A Distance-Measurement-Oriented Distributed TDMA Scheduling Algorithm for Sensor Networks

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Abstract— **In considering home network environment, there is a possibility which provides limited/specific services by configuring the network in accordance with the particular context when linked to a variety of devices. In this paper, a distributed TDMA slot scheduling with prioritized control based on Lamport's bakery algorithm is proposed. The scheduling aims at the realization of media access control methods which can constitute a localized network by measuring the distance to respective node. The proposed scheme can be shown as a possible replacement of DRAND algorithm for Z-MAC scheme with a distance-measurement-oriented manner. The scheme can contribute to the efficient TDMA slot allocation.**

Keywords-component; home networks; wireless sensor networks; media access control; distance measurement

I. INTRODUCTION

In view of HEMS (Home Energy Management System) applications recently, home appliances have become to equip with sensors for power control or environmental monitoring which had been installed on standalone devices. The associated research has been extremely active on the area of not only applications in the home network environment, but various control techniques for wireless sensor networks and their use in various environments [1].

As a requirement for communication scheme of a home network environment, efficient data delivery to multiple devices is an important issue. In such an environment, typically indoor or around the room, it can be considered to be common that multiple devices are scattered within a certain range. Therefore, if we can treat devices which exist in certain areas as a group of category of devices, a local optimization of communications in the system can be achieved, and the effect which the construction of the network depending on the particular context is expected.

In this paper, a distributed TDMA slot scheduling algorithm is introduced aiming at achieving media access control methods which can constitute a localized network by referring inter-device distance under such circumstances. The proposed method can be regarded as an extension of DRAND algorithm [3] for Z-MAC [2] scheme combined with distance measurement. The method can contribute to be faster TDMA slot allocation than DRAND.

II. PROPOSED SCHEME

A. *Premises*

Localized DRAND(L-DRAND, hereinafter) is defined as a distributed slot allocation algorithm which enhanced DRAND characteristics further by adding features for localization with referring distance information between devices. In L-DRAND, following characteristics from DRAND are retained:

1) Any two-hop node is not assigned in a same slot

One of the premises in multi-hop DRAND environment shall be taken over in L-DRAND. Oppositely, only nodes in the two-hop can be in the same network.

2) the maximum slot size of L-DRAND for the node assignment shall be the same as that of DRAND

As described hereinafter, L-DRAND is designed to combine the priority control algorithm with distance measurement information when slotting, with original DRAND. Therefore the maximum slot size will be the same as in both systems.

3) Neighbor Discovery (ND) is the same as DRAND

In L-DRAND, the same Hello procedure in DRAND is used on ND phase. In order to collect accurate information of adjacent nodes, sufficient time is needed and there is a tradeoff between the observation time and accuracy. In this paper, this optimization issue is, however, out of scope. As described below, L-DRAND Hello message includes distance measurement information from its one-hop nodes, and will be transferred. This information is referred when the node determines the processing order of slot assignment.

The extended items of DRAND for L-DRAND are described in the following sections.

B. Prioritized slot assignment control based on Lamport's bakery algorithm

1) Overview

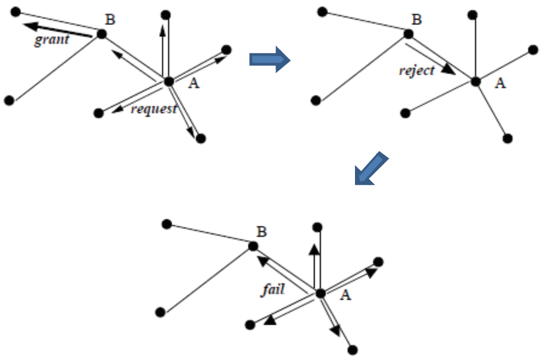

Figure 1. DRAND: A failed round where a node B sends a *grant* message to another one-hop neighbor before receiving the *request* from A

In DRAND, slot allocation control based on Dining Philosophers Problem is implemented. This is to realize simply an exclusive control scheme which only one node can issue a slot allocation request at the same time among multiple nodes. The exclusive control is conducted using slot allocation control packets such as *request*, *grant*, *reject*, and *fail*. Other nodes except the one which had already sent a slot allocation request would be solely rejected its request from respective node to the adjacent nodes. State machines of the nodes go back to WAIT state and wait the time until the next request is enabled to transmit with random backoffs. Consequently, the process will be delayed because a number of backoff behaviors will occur in a common condition when there are many unslotted nodes in the same network（See Fig.1 from [3]).

