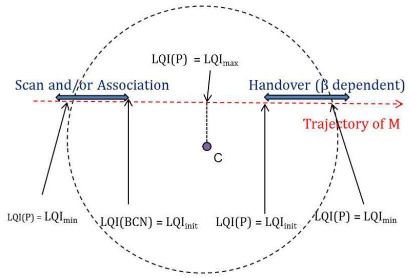

Figure 3. LQI value during node movement through a cell

Fig. 4(a) presents results for the random waypoint mobility model, while Fig. 4(b) provides results obtained with the Manhattan model. As simulations have been done with NS-2 simulator [3], LQI_{min} is equal to 128 and LQI_{max} is equal to 255. The communication channel is considered to be without noise and interferers. Simulation duration is 2400 seconds and other setup parameters are specified in Table I. Manhattan TurnProb parameter is set to 0.2, meaning that a node has a 0.2 probability to change its current road. It is important to note that in this case, energy consumption in reselection cell procedures may also be due to errors of the speculative algorithm. To eliminate the influence of this kind of errors, we varied the velocity of a mobile node M that goes back and forth between the two extremities of a grid road. The next coordinator of association of M should be then correctly chosen each time. There are 24 other mobile nodes (plus node M) that move randomly during the simulation period. The success rate is computed for each velocity value given a β value. The Fig. 5 present the percentage of handover success rate according to different node velocity values as well as different choices of β value. Results highlight that the success rate decreases when the velocity increases. Combining the average energy (Fig. 4) and the success rate metrics, a β value of 2 represents a good tradeoff.

B. Cell reselection based on a speculative algorithm

In [13], authors present an IP mobility performance enhancement using an appropriate IEEE 802.16 L2 trigger based on an ARIMA prediction model. Signal strength is predicted either through scanning of neighbor base stations (BS) or from periodic serving BS measurement. However, signal strength prediction is achieved without any assumption on the statistical properties of the nodes' movement. Their method aims at reducing handover latency and packet drops. Although results obtained demonstrated its efficiency, their method still requires that mobile nodes listen to neighbor attachment point. Our purpose is to avoid scan periods during cell change procedures in order to reduce both energy consumption and latency. Therefore, we propose a speculative algorithm handled by the SC that determines the next coordinator of association of a mobile node. The defined speculative algorithm favors the movement of nodes on the same road. The choice of the next coordinator of association for a mobile node is based on the previous coordinator of association and on its current road. A default road corresponds to the horizontal road containing the coordinator of association. A default direction is also defined and corresponds to the x_axis (Fig. 1) vector for nodes moving on horizontal roads, and to the y_axis vector for those moving on vertical roads.

