2008

Improving Mobile Sensor Connectivity Time in the IEEE 802.15.4 Networks

Kartinah Zen
Edith Cowan University

Daryoush Habibi
Edith Cowan University

Iftekhar Ahmad
Edith Cowan University

10.1109/ATNAC.2008.4783343
This article was originally published as: Zen, K. , Habibi, D. , & Ahmad, I. (2008). Improving Mobile Sensor Connectivity Time in the IEEE 802.15.4 Networks. Proceedings of Australian Telecommunication Networks and Applications Conference. ATNAC 2008. (pp. 317-320). Adelaide, Australia. IEEE Press. Original article available here

Improving Mobile Sensor Connectivity Time in the IEEE 802.15.4 Networks

Kartinah Zen, Daryoush Habibi, and Iftekhar Ahmad
School of Engineering, Edith Cowan University, Joondalup, WA Australia.
kzen@student.ecu.edu.au, d.habibi@ecu.edu.au, i.ahmad@ecu.edu.au

***Abstract*— In the IEEE 802.15.4 medium access control (MAC) protocol for wireless sensor networks, a sensor node needs to associate with a coordinator before it starts sending or receiving data. The sensor node will mostly choose the nearest coordinator to associate with. However, this method is not suitable for a constantly moving sensor node because it will end up switching coordinators too often due to short connectivity time. The IEEE 802.15.4 has a simplistic and inadequate method of choosing a coordinator in this context. In this paper, we introduce a method to increase the mobile sensor node connectivity time with its coordinator in IEEE 802.15.4 beacon-enabled mode. Our method is based on the timestamp of the beacons received from the nearby coordinators and filtering weak beacon signals. By choosing the coordinator which has sent the most recent received beacon with good signal quality, we increase the moving node connectivity time with the coordinator. Our technique results in significant improvement by reducing the number of times the moving node switches coordinators. This increases the throughput and reduces the wasted power in frequent associations.**

I. Introduction

Integrating mobility into wireless sensor network introduces problems due to its low range and low power, especially at medium access control (MAC) layer. In the standard MAC protocol for Low Rate Wireless Personal Area Network (LR-WPAN), IEEE 802.15.4, the device association causes problems when the device is moving constantly and frequently losing its connectivity with beacon-enabled coordinators. The movement causes the device to switch coordinators too often especially in high speed movement due to short connectivity time with the coordinators [1].

According to IEEE 802.15.4, the sensor device has to associate with the coordinator before it starts the data transmission. The association starts with the node scanning for the beacons from the nearby coordinators and choosing one of them as a coordinator. However, the standard protocol does not indicate in detail how the device selects the coordinator [2]. The simulation results using ns-2 [3] show that the moving node tends to choose the nearest coordinator, and as a consequence, it switches the coordinator frequently as it constantly moves. This reduces the throughput and increases the power consumption due to the frequent association process. Besides, the frequent association also introduces more packet collisions due to more association request packets being transmitted [4]. Thus, an effective method to increase the mobile node connectivity time with the coordinator should be implemented. This can be achieved by choosing the coordinator that will give the longest connectivity time, thus reducing the number of associations.

This paper introduces a technique in beacon-enabled mode where all coordinators are stationary and only the sensor nodes are moving. This type of topology applies to smart home and health care applications where sensor nodes are attached to people and coordinators are given selective fixed positions. When a sensor node is moving away from its original coordinator and it is anticipated that it will soon lose connectivity, it should choose the next coordinator with the longest predicted connectivity time.

Our method is based on the use of two parameters: link quality indicator (LQI) and timestamps of the received beacons. We use the signal strength of the received beacons from other coordinators, and use simple localization techniques [5], [6], [7] to identify the position of the node with respect to the other coordinators. By using the timestamps of the beacons, as well as measuring the link quality of the coordinators within reach, we choose the most suitable coordinator which will give the longest connectivity time. It should be noted that the farthest coordinator is not always the best coordinator to be associated with. The farthest coordinator may in fact be the worst pick if the signal strength indicates that the sensor node is around the edges of the coverage area of that coordinator. In this paper we will show that our method results in significant improvement over IEEE 802.15.4 with better throughput, less coordinator switching and hence less power consumption for association.