L-DRAND adopts an exclusive control algorithm which is based on Lamport's bakery algorithm [11] in place of Dining Philosophers Problem. It is designed to enable to be controlled under the existence of multiple N-threads simultaneously. In original Lamport's bakery algorithm, all the numbers which are assigned to the nodes themselves will be incremented when a node as a "guest" joins (Numbering), and the thread whose number is the smallest will be processed with priority, by checking the numbers. In L-DRAND, by adding the numbering scheme combined with distance measurement information, an effective prioritized order control for slot allocation is realized.

2) Rules for prioritized sequencing control using distance measurement information

The basic rules of the proposed method are as follows:

a) The slot allocation priority is given to the node if there is a node in the two-hop whose inter-node distance to relay node is less than the one of which is processing on, and it has not been assigned a slot

Over a range of one-hop, if there is a node where the inter-node distance to the relay node is closer than the one of which is processing on, the node in a closer range would be slotted prior to the others by making adjustments to it to give priority. Thus, the local node which does not exist adjacently to the node but is closer to the relay node than the one can join the network earlier.

b) The slot allocation priority is given to the relay node in the case of above and if the relay node has not been assigned a slot

This rule allows the process order to be adjusted so that a key node will join a network in order to build the local network as soon as possible.

c) The slot allocation priority is given to the node if there is a one-hop node whose inter-node distance in the two-hop is less than the one of which is processing on, and it has not been assigned a slot

This corresponds to the above case a), when viewed from the reverse side of a one-hop node.

By applying these rules, the adjacent nodes would join the network rapidly, and these nodes would be assigned to the slot position closer to each other.

3) Hello message with distance measurement information

In L-DRAND, apart from DRAND, the sending node has the distance information between the nodes in one-hop, and the information is shipped with a Hello message. This includes multiple nodes information according to the circumstances of the neighbor nodes.

When the node receives a Hello message, it merges the Euclidean distance measurement information between the source node and the node itself, with the node information in the two-hop which has been kept in the received packet. The node can manage all the nodes within the two- hop from its own node. The distance measurement information that was captured and stored is referred and used when sending a slot assignment request or receiving it from other one-hop nodes, to determine its behavior of its own node autonomously.

4) Prioritized sequencing control algorithm for slot allocation

Algorithm 1 send request(slot alloc req)

```
ticket_number[self]++;
if has_unslotted_two-hop_node &&
   has_smaller_inter-node_dist(unslotted_two-hop_node):
   ticket_number[unslotted_two-hop_node]++;
   ticket_number[self]++;
if has_unslotted_one-hop_node &&
   has_smaller_inter-node_dist(unslotted_one-hop_node):
   ticket_number[unslotted_one-hop_node]++;
   ticket_number[self]++;
if min(ticket_number[]) != ticket_number[self]:
   random_backoff(sum(less_than(ticket_number[self]))
else:
   send request
```

Algorithm 2 receive reject (backoff toward next slot alloc req)

1 : *ticket_number*[self]++;

2 : if *has_unslotted_two-hop_node* &&
has_smaller_inter-node_dist(unslotted_two-hop_node) :
ticket_number[*unslotted_two-hop_node*]++;
ticket_number[self]++;

3 : if *has_unslotted_one-hop_node* &&
has_smaller_inter-node_dist(unslotted_one-hop_node) :
ticket_number[*unslotted_one-hop_node*]++;
ticket_number[self]++;

4 : *random_backoff*(sum(less_than(*ticket_number*[self]))

By keeping the numbering rules prescribed to reflect the distance measurement information, the sequencing of nodes is determined according to the distance measurement information, as given in ascending priority order. The algorithm when slot allocation is requested is shown in Algorithm 1 and the other when receiving reject is shown in Algorithm 2. Respective node calculates the timing of slot allocation request transmissions or the next processing after the receipt of the refusal based on the algorithms, to determine the processing in the local node.

III. Evaluation

A. Premises

To evaluate the proposed scheme, the above described algorithm was implemented on the network simulator ns-2 [12].

The network topology consists of nodes placed randomly on a 300x300m surface. Nodes have a radio range of 30m, and a link capacity of 2Mbps. Basic simulation parameters are configured according to [2] in order to compare with a reference implementation. The experiments are conducted with10 repetitions of trials, varying the number of nodes between from 10 to 65 at run-time.

