Mobility Management Approach for IEEE802.15.4/ZigBee Nodes in a Noisy Environment

Chiraz Chaabane[1,2], Alain Pegatoquet[1], Michel Auguin[1], Maher Ben Jemaa[2]
[1]LEAT, University of Nice-Sophia Antipolis, France
[2]ReDCAD, National School of Engineering of Sfax, University of Sfax, Tunisia

Abstract

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

1 Introduction

Mobile wireless sensor network applications require an efficient mobility management strategy in order to avoid the decrease in the performance in energy and delay of the network nodes. Many research studied mobility in IEEE 802.15.4 [1] sensor networks and different mobility use cases were evaluated. Evaluations mainly concerned the movement of nodes [9] [10] [11], the nature of mobile nodes (whether they are routers or end devices) [7] [8] and the network architecture [8]. For instance, in [10], the purpose of the study is the evaluation of the deployment of path-constrained mobility of sinks. 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 [2] 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] showed that mobility evaluation has to take into consideration the network topology. Many of the previous research that used simulation in the evaluation phase did not consider the noise which is an important factor in real applications; thus, results were not relevant.

In infrastructure networks, the first step of a handover is the cell reselection procedure. IEEE 802.15.4/ZigBee nodes usually have low energy and low computation capacities. Since the transmitting signal strength range is very low, the effect of noise on the packet reception is important. In [4], we presented an original approach that both anticipates a link disruption and does not require scanning the neighbour 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. The approach was evaluated for several mobility scenarios without considering the noise effect. In this paper, we propose a new speculative algorithm based on the Link Quality Indicator (LQI) and we compare results to those presented in [4]. Results demonstrated that even when the noise is considered, the energy consumption and the delay can be reduced up to 42% and 58% respectively, using the proposed approach compared to the IEEE 802.15.4 standard protocol.

The paper is organized as follows: Section 2 presents the enhanced mobility management approach. Section 3 introduces the characteristics of the channel model used for our experimentations. In Section 4, the network performance is evaluated in a noisy environment. Conclusion is given in Section 5.

2 Enhanced Mobility Management Approach

The studied use case consists of static coordinators that form a grid. As it is illustrated in **Figure 1**, each vertical or horizontal segment can be assimilated to a road. Coordinators are placed in each intersection of a horizontal and a vertical line of the grid as shown in Figure 1.

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 spatial positions and the channel on which they communicate.

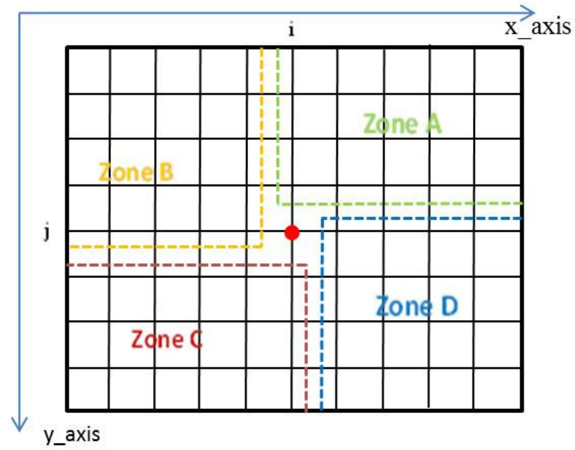

Figure 1 Grid architecture

2.1 Procedure of Cell Changing

The goal of our mobility management strategy is 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. The procedure of change of cell is triggered by a mobile node when the LQI of a received packet is less than a threshold value ($LQI_{threshold}$).

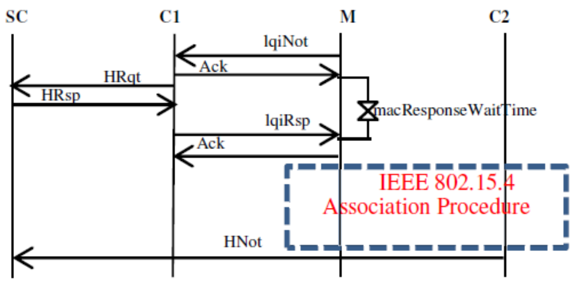

Figure 2 Timing in the cell reselection procedure

The **Figure 2** summarizes our optimized procedure of cell change and shows control packets exchanged during it. As detailed in [4], the new coordinator of association is determined by the SuperCoordinator based on a speculative algorithm. This approach uses two new MAC control frames: the LQI notification packet (lqiNot) and the LQI response frame (lqiRsp). The lqiNot is sent by a mobile node to its coordinator when it receives a packet with an LQI lower than $LQI_{threshold}$. The lqiRsp frame is sent by the current coordinator to the mobile node and it contains the next coordinator of association identifier as well as its channel number.

