A Study of Continuous Object Tracking in Wireless Sensor Network

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Abstract

With the rapid development of MEMS technology, it has become possible that sensor networks can be used in wide range of applications. One of the most important applications is continuous object tracking in wireless sensor networks. In continuous object tracking, fundamentally it's the tracking objects i.e. forest fire or oil spill (phenomenon), which is very challenging because a lot of sensor nodes participate in sensing and communication. In continuous object tracking, the sensing range is an important aspect which affects the performance of object tracking process. In this paper, we discussed sensing a range of sensor nodes, deployment of sensor nodes, and speed of the continuous object (phenomenon) during object tracking. Through the simulated experiments, we exhibit, how the sensing range of sensor nodes, deployment of the sensor nodes and speed of the object make affect the tracking accuracy and network performance.

Index Terms

Boundary Accuracy, Continuous object tracking, Network Performance, Sensing Range, Wireless Sensor Network

1. Introduction

Recent development of wireless communications and electronic techniques enabled the development of sensor nodes in small size [1]. These small size of sensor nodes constructs the wireless sensor network, which are used in a variety of applications, such as environmental monitoring and military surveillance.

One of the most important research areas in wireless sensor networks is object tracking. There are generally two categories of object tracking: individual object tracking and continuous object tracking. There are many types of research on individual object tracking [6, 7, 8], but few efforts were made on continuous object tracking. The continuous object is the object which is continuously distributed over a region i.e. gas and oil spill [13, 14,16, and 17] in industrial applications.

The simplest approach for tracking the continuous object is to let all the sensor nodes report back to the base station, those who sense the continuous object in the proximity. In this way, the energy of sensor nodes will be exhausted quickly since too many nodes report back to the base station.

In [3], Xiang Ji et al. the researchers proposed a dynamic cluster algorithm for tracking the continuous object. In its approach, it dynamically groups the boundary node into clusters. This approach can save energy because only the nodes which locate near the boundary participate in the communication. As in [6], C. Zhong and M. Worboys proposed energy efficient boundary detecting algorithm. Comparing to [3], the number of nodes in [6] which are responsible for reporting back to the base station is reduced. In [2], Jung-Hwan Kim et al. provided an energy-efficient approach for tracking the continuous object. The algorithm save energy by selecting a small number of boundary nodes than [6] and select a subset of them to report back to the base station.

In this paper, we examined several cases to discuss sensing range in continuous object tracking in different continuous object speed and different type of network deployment i.e. high dense deployment or low dense deployment. That is, if the sensor nodes have short sensing range, the network could achieve higher accuracy in boundary detection of the continuous object. However, if there are a small number of sensor nodes that report back to the base station, the detected boundary of the continuous object would lose a lot of accuracies even though sensor nodes have short sensing range. On the other hand, if the density of the network is high, then it is important to consider more short sensing range of sensor nodes because of overlapped sensing areas. The rest of paper consists as follows, we discuss several continuous objects tracking algorithms and propose a problem in related work in section 2. In section 3, we shall discuss and analysis about the relationship between sensing range and density of deployment in different object speed using experimental results. Finally, in the last section, we will conclude the paper

2. Related Work

Many types of research focus on the energy efficient detecting and tracking object in wireless sensor networks [6, 7, 8]. Indeed, most of them focus on individual object tracking such as vehicles, animals, humans etc.

In COBOM [5], an energy-efficient boundary detection algorithm is proposed. That is, if a sensor's current reading is different from previous reading, that sensor broadcasts its reading and its ID to its one-hop neighbor. A node which receives the reading and ID stores the information it received in an array. If the node finds that there is at least

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one different reading in the array from itself, then that node becomes a boundary node. To achieve energy efficiency, a small number of the representative node (RN), which is responsible for the report back to the base station, will be selected. If a sensor node received a higher number of different reading in its array, then it has high chance to become RN. RN's report message is consisting of RN's ID, its reading and node's BN-array.

