A Network Performance Improvement for One-to-One and Many-to-One Communication Environment in ZigBee

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Abstract:
The increasing network traffic often causes various problems depending on different communication requirements in ZigBee. In particular, in a one-to-one communication environment, there exists a data loss problem as the network traffic increases, while in a many-to-one environment, there exists a data congestion problem on a specific device. In this paper, we propose a simple mesh routing (SMR) method as an effective solution to the data loss problem in the one-to-one communication environment. We also present a data aggregation mechanism (DAM) in order to deal with the data congestion problem in the many-to-one communication environment. Simulation results are included in order to demonstrate performance improvements of the whole network.

1. INTRODUCTION

Recently, ZigBee has received lots of attentions for its numerous superior features like rich functions in a small size of device, effective data communication capability in short distance, as well as a low power request and implement cost. Due to these fine features, ZigBee has been widely applied in various areas as a good wireless network solution, especially where wired network service is infeasible.

IEEE 802.15.4[1] was released by the IEEE 802 wireless personal area network (WPAN) group in 2003, while the ZigBee V1.0 [2] and ZigBee-2006 [3] based on the IEEE 802.15.4 were released by the ZigBee Alliance. In recent ZigBee applications, we often encounter a one-to-one or a many-to-one communication environment, in both of which some network problems always exist:

In one-to-one communication environment, the tree routing algorithm is used as a basic routing method. However, when using this method, there often exists such a problem that the data is transmitted using an inefficient path. As an alternative routing method, the ad-hoc on-demand distance vector (AODV) routing is used to recover the broken link and re-transmit the data through an efficient path. However, it needs a complex control mechanism and requires a large memory capacity. Therefore, due to the disadvantages of the tree and AODV routing methods stated above, the whole network performance [4] is usually affected.

In many-to-one communication environment, a common case is that a small size of data sensed by lots of devices is requested to be sent to the gateway connected to external network like internet or CDMA. In this situation, data loss rate can be usually increased on a growing number of devices in the network.

Even though we often encounter many problems in one-to-one or many-to-one communication networks, no specific solutions have been recommended by the ZigBee specification. In this paper, we present the SMR and DAM methods to overcome the problems in one-to-one or many-to-one communication networks. Employing Network Simulator-2 (NS2), we implemented our SMR and DAM methods for the one-to-one and many-to-one applications, respectively, and we are able to show that the network performances are greatly improved in both cases.

2. ZIGBEE NETWORK

ZigBee network can be configured in star, tree or mesh topology and classified into 3 types of devices as follows:

- Coordinator: It initializes the network, has routing capacity and is able to communicate with all devices.
- Router: This device makes it possible to expand network, ensure routing capacity and communicate with all devices.
- End device: It is able to communicate only with its ancestor, coordinator or router, and selectively turns the receiver on/off for power saving.

2.1. An analysis of distributed address assignment mechanism

ZigBee identifies other devices basing on their addresses which are assigned by the distributed address assignment mechanism [2] [3]. When the coordinator establishes a new network, it will assign itself a network address as 0x0000 and a network depth as 0.

If a new device requests a connection to the coordinator, then the coordinator will assign an address for this new device. The coordinator decides the address upon the type of the device requesting for connection. If the requesting device is a router, then the address assigned to this device will be given as

$$Address = a + Cskip(d) \times m + 1 \qquad (1)$$

where m denotes the number of routers which are connected to itself, a denotes the address of coordinator, and d is the current network depth. The finite sub-block address for a specific d, Cskip(d) is defined as

$$Cskip(d)=\begin{cases}1+Cm(Lm-d-1), \text{ if } Rm=1\\ \dfrac{1+Cm-Rm-Cm\times Rm^{Lm-d-1}}{1-Rm}, \text{otherwise}\end{cases}$$

where *Cm* represents the maximum number of devices that can be connected to the device, *Rm* denotes the maximum number of routers that can be connected to the device, and *Lm* is the maximum depth of the network.

If the device requesting for connection is an end device, then it will be assigned an address give by

$$Address = a + Cskip(d)\times Rm + n + 1 \qquad (2)$$

where *n* denotes the number of end devices that are connected to itself. The depth of the device connected to coordinator is increased by 1. If *Cskip*(*d*) of the device is 0, then this device does not have the capacity of address assignment.