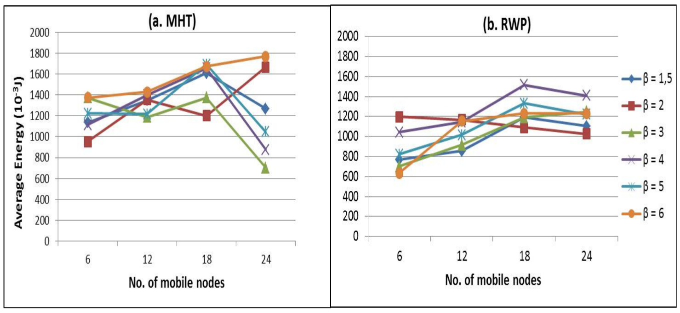

Figure 4. Energy spent in cell reselection procedures for different β values

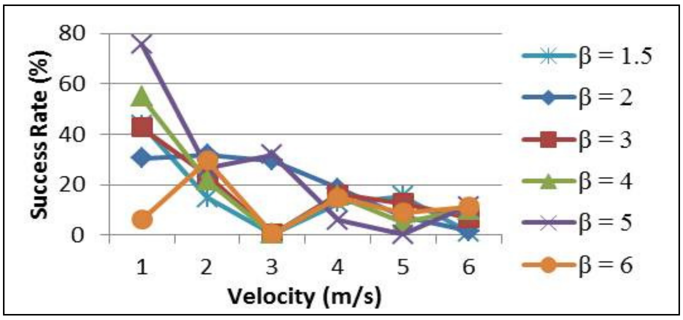

Figure 5. Success rate Vs. Velocity of node for different β values

If the previous coordinator is situated on the left of the current coordinator, then the next coordinator will be the coordinator which is on the right of the current one (and vice-versa). Of course, in mobility scenarios, nodes can turn left or right which leads to some wrong selections of the next coordinator. A network matrix (Nt Matrix) in the superCoordinator is used to describe the geographical distribution of coordinators. In [4] the initialization of coordinators was organized in relation to their geographical positions and coordinators belonging to the same road had to be sequentially initialized so that they have successive addresses. Each road in [4] was therefore represented by a column in the Nt matrix. A shortcoming of this organization is that some roads may not be explicitly represented. This is for instance the case, when all coordinators of a road are already initialized in previous defined roads. As a consequence, in this case some handover procedures will fail. In this paper we propose a new matrix structure without constraints on the initialization time of coordinators. In this study, columns describe vertical roads and rows describe horizontal roads of the grid. The matrix is then a purely spatial representation of the network topology. This organization of the matrix allows an easier and more efficient management of mobility.

Let hist be a vector of size N containing the value of the previous coordinator of association for each mobile node M. Let rd be a vector of size N that corresponds to the current road of a mobile M. The hist and rd vectors are located in the superCoordinator which updates them at the end of each new successful association. The position of the current coordinator in the matrix is determined based on two attributes which are the current road of the mobile and the position of the coordinator in the matrix (pos). The algorithm of selecting the new coordinator is as follows:

```
road = rd[M]
if (road isVertical)
if (hist[M] == Nt[pos+1,road] and hist[M] <> 0 and pos ≥ 1)
 then  return Nt[pos-1,road]
else if (Nt[pos+1,road] <> 0)
then       return Nt[pos+1,road] // e.g. at the first cell changing
else return Nt[pos-1,road] //e.g. the last coordinator of a road
end if
else //horizontal movement
if (hist[M] == Nt[road,pos+1] and hist[M] <> 0 and pos ≥ 1
and Nt[road,pos+1]<>0)
then       return Nt[road,pos-1]
else if (pos ≥ 1 and Nt[road,pos-1] <> 0)
then return Nt[road,pos+1] // e.g. at the first cell changing
else return Nt[road,pos-1]//e.g. the last coordinator of a road
end if
end if
```

III. SIMULATION PARAMETERS

In this study, the main concern is the optimization of the energy consumption end devices when they move in an area covered by a grid network composed of coordinators as illustrated in Fig. 1. In this section, an overview of three mobility models is done. Then, simulation setup is given.

A. Mobility models overview

Using mobility models to define mobility scenarios of nodes is necessary to handle the complexity of setting movements of multiple nodes in simulation scenarios. In addition to that, it allows having scenarios that approaches real cases. Thus, the chosen mobility model has to fit the targeted application. Simulations were done with NS-2 simulator [3] and mobility scenarios were generated with BonnMotion tool [12]. In this study, three mobility models are evaluated:

1) Random waypoint model (RWP): It is the most simplistic and common mobility model. Destination positions are determined randomly and selected speed is uniformly distributed between a minimum and a maximum value. The minimum speed, the maximum speed and the maximum pause time periods are the parameters that can be tuned.

2) Gauss-Markov mobility model (GM) [14]: In this mobility model, two parameters are updated in each period to determine the next destination position. These parameters are the speed and the movement direction. They are chosen from a normal distribution of previous values.

3) Manhattan Mobility Model (MHT) [15]: The Manhattan mobility model is proposed to model movement in an urban area. In the Manhattan model, a mobile node is allowed to move along the horizontal or vertical streets of an urban map. At an intersection, the mobile node can turn left, right or go straight. Fig. 10 shows node movements according to this model. TurnProb is the probability that a node changes its current street. The velocity of a mobile node at a time slot is dependent on its velocity at the previous time slot. Also, a node velocity is limited by the velocity of the node preceding it on the same lane of the street.

