MRP-NEP: A Non-Equal-Probability Multicast Routing Protocol for Target Tracking in Wireless Sensor Networks

Boyu Diao[1,2], Peipei Li[1], Zhulin An[1], Fei Wang[1,2], and Yongjun Xu[1]

[1] Institute of Computing Technology, Chinese Academy of Sciences,
Beijing 100190, China
{diaoboyu2012,lipeipei,anzhulin,wangfei,xyj}@ict.ac.cn
[2] University of Chinese Academy of Sciences,
Beijing 100049, China
diaoboyu12@mails.ucas.ac.cn

Abstract. Target tracking is regarded as one of the key applications of wireless sensor networks (WSNs). Due to the limited energy in sensor nodes, reducing energy consumption while maintaining acceptable accuracy is an important issue in target tracking. Previous work usually awakens only those nodes adjacent to the target to save power. However, simple full-flood routing protocol used in those work for awakening brings significant communication overhead, which consumes energy two more orders of magnitude compared with computing. In this paper, we proposed a novel routing protocol with non-equal-probabilistic forwarding to reduce communication overhead. In our protocol, sensor nodes forward packets with a probability which is mainly determined by how much the node's location deviates from the direction of target motion. The simulation results show that our protocol can save energy by 30% while tracking a moving target.

Keywords: mobicast routing protocol, non-equal-probability, target tracking, wireless sensor networks.

1 Introduction

Wireless Sensor Networks (WSNs) is becoming increasingly important in both civilian and military applications. With various sensors equipped, WSNs can provide comprehensive sensing information of the environment. Target tracking is one of the key applications in WSNs. A large number of nodes deployed in a particular zone, once a target steps into the zone, sensor nodes will work cooperatively to achieve the data of interest, such as velocity, direction, number of targets, and etc. With the advantages of flexible deployment and self-organizing, target tracking in WSNs has been widely used in fields like habitat monitoring, battlefield monitoring, vehicle tracking and so on. As the tiny sensor nodes cannot provide sufficient energy, low-power consumption is a serious challenge.

H.-Y. Jeong et al. (eds.), *Advances in Computer Science and Its Applications*,
Lecture Notes in Electrical Engineering 279,
DOI: 10.1007/978-3-642-41674-3_30,

Target tracking protocols are widely researched in last decade. If energy consumption is not considered, all nodes can be set awake to monitor the environment [1-2]. Of course this approach may waste large amount of energy and is not practical. There is a variety of energy management approaches for target tracking in WSNs, for example, we can only set cluster heads in awake state and others asleep. When targets approaching, cluster heads will wake up their members as soon as possible [3-4]. This is a feasible method but cluster heads suffer a high risk of running out of energy much earlier. Another approach is dynamically setting nodes around targets in wake state to track targets and other nodes asleep [5-6]. This approach is obviously effective to leverage between energy consumption and tracking accuracy. In order to wake up nodes in exact positions when targets approaching, sensor nodes must work in a cooperative way by communicating with each other, thus an energy efficiency routing protocol is necessary as support. Multicast routing protocol can provide a good guarantee for both time and space, that is, the protocol can guarantee packets forwarded only in a specific area at a particular moment. In view of the advantages, various multicast routing protocols are applied for target tracking in WSNs.

Qingfeng Huang et al. proposed a just-in-time multicast protocol in constraints of spatiotemporal for target tracking in wireless sensor networks [7]. They introduce the conception of k-coverage zone. But the k-coverage zone which is based on Δ-compactness of the whole networks is difficult to calculate. This protocol has low scalability and high computational cost. To improve scalability and reduce computational cost, Qingfeng Huang et al proposed another multicast protocol for wireless sensor networks [8] which optimized the algorithm to calculate local compression value, but this protocol cannot provide spatiotemporal guarantee. To overcome the disadvantages in [7-8], Qingfeng Huang et al. proposed a planar-based reliable multicast protocol [9] which introduces the concept of a node's planar spatial neighborhood, the mechanism of *Greedy Forwarding* and *Timed Forwarding*. It provides a high scalability, but each node must update its planar spatial neighborhood list periodically, and this will bring a large amount of extra energy consumption.