2.2. An Analysis of Tree Routing Algorithm

Assigned an address based on the rule stated in Section 2.1, ZigBee could carry out the hierarchical tree routing without a specific routing table needed due to the fine features of ZigBee.

Figure 1 shows a flow chart of the tree routing process. On receiving a frame from a higher or lower layer, the router compares the frame's destination address with its own address, if not matching, the router will search the neighbor table (It contains information on every device within transmission range [2] [3]) for an identical address to the frame's destination address. If the identical address exists, the frame will be immediately sent to destination. Otherwise, the router will judge whether the destination address is its descendant on a judgment rule as

$$a < D < a + Cskip(d-1) \qquad (3)$$

where *a* denotes the address of router, *D* denotes a destination address and *d* denotes a current network depth.

If the destination address is judged to be the descendant, then the frame will be sent to the next hop address(*N*), which can be obtained by

$$N = a + 1 + C \qquad (4)$$

where

$C = floor((D-a+1)/Cskip(d))\times Cskip(d)$.

Otherwise, the frame will be sent to the next hop address, which will be set as the router's parent address.

From the routing process described above, it can be seen that in tree routing protocol, router will transmit the received frame to its parent or child address if there isn't the destination address in the neighbor table. Therefore, we can see that the tree routing protocol has adopted an inefficient routing path to transmit data frames.

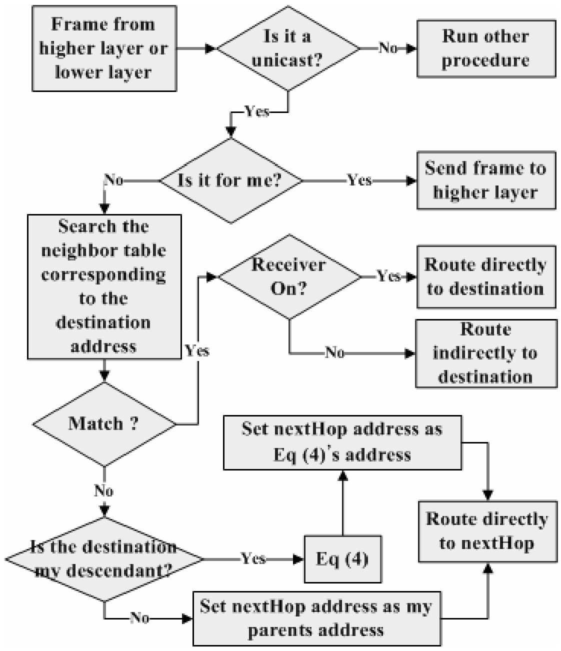

Fig. 1: Tree routing flow chart.

3. THE SIMPLE MESH ROUTING (SMR) METHOD

We designed SMR by making using of the characteristics stated in Section 2.1 and an improvement from the tree routing algorithm. SMR is designed to obtain a high data transmission efficiency in a one-to-one communication environment. In SMR method, during the searching process for the identical destination address in the neighbor table, the largest depth satisfying (5) will also be searched out, where the condition (5) is defined as

$$\begin{aligned}MaxBlockAddr &= AN + Cskip(d-1)\\ AN \le D &< MaxBlockAddr\end{aligned} \qquad (5)$$

where *AN* denotes the address in neighbor table, *MaxBlockAddr* denotes a next router's address and *D* denotes a destination address.

Figure 2 shows an example network with *Cm* = 6, *Rm* = 4 and *Lm* = 6 defined in Section 2.1. The dotted line indicates the data flow of SMR while the solid line indicates the data flow of tree routing. There are several addresses such as 1537, 1536, 2051 and 2050 in the neighbor table of the source node. The source node searches 2052 to send data to the destination 2052. In conventional tree routing algorithm, since there is no identical address of 2052 in the neighbor table, therefore, by tree routing, the data will be sent to its parent. On the other hand, in SMR method, by making use of (5), the address of 2050 and 2051 are searched out. Since the depth of 2051 is larger, data will be sent to 2051, through a more efficient path compared with the tree routing algorithm.