2.2 Speculative Algorithm

Our purpose is to avoid scan periods during cell change procedures in order to reduce both the energy consumption and the latency. Thus, we propose a speculative algorithm handled by the SC that determines the next coordinator of association of a mobile node. We consider the statistical properties of the nodes' movement in the signal strength prediction. In [4], we proposed matrix structure (*Nt* matrix) that gives a spatial representation of the network topology. *Nt* Columns describe vertical roads and *Nt* rows describe horizontal roads of the grid. The defined speculative algorithm favored the movement of nodes on the same road. The choice of the next coordinator of association for a mobile node was based on the previous coordinator of association as well as its current road. A default road was defined which corresponds to the horizontal road containing the coordinator of association. The default direction corresponds to the x_axis vector direction (Figure 1). According to this algorithm, if the previous coordinator is situated on the left of the current coordinator, then the next coordinator is the coordinator which is on the right of the current one (and vice-versa). The method did not take into consideration the fact that nodes are able to turn left or right. Moreover, a node may leave the coordinator coverage area before it finishes the association procedure, which may be due to its speed, to the delay of the reselection cell procedure or to the noise. In this case, even if the previous coordinator of the mobile node and its current coordinator belong to the same vertical road, the default horizontal direction will be used.

In this paper, we propose a new speculative algorithm that takes into consideration the cases where nodes change roads (turn left or right) and the cases where the previous coordinator and the current coordinator of a mobile node are not two successive coordinators of the same road.

Let (i,j) be the coordinates of the current coordinator of association in the *Nt* matrix and let (i',j') be the coordinates of the previous coordinator of association in the *Nt* matrix. As shown in Figure 1, around the current coordinator (red circle in Figure 1), the grid is divided into four zones (A, B, C, D). The previous coordinator of association is located in one of these zones (denoted previous zone). The previous zone is determined by comparing the coordinates (i',j') of the previous coordinator in the *Nt* matrix and the coordinates (i,j). The results of the comparison are given in **Table 1.** The previous zone is randomly chosen if the previous coordinator and the current coordinator are the same or if it is the first cell reselection of the mobile node.

Previous Coordinator X-coordinate	Previous Coordinator Y-coordinate	Previous Zone
$i' \geq i$	$j' < j$	A
$i' < i$	$j' \leq j$	B
$i' \leq i$	$j' > j$	C
$i' > i$	$j' \geq j$	D
$i' = i$ or i' undefined	$j' = j$ or j' undefined	Random

Table 1 Zones of a coordinator

The new speculative algorithm uses the previous zone and a random direction determined using a normal distribution of a set of 3 possible directions:

- Straight (*S*): the probability of S is 0.5
- Right (*R*): the probability of R is 0.25
- Left (*L*): the probability of L is 0.25

The algorithm first predicts the next zone to which the mobile node is moving using the rotation table given in **Table 2**. Then, it determines the coordinates of the next coordinator of association based on **Table 3**.

		Predicted Direction		
		S	*L*	*R*
Previous Zone	A	C	D	B
	B	D	A	C
	C	A	B	D
	D	B	C	A

Table 2 Rotation Table to determine the next zone

Next Zone	X-Coordinate	Y-Coordinate
A	*i*	*j - 1*
B	*i – 1*	*j*
C	*i*	*j + 1*
D	*i + 1*	*j*

Table 3 Coordinates of the next coordinator

If the current coordinator is in the extremity of the grid, then some zones are not available. The algorithm has to choose a direction corresponding to one of the available zones. For instance, if $i = 0$ and $0 < j < N - 1$, where N is the maximum number of coordinators per road, zone B is eliminated from the direction prediction algorithm.

3 Channel Characteristics

The IEEE 802.15.4 standard defines the LQI as an integer ranging from 0 to 255. IEEE 802.15.4 specifies that the LQI measurement is a characterization of the strength and/or the quality of a received packet. The measurement may be implemented using receiver energy detection (ED), a signal-to-noise ratio estimation (SNR), or a combination of these methods. The use of the LQI metric by the network or the application layers is not specified in the standard as well.

In this paper, we consider that only the IEEE 802.15.4 beacon-enabled mode is used. Thus, end devices are periodically receiving beacon messages. Nodes do not send data. The cases where LQI decreases due to interferences are in consequence ignored since all associated nodes are not allowed to transmit during the beacon time slot. In fact, during the contention access period (CAP) the LQI may depend on interferences caused by communicating nodes. In [4], we did not consider the impact of noise. The LQI of a beacon packet depends only on the distance between the sender and the receiver.

