RELIABLE DATA BROADCAST FOR ZIGBEE WIRELESS SENSOR NETWORKS

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Abstract- As we know, the data transmission in the wireless networks is more unreliable than it is in the wired network environment. Although the virtual carrier sensing scheme can be used in the wireless unicast transmission, the multicast and broadcast still not utilize the acknowledgement mechanism for reliable transmission. This is due to the acknowledgement packets of broadcast transmission will cause much higher communication traffic and overhead. Since reliable data broadcast is critical and required in many applications in the wireless sensor networks, our study focuses on the ZigBee network which is a new industrial standard for sensor networks. Some previous related papers improved the broadcast reliability by introducing redundant transmission and increasing coverage ratio of every receiver node, but there still exists probability of packet loss and extra communication cost due to redundant broadcast. This paper proposes an efficient acknowledgement-based approach for reliable data broadcast in wireless sensor networks. Hierarchical acknowledgement mechanism, reduction of rebroadcast packets and ACK packets, degree-based ACK/rebroadcast Jitter, and parent-oriented retransmission are the key schemes to achieve the efficient data broadcast. Simulation results show that the proposed schemes can efficiently reduce the acknowledgement traffic as well as communication overhead and provide the high reliable data broadcast transmission in ZigBee networks..

Index terms*: ZigBee, wireless sensor network, reliability, data broadcast, acknowledgement.*

I. INTRODUCTION

Generally, IEEE 802.11 wireless network is used in the environment with network infrastructure, using base station or access point for data communication in the mode of star topology. However, in some applications of wireless networks, the peer-to-peer and multi-hop communication and data transmission among wireless devices must be carried out in IBSS mode in the infrastructure-less environment, namely without access point. The Wireless Sensor Network [1, 2, 3] is of this type of network. In the wireless sensor network, besides two important issues, the sensor coverage [4, 5] and the network connectivity [6, 7] are closely related to the sensing range and the effect of data delivery, the efficiency and reliability of data broadcast transmission are also important research subjects. As the wireless network has lower data rate and higher bit error ratio, as compared with the wired network, and the wireless devices in the wireless sensor network have the task of packet forwarding and must execute routing protocol related operation, if a favorable algorithm is not used in data broadcast, the network overhead will be increased, and the efficiency and reliability of the network will be decreased. Such situation is especially obvious in a wireless sensor network because the data transmission rate, power and internal storage capacity of wireless sensor devices are usually limited in consideration of the volume and cost.

At present, studies on the data broadcast in wireless sensor network mostly focus on the improvement of broadcast efficiency, namely, use the number of rebroadcast nodes and redundant broadcast packets as main efficiency index, so as to avoid unconspicuous efficiency resulted from flooding and simple broadcast. However, the importance of reliable transmission is not considered, and some approaches considering reliable transmission fail to guarantee correct delivery of broadcast data. On the contrary, the due broadcast efficiency was sacrificed. Since in some applications of wireless sensor network, the reliable data broadcast is an important functional item, and the ZigBee network has become a widely adopted wireless sensor network standard. This study proposes an improved method with broadcast efficiency and reliable transmission for data broadcast of ZigBee network. The key solution design is to add active and passive convergence acknowledgement mechanism and parent node retransmission mechanism in tree topology, and improve self-pruning algorithm and rebroadcast waiting time to maintain the broadcast efficiency, so as to reach the reliability of data broadcast and avoid sacrificing the broadcast efficiency.

The remainder of this paper is organized as follows: Section 2 introduces IEEE 802.15.4 and ZigBee, and reviews related literature on wireless sensor network in data broadcast. Section 3 details the high reliable data broadcast mechanism proposed in this study. Section 4 presents the network simulation and result analysis. Finally, Section 5 gives the conclusion.

II. BACKGROUND AND RELATED WORKS

a. IEEE 802.15.4

IEEE 802.15.4 standard [8] defines and normalizes PHY layer and MAC layer related to ZigBee network. It is a Low-Rate Wireless Personal Area Network (LR-WPAN) communication protocol standard, designed for low cost, low data rate and low power wireless communication devices (e.g., devices of wireless sensor networks). It can be applied to wireless monitoring systems for industrial automation, intelligent home, medical care, military use and security. The available communication channels include 16 channels at the transmission rate of 250 kb/s and frequency of 2.4-2.4835 GHz, 10 North American channels at 40 kb/s and 902–928 MHz and 1 European channel at 20 kb/s and 868–868.6 MHz. Two types of device are defined, one is the Full Function Device (FFD) for network coordination and routing or general functions; another is the Reduced Function Device (RFD) only for general purposes. As for physical address, two address formats including Short Address (16 Bits) and Extended Address (48 Bits) are supported. As for media access, Slotted or Unslotted CSMA/CA mode is used, the message box provides GTS (Guaranteed Time Slots), and an optional ACK message box is supported to improve the transmission reliability. However, this ACK message box is only applicable to Unicast, and it is unavailable in broadcast transmission. Therefore, the reliability of broadcast should be processed in the upper layer protocol, this is one of the purposes of this study.

