Random Basketball Routing for ZigBee based Sensor Networks

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Abstract—Random basketball routing (BR) [1] is a simple protocol that integrates MAC and multihop routing in a cross-layer optimized manner. Due to its lightness and performance, BR would be quite suitable for sensor networks, where communication nodes are usually simple devices. In this paper, we describe how we implemented BR in a ZigBee-based (IEEE 802.15.4) sensor network. In [1], it is verified that BR takes advantages of dynamic environments (in particular, node mobility), however, here we focus on how BR works under static situations. For implementation purposes, we add some features such as destination RSSI measuring and loop-free procedure, to the original BR. With implemented testbed, we compare the performance of BR with that of the simplified AODV with CSMA/CA. The result is that BR has merits in terms of number of hops to traverse the network. Considering the simple structure of BR and its possible energy-efficiency, we can conclude that BR can be a good candidate for sensor networks both under dynamic and static environments.

Index Terms—random basketball routing, relay probability, wireless sensor networks, IEEE 802.15.4.

I. INTRODUCTION

Wireless sensor networks are composed of a number of cooperative sensor nodes that are usually powered by batteries, equipped with small memory components, and operated by poor processing units. Therefore, energy, memory, and computation efficiency must be considered for designing communication protocols in a sensor network. In particular, the routing protocol should be simple and light. Self-configurability is also required, because any node in the network can disappear or break down. If a fixed path contains broken nodes, transmission is failed and energy efficiency may be severely deteriorated by retransmission through the broken path.

Random basketball routing (BR) is a simple per-hop-based multihop routing that incorporates node mobility into the routing design [1]. In BR, a node (possibly moving) may receive and forward the same packet multiple times. BR is fully self-configurable in the sense that the next forwarder (relay node) is determined adaptively (opportunistically), without knowledge of the entire network topology. BR integrates the media access control (MAC) and routing in a cross-layer optimized manner. This intrinsic feature makes BR attractive to sensor networks, where the sensor is a simple device in most cases.

In BR, there is a key parameter called relay probability, \( p \). For a given time slot, a node having data either transmits its own packets with probability \( 1 - p \) (transmitting) or relays for the other nodes with probability \( p \) (listening). When transmitting, a node sends its packets either to a relay node or directly to the destination, whichever is appropriate (for example, closest). By simply controlling the relay probability, we can handle not only routing but also MAC of the network. When \( p = 0 \), an extreme case, there is no relay and the routing is reduced to the single-hop transmission, where every node simultaneously transmits. As the probability \( p \) increases, there are more relay nodes (i.e., less transmitting nodes) around a transmit node, reducing the average transmission distance and the delay from retransmissions. However, the transmission probability \( 1 - p \) of a node also decreases and the opportunity for the transmission itself becomes smaller. In the other extreme case, \( p = 1 \), no node is transmitting. Therefore, the optimal relay probability exists, under which the maximum network throughput can be obtained.

In [1], we analyzed the optimal relay probability as a function of the link data rate and the node density over the service area. According to our simulations and theoretic investigations, with BR, the average end-to-end throughput has been improved as the average speed of nodes increases (as was also noted by [2]). The higher the node density is, the more the gain from node mobility is.

The purpose of this paper is how we implement BR in a real ZigBee-based (IEEE 802.15.4) sensor network. Our main emphasis is how BR works under static situations and we test its performance using our testbed network. In this paper, we describe how we design signaling processes, packet structure/type, and other implementing details. Our experiments are encouraging in that BR outperforms the conventional AODV (ad hoc on-demand distance vector) routing with CSMA/CA (carrier sensing multiple access/collision avoidance) MAC.