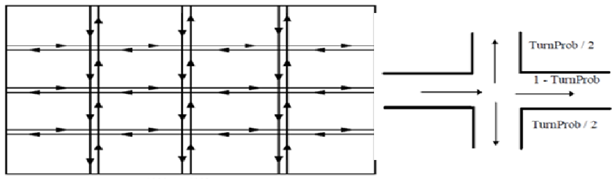

Figure 6. Manhattan mobility model

B. Simulation Setup

The IEEE 802.15.4 beacon-enabled mode is used to synchronize end devices. Adjacent cells operate on different frequency channel and the hierarchical addressing mode is used to assign addresses to coordinators and end devices. The propagation model two-ray ground is used. In simulation scenarios, all nodes are already associated before they begin to move. For each mobility model scenario, all end devices are mobile and their number is varied. Table I gives common setup parameters for all mobility scenarios. Positions of coordinators correspond to intersections in Manhattan mobility model.

TABLE I. SIMULATION SETUP

Parameter	Definition	Value
BI (ms)	Beacon Interval	245.76
Xdim (m)	Size of the grid on x-axis	100
Ydim (m)	Size of the grid on y-axis	100
N	Number of coordinators per road	5
Duration (s)	Duration of the mobility scenario	300
speedChangeProb	Probability for the mobile to change its speed	0.2
minSpeed (m/s)	Mobile's minimum speed	0.5
meanSpeed (m/s)	Mobile's mean speed	3.0
pauseProb	Probability for the mobile to pause	0

IV. EVALUATION OF THE PROPOSED APPROACH

In this section, some parameters of mobility models are varied in order to study their impact on the node energy consumption and cell reselection delay.

A. Impact of mobility model on network performance

Different simulations have been performed in order to figure out the performance of the network in term of energy and cell change delay when nodes are moving according to one of the three different mobility models: RWP, GM and MHT. In these simulations, nodes do not have pause periods. The turn probability (TurnProb) in Manhattan mobility model scenarios is set to 0.2. The number of moving nodes has been varied from 6 to 30 with a step of 6. Fig. 7 shows the average energy (Fig. 7(a)) and the average delay (Fig. 7(b)) for the three different mobility models when using the standard mobility management procedure as defined in IEEE 802.15.4 protocol. Average gain in energy and delay when using our approach are shown in Fig. 8 (respectively in (a) and (b)). As it can be observed in Fig. 7, the average energy and delay consumed during procedures of change of cells in Manhattan is higher than the other two models. In fact, in Manhattan model, nodes are moving along roads. Thus, even though their trajectories may be slightly deviated, they still have more or less straight trajectories to reach a cluster coverage area during change of cell procedure.

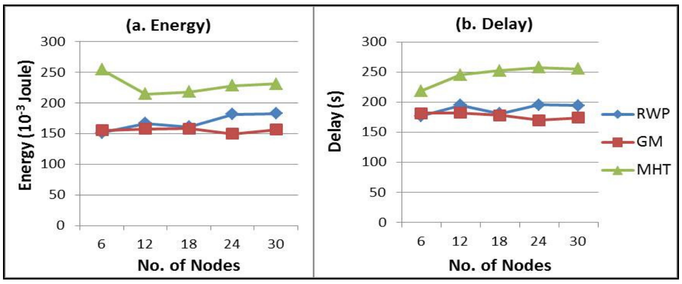

Figure 7. Average energy and average dalay during cell reselection procedures

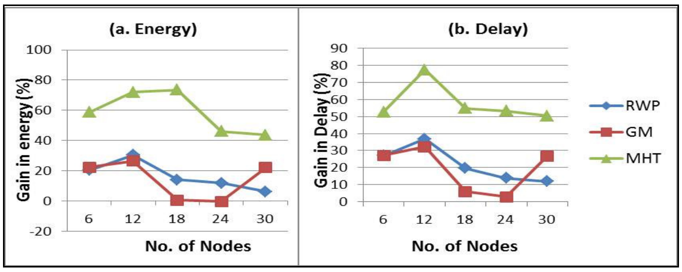

Figure 8. Gain in average energy and average delay using 3 different mobility models