b. ZigBee

ZigBee standard [9] is designed for low cost, low data rate and low power wireless sensor network, as shown in Figure 1. The PHY and MAC lower layer protocol uses IEEE 802.15.4 standard directly, and additional specifications of Network layer (NWK), Application Support Layer (APS), AP Framework and ZigBee Device Object (ZDO) are stipulated. It is also applicable to wireless monitoring systems for industrial automation, intelligent home, medical care, military use and security.

ZigBee has defined three types of device object: ZC (ZigBee Coordinator), ZR (ZigBee Router) and ZED (ZigBee End Device). One ZigBee Network has only one ZC device as the network control center. The ZR device is in charge of fundamental functions as well as routing, forwarding and address allocation. The ZED device is mainly in charge of environment sensing and data feedback, and it does not have the function of forwarding packets as ZC or ZR does. ZC and ZR are of FFD device according to IEEE 802.15.4 standard, and ZED is of RFD device. As for the network logic address, ZigBee uses the addressing space of 16 Bits, and uses hierarchical network address assignment mechanism. In addition, ZigBee network layer supports three kinds of network topology: Star, Tree and Mesh topologies. The data broadcast related mechanism designed in this study uses the characteristics of tree topology. Therefore, ZigBee tree topology related protocol specification is used as the basis of research.

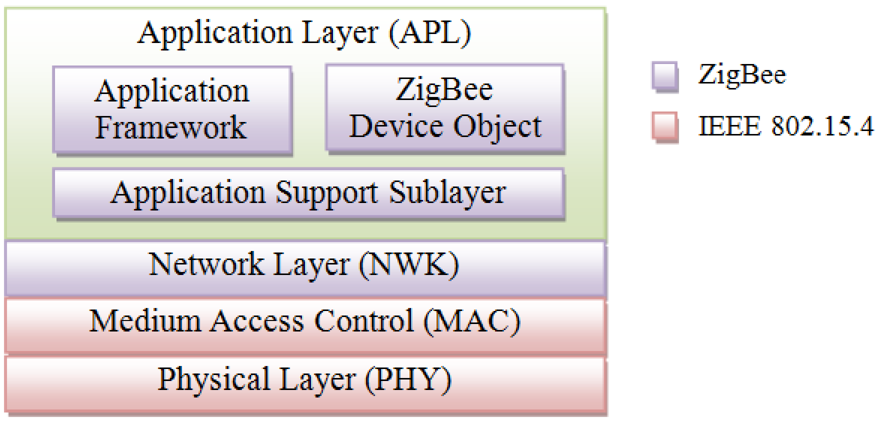

Figure 1. ZigBee protocol stack

c. Related works

The main problem during data broadcast in wireless sensor networks is to avoid the flooding broadcast which may result in broadcast storm [10], which means that when a certain node in the network receives a broadcast packet and is going to rebroadcast it. If its adjacent nodes have received the same broadcast packet from other nodes, the rebroadcast of this node is redundant and unnecessary. It will occupy the network bandwidth and influence the overall network efficiency, such situation is especially severe in multiple nodes. Therefore, Peng & Lu proposed a method with self-pruning idea, which is called the Scalable Broadcast Algorithm (SBA) [11] based on 2-hop neighbor information exchange. When a node finds that all its neighbors have received the broadcast packet to be transferred, it would cancel the rebroadcast. Peng & Lu proposed another approach with the forward node selection idea, which is called AHBP [12]. It is also be based on 2-hop neighbor information exchange. Before broadcast or rebroadcast, a node chooses and determines which neighbors have to rebroadcast after receiving packets. The aggregation of these neighbors is called Forward Node Set, and then all 2-hop neighbors can be covered through their rebroadcast. The nodes out of the forward node set do not need to rebroadcast. Both SBA and AHBP algorithms have effectively avoided the broadcast storm, and the attenuation of broadcast efficiency resulted from direct flooding mode. Ding, Sahinoglu, Orlik, Zhang & Bhargava proposed two algorithms: OSR (On-tree Self-pruning Rebroadcast) and ZOS (ZigBee On-tree Selection) [13], which have respectively improved SBA and AHBP. Thus, the two algorithms can be applied to Self-pruning and Forward Node Selection approaches for efficient data broadcast without 2-hop neighbor information exchange in the resource-limited ZigBee network. However, the abovementioned algorithms assume that it is in an ideal network environment without signal collision and packet loss, and the high possibility of broadcast packet transmission failure in a real wireless network environment is neglected. In other words, reliable data broadcast transmission is not achieved in the actual environment by using these methods, and some nodes will not complete packet reception smoothly.