If the medium is not shared with any other RF sources, the signal propagation of simulated transmitters and AWGN can describe the entire channel. Our noise model is an additive Gaussian white noise (AGWN). The variance of the AWGN is set to 0.3. In this work, simulations are carried out using the NS-2 simulator [3]. The LQI formula in NS-2 was implemented using the SNR. A white Gaussian noise has been included to NS-2. The noise modeling is done according to the Box-Muller method [6]. The propagation model used is the two-ray ground model. The $LQI_{threshold}$ formula has been defined in [4] and is as follows:

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

Where LQI_{min} is a constant and $\beta \geq 1$. LQI_{init} is the LQI corresponding to the first beacon frame received after a successful end of an association procedure. Note that LQI_{min} depends on the RF transceiver LQI calculation. The β factor is set to 2. In [4], it was proved that this value is a good tradeoff combining the average energy and the cell reselection success rate metrics.

Using a noise model will change considerably simulation results since the LQI will not only be a function of the distance, but in this case it will also depend on a random phenomenon. Besides, the $LQI_{threshold}$ formula was evaluated for use cases that did not consider noise, it is interesting to evaluate its efficiency in a noisy environment.

4 Evaluation of the Approach

Different simulations have been performed in order to figure out the performance of the network in term of energy and delay when nodes are moving. Three sets of simulations have been carried out. Each set corresponds to a different mobility model. The three mobility models are random way point (RWP), Gauss-Markov (GM) [12] and Manhattan (MHT) [13]. 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. The **Table 4** gives common setup parameters for all mobility scenarios.

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

Table 4 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. All nodes may not be associated before they begin to move. For each mobility model scenario, all end devices are mobile and their number is varied. Positions of coordinators correspond to intersections in Manhattan mobility model.

4.1 Impact of Noise

Each mobility model scenario has been simulated first without considering noise, and then with AWG noise. MHT_N, RWP_N and GM_N correspond to the simulation scenarios when the noise is considered. The results of the scenarios without considering noise (MHT, GM and RWP) correspond to the results obtained in [4]. The speculative algorithm that favors node movements on the same road is used. The **Figure 3** and the **Figure 4** respectively show simulation results that correspond to the average energy and the average delay during cell reselection procedures. The **Figure 5** and the **Figure 6** respectively show simulation results that correspond to the gain in energy and the gain in delay during cell reselection procedures in comparison with the standard IEEE 802.15.4 procedure.

Due to the random behaviour of the noise combined with the pseudo-randomness of packet transmissions (MAC backoff period), the results related to the simulations that used the noise model are not always worse than those that did not. Moreover, the results demonstrated that even when the noise is considered, the energy consumption and the delay can be reduced up to 42% and 58% respectively. Thus, we verify that the proposed $LQI_{threshold}$ formula is efficient even in a noisy environment.

4.2 Evaluation of the Speculative Algorithms

Both speculative algorithms are compared in this section. The first algorithm was proposed in [4] and supposes that nodes stay on the same road. We name it the same-road algorithm. The second algorithm is a probabilistic speculative algorithm that randomly selects the direction of a mobile node.

The **Figure 7** shows simulation results that correspond to the gain in energy when the probabilistic speculative algorithm is used in comparison with the same-road algorithm. The **Figure 8** shows simulation results that correspond to the gain in delay when the probabilistic speculative algorithm is used in comparison with the same-road algorithm. As it can be seen in Figure 7 and Figure 8, for the random waypoint scenario, the probabilistic algorithm is better than the same-road algorithm. When the Manhattan model is used, the same-road algorithm gives better results. This can be explained by the fact that the turnProb parameter (the probability that the node turns left or right)