All aforementioned protocols [7-9] have their own advantages and disadvantages, but they all share a common disadvantage, that is, nodes in transfer zone employ a full flooding routing protocol to wake up nodes in forwarding zone. In scenarios of low speed (below 10 m/s) target tracking, energy wasted by full flooding is not obvious. But in scenarios of high speed (above 50 m/s) target tracking, the situation is different. For UAVs tracking as an example, UAVs have a general speed between 50 m/s and 100 m/s. If the sampling frequency is 1 Hz, network must wake up nodes in right direction in advance. As the target speed is as high as 100 m/s, sensor network has to forward the wake-up packets in range of 100 meters. If full flood protocol is employed, it will waste huge energy which is limited.

And this is precisely the problem addressed by this paper.

In scenarios of high speed targets tracking in WSNs, we bring geographical-position-based forwarding probability to decide whether a node forwards packages or not, and use this idea for delivering information of moving targets from nodes to nodes in certain directions. With this idea we present a novel target tracking protocol for target tracking in WSNs.

Rest of the paper is organized as follows: In section 2, we illustrate the basic idea of proposed protocol and clarify some main conceptions. In Section 3, the protocol is formulated. In Section 4, we will present how the protocol works in detail. In Section 5, simulation and results are given. And in Section 6, we conclude the paper with summary.

2 Basic Idea

Multicast routing protocols in [7-9] are only suitable for a low speed targets. Under the condition of network nodes location self-aware, aiming at tracking high speed targets like UAVs, we will propose a novel low power consumption protocol: non-equal-probability multicast routing protocol (MRP-NEP) in this chapter

Some concepts must be clarified here. Target sensing area is a circular area which takes the target as the center of the circle and a certain length D as radius (Area A in Fig. 1). Target related area is the area between the target sensing areas of two adjacent moments, likes Area B in Fig. 1 which is made up of two symmetry right triangles.

In order to ensure the continuity of tracking, nodes in area of the following moment should be waken up earlier. When wake-up packages transferring in the target related area. To reduce the unnecessary energy consumption caused by full-flooding, we introduce geographical-position-based forwarding probability to decide whether a node in target related area forwards the wake-up package or not. The forwarding probability is set as follows: nodes close to the direction of targets' motion have a higher forwarding probability, because packages forwarded by nodes close to the direction of targets can be received more easily by nodes in predicted target sensing area.

3 Protocol Formulation

In this paper, the application scenario is based on the following assumptions:

1. Nodes are homogeneous, and are randomly deployed in a rectangle area.
2. Every node is aware of its own position. (We can use trilateration with some anchor nodes during network initialization phase)
3. Every target maintains uniform liner motion from time t to time $t+1$.

As shown in Fig.1, two solid black spots represent target positions at two adjacent moments. As mentioned above, Area A in Fig.1 is target sensing area in time t. Area B in Fig.1 is target related area in time $t+1$. Area C in Fig.1 is target sensing area in time $t+1$ which is predicted by nodes in Area A. Nodes in Area A will work cooperatively both tracking the target and make prediction of the following trajectory.

Then with the help of nodes in Area B, wake-up packages will be delivered to nodes in Area C. When a target steps into Area C, the nodes will repeat the steps mentioned above, and nodes in Area A will go back to sleep to save energy.

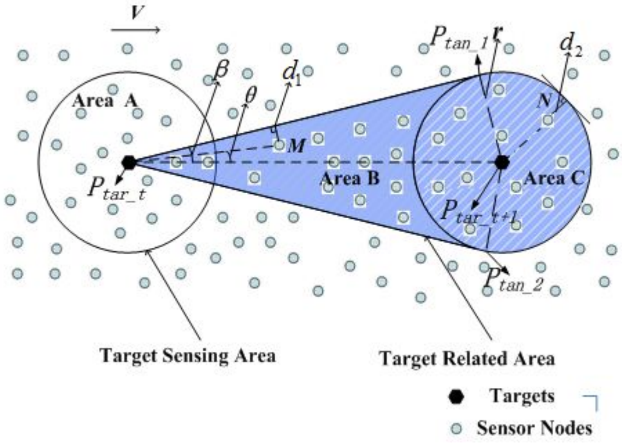

Fig. 1. Model of MRP-NEP

A wake-up package is formed in this manner:

$$<M_t, M_{t+1}, P_s, T>$$

Where M_t is the target position in time t, M_{t+1} is the target position in time $t+1$, P_s is position of the sender node, T is the time when package generated. During the package delivery, the contents of the package will change correspondingly.

4 Protocol Description

MRP-NEP is a gradually screening process to decide which node to forward the wake-up package and has following main steps. We will present what is forwarding probability made up of and how to calculate it in detail. Notations used in MRP-NEP are listed in Table 1.

Step 1. Predict the target position of next moment and target sensing area of next moment. Prediction algorithm has a variety of choices, like unscented Kalman filter [10], etc.

Step 2. Determine the target related area and target sensing area of next moment. Calculate the coordinates of tangency points. As shown in Fig. 1, target related area is determined by target positions P_t, P_{t+1} and two tangency points P_{tan1}, P_{tan2}. P_{tan1}, P_{tan2} can be Calculated by the following formulas. In Formula (1) and (2), X_{tan1} and Y_{tan1}, represent abscissa and ordinate of point P_{tan1}. After two tangency coordinates are determined, the target related area is formed.

$$(X_{\tan 1} - X_{t+1})^2 + (Y_{\tan 1} - Y_{t+1})^2 = r^2 \tag{1}$$

$$\frac{Y_{\tan 1} - Y_t}{X_{\tan 1} - X_t} \times \frac{Y_{\tan 1} - Y_{t+1}}{X_{\tan 1} - X_{t+1}} = -1 \tag{2}$$

Table 1. Parameters Instruction

Parameters	**Instruction**
$P_t(X_t,Y_t)$	Target position at time
$P_{t+1}(X_{t+1},Y_{t+1})$	Target position at time $t+1$
$P_{tan1}(X_{tan1},Y_{tan1})$ $P_{tan2}(X_{tan1},Y_{tan2})$	Coordinates of two tangency points
R	Radius of target sensing area
M	A certain sensor node in target related area
θ	Angle between *Line* P_mP_t and *Line* $P_{t+1}P_{tan1}$
β	Angle between *Line* P_tP_{tan1} and *Line* P_tP_{t+1}
d_1	Distance from M to Line P_tP_{tan1}

Step 3. Determine whether a node in the target related area. If in, turn to Step 4; if not, drop the package and keep asleep.

Step 4. Determine whether nodes located in target relates area to send packages or not. This is the key process of protocol, we will describe it in more detail.

Step 4-1. Determine the *forwarding probability* of the nodes in target related area. Forwarding probability is consisted by two parts: *angle probability* which depicting how well the node fits the direction of the target, and *distance probability* which depicts how near the node is to the edge of target related area. Taking Fig. 1 as an example, we can get values of angle probability and distance probability from Formula (3) and (4).

Step 4-2. Get the *forwarding probability* from *angle probability* and *distance probability*. Forwarding probability is a linear combination of the angle probability and distance probability, according to Formula (5)

Step 4-3. Determine whether to forward the package or not. Generate a random float number P between 0 and 1. If $P_{send} > P$, forward the package, otherwise drop the package.

$$P_{angle} = \frac{\theta}{\beta} \tag{3}$$

$$P_{edge} = \frac{d_1}{r} \tag{4}$$

$$P_{send} = ratio \times P_{edge} + 1 - ratio \times (1 - P_{angle}) \tag{5}$$

5 Simulation and Results

To verify the validity of our protocol, we simulated it on OPNET 14.5, the MAC protocol is based on IEEE 802.15.4. 1000 sensor nodes are uniformly randomly distributed over a 600×250 m^2 fit field. Communication and sensing radius is randomly set as 35 m. We ran the simulator 1000 times, and take the average as our final results to reduce error.

In the model of our protocol, packet forwarding probability is affected by probability combination coefficient ratio, we firstly determine the optimal value of ratio and we can get it when the average forwarding angle is the smallest.

We ran our simulator in the following two scenarios: first is velocity changing over time, from 50 m/s to 80 m/s, increasing by 5 m per second. Second is direction changing over time, angle between target direction and horizontal line changing from 5° to 35°, increasing by 5° per second. In both two scenarios, we mainly care about following three system parameters:

1. Energy consumption: total energy consumption of target related area.
2. Package cost in target related area: Total packages forwarded in target related area.
3. Wake-up rate: The ratio of nodes wakened up and total number of nodes in target sensing area of the following moment. The more nodes be wakened, the more nodes participating to track targets, and the higher accuracy we get [5]. That is to say, wake-up rate is significantly positively related to tracking accuracy.

We will compare our protocol, a non-equal-probability multicast protocol for target tracking, which is recorded as MRP-NEP for short, with the full flood protocol in target related protocol, which is recorded as MRP-FF. Results and analysis are shown below.

5.1 Get Optimal Value of Ratio

First of all, we examined how probability combination coefficient will affect average angle of nodes delivering packages. As shown in Fig. 2(a), it could be seen the node average angle is minimum when *ratio* = 0.6, average angle is 0.16283. So, all the results below are in the condition of *ratio* = 0.6.

5.2 Total Energy Consumption

From Fig. 2(b) and Fig. 2(c), we can see MRP-NEP reduce package cost by 30% compared to MRP-FF and also saves about 30% energy compared to MRP-FF in both scenarios, because energy consumption is mainly made up of package forwarding, we reduce the package cost and energy is saved as well.

5.3 Wake-Up Rate

Finally, we will analysis wake-up rate. Fig. 2(d) shows how wake-up rate changes over time in two scenarios. We can see that wake-up rate is more than 50% when target velocity changes over time which can provide wonderful support for the collaborative tracking. In scenarios of direction changing over time, 40% awake nodes can also ensure the accuracy of tracking.

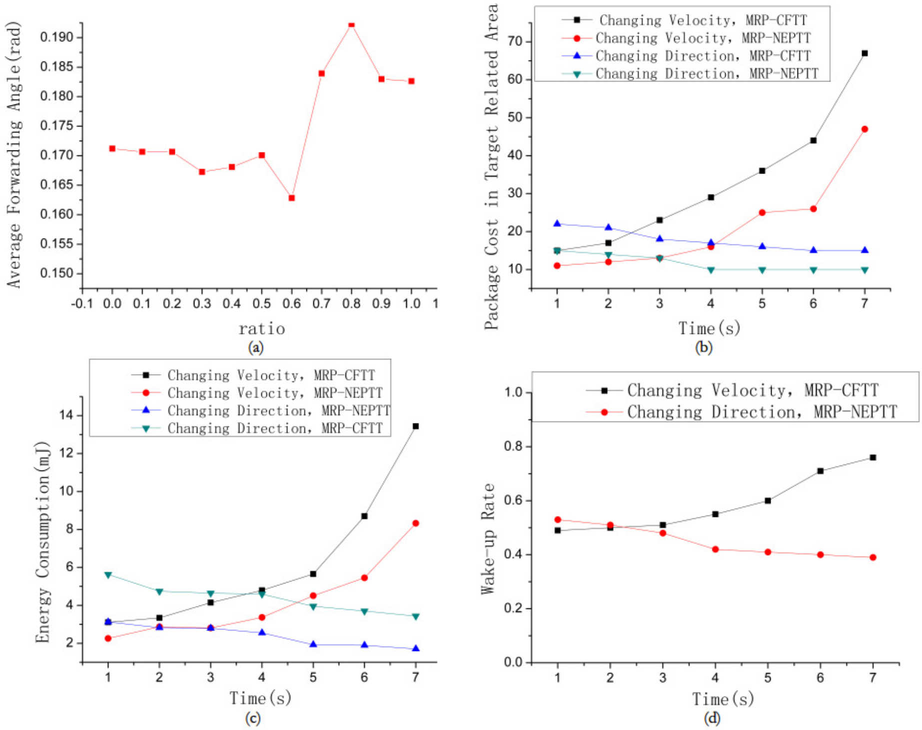

Fig. 2. (a) Comparing *ratio* due to average forwarding angle. Comparing Package cost (b) and energy consumption (c) due to two protocols in two different scenarios, Wake-up rate in two different scenarios (d).

6 Conclusion

Wireless sensor networks are generally deployed in critical environments, energy consumption is a severe problem, especially in target tracking. Predicting and just waking up nodes close to the direction of target motion is an effective way to save network energy resource. A non-equal-probability multicast protocol, proposed in this paper, is an effective routing protocol supporting the solution above. The simulation results show the proposed protocol reduces energy consumption by 30% compared with traditional flooding routing protocol [7-9], to save network energy even further and prolong the network lifetime. At the same time, the idea of spatial-probability-based multicast routing protocol will be a useful reference for design of wireless sensor network routing protocol.

Acknowledgments. This paper was supported in part by Important National Science & Technology Specific Projects under grant No.(2010ZX03006-002), the National Basic Research Program of China (973 Program) (No. 2011CB302803), National

Natural Science Foundation of China (NSFC) under grant No.(61173132, 61003307), the National Science Foundation for Young Scientists of China under grant No. (61202430, 61303245), and Internet of Things Technology R&D and Industrialization Specific Projects entitled "R&D and Industrialization of Conformance Testing Smart Instruments for IPv6 Network Protocol in Wireless Sensor Networks".

References

1. Kung, H.T., Vlah, D.: Efficient location tracking using sensor networks. In: 2003 IEEE Wireless Communications and Networking, WCNC 2003, vol. 3, pp. 1954–1961 (2003)
2. Lin, C.Y., Peng, W.C., Tseng, Y.C.: Efficient in-network moving object tracking in wireless sensor networks. IEEE Transactions on Mobile Computing 5(8), 1044–1056 (2006)
3. Guo, M., Olule, E., Wang, G., Guo, S.: Designing energy efficient target tracking protocol with quality monitoring in wireless sensor networks. The Journal of Supercomputing 51(2), 131–148 (2010)
4. Chen, W.P., Hou, J., Sha, L.: Dynamic clustering for acoustic target tracking in wireless sensor networks. In: Proceedings of the 11th IEEE International Conference on Network Protocols, pp. 284–294 (2003)
5. Zhang, W., Cao, G.: Dctc: dynamic convoy tree-based collaboration for target tracking in sensor networks. IEEE Transactions on Wireless Communications 3(5), 1689–1701 (2004)
6. Zhao, F., Shin, J., Reich, J.: Information-driven dynamic sensor collaboration. IEEE Signal Processing Magazine 19(2), 61–72 (2002)
7. Huang, Q., Lu, C., Roman, G.-C.: Mobicast: Just-in-time multicast for sensor networks under spatiotemporal constraints. In: Zhao, F., Guibas, L.J. (eds.) IPSN 2003. LNCS, vol. 2634, pp. 442–457. Springer, Heidelberg (2003)
8. Huang, Q., Lu, C., Roman, G.C.: Spatiotemporal multicast in sensor networks. In: Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, pp. 205–217. ACM (2003)
9. Huang, Q., Lu, C., Roman, G.C.: Reliable mobicast via face-aware routing. In: Twenty-Third Annual Joint Conference of the IEEE Computer and Communications Societies, INFOCOM 2004, vol. 3, pp. 2108–2118. IEEE (2004)
10. Wan, E.A., Van Der Merwe, R.: The unscented kalman filter for nonlinear estimation. In: The IEEE 2000 Adaptive Systems for Signal Processing, Communications, and Control Symposium, AS-SPCC, pp. 153–158. IEEE (2000)