Ding, Sahinoglu, Bhargava, Orlik & Zhang developed a data broadcast algorithm considering reliable transmission in ZigBee network, which is called ZiFA-R (ZigBee Forward node selection Algorithm-Reliable) [14]. Its principle is that each node can be covered by the broadcast signals from other neighbors at least twice based on the Forward Node Selection method. In other words, each node receives broadcast packets at least twice. The probability of successful reception can be increased by using this method, so as to improve the reliability of data broadcast. However, this method just increases the number of Rebroadcast Nodes and Redundant Broadcast Packets, while sacrificing part of broadcast efficiency. It cannot reach a high reliability actually, because the increase in Rebroadcast Nodes and Redundant Broadcast Packets means the increase in the probability of collision and packet loss. Based on the above, the Acknowledgement (ACK) packet mechanism has to be introduced in to reach a real high reliable data broadcast, and the effect of ACK packets on network load and broadcast efficiency must be considered and reduced, this is one of the purposes of this study.

III. ZARD ALGORITHM

This section describes the high reliable data broadcast algorithm ZigBee proposed by this study. Since one of the key mechanisms is the introduction of Acknowledgement packet, this algorithm is called the ZigBee Acknowledgement-based Reliable Broadcast (ZARB). Besides efficient data broadcast, the reception situation of each node after broadcast is monitored. If there is any reception failure, the retransmission-related mechanism should be started to ensure the broadcast packets to be received by all receiving nodes successfully, so as to reach a high reliable data broadcast transmission. First, the sending end of broadcast packets is assumed to be the ZC device in ZigBee. This assumption is identical with that of other related studies, and it occurs most frequently in practical situations. For example, the ZC device as the control center broadcasts control command or mission instruction to all nodes distributed everywhere. If ZR or ZED is used as the source end of data broadcast, the Tree Rotation algorithm can be carried out at first to translate the ZR or ZED into root logically.

a. Acknowledgement packets

The acknowledgement mechanism is usually used in unicast transmission. The receiving end sends an ACK packet when it receives a packet to notify the sending end that the packet has been received, e.g. RTS/CTS/DAT/ACK mechanism of Layer 2 IEEE 802.11 protocol and ACK packet of Layer 4 TCP protocol. However, many protocols cannot use ACK mechanism in multicast or broadcast. This is because multicast or broadcast packet has more than one receiving end. If each receiving end sends ACK to the original sender when receiving a packet, and uses multi-hop multi-forwarding in the same way, that would result in severe congestion and collision. Thus, the purpose of ACK mechanism cannot be reached, additionally. The network bandwidth resource is wasted. This section describes the ACK packet type and transmission mode in the hierarchical ACK mechanism designed in this study. As the timing for transferring ACK packet is related to broadcast efficiency design, it will be described in the next section.

As for the tree structure of ZigBee, as shown in Figure 2, regardless of the actual distribution topology of all nodes in the network, all the nodes will form a tree-like logical topology after the association is completed. In other words, although the transmission signals of Node A and Node B can cover the neighbors of the other one, they may not be neighbors in the tree ZigBee network that they are in. This is because they do not have the parent-child relationship in the tree structure. The ZigBee tree logical topology is formed when all nodes complete association, ZC and ZR can respond to and receive the association request of other ZR or ZED device, and they can assign network logic address, but ZED is not able to do so. The ACK packets in the ZARB data broadcast algorithm proposed in this study are uniformly sent to parent node from child node, and each node will discard the received ACK packet not from its child node. In Figure 2, each solid arrow line is the start and end of an ACK packet transfer. For example, C, D and E send ACK packets back to the parent node F when they receive a broadcast packet; and F, H and J forward ACK packets to G. ZigBee uses a hierarchical address allocation mechanism and a parent node allocates logical address to the its associated child node. Therefore a parent node can determine whether the sender of an ACK packet is its child. The address allocation is as follow:

$$C_{skip}(d) = \begin{cases} 0, & d = L_m \\ 1 + C_m \cdot (L_m - d - 1), & R_m = 1 \\ (1 + C_m - R_m - C_m \cdot R_m{}^{L_m - d - 1}) / (1 - R_m), & \text{otherwise} \end{cases} \quad (1)$$