Compared with the tree routing protocol, SMR method could find out a near transmission path more efficiently on performing only a simple calculation process without need of complex control or a large memory capacity. In addition, SMR method is compatible with ZigBee V1.0 [2] and ZigBee-2006 [3].

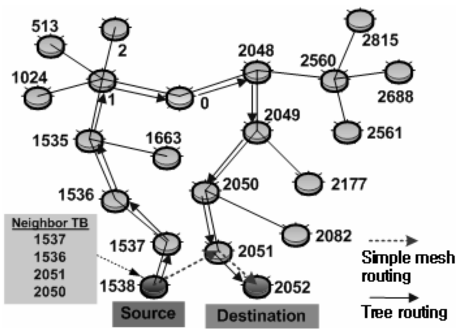

Fig. 2: Data flow of tree routing and SMR.

4. DESIGN OF THE DATA AGGREGATION MECHANISM (DAM)

DAM is used for solving data congestion problem in a many-to-one communication environment. In the many-to-one environment, if the data from many devices need to be sent to the gateway, then instead of sending the data separately in a normal way, in DAM, these small sized data from all devices will be filled into a frame within a specified time period, and then sent to the gateway.

From Table 1 to Table 6, the specifications needed by DAM implementation are shown. A router having DAM function is called as Merge Center.

Table 1 shows the primitives added to the network layer.

· NLME-MERGE.Request: It serves as a role to register and delete itself from the merge center.

· NLME-MERGE.Confirm: It informs the higher layer of the request result.

· NLME-MERGE.Indication: It is called from the lower layer when it receives a merge command from the children.

· NLME-MERGE.Response: It serves as a role to give a response to the children that asked a request.

Table 2 shows a merge sub-field with a length of 2 -bit in the frame control field to identify General Data and Merge Data. Table 3 shows a merge sub-field of the frame control field in Table 2. Table 4 shows the frame format of network(NWK) merge request/reply command. The gateway field is reserved for the destination address, while the period field is reserved for the transmission interval and the data length field is reserved for size of the data. If the option field of Merge Request is set as 0x01, then it will register itself to the Merge Center, otherwise if the option field is 0x02 then , it will delete itself from the Merge Center. The status field indicates the success or denial. Table 5 shows the added attributes to NWK Information Base (NIB). The NIB holds the attributes required to manage the NWK layer of a device [2] [3]. Table 6 is a NWK Merge Table generated by the Merge Center. The merge table can be generated up to nwkMaxMergeTableSize of NIB.

Table. 1: Primitive for DAM.

Name	Request	Indication	Response	Confirm
NLME-MERGE	○	○	○	○

Table. 2: Frame control field.

Bits:0-1	2-5	…	13-14	15
Frame Type	Protocol version	…	Merge	Reserved

Table. 3: Merge sub-field.

Type value b_1 b_0	Description
00	General Data.
01	Merged Data from Source.
10	Merged Data from Center.
11	Reserved.

Table. 4: NWK merge request/reply command frame format.

Octets: 1	2	4	1	1
NWK command identifier(0x0b)	Gateway a ddress	Period	Data length	Option
Payload				

Octets: 1	2	1
NWK command identifier(0x0c)	Gateway address	Status
Payload		

Table. 5: NWK IB attributes.

Attribute	ID	Description	Default
nwkMaxMergeTable Size	0xac	Maximum merge table size	1
nwkGatewayCount	0xad	Gateway number	0
nwkGatewayAddrList	0xae	Gateway address Lis t	Null

Table. 6: NWK merge table.

Name	Description
Gateway address	Octets: 2 It is a gateway's address.
Source address List	Octets: Variable
nwkMergePeriod	Octets: 4 The time in Millisecond.
nwkStoredDataLength	Octets: 1
nwkData	Octets: nwkMaxPayloadSize(100)
nwkRemainDataSize	Octets: 1 (nwkMaxPayloadSize-nwkStoredDataLength)

As shown in Figure 3, the end device transmitting small sized data to the gateway periodically registers its address to the merge center by using merge request/reply command. When the merge center receives the merge data, it checks the registration of the device. It compares the destination address with the gateway address in the merge table. If they match, then the data of the end device will not be transmitted immediately, instead, the data will be stored into the nwkData in the merge table and then sent out when the nwkMergePeriod time terminates. Otherwise, if not matching ,then the data will be sent directly to its destination address.