Jung-Hwan Kim et al. [2] proposed DEMOCO, an energy-efficient object tracking algorithm to detect and monitor continuous object. In DEMOCO, the author reduced the number of boundary nodes and representative nodes in COBOM and reduced the size of report message to the base station. If a node has the current reading which is different from the previous reading, then that node become "changed value node (CVN)" and broadcasts COZ message which includes sender's ID and sender's current reading to its one-hop neighbors. If a node which is the neighbor of CVN received at least one different reading, then that node will be boundary node. Among these boundary nodes, few numbers of RN will be selected. The BN which received a number of COZ message, the shorter back-off time it will have. A BN which has shorter back-off time will wake up early, broadcasts suppression message to prohibit other BNs in its communication range from being RN. (The function of RNs in the DEMOCO is similar to that in COBOM, it is responsible for the report back to the base station. The report message consists of sender's ID and reading, and closest neighbor's ID.

In the previous works, they didn't consider sensing range. Indeed, Sensing range is an important factor in wireless sensor networks. The sensor node could detect the change of object if the boundary of the object is inside the sensing range. Therefore, how far could sensor node reading be a very important factor which affects the performance. As if sensing range is very short in sparse deployment, there will be a lot of vacuum which couldn't be sensed by sensors nodes or if sensing range is longer in dense deployment, then there will be too many overlapped areas in network field.

In the previous part, we mentioned the industrial applications, it is important to know the range, or how big the object is and the location of the object. This could help us to locate the object more precisely and could prevent other things enter the polluter area [15]. The sensor node should adjust its sensing range according to the specific conditions so that it saves energy and monitor the object longer time as possible. The sensor nodes which could adjust its sensing range are available commercially [11, 12].

In this work, we discussed the sensing range in continuous object tracking. Through the analysis and discussion, we showed that according to different cases, we should adopt appropriate sensing range to achieve better performance.

3. Analysis and Discussion

In this section, we discuss the sensing range in continuous object tracking, in different cases. In case of performance, we discuss it according to two aspects: accuracy and energy cost. In some cases, and under some specific conditions, the network could acquire high accuracy and low energy cost. But in other cases, it may acquire high accuracy but more energy cost or saving energy with low accuracy. Thus, it's hard to decide which case is better, performance of the network may differ depending upon on the type of object or type of tracking requirements of the object.

Sensing range is an important factor in wireless sensor networks. In continuous object application area, the distance of sensing range will affect the performance of applications. Usually, if there are many nodes situated very close to the boundary, the base station could draw out the more accurate detected boundary. But if the sensing range is long, then the representative node would be far from the assumed boundary. Accordingly, this will cause loss of accuracy.

Prior to the analysis and discussion phase, some assumptions and definitions are given.

A. Assumptions

- Nodes are randomly deployed in the sensing area.
- Nodes have similar capabilities, such as sensing, energy, and computation.
- Each node has a unique ID.
- The sink node knows every node's ID and position.
- Possible data loss or contention is not considered.
- Any destruction of nodes in the targeted application is not considered.

B. Definitions

1) Boundary Accuracy:

Boundary accuracy is defined as following

$$“(1-\frac{d_{ave}-d_o}{d_{ave}})” \quad (1)$$

Where "dave" is the average of "distance from each representative node to the geometric center of the object". "do" is the distance between the geometric center of the object and a point on the real boundary which is the intersection of a line through a representative node and geometric center of the object. This equation means that if the representative node is far from the object relative to the object size, then the accuracy will be low.

2) Average accuracy:

Average accuracy is taken by an average of the value of accuracy in each time slot.

3) Representative Node (RN):

The representative node is responsible for reporting back to the base station. We could use the term "total number of representative nodes", which is the sum of RN in total time slots, to indicate the energy cost because RNs are responsible for the report back to the base station. The larger number of RNs were generated, means more energy is consumed.