$$A_{R^i} = A_p + 1 + C_{skip}(d) \cdot (i - 1), \qquad 1 \le i \le R_m \quad (2)$$

$$A_{ED^j} = A_p + C_{skip}(d) \cdot R_m + j, \qquad 1 \le j \le (C_m - R_m) \quad (3)$$

where $A_R{}^i$ is the address a parent should assign to its i^{th} ZR child and $A_{ED}{}^j$ is the address a parent should assign to its j^{th} ZED child; A_p represents the address of the parent; C_m, R_m, and L_m respectively indicate the number of children a device is allowed to have in its current network, the number of routers any one device is allowed to have as children, and the maximum depth of the ZigBee tree.

In addition, the ACK packets in ZARB method proposed in this study are divided into two types: Active ACK, and Passive ACK. The Active ACK refers to an acknowledgement response packet sent to the parent node when a data broadcast packet is received; the Passive ACK means when a node receives a data broadcast packet. If it must rebroadcast the data packet to other nodes, it is not required to return an Active ACK packet to its parent node. This is because once it rebroadcasts, its parent node will receive the packet, meaning that its child node has broadcast the data packet correctly. Therefore, the Rebroadcast Packet is namely the Passive ACK. The red arrow examples in Figure 2 represent Active ACK, and the blue arrow examples represent Passive ACK (if B and J have done Rebroadcast).

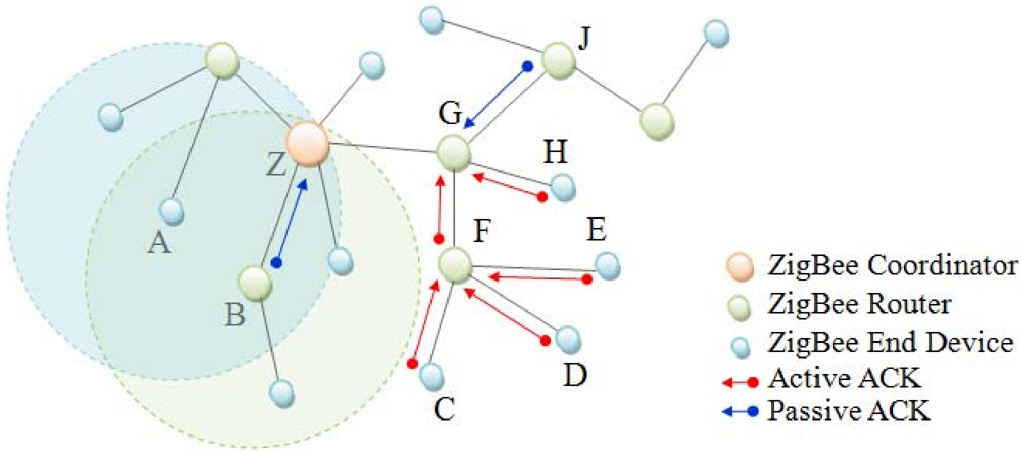

Figure 2. ZigBee tree-based network topology

b. ACK-based self-pruning algorithm

The previous section has not described the situation that a node needs to or does not need to rebroadcast, nor the relation of hierarchical acknowledgement. This section will give more detailed discussion. As mentioned in literature review, general Ad-hoc or Sensor Networks data broadcast must avoid the broadcast storm resulted from flooding broadcast, this study adopts the algorithm of Self-pruning idea to reduce the number of Rebroadcast Nodes, and further reduce the number of redundant broadcast packets. The difference to other algorithms is that the Self-pruning mechanism of this study must be combined with Active ACK and Passive ACK operation. Once a node decides to leave the rebroadcast list, it has ensured that all its child nodes have completed the reception of broadcast data correctly, and no retransmission is started.