However, the standard procedure requires that nodes enter in a scan period before beginning the association procedure. As a consequence, nodes may leave the coordinator coverage area before they finish the association procedure. In Fig. 8, it can be seen that the average gain in delay and energy is higher when the Manhattan model is used. This gain is also observed in [13]. In fact, since coordinators cover all the grid area, when using Manhattan; nodes enter more rapidly the next coordinator coverage area. Using our scan-free approach, packets sent during association procedures are then more likely to be successfully received, thus decreasing the amount of control packets as well as the delay of the procedure. In our case, this improvement is also due to our speculative algorithm since, in Manhattan, nodes are more likely to stay on the same road (TurnProb 0.2).

B. Evaluation of the approach whith Manhattan model

In the previous paragraph, the turn probability was set to 0.2. Thus, the probability that nodes stay on the same road is very high (0.8). This represents almost the best case as our speculative algorithm favors movement of nodes on the same road. In this section, we present simulation results when TurnProb changes (0.2, 0.5 and 0.8) and when the number of mobile nodes varies from 6 to 24 with a step of 6. Two kinds of cases have also been considered: with pause (WP) and without pause (WOP) of mobile nodes. In the first set of simulations (WP) pause probability is equal to 0.1.

Fig. 9 shows the average energy spent in change of cell procedures when our approach is used. WP 0.2 means that TurnProb is equal to 0.2 and nodes are having pause periods. It can be seen that the enhanced procedure is more efficient when pause periods are allowed. In fact, since the grid area is covered by coordinators, when a mobile node stops moving for a period of time, it is more likely that it successfully finishes a handover procedure in a short period of time. However, if it is moving for a longer period, it may not have enough time to finish a handover procedure and leaves the average area of the new association coordinator before the end of the procedure. In this case, the number of transmitted control packets (association request/response, handover request/response, data request, beacon request) increases. So does the energy. Fig. 10 and Fig. 11 represent respectively the corresponding gain in energy and in delay compared to the standard procedure. It can be noticed that they are both important when TurnProb parameter is low (0.2). That is expected due to our speculative algorithm. However, even if TurnProb parameter is higher (0.8), the gain is still around 20% for 24 mobile nodes.

C. Analysis of the energy consumption of a mobile node

So far, presented results have dealt with the average energy and delay of all the mobile nodes for different mobility models, with or without pause, and different number of mobile nodes. In this section, the objective is to study the behavior in terms of energy consumption of a specific mobile node called M (instead of all the nodes) for different network conditions. For instance, M keeps the same trajectory while the number of mobiles varies. Pause probability value is the same for all mobile nodes in each scenario. Common simulation parameters are set as in Table I.

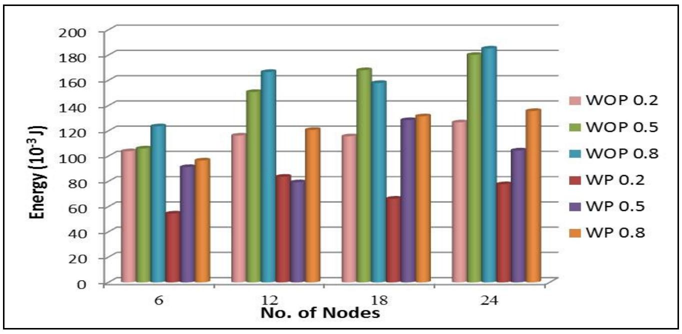

Figure 9. Average energy spent in cell reselection procedures (MHT model)