4) Detected Boundary:

The detected boundary is the boundary which was drawn by the base station via the information in the report message from the representative node.

5) Assumed boundary:

The assumed boundary is the boundary that we established in the simulation environment to evaluate the performance through comparing with detected boundary.

C. Boundary Accuracy Continuous Object Tracking

In continuous object tracking, a representative node (RN) is a sensor node that sends data to the sink node. Only a few representative nodes get selected among boundary nodes (BNs) [5], [2] and [16]. The scope of this paper is to investigate the boundary accuracy in different condition i.e. densities of the network, different sensing range of sensor and different moving speed of the continuous objects.

We used DEMOCO [2] approach for selection of BNs and RNs. If it detects the status different from the status at previous sampling time, it becomes a candidate boundary node. These Boundary nodes, in DEMOCO, can be defined differently from boundary nodes in COBOM. (This is not considered in counting messages in simulation because we considered the communication after the selection of RNs).

4. Simulation Results

We setup simulation environment using JAVA. In the simulation, we modified the DEMOCO [2], added the sensing range to examine.

We used simulation environment as table 1. As the table shows, we used two different densities of the network, three different sensing range, and two different continuous object speeds. Density means how many sensor nodes are deployed in the certain a unit area. If many nodes are deployed in the unit area, this means that the network has high density. In dense deployment, many nodes may detect the same boundary while in sparse deployment, only few sensor nodes could detect the boundary. We assign different sensing value to avoid severe overlapping or blank area that the sensor nodes couldn't sense.

In the simulation, we use binary sensing model [4]. In binary sensing model, if the change of the object is inside the sensing range, then the node will change the current reading to 1 if it detects the appearance of an object, to zero if it detects the disappearance of the object.

Table 1: Simulation Environment

Network Field	500m × 500m
Number of Sensor Nodes	1500 (sparse deployment) 5000 (dense deployment)
Sensing Range	For sparse deployment: 15m (short), 25m (long)
	For dense deployment: 8m (short), and 12m (long)
Object Speed	5m / time slot (slow), 10m / time slot (fast)
Total Time Slots	20 slots

The results show that we could save more energy if we choose short sensing range. According to the object tracking algorithm, the longer sensing range mean, more sensor nodes will detect the object. This will increase the number of the generated representative node. Also, if a node has shorter sensing range, it will detect the object more accurately. The shorter sensing range the sensor node has, the more the chances it may have to close to the real boundary of the object, so the base station will get more accurate information of the boundary. But if we consider other factors, like the speed of the object and the density of network deployment, we'd better adjust the sensing range to get better performance.

D. Tracking Slow Object Movement in Low Network Density

In this case, we change only the value of sensing range to examine how the network performance will be changed according to the change of sensing range.

We first consider the case of short sensing range, a slow object with sparse network deployment. In this case, 1500 sensor nodes arbitrarily deployed in the field which has 500 m × 500 m network field. Each node has a sensing range of 15 meters, and the object change speed is 5 meters per slot. The Figure 1 shows how accuracy can change according to the different sensing range under conditions of low density and slow object. When the sensor nodes monitoring slow object with low density, the difference of accuracy becomes bigger as sensing range increasing. Whereas in Figure 4, except the first several time slots, there is no big difference between the accuracy of each sensing range. This is because in the same time slot, the fast object expands more than a slow object. There are large number of sensor nodes that detect the boundary of the continuous object , which will lead to acquire more accuracy. We should notice that in fast object case, as the Figure 2 shows, the number of representatives is increased, then the energy cost will be increased too.