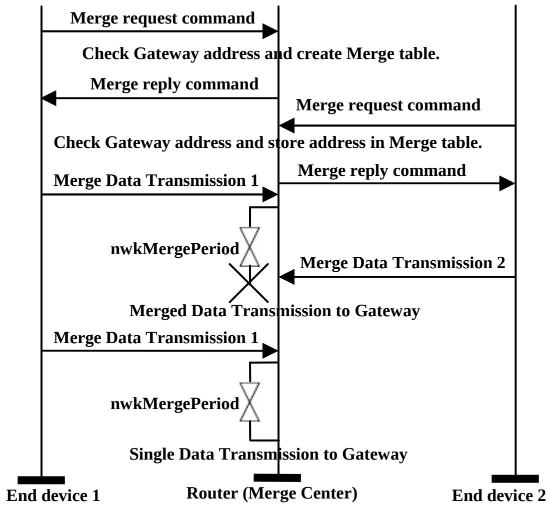

Fig. 3: DAM transaction sequence chart.

5. SIMULATION

In a NS2 simulation environment, we implemented the ZigBee Stack, our DAM and SMR methods. We use a $50m \times 50m^2$ square simulation area, and the number of nodes are 100, 200, 300 and 400 respectively. And 15-meter transmission range is adopted. The data size is 20 bytes and the data rate is 250kbps. An efficiency parameter is defined as the ratio between the number of transmitted frames and the number of received frames. In the simulation, we compared performance of the general ZigBee network (GZN) and SMR-added ZigBee network (SZN) in the one-to-one communication environment, and compared the performance of the GZN and the DAM-added ZigBee network (DZN) in the many-to-one communication environment. Under the assumption that all nodes have no mobility, the simulation process was repeated 100 times under each condition, and the average result was recorded.

Figure 4 shows the result of comparison between GZN and SZN in the one-to-one communication environment. A randomly selected group of *NodeNumber*/2 nodes transmit data to another randomly selected group of *NodeNumber*/2 nodes every 0.5 seconds (*NodeNumber* denotes the number of total nodes). From the result, it can be seen that SZN shows an improved performance over GZN. Specifically, on a group of 400 nodes, SZN shows about a 12.2% higher efficiency than the GZN.

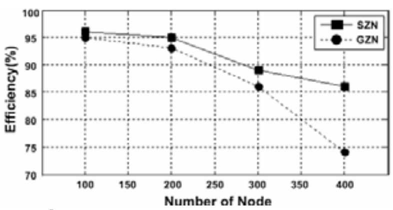

Fig. 4: GZN and SZN in one-to-one communication environment.

Figure 5 shows the results of comparison between GZN and DZN in the many-to-one communication environment. The coordinator serves as the gateway and all the other nodes except the gateway node transmit the data to the gateway every second. It can be seen that, as the number of devices increases, the efficiency of GZN falls more rapidly than the DZN. Specifically, when the number of nodes is 400, the DZN shows a higher efficiency of about 26.1% than the GZN.

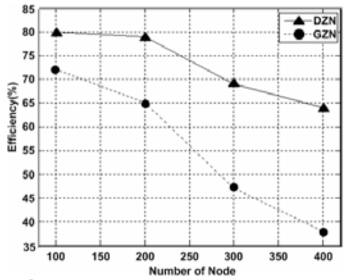

Fig. 5: GZN and DZN in many-to-one communication environment.

As shown by the simulation results, it can be seen that by using our SMR and DAM methods, the network performance has been greatly improved.

6. CONCLUSION

In this paper, we presented our designed SMR and DAM methods to effectively solve the data loss and data congestion problems caused by network traffic increasing. By simulation, we showed that by using our methods, the network performance is improved. Specifically, in situation of 400 nodes, by using the SMR method, the network efficiency is increased by 12.2% in the one-to-one environment, while by using DAM, an increased efficiency of 26.1% is obtained in the many-to-one environment. In the future studies, more research about the network layers of the ZigBee will be done to support the communication environment required by a diverse range of applications.

REFERENCES

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