Figure 3 illustrates the algorithmic detail of ACK-based Self-pruning. First, the broadcast source end S carries out data broadcast, and Node A will wait for a period of time (Rebroadcast Jitter) before determining whether to rebroadcast. If all child nodes of A have sent ACK packets back to A (including Active and Passive ACKs) during this period, A will send back an Active ACK to S (Rebroadcast Jitter is namely ACK Jitter), otherwise, A will rebroadcast. Whether S receives the Active or Passive ACK of A, S ensures that its child node A has received the broadcast data correctly. However, in this case, A does not send an Active ACK to S after Rebroadcast Jitter timeout because a_2 and C of A's child nodes have not received any broadcast data at this moment, thus, A will carry out rebroadcast. One of the key points of the mechanism designed in this study is that any node receives broadcast data from anywhere, and it will send an ACK to its parent node rather than the sending end node or the original source end. For example, nodes d_1, d_2, d_3 will receive packets rebroadcast from A and send Active ACK back to D instead of A or S. D sends back an Active ACK to its parent node C after Rebroadcast Jitter timeout, and this single Active ACK means that all child nodes of D have completed reception correctly. This is one of advantages of hierarchical ACK because the ACK is transferred from the destination to the source. Thus, there will be three ACKs sent to C from D. The method proposed by this study can avoid this situation. For node C, c_1 and c_2 receive the packet rebroadcast by A, and send back Active ACK to parent node C. As C has received the ACK of all child nodes, c_1, c_2 and D, it will send an Active ACK to A. As for node A, we design that any node which receives the same broadcast packet repeatedly, it will discard the latter repeated packets, therefore, a_1 receives the broadcast packet from S and has returned ACK to A, although it has received the packets rebroadcast by A, it will not send back an Active ACK to A anymore. Then, A will not send Active ACK to S when it receives the Active ACK of a_2 and C. Since the rebroadcast of A is equivalent to sending Passive ACK to S, S will determine that A will be in charge of the receiving tasks of its child nodes automatically, in fact A has done it.

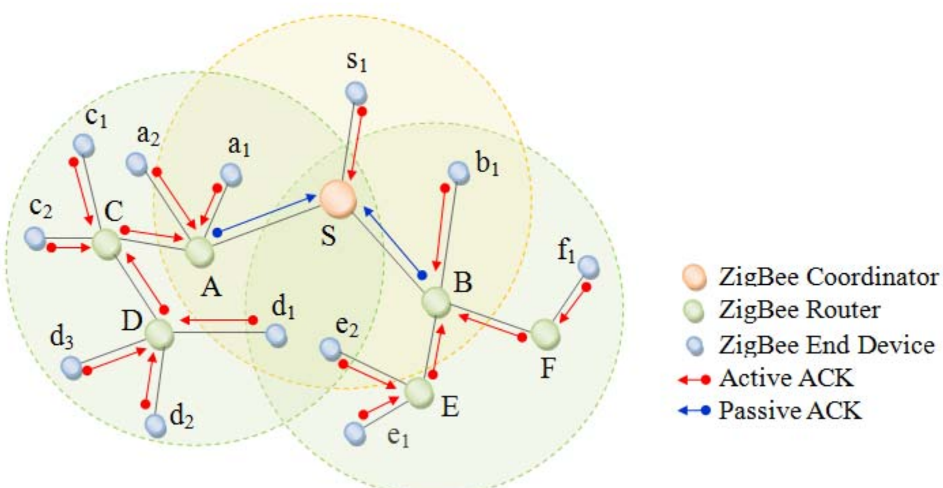

Figure 3. An example of ACK-based self-pruning

Based on the above, there is one result and one question. The result is that both C and D have completed the self-pruning picking themselves out of the rebroadcast list without rebroadcasting the broadcast data, so that relevant resources required for broadcasting data are economized. The question is that the ACK/Rebroadcast Jitter of the node closer to the Root (node S) is larger to meet the abovementioned operation requirement. Therefore, a very important design is hierarchical descending ACK/Rebroadcast Jitter, while the collision probability of ACK/Rebroadcast packets is reduced. Although the Active ACK itself is a packet in very small size with low collision probability, the reliability can be further improved. This ACK/Rebroadcast Jitter with characteristics of hierarchical descending and collision avoidance will be described in the next section.

As for Node B in Figure 3, according to the above algorithm design, nodes E and F will reach Self-pruning condition without rebroadcasting any data. In addition, one of advantages of using tree topology structure is that all leaf nodes (e.g. s_1, a_1, a_2, b_1, c_1, c_2, d_1, d_2, d_3, e_1, e_2, f_1 in Figure 3) can be designed without any rebroadcast when they receive broadcast packets, thus, the number of rebroadcast nodes can be reduced greatly. Therefore, according to Figure 3, except that the data broadcast source end S initiates the broadcast, only A and B become rebroadcast nodes and have rebroadcast operation. The rebroadcast nodes and redundant broadcast packets are reduced effectively, while the broadcast reliability is improved greatly. The broadcast data packets can be delivered to all receiving ends smoothly.

c. ACK/Rebroadcast jitter

As the tree hierarchical ACK-based Self-pruning mechanism mentioned in the above section, the waiting time for sending back Active ACK and rebroadcast is adjusted on the nodes of each degree in the tree structure in order to improve the effect. Thus, the nodes of each degree can have enough time to receive the successive Active or Passive ACK packets from their child nodes, and then determine whether to rebroadcast or send back Active ACK upwards according to the response results. Each node waits for a timeout called Degree-based ACK/Rebroadcast Jitter when it receives a data broadcast packet from any node, as shown below.