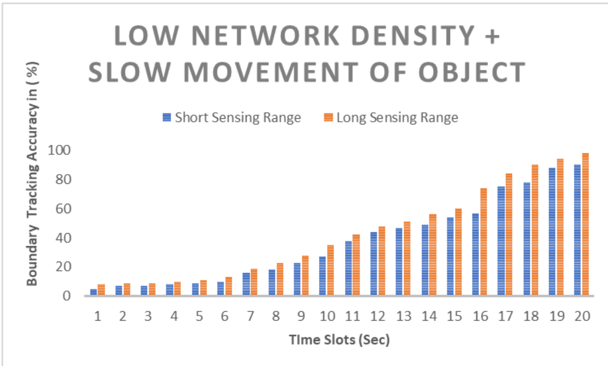


Fig. 1 The Boundary Tracking Accuracy with Short and Long Sensing Range, at the time of low network deployment and slow movement of the object

It shows that generally if the sensor nodes have shorter sensing range, the network can achieve higher accuracy and less energy cost. As the sensing range increasing, the total number of RN also increased. This means that in the case of short sensing range in the slow object, if we adopt short sensing range, then we will get better performance. But, if we look at the shape of detected boundary, especially in the case of short sensing range in the slow object, we will find that the shape of the detected boundary accuracy decreased. The up part in Figure 2. shows the shape of the detected boundary when the object changes slowly, and when the sensing range is short. Since the object changed its shape slowly, the object would be small in slightly long-time slots. The sensing range is short, the number of representatives' nodes are not many because of low density. The above Figure 2. shows when the tracking of continuous object with a regular shape, adequate representative node around the object boundary, we could acquire more accurate shape. But if some representative nodes are close to the assumed boundary and the quantity is small, then the detected boundary line will be very rough, and cannot represent the assumed boundary very well. In above part of the Figure 2, especially the upper-down corner of the continuous object boundary lost a lot of accuracy because of lack of the representative node. Accordingly, this will affect the performance boundary detection accuracy. Tracking continuous object require accuracy, therefore in this sort of case, we couldn't adopt the short sensing range.

Therefore, we tried to increase the sensing range in the same environment (sparse deployment and slow object changing) to check how the shape of detected boundary line would be changed. According to the algorithm of DEMOCO, if we increase the sensing range, then the number of the representative nodes would be increased. Theoretically, this will increase the accuracy of the detected boundary line. In below part of the Figure 2, the simulation result shows that the detected boundary has more accuracy than the case of the short sensing range. Even though the detected boundary line is a bit far from the assumed boundary, we expect that the detected boundary is similar to the assumed boundary. In this sense, we can get a more accurate detected boundary through increasing the sensing range when deployment is sparse, and the object changes slow.

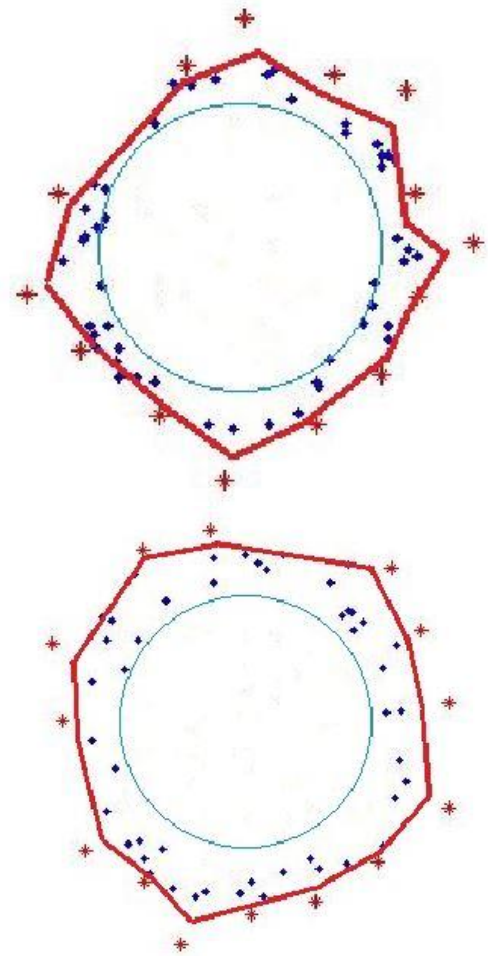


Fig. 2 Low density, slow object, short sensing range [above] and long sensing range [below]

(In the above Figure, the blue circle is an assumed boundary, the red line is a detected boundary, whereas the star is a representative node.)