II. SIGNALING, FRAME STRUCTURE AND LOOP-FREE PROCEDURE

A. Signaling Process

Figure 1 shows the signaling process of BR for choosing a relay. Destination node \( D \) periodically broadcasts a beacon signal so that the strength of the signal is measured and stored by each receiving node. When transmit node \( S \) wants to transmit some packets, it sends out Request-to-Send (RTS)
to its neighboring relay nodes within the radio range. In the RTS frame header, there should be the identification (ID) of node \( S \), the owner of the RTS. Each neighboring relay node (determined by the relay probability \( p \)), after receiving RTS, waits short random time slots to avoid collision, and then sends out acknowledgement (ACK). In the ACK packet header, there should be at least two information: one is the measured signal strength of the periodic beacon signal from the destination and the other is the ID of the relay node. After receiving ACK packets from neighboring relay nodes, node \( S \) compares them and chooses a relay node (pass) that reports the strongest received beacon signal. If node \( S \) does not receive any ACK, it sends its packets directly to the destination (shoot) as shown in Figure 2 usually not expecting any success of delivering the packet to its destination.

When node \( S \) transmits to a relay node or the destination, a packet can be transmitted successfully on the condition that the received SIR at a receiving node is not less than the target SIR \( \gamma \). If the transmission fails, the network adopts the Binary Exponential Backoff (BEB) [3] for collision resolution (Figure 3). In BR, such retransmission occurs independently of the probability \( 1 - p \), after the random backoff slots.

### B. Packet Structure

Figure 4 shows our design of a BR packet, where we assigned 16 bits to each field of the packet, except the hopCount field (32 bits). Tables I and II contain message types of a BR packet and brief description of each packet field, respectively.

When sensors are powered on, they listen to a channel to receive packets. A TYPE_DSTBCAST message is periodically broadcasted by a destination so that the destination informs other nodes of its own location. After receiving TYPE_DSTBCAST, each node measures RSSI and stores it into dstRSSI. A source node broadcasts a TYPE_SRCBCAST message to choose the next forwarder. The neighboring nodes, after receiving TYPE_SRCBCAST decide whether to send out TYPE_RESPONSE or not, depending on their relay probabilities. Then, the source node compares its own dstRSSI and those in received TYPE_RESPONSE. If the source’s dstRSSI is the largest, the source node transmits TYPE_ROUTING directly to the destination. Otherwise, the source node sends TYPE_ROUTING to the relay node which has the largest value of dstRSSI. The node which receives
FIG. 4. BASKETBALL ROUTING PACKET STRUCTURE

| Message Type      | Description          | Elements                                      |
|-------------------|----------------------|-----------------------------------------------|
| TYPE_SRCBCAST     | RTS message          | broadcastNodeID                              |
| TYPE_DSTBCAST     | Location informing   | broadcastNodeID, responseNodeID, dstRSSI      |
| TYPE_RESPONSE     | ACK to RTS message  | broadcastNodeID, responseNodeID, dstRSSI      |
| TYPE_ROUTING      | Data message         | sourceNodeID, destNodeID, sendNodeID, recvNodeID, hopCount |
| TYPE_ACK          | ACK to data message  | responseNodeID                               |

TABLE I
MESSAGE TYPE OF A BASKETBALL ROUTING PACKET

TYPE_ROUTING sends a TYPE_ACK packet to the source node, and checks if destNodeID is same as its local address. If then, the routing is completed, otherwise the relay node who has received TYPE_ROUTING broadcasts TYPE_SRCBCAST and the above procedure is repeated.

C. Loop-free Procedure

With all the merits of BR, there are also some drawbacks from using it. One problem is that there might be some loops on the routing paths created by BR and traffic would circulate within a loop. This can occur in the static environment, because BR allows a node to relay the same packet more than once. To avoid such loops, if hopCount exceeded LOOP_THRESHOLD at a node, a simple loop-free mechanism is applied; The node does not forward the packet to a specific node that previously forwarded the same packet to the current node. The procedure specification is presented in Figure 5.