II. Related Work

There has not been extensive research on IEEE 802.15.4 device association. In [8], Zhang *et al.* improve the association process using a method called Simple Association Process (SAP). It eliminates the redundant primitives, therefore, avoids packet collisions and decreases the association delay. In SAP, the device does not need to send a data request command while waiting for the response from the coordinator during the association process. In fact, the device waits for the association response which will be sent by the coordinator. Attia *et al.* of [9] enhance the reliability of IEEE 802.15.4 device association by reducing the inaccessibility time. They propose a method to choose the coordinator based on LQI, the depth of the coordinator in the tree, traffic load and the power indicator. The coordinator with the higher link quality, higher power, lower traffic load and lower depth in the cluster tree will be

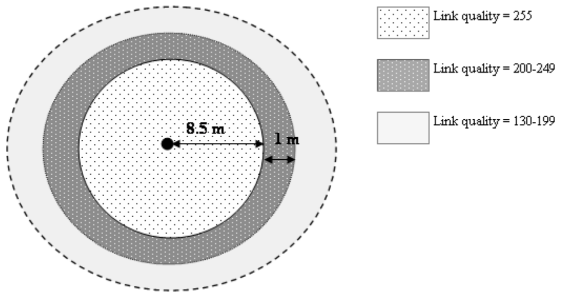

Fig. 1. Range of LQI values at different distances from the coordinator

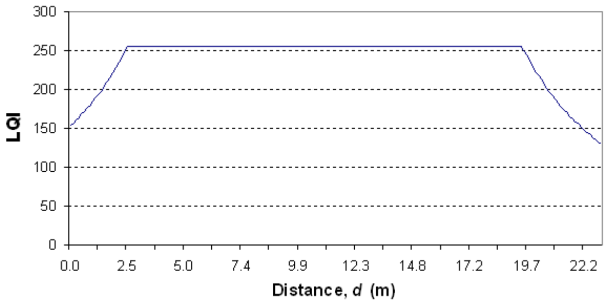

Fig. 2. LQI for a node moving across the center of the coverage area

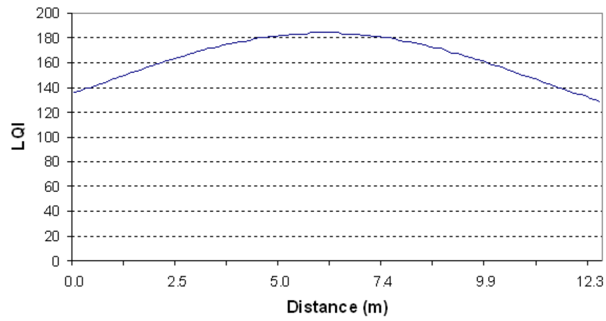

Fig. 3. LQI for a node intersecting the coverage area with a small angle

chosen. However, these papers do not consider node mobility which causes frequent switching between the coordinators due to short coverage range. As such, the improvement in device association are targeted only for static sensor networks.

In the performance evaluation of IEEE 802.15.4 for mobile sensor networks, we have found that the moving node experiences serious problems in association and synchronization because of short connectivity time [1]. At higher speeds, a node may continuously lose its connectivity and fail to associate with any coordinator [10].

III. Our Proposed Algorithm

Our proposed algorithm is based on the timestamps of the received beacons as well as the link quality. The timestamps are used to estimate the distances of the sensor nodes from the nearby coordinators.

Coordinators whose beacons indicate low link quality, indicated by LQI, will be filtered. LQI is proportional to the signal level, a signal-to-noise estimation, or a combination of these methods and with a value between 0-255 [11]. The sensor node will associate with the coordinator which is farthest from the node and also has a strong beacon signal. For filtering the weak beacon signals we consider a threshold LQI value of 200. This will filter out the coordinators which are too far from the sensor, where the sensor is only around the edges of their coverage area.

We use the NS-2 simulator to derive the pattern of signal strength received by a node moving within the coverage range of a coordinator. Fig. 1 shows a coordinator with a 12 meter radius coverage range. At a distance of 8.5 meters from the coordinator, the LQI value is 255. The node receives the beacon with link quality in the range of 200-249 within a distance of 8.6-9.5 meters from the coordinator. Fig. 2 shows the graphs of beacon signal value when a node moves from end to end across the center of a coordinator. Fig. 3 shows when it intersects the coverage area at a small angle.