E. Tracking Slow Object Movement in High Network Density

When we scattered a lot of sensor nodes in the network field, the density of deployment was high. (connecting word needed) High density means that the probability of sensor nodes around the object boundary will be increased. In this time, we deployed 5000 sensor nodes in the network field with the same size as the previously discussed, then we adjusted the sensing range in the densely deployed network and tracked the object with low speed.

In the up part of Figure 4, the sensor nodes have short sensing range, while in the below part of the Figure the sensor nodes have long sensing range. When sensor nodes have short sensing range, we can notice that there is a large number of representative nodes compared to sparse deployment. The detected boundary line is more accurate than the detected boundary in sparse deployment but still a bit rough. We also notice in Figure 3 that in the first several time slots, the accuracy is not high. But in long sensing range case, in the low below part of Figure 4, even the accuracy is low, because of long sensing range, there are a large number of representative nodes are generated. The shape of the detected boundary line is smoother and more accurate than the short sensing range case. As we discussed before, if sensing range is longer when we track regular shape object, we can acquire more accurate detected boundary line theoretically because of the increase of representative node. (connecting word needed) the More representative nodes we have, the smoother and the more accurate detected boundary we could achieve. Therefore, we should increase the sensing range when we monitor slow object in dense deployment.

In the previous part we discussed the slow object movement. Now will discuss high object movement in the next part.

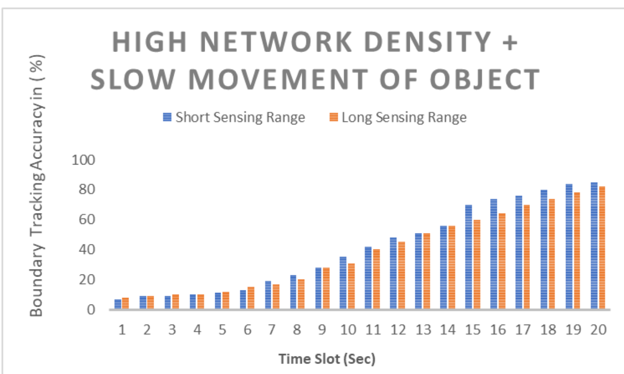


Fig. 3 Shows the boundary tracking accuracy with short and long sensing range, at the time of high network density and slow movement of the object.

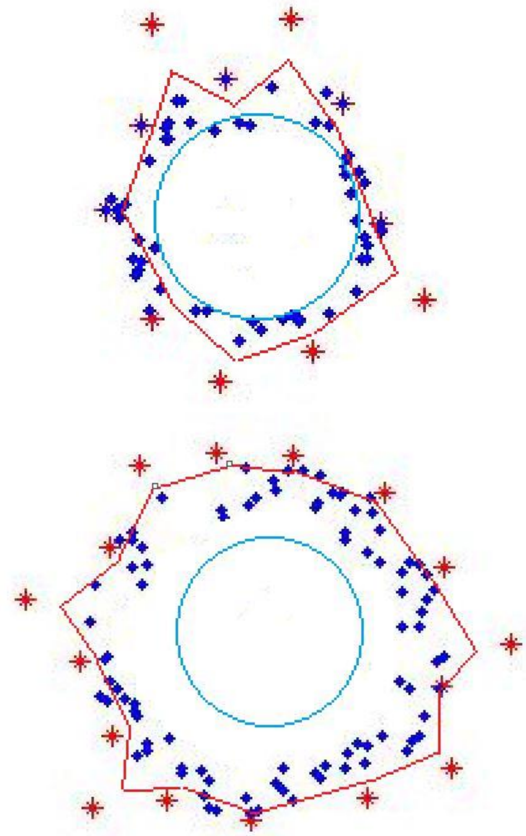


Fig. 4 High network density, slow movement of object, short sensing range [above], and long sensing range [below]

(In the Figure 4. the blue circle is assumed boundary, the red line is detected boundary, the star is a representative node.)