FIG. 5. MESSAGE-LOOPING RESOLUTION IN STATIC NETWORKS

III. IEEE 802.15.4 ZIGBEE TESTBED RESULTS

We have implemented BR on a ZigBee-based (IEEE 802.15.4) testbed. All hard- and softwares in our experiments are based on ZigbeX bundle manufactured by Hanback Electronics. Each sensor node runs TinyOS and is equipped with 8-bit RISC ATmega128 and CC2420 chip as a microcontroller and a radio transceiver, respectively. Sensors operate on 2.4GHz and communicate at the maximum capacity of 250 kbps within the transmission range.
A. Motion-Detection Sensor Testbed

Figures 6 and 7 show the network topology of our indoor testbed. Parameters for experiments are specified in Table III. The shaded region represents walls and there is a door on the right side. In our experiments, each node (1-9) senses the motion of objects and reports the sensed data to the destination (dst). The destination node is connected to a laptop computer and the packet arrival from each sensor node is displayed on the computer. Nodes are distributed so that they can cover all over the network area with the minimum number of sensors. In this case, we used the optimal relay probability \( p^* = 0.73 \) derived in [1] for the node density \( \lambda = 0.2 \) (number of nodes per unit square meter). When a node having data is activated with probability \( 1 - p \), BR is executed to transmit the data to the destination or a relay node, whichever is closest.

Figures 8 and 9 show the routes of data sensed at two different nodes. In Figure 8, the routing succeeded in three hops. With the other routing protocols using the shortest path as a metric, just two hops (5-4-dst) would be needed. In BR, however, a node can receive data from the other nodes only when it acts as a relay with probability \( p \). Therefore, if all intermediate nodes between a source-destination pair transmit their own data with probability \( 1 - p \), the next hop (e.g., node 4 in Figure 8) does not respond to the source node (node 5). This might increase the delay, yet the route taking a roundabout way does not always have a negative effect on the throughput, as shown in Figure 9.

In Figure 9 transmission is completed in three hops, going round to the door. This takes more number of hops traveling a long distance than the shortest path transmission which needs only one hop (from node 9 directly to the destination). However, with the shortest path, delay from retransmissions might be considerably large because of packet failures, since the destination is shadowed by the wall. In this case, going round via some nodes by BR would be better in the delay performance. Like in this case, if there are obstacles between nodes or a static route is impossible due to node failures (e.g., battery discharge, sensor breakdown), then a certain per-hop-based routing is required.

B. BR versus AODV+CSMA/CA on a Tandem Network

BR integrates MAC- and network layer into one, making itself light and simple. In this subsection, we compare the performance of BR with that of a simplified AODV+CSMA/CA. We apply a simplified AODV routing, where the node with the largest RSSI is chosen as the next forwarder. To determine the effectiveness of BR, we perform experiments on a tandem wireless network as shown in Figure 10. The network contains 5 to 15 nodes positioned linearly on a \( 2.05 \times 14 \text{ M} \) floor. The source and the destination are located at both ends, where the relay nodes are located between them. The transmission range of a node is set to 6M and the optimal relay probability \( p^* = 0.83 \). The other parameters are the same as those in Table III.

Figure 11 compares the average number of hops required to route a packet from the source to the destination. The results show that BR performs better than the simplified AODV+CSMA/CA. Moreover, the larger the network is, the greater the performance improvement is. In case of the network with 12 nodes (Figures 12 and 13), almost every node relays packets when the simplified AODV is executed. In contrast, with BR, it is possible to skip some nearby nodes due to its opportunistic nature. Similar results are also shown in [4]. Figure 14 shows that as the number of nodes increases, per-hop transmission distance decreases in both cases. However, BR utilizes the longer transmission distance.
IV. Conclusions

In this paper, we described how we implemented our random basketball routing (BR) in a ZigBee-based sensor network. Even if BR gets benefits of dynamic environments, we tested how it works under static situations, by adding some features like destination RSSI measuring and loop-free procedure, to the original BR. With BR, at a given time slot, each source node having data can transmit or receive packets according to the relay probability. A transmit node sends its packet to a relay node in the relaying region or directly to the destination. When transmission fails with a certain level of collision probability, the Binary Exponential Backoff (BEB) is executed for collision resolution. BR can be easily applicable in real sensor networks. Especially, its self-organizing feature can solve problems like node disappearance or node disorder. Current work on BR implementation includes comparison with other routing protocols, measuring actual lifetime of the network both under dynamic- and static environments.

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