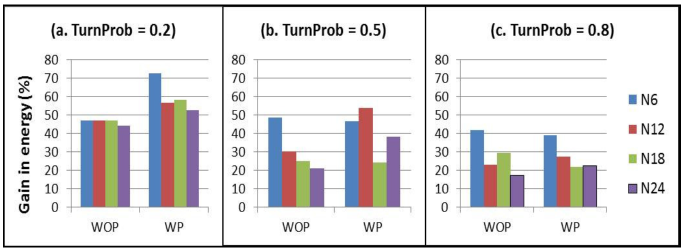

Figure 10. Gain in energy (MHT model)

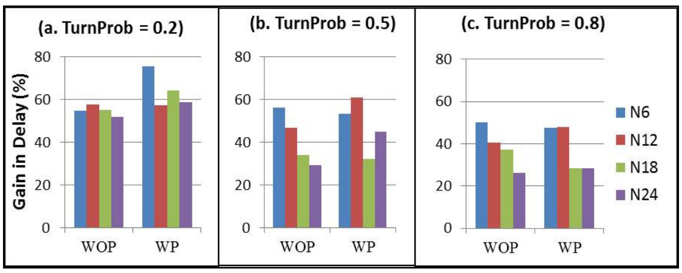

Figure 11. Gain in delay (MHT model)

Given the pause probability, two sets of simulations are defined. In the first set of simulations, we do not define pause periods. In the second set, pause probability is equal to 0.1. Turn probability is set to 0.2 in all simulations. Trajectories of other end devices are different in each simulation. Fig. 12 shows the remaining energy in M at the end of the simulation when the total number of mobile end devices varies for both scenarios (WP and WOP) using our approach (ENH) and the standard (STD). Globally, the remaining energy decreases when the total number of mobile nodes increases. This is expectable since increasing the number of communicating nodes increases collisions and thus retransmissions of packets. Network conditions (here number of mobile nodes and trajectories) have then an important impact on the energy consumption of a mobile node M having the same trajectory. We can also observe that the remaining energy is in some cases higher using the standard protocol than using our approach. The reason is that the mobile node M is synchronized for a longer period of time to network coordinators. This is observed on Fig. 13. This figure illustrates the number of received beacons by the mobile node M for the same scenarios that correspond to Fig. 12. As it can be seen, the number of received beacons is higher using our enhanced handover procedure than when using the standard. This is verified for any value of the pause probability. So, having a mobile node synchronized for a longer period is energy consuming but the energy is spent for good reasons, mainly for maintaining a good link and reducing the latency.

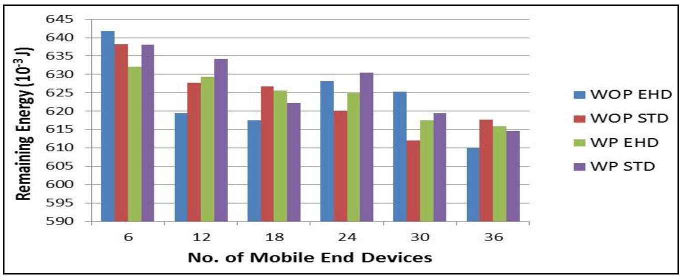

Figure 12. Remaining energy of node M vs. number of end devices

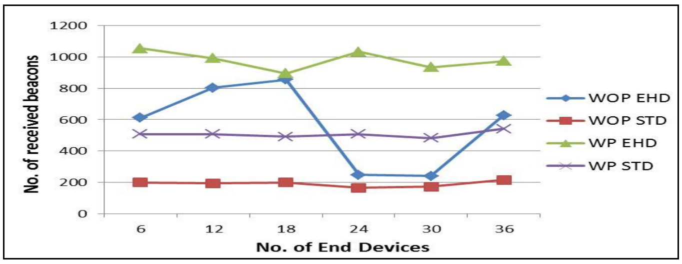

Figure 13. Number of received beacons by node M vs. Number of end devices

V. CONCLUSION

This paper proposed an approach to manage mobility of end devices in an IEEE 802.15.4/ZigBee grid network connected to a backbone network. It is based on the anticipation of the link disruption between a mobile end device and its coordinator using an $LQI_{threshold}$. An $LQI_{threshold}$ formula was proposed and evaluated. The study aimed at pointing out some parameters that have an impact on the gain in energy and delay of the proposed approach in comparison with the standard approach. The main parameters that were investigated are the trajectory of mobile nodes, pause periods during mobility and the total number of nodes. Simulations demonstrated that the gain in energy and delay can be respectively up to 72% and 75%. We also demonstrated that even though the energy consumed can be higher using our approach, this energy is spent to maintain a good link and to reduce the latency.