F. Tracking High object Movement in Low Network Density

First, we considered the low network density deployment. When object speed is high, the object can change its shape a lot in short time slot. Figure 6 shows that the accuracy in each time slot is higher than when the sensor nodes monitoring the slow object with low density. In Figure 5, we can see that when the object is expanding, because of its high expansion rate, the object is big. Therefore, the number of representative nodes around the object will be high even though the sensor nodes were sparsely deployed. This can be seen in the above part of Figure 5. The detected boundary line is like the assumed boundary line, in Figure 2. The detected boundary line is too rough to show the assumed boundary line. We tried to increase the sensing range. In the slow object case, if we increased the sensing range, we could still acquire accurate and smooth detected boundary line. But in this case, like what is shown in the below part of Figure 5. The shape of the detected boundary line is like the up one. The reason for that is that if we have enough point (Here, that kind of point is the representative node) when we are monitoring an object with a regular shape, we could get accurate detected boundary line.

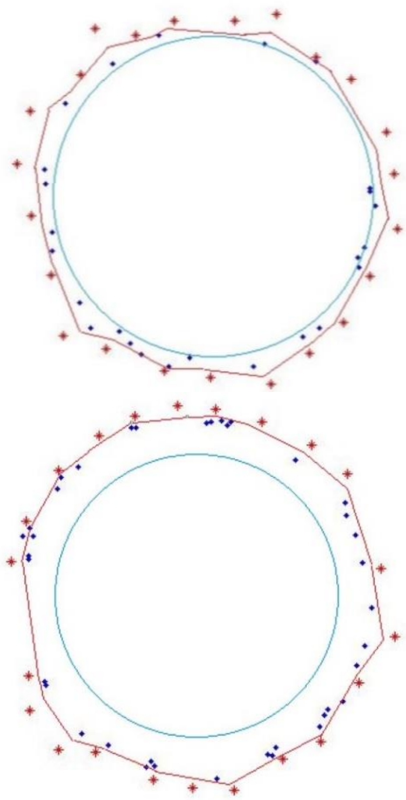


Fig. 5 Low network density, high movement of object, short sensing range [above], long sensing range [below]

(In the Figure 5. The blue circle is assumed boundary, the red line is detected boundary, whereas the star is a representative node.)

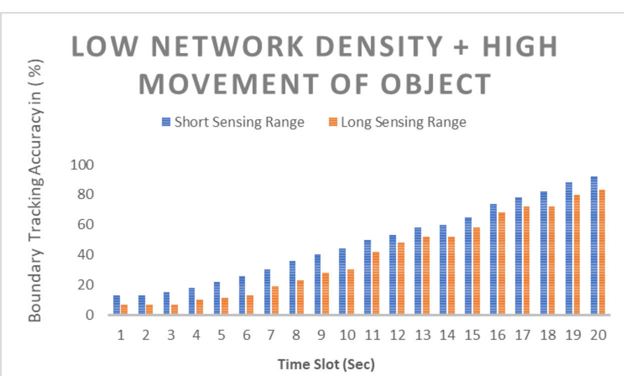
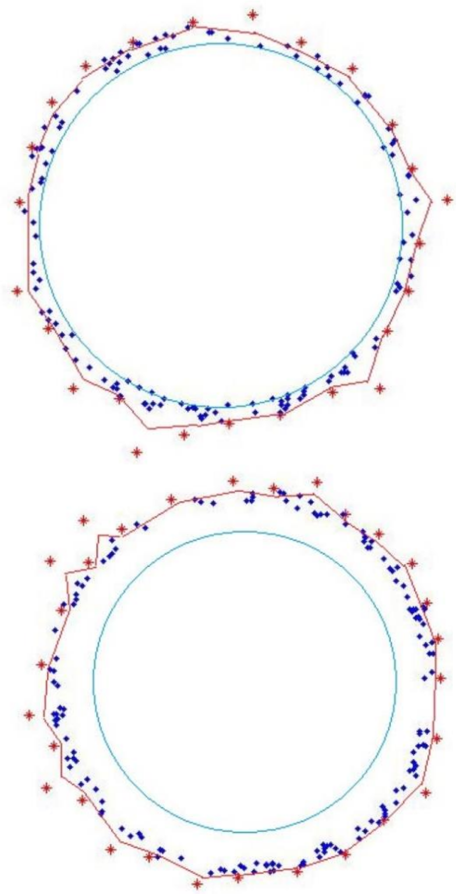