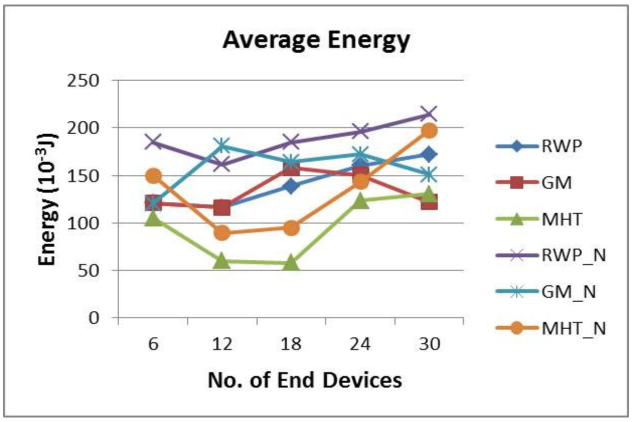

Figure 3 Average energy during cell reselection procedures

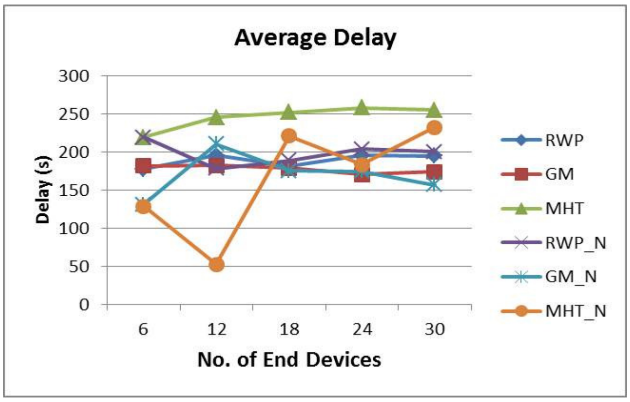

Figure 4 Average delay during cell reselection procedures

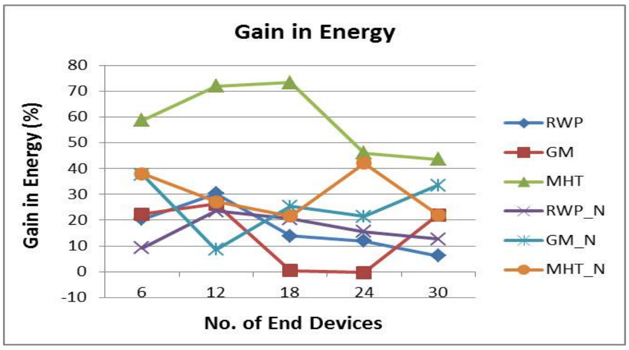

Figure 5 Gain in average energy using 3 different mobility models

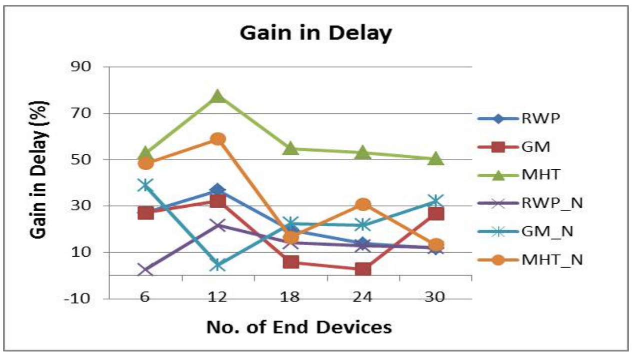

Figure 6 Gain in average delay using 3 different mobility models

is relatively low (0.2). The gain in energy and delay is almost equal to zero for the Gauss-Markov mobility model.

5 Conclusion

In this work, a Gaussian white noise model has been evaluated with a mobility management approach for end devices in an IEEE 802.15.4/ZigBee grid network connected to a backbone network. This approach is based on the anticipation of the link disruption between a mobile end device and its coordinator using an $LQI_{threshold}$. The $LQI_{threshold}$ formula has been evaluated in a noisy environment. We also compared the performance of two different speculative algorithms: the same-road algorithm and the probabilistic speculative algorithm. Simulations have demonstrated that even in a noisy environment the gain in energy and delay can be respectively up to 42% and 58%.

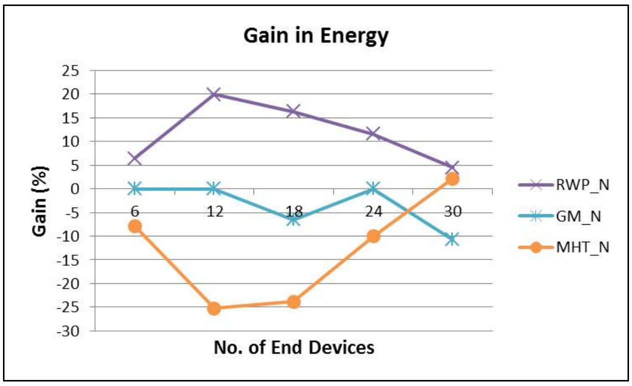

Figure 7 Gain in energy of the probabilistic speculative algorithm in comparison with same-road algorithm

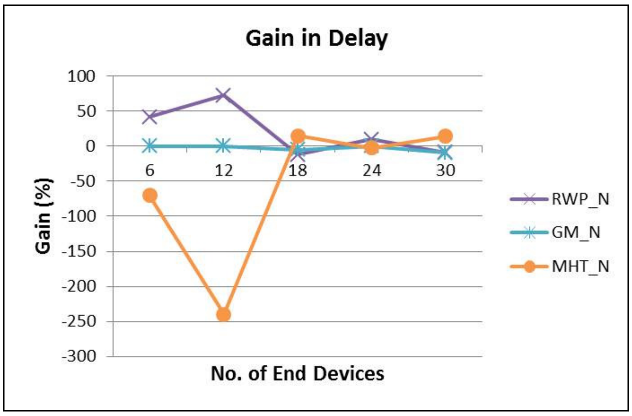

Figure 8 Gain in delay of the probabilistic speculative algorithm in comparison with same-road algorithm

6 References

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