$$t_{jitter} = \frac{T_{const}}{d_{tree}} + t_{random} \qquad (4)$$

where, T_{const} is a predetermined constant parameter which can be set when ZigBee Coordinator starts a network, and it can be equal to the maximum permissible waiting time; d_{tree} is the degree in the tree structure the node exists in, ascending from 1 to *ztMaxDepth* from the root node to the leaf node in turn, *ztMaxDepth* parameter is the maximum tree depth of ZigBee tree network; t_{random} is the random time value, the maximum value can be set considering the maximum child node number *ztMaxChildren* parameter of single node in ZigBee tree network. The T_{const}/d_{tree} in the equation will make the nodes of different degrees (e.g. S, A, C, D in Figure 3) wait for different time bases. The closer the node is to the leaf node, the shorter the waiting time will be, and the closer the node is to the root node, the longer the waiting time will be. Besides reaching the operation of progressive reception of response and responding upwards in the algorithm, the collision among ACK packets of different degrees can be avoided. As for the nodes of the same parent node (e.g. d_1, d_2, d_3 in Figure 3) or of the identical degree but different parent nodes (e.g. a_1, b_1 or e_1, f_1 in Figure 3). The collision can be avoided by using the timing difference of t_{random} part. t_{jitter} combines the above two parts, and determines the time point for each node to send back Active Ack and Passive ACK (Rebroadcast).

d. Buffering and retransmission

In the ZARB algorithm of this study, if a node has not become a self-pruning node, it will rebroadcast after ACK/Rebroadcast Jitter timeout. Although the probability is reduced greatly, the packet still may be received incorrectly as a result of collision or packet loss, or the ACK sent by the child node is collided or lost. The parent node will rebroadcast to start up the retransmission mechanism, this retransmission mechanism is repeated until all child nodes send back ACK correctly or the times of retransmission has reached the maximum value of *ztMaxRetransmission* parameter. The ACK/Rebroadcast Jitter is reset after each retransmission. There is a key point in the retransmission mechanism that the nodes must store the broadcast packets in the buffer temporarily, but this is limited to ZigBee Coordinator and Router devices of non-leaf nodes (e.g. S, A, B, C, D, E, F in Figure 3). The Router device of ZigBee End Device or leaf node is not required to prepare the buffer for retransmission or store broadcast packets temporarily. Additionally, when a node is identified as a self-pruning node, or it receives the ACK of all child nodes successfully after Broadcast/Rebroadcast/Retransmission. The Broadcast Packet can be dropped and the buffer space can be withdrawn. Such a retransmission mechanism replacing the original sender by the parent node as the retransmitter will make data broadcast a completely reliable transmission more efficiently.

Figure 4 shows the ZigBee Acknowledgement-based Reliable Broadcast (ZARB) Algorithm proposed in this paper. The experimental results of network simulation of this algorithm are detailed in the next section.

ZigBee Acknowledgement-based Reliable Broadcast Algorithm (ZARB)

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v is receiving node; u is broadcasting node;
a is acknowledging node; C is to-be-cover set