Fig. 6 Shows the boundary tracking accuracy with short and long sensing range, at the time of low network density and high movement of the object.

What we should notice is that when we adopt the long sensing range, the detected boundary line is somewhat far from assumed boundary line. In short, sensing range case, the detected boundary line is very close to the assumed boundary line while it has nearly same accuracy with long sensing range case. Furthermore, in the case of long sensing range, the total number of RN is higher. This means that in that case, the network cost more energy. Therefore, it is better to adopt the short sensing range in monitoring high-speed object in sparse deployment.

G. Tracking High Object Movement in High Network Density

In this section, we will continue discussing monitor high-speed object. But this time we deployed more sensor nodes than the previous section. Figure 8 shows the experiment results. As we can see, in both cases, the shape of the detected boundary line is very similar. Figure 8 also shows that the accuracy of each different sensing range is very close. The reason is similar as we discussed above because of the high density of the network, the number of the representative nodes would be higher than the sparse deployment case. Since we could get more accurate detected boundary line in short sensing range. The detected boundary line is closer to the assumed boundary line more than the case of long sensing range; therefore, we'd better adopt the short sensing range when we monitor the fast object in dense deployment.



Fig, 7 High network density, high object movement, short sensing range [above], and long sensing range [below]

(In the Figure7 the blue circle is assumed boundary, whereas the red line is detected boundary, the star is a representative node.)

Theoretically, we could get more accurate detected boundary line if we adopt short sensing range, but in some cases, according to the surrounding environment, we should adjust the sensing range to improve the performance continuous object tracking not only needs energy-efficient but also need accuracy. Therefore, it is better to adopt long sensing range when we monitor slow object either in sparse deployment or in dense deployment.

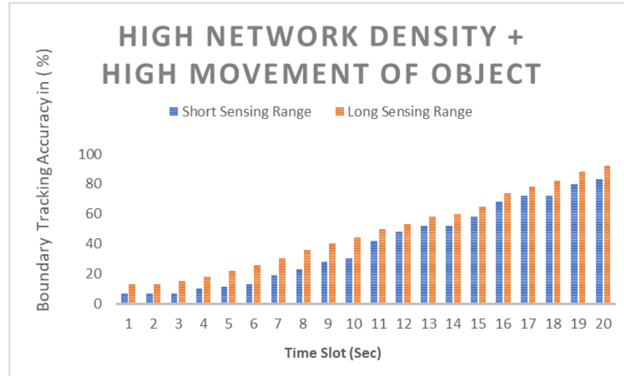


Fig. 8 Shows the boundary tracking accuracy with short and long sensing range, at the time of high network density and high movement of object

5. Conclusion

This paper discussed sensing range in continuous object tracking, in wireless sensor networks. Through the simulation and analysis, we could see, by adopting the different sensing range, we could achieve a different aspect of performance. In the case of the same density and same object with different sensing range, we should adopt appropriate sensing range to achieve improved performance. Generally, the shorter sensing range is better. But in some specific cases, it is required to choose sensing range very carefully because of the shape of the object is an important factor in continuous object tracking. When we are tracking a slow object, we should choose long sensing range for a smoother and a more accurate boundary line even if it costs more energy, while we could choose short sensing range when we are tracking the fast-moving object.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci; “A survey on sensor networks,” IEEE Communications Magazine, pp. 102-114, August 2002