A. Measuring distance and connectivity time

To understand the device connectivity time with its coordinator, we consider a simple scenario where all coordinators are along a straight line, have the same coverage range, and are uniformly spaced. The calculations performed for this simple scenario will give a quantitative measure of performance improvement due to our algorithm. Fig. 4 shows a scenario for three coordinators in a personal area network (PAN), where all coordinators are along a straight line, with equal distances between adjacent coordinators. In Fig. 4, let us consider a node moving at a speed of s ms^{-1} that associates with coordinator a. The node moves away from the center of a to the right, and when it reaches the edge of a coverage, it loses connectivity with a. At this point it will most probably associate with b because it is nearer to it.

The problem arises here because b only has a distance of d_b left within its coverage range before the moving node loses its connectivity with b. If we have more coordinators along that line with equal distances, then the moving node will switch coordinators every t_b seconds, where $t_b = \frac{d_b}{s}$. To reduce the frequency of switching coordinators, we propose that the moving node should choose coordinator c. If the moving node chooses c as the coordinator when it loses its connectivity to a, it will have t_c seconds of connectivity time with c where $t_c > t_b$ because $d_c > d_b$.

To calculate the connectivity time remaining for the moving node, we need to know the distance d_b. We model d_b as

$$d_b = D - x \tag{1}$$

where,

$$x = \gamma + ((r_a - \gamma) + (r_b - \gamma)) \tag{2}$$

D is a diameter of a coordinator's coverage range and γ is the

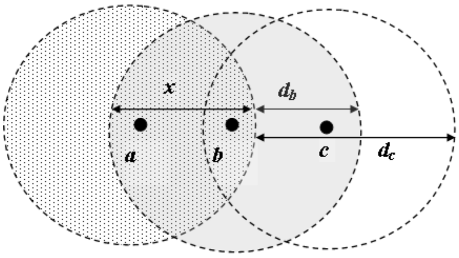

Fig. 4. Three coordinators with overlapping radio coverages

distance between two coordinators. r_a is the radius coverage range of a and r_b is the radius coverage range of b. If we assume that all coordinators have the same range r, then we can write x as:

$$x = \gamma + 2(r - \gamma) \quad (3)$$

From the equations of (1) and (3) above, d_b and d_c can be expressed as:

$$d_b = D - (\gamma + 2(r - \gamma)) \quad (4)$$

$$d_c = D - 2(r - \gamma) \quad (5)$$

From Equ. (4) and (5) , we have $d_c = 2d_b$. Therefore, in this scenario, by choosing c as a coordinator instead of b, the moving node will increase its connectivity time by 100%, whilst also reducing the number of times that the moving node must switch coordinators. The overall outcome is a significant increase in the throughput.

In the standard protocol, the orphan node will choose the coordinator with the first beacon received. The nearest coordinator to the orphan node will send the beacon signal in the shortest time, and is normally chosen as the preferred coordinator for association. Based on the previous example in Fig. 4, we can calculate the distance from orphan node to b, Δ_b and the distance from the orphan node to c, Δ_c.

$$\Delta_b = r_a - \gamma \quad (6)$$

$$\Delta_c = \gamma - (r_a - \gamma) \quad (7)$$

From Equ. (6) and (7) above, we know that $\Delta_b < \Delta_c$. This scenario is true for γ in relation to r, is in range $0.7 < \frac{\gamma}{r} < 1.0$. This range is the normal position for the coordinators and their coverage in wireless sensor networks. As stated earlier, our method is based on choosing the farthest coordinator, thus gives a longer connectivity time. The timestamp of the beacons received determined which coordinator is the furthest from the sensor node. Together with the link quality of the beacon signal, these two parameters will help the orphan node to choose a coordinator with better connectivity time.

Our proposed association algorithm is outlined below:

1) Step 1: The node scans the channel by sending a beacon request command to all nearby coordinators.
2) Step 2: The node receives all the beacons from the coordinators and analyses the link quality value of each beacon.
3) Step 3: The node filters any weak beacon signals, dropping all beacons with link quality less than 200.
4) Step 4: The node chooses its coordinator based on the beacon timestamp and selects the last beacon received as its coordinator.