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Let C is the set of the children of node v
Set ACK/Rebroadcast Jitter t_jitter = (T_const / d_tree + t_random) where T_const is a constant parameter,
d_tree is depth of node v, and t_random is a random value
If it is the first time of node v to received a broadcast packet
   If node v is not a leaf node
      Reserve a buffer and store the packet in the buffer
   EndIf
   Start a timer with the timeout value of ACK/Rebroadcast Jitter t_jitter
Else
   If node v has previously acknowledged for the broadcast packet
      Discard the packet
   EndIf
   If the early copy of this packet has been waiting
      Update the set C with C = C - u
   EndIf
EndIf
If node v received the ACK packet and v is not a leaf node
   Update the set C with C = C - a
   If C is empty
      Stop the timer
      Send an active ACK packet to parent node
      Drop the waiting broadcast packet
      Release buffer space
   EndIf
Endif
If it is time out for a waiting packet
   If node v is a leaf node
       Stop the timer
       Send an active ACK packet to parent node
   Else
      If C is empty
         Stop the timer
         Send an active ACK packet to parent node
         Drop the waiting broadcast packet
         Release buffer space
      Else
         If the value of retransmission counter < ztMaxRetransmission parameter
            Rebroadcast the broadcast packet
            Increase retransmission counter
            Reset the timer to the timeout value of ACK/Rebroadcast Jitter t_jitter
         EndIf
      EndIf
   EndIf
EndIf
```

Figure 4. ZARB algorithm

IV. EVALUATION

a. Simulation parameters

This study proposes a highly reliable ZARB data broadcast algorithm in this paper. This section will carry out efficiency and reliability assessment based on simulation. There are three objects to be compared, one is the broadcast algorithm used in ZigBee Specification v1.0, which is called ZigBee, it is a Tree-based Flooding simple algorithm. Another one is the OSR algorithm mainly focusing on broadcast efficiency. The third one is the ZiFA-R algorithm using node overlapping coverage to increase the reliability. These three algorithms have been introduced in the related researches in Section 2. Two indexes are compared, one is the number of Rebroadcast Nodes which rebroadcast during broadcast, it can indicate the data broadcast efficiency; the other is the number of Packet Arrival, it can indicate the data broadcast reliability. The simulation environment and parameters are shown in Table 1. The maximum tree depth *ztMaxDepth* parameter is set as 6, and each ZC or ZR device owns at most 3 child nodes (ZR or ZED), namely *ztMaxChildren* parameter is set as 3. The packet transfer failure occurs once a collision happens, the node transmission signal radius is 25 meters. This study simulates 50 to 300 nodes existing in a range of 100 meters square. The location of each node is generated randomly. The preset parameter T_{const} of ACK/Reboardcast Jitter is 1 ms, the maximum value of t_{random} is 0.5 ms, and the parameter *ztMaxRetransmission* of the maximum retransmission times is set as 3. Each data shown in the experimental results is the average value of 100 simulations.

Table 1: Simulation environment and parameters

Square Area	100m x 100m
ACK/Rebroadcast Jitter	T_{const} = 1ms ; $t_{random(\max)}$ = 0.5ms
Network Size	50 to 300 nodes
ztMaxChildren	3
ztMaxDepth	6
ztMaxRetransmission	3
Transmission Range	25m radius
Packet Loss	collisions occur
Node Location	represents the average result of 100 runs
Simulation Result	randomly generated in each simulation run

b. Efficiency