[2] J. H. Kim, K. B. Kim, S. H. Chauhdary, W. Yang, and M. S. Park; “DEMOCO: Energy-efficient detection and monitoring for continuous objects in wireless sensor networks,” IEICE TRANS. COMMUN., VOL. E91-B, NO.11, pp. 3648-3656, November 2008

[3] X. Ji, H. Zha, J. J. Metzner, and G. Kesidis, “Dynamic cluster structure for object detection and tracking in wireless ad-hoc sensor networks,” Proc. IEEE ICC, pp.3807-3811, June 2004

[4] C. Zhu, C. Zheng, L. Shu, G. J. Han, “A survey on coverage and connectivity issues in wireless sensor networks,” Journal of Network and Computer Applications, vol. 35, issue 2, pp.619-632, March. 2012

[5] C. Zhong and M. Worboys, “Energy-efficient continuous boundary monitoring in sensor networks,” Technical Report, 2007. Available: http://ilab1.korea.ac.kr/papers/ref2.pdf

[6] W. Zhang and G. Cao, “DCTC: Dynamic Convoy Tree-Based Collaboration for Target Tracking in Sensor

Networks," IEEE Transaction on Wireless Communication, vol. 3, no. 5, Sept.2005
[7] Y.Q. Xu, Winter J, and W.C. Lee, "Prediction-based strategies for energy saving in object tracking sensor networks," Proc. IEEE MDM, pp. 346-357, Jan. 2004
[8] W.P. Chen, J.C. Hou and L. Sha, "Dynamic clustering for acoustic target tracking in wireless sensor networks," IEEE Trans. On Mobile Computing, vol. 3, issue. 3, pp. 28-271, Aug. 2004
[9] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less low-cost outdoor localization for very small devices," Personal Communications, IEEE, vol. 7, issue. 5, pp. 28-34, Oct. 2000
[10] J. Hightower and G. Borriello, "Location systems for ubiquitous computing," Computer, vol. 34, issue. 8, pp. 57-66, Aug. 2001
[11] M. Cardei, J. Wu, M. Lu and M. O. Pervaiz, "Maximum network lifetime in wireless sensor networks with adjustable sensing ranges," IEEE International Conference on WiMob'2005, vol. 3, pp. 438-445, Aug. 2005
[12] M. Cardei, J. Wu and M. Lu, "Improving network lifetime using sensors with adjustable sensing ranges," International Journal of Sensor Networks, vol. 1, pp. 41-49, Sep. 2006
[13] K. S. Low, W. N. N. Win, and M. J. Er, "Wireless sensor networks for industrial environments,", CIMCA-IAWTIC'05, vol. 2, pp. 271-276, Nov. 2005
[14] M. P. Akhondi, A. Talevski, S. Carlsen and S. Petersen, "Application of wireless sensor networks in the oil, gas, and resources industries,", 2010 24th IEEE International Conference on Advanced Information Networking and Applications (AINA), pp. 941-948, Apr. 2010
[15] Y. P. Zhang, Y. Xiao, "A boundary surveillance strategy based on critical line in wireless sensor networks," International Conference on Mechatronics and Automation, 2009, pp. 459-464, Aug. 2009
[16] H.J. Lee, M. T. Soe, S. H. Chauhdary, S. Rhee, M.-S. Park, "A data aggregation scheme for boundary detection and tracking of continuous objects in WSN", Intell. Autom. Soft Comput., vol. 23, no. 1, pp. 135-147, 2016.
[17] Hussain, Chauhdary Sajjad, et al. "A collaborative scheme for boundary detection and tracking of continuous objects in WSNs." Intelligent Automation & Soft Computing 19.3 (2013): 439-456.

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