B. Average time for a node to acquire a time slot

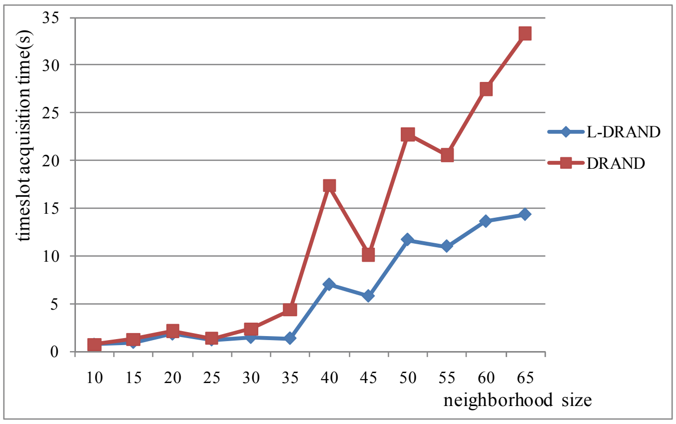

Figure 2. The average time taken for a node to acquire a time slot

By referring to Fig.2, both DRAND and L-DRAND can be seen to complete their processes within nearly the same duration up to 30 neighbors. In the case of larger number of the nodes, L-DRAND can reduce its slot allocation time to 31.7 percent maximum compared to that of DRAND. This result shows that the process can be optimized by the effect that the exclusive control based on Lamport's bakely algorithm with the distance measurement information can effectively perform.

IV. Conclusion

In this paper, a distributed TDMA slot scheduling with prioritized control based on Lamport's bakery algorithm is produced. The scheduling achieves media access control methods which can constitute a localized network by measuring inter-device distances with efficiency.

By using this proposed scheme, priority control for nodes in the network can be performed in the MAC layer according to the collected distance measurement information. It can also increase efficiency for slot allocation by reducing the processing time for it. In addition, the localized network can have benefits such as reducing the interference from another sensor networks, or even building a context-oriented network autonomously.

References

[1] A. Boukerche, "Algorithms and protocols for wireless sensor networks," John Wiley & Sons, 2009.

[2] I. Rhee, A. Warrier, M. Aia, and J. Min, "Z-MAC: a hybrid MAC for wireless sensor networks," in Proc. 3rd international conference on Embedded networked sensor systems (SenSys '05), pp.90-101, 2005.

[3] I. Rhee, A. Warrier, J. Min and L. Xu, "DRAND: Distributed randomized TDMA scheduling for wireless Ad-Hoc networks," in Proc. 7th ACM International Symposium on Mobile Ad Hoc Networking and Computing, pp.190-201, Florence, 2006

[4] I. Demirkol, C. Ersoy, F. Alagoz, "MAC protocols for wireless sensor networks: a survey," IEEE Communications Magazine, vol 44(4), pp.115-121, 2006.

[5] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks," in Proc. 2nd International Conference on Embedded Networked Sensor Systems (SenSys'04), pp. 95-107, Baltimore, MD, USA, Nov. 2004.

[6] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-effcient communication protocol for wireless microsensor networks," in Proc the Hawaii International Conference on System Sciences(HICSS), Maui, Hawaii, Jan. 2000.

[7] I. Rhee, A. Warrier, and L. Xu, "Randomized dining philosophers to TDMA scheduling in wireless sensor networks," in technical report, Computer Science Department, North California State University, Raleigh, NC, 2004.

[8] The Cricket Indoor Location System: http://cricket.csail.mit.edu/

[9] Memsic: http://www.memsic.com/products/wireless-sensor-networks/wireless-modules.html

[10] N. B. Priyantha, A. K. L. Miu, H. Balakrishnan, S. Teller, "The Cricket Compass for context-aware mobile applications," in Proc. 6th ACM MOBICOM Conf., Rome, Italy, July 2001.

[11] L. Lamport, "A new solution of Dijkstra's concurrent programming problem," Communications of the ACM 17, 8, pp.453-455, Aug. 1974.

[12] The Network Simulator – ns-2: http://www.isi.edu/nsnam/ns/

[13] K. Sato, and S. Sakata, "ManueverXML:Distance-Measurement based Operation Event Description Model and User Interaction Interpretation," Proc. the 10th Annual Symposium on Application and the Internet(SAINT2010) WS-1(EUCASS), July 2010.