# Distributed Forwarder Selection on Beaconless Routing for Real-time Services in Wireless Sensor Networks

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Abstract: In wireless sensor networks (WSNs), real-time service is one of the important issues. Typically, existing studies for the service are relied on beacons. Recently, beaconless routing has been proposed to overcome control overhead for resource constrained environment of WSNs. Thus, real-time communication based on the beaconless scheme could give great advantages with less energy consumption. To do that, however, it brings new challenges. For the real-time communication, each node needs to be aware of single hop delay for data forwarding within desired time. In conventional approaches, it is based on delay in neighbor information through beacons. An appropriate next forwarder is selected by a sender. However, in the beaconless scheme, a sender could not select a next forwarder since that is determined by a receiver. Also, contention delay is included in single hop delay for beaconless routing. Thus, the delay estimation principle should be renovated. In this paper, we present a receiver-based real-time routing protocol, called RBRR. We design a novel delay estimation strategy. The single hop delay from a sender to a receiver could be calculated by a receiver but not a sender. Therefore, the receiver itself makes a decision whether desired time requirement is satisfied. Simulation experiments show that the strategy achieves higher performance in terms of energy consumption.

## 1 INTRODUCTION

Wireless sensor networks (WSNs) are composed of a large number of sensor nodes with low power battery. Besides, most of power resources are dissipated in transmission. Therefore, design of energy conserving routing protocol is one of the important issues in these WSNs. Though earlier position-aware routing protocols are considered as energy efficient, they still suffer periodic beacons to maintain knowledge of presence of neighboring nodes. Nodes even not taking part in any routing process should emit beacons. Also, it is may not be appropriate for WSNs in highly dynamic scenarios where network topology changes frequently due to nodes availability.

Recently, beaconless routing protocols have been proposed in an effort to overcome such drawbacks (H. Fuessler and Hartenstein, 2003; B. Blum and Stankovic, 2003). When data packets are needed to transmit, next forwarder is selected by contention. Contention is completed through waiting function, which is uniquely assigned to each candidate for a next forwarder selection. The winner for the contention has permission to deliver data. Typically, a node with the largest progress to a destination has the shortest waiting time. This obtains an outcome of energy saving effect. Also, since actual existent neighbors participate in the contention, it could avoid selection of non-valid next forwarder caused by outdated neighbor information.

One of essential application categories that are indispensable in WSNs is real-time service. Existing real-time communication protocols are mostly governed by the conventional geographic routing scheme, which each node has to periodically broadcast beacons. Therefore, real-time communications based on the beaconless scheme could give great advantages with less energy consumption.

To do that, however, it brings new challenges. In conventional real-time communication, a sender selects an appropriate node which satisfied real-time constraints and forwards data to the node by maintaining information of neighboring nodes. For deciding whether a neighbor node satisfies real-time constraints, a sender calculates delay between entering time to output queue and sending time of the last bit for a packet. Namely, delay information maintained by each node is duration while data is for-


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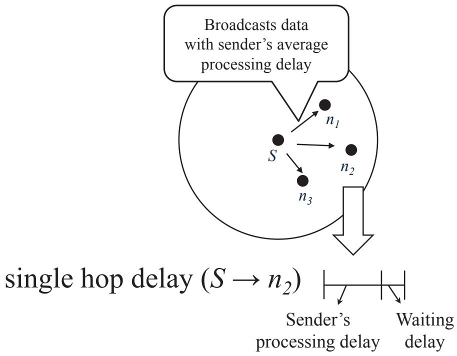


Figure 1: Delay estimation in RBRR.

warded from the node itself to a neighbor node. However, in receiver-based beaconless schemes, a receiver itself should decide to become a next forwarder. The receiver requires delay of duration from a sender to the receiver itself in such routing schemes. Thus, existing schemes could not support this delay information. Also, the receiver-based beaconless schemes have contention delay to select a next forwarder without neighbor information. Each candidate has unique waiting time to avoid transmission collision. The node having the shortest waiting time wakes up firstly and wins permission to forward data. Therefore, this contention delay should be included to the single hop delay but existing schemes could not support this delay estimation principle.

In this paper, we present a receiver-based beaconless real-time routing protocol, called RBRR. The single hop delay is calculated at a receiver. When a sender broadcasts data, the data includes average single hop delay. After a neighbor wakes up, the node decides to become a next forwarder by the average single hop delay information and waiting time consumed for contention. Simulation results show that our protocol has less energy consumption and high performance for real-time service.

The remainder of this paper is organized as follows. In section II, we review related work. The proposed protocol is presented in Section III and the experiment result of the proposed protocol is Section IV. Finally, the paper is concluded in Section V.

## 2 RELATED WORK

Beaconless routing reduces energy consumption by eliminating beacon message exchange. Beaconless routing protocols are categorized into two types according to selection scheme of relay node: sender-based and receiver-based.

There are IGF (B. Blum and Stankovic, 2003),

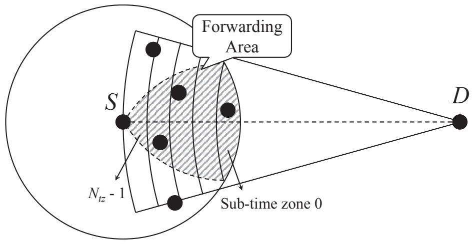


Figure 2: Waiting delay assignment by sub-time zone for contention.

CBF (H. Fuessler and Hartenstein, 2003) in sender-based scheme. These studies exploit RTS/CTS handshaking. A sender broadcasts RTS and then neighbors receiving this message have unique waiting time respectively. A node waking up first sends CTS to the sender. The sender selects the node as a relay node and delivers data to the node.

BLR (M. Heissenbuttel and Wachli, 2004), BGR (Turau, 2005) could be defined as receiver-based scheme. In these studies, a sender deliver data first rather than RTS/CTS messages. Neighbors receiving data also wait for contention. A node waking up first resends data for next forwarding. In other words, receivers themselves whether to decide deliver data or not.

SPEED (T. He and Abdelzaher, 2005) exploits feedback control technique to maintain delay of neighbors. The study selects relay nodes by non-deterministic geographic forwarding scheme. Each sensor node sends 1-hop delivery speed information to neighbors which want the information. It maintains nodes which meet desired speed among its neighbors into routing list. Then a sender transmits packets to one of the nodes in the list. At this time, selected node as a relay node reports its own delivery speed to surrounding nodes after transmitting a packet by the feedback control technique. SPEED of this kind method is the first spatiotemporal communication scheme.

CBRR (Huang and Wang, 2010) is recent one of studies for providing real-time service based on beaconless routing. CBRR exploits sender-based relay node selection scheme. Since sender-based schemes need additional control process such as RTS/CTS message exchanging, sender-based schemes have longer delay than receiver-based schemes have. Thus, delivery success ratio within desired time could be decrease.

# 3 RECEIVER-BASED BEACONLESS REAL-TIME ROUTING

Unlike convention real-time routing protocols which maintain neighbor list and select a next relay node utilizing the list, in RBRR, a receiver itself determines whether to be a relay node. