Poster: Selective Reference Mechanism for Neighbor Discovery in Low-Duty-Cycle Wireless Sensor Networks *

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Abstract

Based on spatiotemporal properties of neighborhood and mobile properties of nodes in the networks, we propose *Selective Reference Mechanism* to trade off between the delay and overhead of neighbor discovery in low-duty-cycle WSNs. Extensive simulation and test-bed experiment confirm our theoretical analysis, showing as much as 35.4% increase in discovery probability, 38.6% reduction in discovery delay and 27.7% reduction in total energy consumption.

Categories and Subject Descriptors

C.2.2 [**Computer Communication Networks**]: Network protocols

General Terms

Performance, Design

Keywords

Selective Reference, Neighbor Discovery, Low-duty-cycle WSNs, Group

1 Introduction

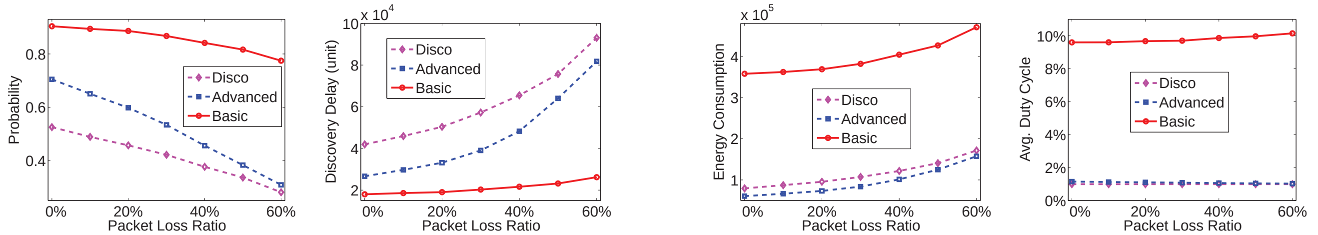
Energy-saving is very important in sustainable deployment of Wireless Sensor Networks systems. Extensive research has indicated that *idle listening*, which is ready to receive packets in communication, is a mainly factor in energy consumption. Therefore, as the most effective energy conservation technique, low-duty-cycle, which makes node in the networks listen briefly and shut down radios in most of the time, has been paid attention by more and more research groups. However, low-duty-cycle operation leads to a challenging issue: how mobile nodes can quickly discover each other if they listen to the same channel in an asynchronous manner.Previous notable neighbor discovery designs include: quorum-based protocols [3], Disco [1], U-Connect [2] and etc. Although these designs successfully ensure that a pair of nodes, always in one-hop distance, can finish discovery within a bounded delay through pre-scheduled methods, none of them investigates how to increase discovery probability and how to decrease discovery delay through referring schedules of known nodes. This paper presents *Selective Reference Mechanism* that builds upon any existing pairwise discovery designs to speed up neighbor discovery through sharing schedules of common neighbors. It can trade off between discovery delay and overhead to achieve that.

2 Basic Reference Design (Basic)

Suppose there is a group N with n nodes knowing each other, and a new node i wants to join, which is typical in neighbor discovery. Suppose $P_{ij}(t)$ is the probability that i and j discover each other before time t. In previous pairwise designs, the probability of i discovering all n nodes before time t can be represented as $P_p(t) = \prod_{j=0}^{n-1} P_{ij}(t)$, the probability density is $p_p(t) = \sum_{j=0}^{n-1}[P_{ij}(t)' \prod_{k=0,k\neq j}^{n-1} P_{ik}(t)]$. So, the expected time of i to discover all n nodes is: $t_p = E_p(t) = \int_0^{T_{\max,i}} t \sum_{j=0}^{n-1} [P_{ij}(t)' \prod_{k=0,k\neq j}^{n-1} P_{ik}(t)]dt$, where, $T_{max,i} = Max(T_{i,0}, T_{i,1}, ..., T_{i,n-1})$. In the basic reference design, node will actively refer schedules of its known neighbors to its new neighbor. Then, the new neighbor can proactively wake up to discover its real neighbors at their wake-up times,

*This research was supported by the US National Science Foundation (NSF) grants CNS-0845994 and CNS-0917097, by the SUTD-ZJU Collaboration Grant SUTD-ZJU/RES/03/2011, by the Science and Technology Support Projects Foundation of Sichuan Province of China under Grant No. 2010GZ0170.

SenSys'11, November 1–4, 2011, Seattle, WA, USA.
ACM 978-1-4503-0718-5/11/11



(a) Discovery Probability vs. Packet Loss Ratio (b) Discovery Delay vs. Packet Loss Ratio (c) Total Energy Consumption vs. Packet Loss Ratio (d) Actual Duty Cycle vs. Packet Loss Ratio

Figure 1. Impact of Packet Loss Ratio

which will expedite the discovery. The probability that i has discovered one node in group N before time t in the basic design is $P_g(t) = 1 - \prod_{j=0}^{n-1}(1 - P_{ij}(t))$, the probability density is $p_g(t) = \sum_{j=0}^{n-1}[P_{ij}(t)' \prod_{k=0,k\neq j}^{n-1}(1 - P_{ik}(t))]$. So, the expected time that i has discovered at least one node of group N is: $E_g(t) = \int_0^{T_{\min,i}} t \sum_{j=0}^{n-1} [P_{ij}(t)' \prod_{k=0,k\neq j}^{n-1} (1 - P_{ik}(t))]dt$, where $T_{min,i} = Min(T_{i,0}, T_{i,1}, ..., T_{i,n-1})$. So, the total time that i has discovered all n nodes of group N is $t_g \leq E_g(t) + 2T_{max\_gap}$. Where T_{max_gap} means the maximal wake-up interval between any pair of nodes, within which referring and verifying have finished.

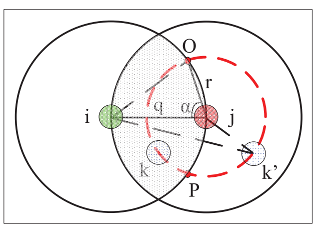


Figure 2. Neighbor Probability of i and j

3 Selective Reference Design (Advanced)

See Fig 2, the overlapping area between i and j with a distance of q reflects the common neighbor number ($N_{ij}(q)$) of them. We have formula: $N_{ij}(q) = \frac{\lambda}{\pi R^2}(2R^2 \arccos(\frac{q}{2R}) - q\sqrt{R^2 - (\frac{q}{2})^2})$, where λ is average node density, R is radio radius. Since $N_{ij}(q)$ is monotonically, its inverse function can be used to estimate q and r. The probability $P_{j,ik}(r,q)$, that j treats i and k as neighbor, is: $\frac{1}{\pi}\arccos(\frac{r^2+q^2-R^2}{2rq})$, when $r+q > R$; 1, when $r+q \leq R$. In the worst case, two neighbors of one node only have 39.1% chance to be neighbor for each other. It is obvious that the referring node should refer nodes with high probability of being the neighbor of the receiver, so the selective reference design, based on neighbor probability estimated currently by the referring node, is quite reasonable and feasible.

4 Evaluation

We completely simulate the performances (such as Discovery Probability, Discovery Delay, Total Energy Consumption, Average Duty Cycle) of networks with different neighbor discovery mechanisms in various average node movement velocity, duty cycle, node density, node radio range, packet loss ratio, radio irregularity, mobility model, etc. Figure 1 shows that with the increase of packet loss ratio, the discovery probability of all discovery designs decreases. However, even in 60% of packet loss ratio, to discover the same number of neighbor, the selective reference method is still about 6.7% higher in discovery probability, 12.9% lower in discovery delay and 11.1% less in energy consumption than Disco (pairwise design). Moreover, we have fully implemented several discovery designs on TinyOS/Mote platform in nesC. The test results are in good conformity with theoretical analysis and the simulation.

5 Conclusion

This paper presents a novel discovery method (selective reference mechanism) as a performance add-on to existing pairwise discovery designs. It can speed up the discovery process of previous pairwise discovery designs with slight actual duty cycle increase. Our work is the first to provide theoretical analysis of reference-based discovery delay. We selectively choose neighboring nodes for energy-efficient reference. We fully evaluate our designs in a physical testbed and simulation system elaborately developed by our research team. Compared with the state-of-the-art pairwise solutions, our designs trade off between discovery delay and total energy consumption of the networks.

6 Acknowledgment

The authors would like to thank Ziguo Zhong, Ming Huang, Dingcheng Li and Hong Sha for their help.

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