As future works, we will extend our approach for data transmission having a strong constraint on latency (e.g. an audio application). In addition to that, we will investigate a reactive algorithm that dynamically adjusts the β value to network conditions, for example the number of nodes.

VI. REFERENCES

[1] IEEE 802.15.4-2006 standard: http://www.ieee802.org/15/pub/TG4.html.

[2] Zigbee alliance homepage - http://www.zigbee.org.

[3] Ns2: http://nsnam.isi.edu/nsnam/index.php/main page.

[4] C. Chaabane, A. Pegatoquet, M. Auguin, and M. B. Jemaa, "Energy optimization for mobile nodes in a cluster tree IEEE 802.15.4/ZigBee network," Computing Communications and Applications Conference, pp. 328–333, 11-13 January 2012.

[5] L. Chen · T. Sun, and N. Liang, "An Evaluation Study of Mobility Support in ZigBee Networks," Journal of Signal Processing Systems, vol. 59, no. 1, pp. 111–122, 1 April 2010.

[6] C. Gao, and R. Jantti ; "Link-State Clustering Based on IEEE 802.15.4 MAC for Wireless Ad-hoc/Sensor Networks," Wireless Communications and Networking Conference (WCNC 2006), pp. 499–504, 3-6 April 2006.

[7] L. Nia-Chiang, C. Ping-Chieh, S. Tony, Y. Guang, C. LingJyh, and G. Mario, "Impact of Node Heterogeneity in ZigBee Mesh Network Routing," Systems, Man and Cybernetics (ICSMC '06), vol. 1, pp. 187–191, 8-11 October 2006.

[8] Braem, B., Blondia, C, "Supporting mobility in Wireless Body Area Networks: An analysis," Body Sensor Networks (BSN), pp 52–55, 7-9 June 2010.

[9] A. Abbagnale, E. Cipollone, and F. Cuomo, "A Case Study for Evaluating IEEE 802.15.4 Wireless Sensor Network Formation with Mobile Sinks," ICC'09, pp.1-5, 14-18 June 2009.

[10] N. Vlajic, D. Stevanovic,and G.Spanogiannopoulos, "Strategies for improving performance of IEEE 802.15.4/ZigBee WSNs with path-constrained mobile sink(s)," Elsevier Computer Communications Journal, pp. 743-757, vol. 34, issue 6, May 2011.

[11] F. Cuomo, E. Cipollone, and A. Abbagnale, "Performance analysis of IEEE 802.15.4 wireless sensor networks: An insight into the topology formation process," Computer Networks, vol. 53, issue 18, 24, pp. 3057–3075, December 2009.

[12] N. Aschenbruck, R. Ernst, E. Gerhards-Padilla, and M. Schwamborn "BonnMotion: a mobility scenario generation and analysis tool," the 3rd International ICST Conference on Simulation Tools and Techniques (SIMUTools '10), pp. 51:1—51, 2010.

[13] J. Lee, H. Kim, Y. Choi, Y. Chung, S. Rhee, " IP Mobility Performance Enhancement Using Link-Layer Prediction," FGIT, pp. 171-179, 2010.

[14] T. Camp, J. Boleng, and V. Davies, "A Survey of Mobility Models for Ad Hoc Network Research," Wireless Communication and Mobile Computing (WCMC), Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications, vol. 2, no. 5, pp. 483–502, September 2002

[15] European Telecommunications Standards Institute (ETSI): Universal Mobile Telecom-municatios System (UMTS) - Selection procedures for the choice of radio transmission technologies of the UMTS, UMTS 30.03 version 3.2.0, TR 101 112. 1998.