TABLE I
SIMULATION SETTINGS

Parameter	
Network dimension	120 m x 120 m
Simulation duration	140 s
No. of mobile nodes	1
No. of coordinators	11
Speed of mobile nodes	1 ms^{-1}
Beacon interval	3
Distance between coordinators	10 m
Coordinator range	12 m

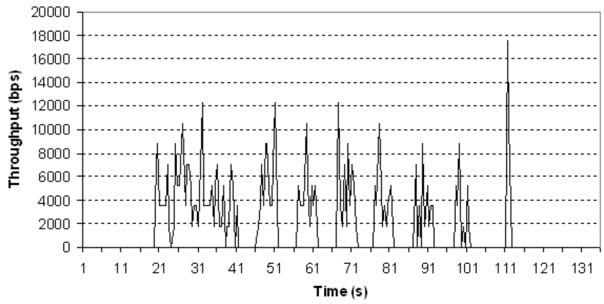

Fig. 5. Throughput in the IEEE 802.15.4

IV. Experimental Results

All the simulations in this paper are carried out using NS-2. They are based on the IEEE 802.15.4 beacon-enabled mode with one mobile node and 11 coordinators. The simulation settings are given in Table I. We monitor the throughput and the beacon signal level received by the mobile node as the node moves at the speed of 1 ms^{-1}. We also observe the power consumed in the association process when the node passes through the coverage ranges of different coordinators.

Figs. 5 and 6 demonstrate the throughput experienced by the mobile node. In Fig. 5, by using the IEEE 802.15.4 protocol, the node can only receive data for less than six seconds in each interval before connectivity is lost. However, the results for our enhanced protocol in Fig. 6 shows that the mobile node receives data within the longer period in each interval.

Fig. 7 shows that in a 100 seconds interval of simulation, the power consumed by the mobile node is reduced in our enhanced protocol by 10065 mW (i.e. 37.5%) when compared to the standard protocol. The more coordinators the node passes without association, the more significant the power

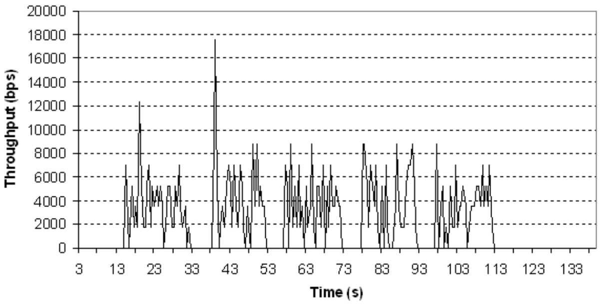

Fig. 6. Throughput in the enhanced protocol

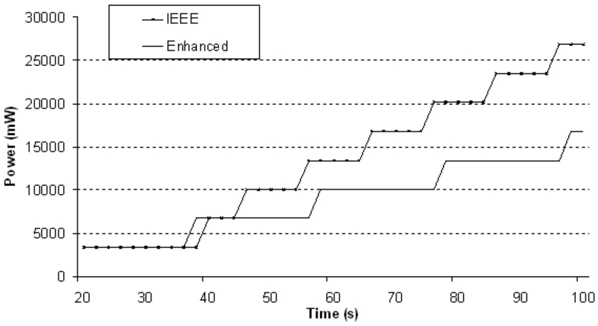

Fig. 7. Power consumption for the IEEE 802.15.4 and the enhanced protocol

savings can be observed in our proposed protocol. Figs. 8 and 9 depict the beacon signal level received by the mobile node when it passes through the coverage range of eleven coordinators. In the standard protocol, as shown in Fig. 8, the mobile node switches coordinators eight times compared to the five in our enhanced protocol (Fig. 9). Moreover, the connectivity time is longer in our proposed protocol, which is illustrated by the length of the beacon signal.

V. Conclusion

In this paper, we considered the problem of mobile node connectivity time with the coordinators in IEEE 802.15.4 beacon-enabled mode, and proposed a method to solve this problem.