The efficiency can be obtained by comparing the numbers of Rebroadcast Nodes required by different algorithms in data broadcast behaviors. When reaching the same broadcast purpose, using less rebroadcast nodes means lower probability of collision between nodes, and the number of redundant broadcast packets in the network will be reduced, so that the transmission is smooth, and the waste of limited device resources such as bandwidth can be reduced. On the contrary, if there are excessive rebroadcast nodes, the broadcast storm will be severe and influence the broadcast efficiency greatly. Figure 5 shows the comparison between the ZARB algorithm and the other three data broadcast algorithms in the percentage of rebroadcast nodes in the simulation results. The ZigBee algorithm is almost 100% with the worst efficiency performance, This is because it is Tree-based Flooding mode, that each layer and point from root and leaf nodes will carry out rebroadcast operation. The result data of OSR are also worse than that of ZARB, which is because ZARB combines ACK Packets with relevant mechanisms for Self-pruning to reduce redundant rebroadcast nodes. Although ZiFA-R is not much different from ZARB, ZiFA-R seems to be a little better, which is because the ZARB uses the self-pruning-based approach to reduce the rebroadcast nodes, whereas ZiFA-R uses the method of Forward Node Selection idea. However, this paper focuses on "high reliable" broadcast, ZARB is much better than ZiFA-R on this point (see next section).

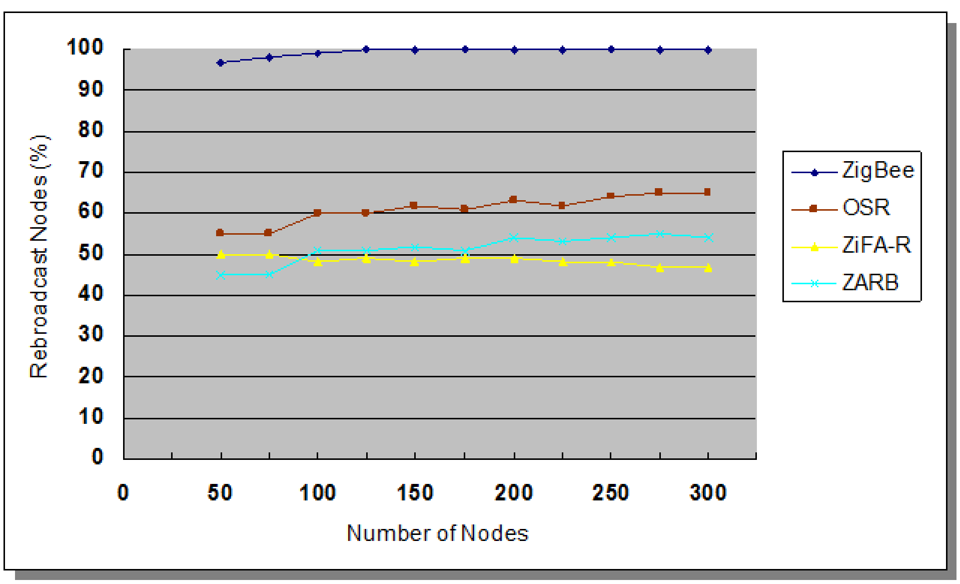

Figure 5. Percentage of rebroadcast nodes

c. Reliability

The reliability of broadcast represents whether the broadcast packets can be received by all nodes completely and correctly. This is also the purpose of "broadcast", especially in some applications. The reliability is an important index of QoS (Quality of Service). Therefore, the percentage of successful delivery of broadcast packets to the destination node is the index data for measuring the reliability. Figure 6 shows the comparison between the ZARB broadcast algorithm proposed in this study and other algorithms in the Packet Arrival percentage. Under the operation of various mechanisms of the ACK-based broadcast designed in this study, the ZARB obtains the optimal reliability. The second one is ZiFA-R algorithm, because ZiFA-R algorithm also considers the reliability design, but the achievement of its design for increasing the reliability by covering the nodes twice with broadcast packet signals is less remarkable than ZARB using ACK and Retransmission to reach the reliability. The third one is the OSR algorithm, it does not consider the reliability though it considers the efficiency. Therefore, the reliability is low, but the decrease of rebroadcast nodes can reduce collisions and is helpful to the reliability, so it is unlikely to be worse than ZigBee algorithm. The broadcast algorithm of ZigBee standard has the worst performance, which is because it is a flooding-based method. All nodes will carry out rebroadcast, so that the collision is severe, and more packets are lost. This situation is especially obvious when the number of nodes is increased.

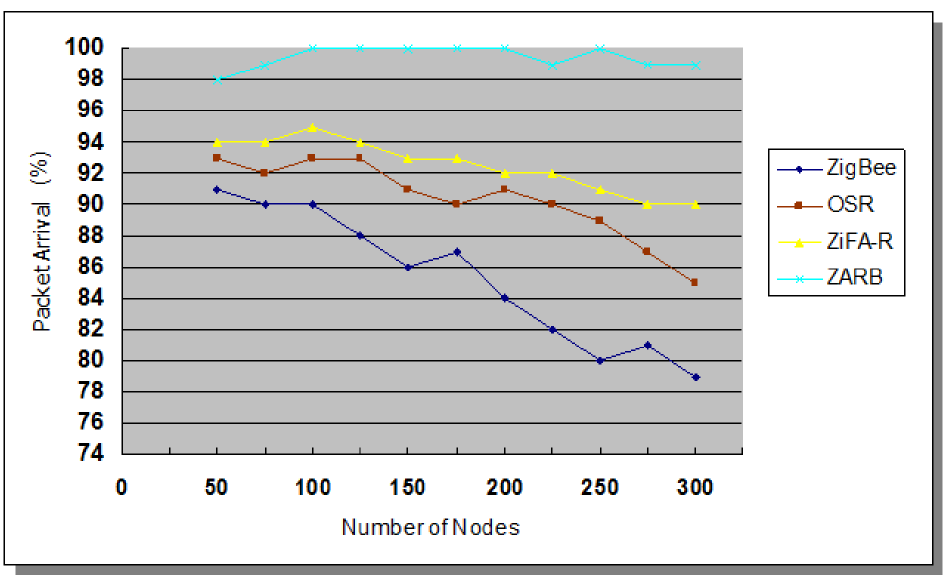

Figure 6. Percentage of broadcast packet arrival

V. CONCLUSION

In wireless sensor networks, the design of data broadcast algorithm becomes a challenging subject because of the characteristics of multi-hop transmission and wireless signals. Besides the efficiency of broadcast operation, the reliability is also an important consideration in design, whereas these two indexes are always a trade-off problem. This paper proposes the ZARB data broadcast algorithm. According to the results of network simulation, in the integrated operation of various mechanisms, a good broadcast efficiency can be maintained, so that high reliable broadcast transmission can be attained. Our future study will design an improved algorithm for shortening the broadcast coverage time. The preliminary idea is to use the Topology Information and the Forward Node Selection idea to shorten the ACK/Rebroadcast Jitter and avoid packet collisions. In addition, due to the ZigBee does not consider the mobility, the algorithm can be modified in the future to extend its application to Mobile Sensor Network (MSN) with mobile characteristics, so as to become a data broadcast method with mobility.

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