In the design of our algorithm we used two parameters: the timestamp of every beacon received during the scan procedure as well as the link quality of each beacon signal, to determine the most appropriate coordinator for the mobile node to associate with. Relative to the standard protocol, our enhanced protocol has shown that the mobile node consumes less power due to less frequent associations, and the throughput is increased because of longer connectivity time.

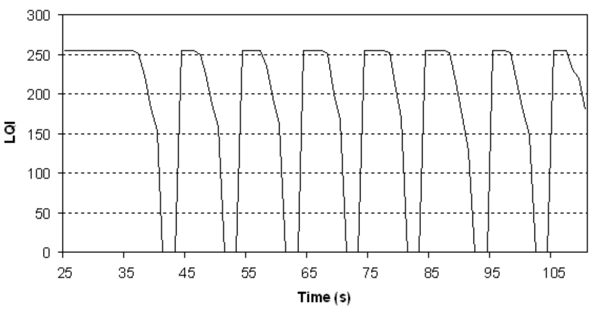

Fig. 8. Beacon signal level for IEEE 802.15.4

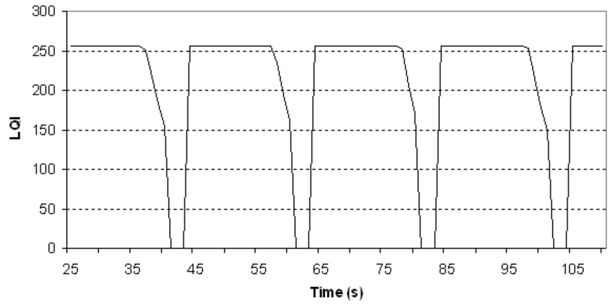

Fig. 9. Beacon signal level for the enhanced protocol

References

[1] K. Zen, D. Habibi, A. Rassau, I. Ahmad, "Performance Evaluation of IEEE 802.15.4 For Mobile Sensor Networks," in Proceedings of the 5th Wireless and Optical Communications Networks, 2008 (WOCN 08) pp:1-5, 2008.

[2] IEEE Std 802.15.4TM 2003, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), Institute of Electrical and Electronics Engineers, 2003

[3] http://www.isi.edu/nsnam/ns/

[4] A. Cunha, "On the use of IEEE 802.15.4/ZigBee as federating communication protocols for Wireless Sensor Networks," Technical Report IPP Hurray!, HURRAY-TR-070902, 2007.

[5] S. Tilak, V. Kolar, N.B. Abu-Ghazaleh, K.D. Kang, "Dynamic Localization Protocols for Mobile Sensor Networks," In 24*th* IEEE International Performance, Computing, and Communications Conference (IPCCC), pages 587-592, 2005.

[6] U. Bischoff, M. Strohbach, M. Hazas, G. Kortuem, "Constraint-Based Distance Estimation in Ad-Hoc Wireless Sensor Networks," In Proceedings of the Third European Workshop on Wireless Sensor Networks (EWSN), pages 54-68, 2006.

[7] L. Hu and D. Evans, Localization for mobile sensor networks, In Proceedings of the 10th annual international conference on Mobile Computing and Networking (MobiCom), pages 45-57, 2004.

[8] F. Zhang, F. Wang, B. Dai, Y. Li, "Performance Evaluation of IEEE 802.15.4 Beacon-enabled Association Process," 22nd International Conference on Advanced Information Networking and Applications-Workshops, 2008, AINAW 2008, pp. 541-546.

[9] S. B. Attia, A. Cunha, A. Koubaa, M. Alves, Fault-Tolerance Mechanisms for Zigbee Wireless Sensor Networks, Work-in-Progress (WiP) session of the 19th Euromicro Conference on Real-Time Systems (ECRTS 2007), Pisa, Italy, July 2007, pp. 37-40.

[10] K. Zen, D. Habibi, "Improving the IEEE 802.15.4 Re-association Process in Mobile Sensor Networks," To appear In the Proceedings of the IASTED International Conferences on Communications Systems and Networks (CSN 2008), 2008.

[11] J. Blumenthal, R. Grossmann, F. Golatowski, D. Timmermann, "Weighted Centroid Localization in ZigBee-based Sensor Networks," In Proceedings IEEE International Symposium on Intelligent Signal Processing 2007, Madrid, WISP 2007, .pp.1-6.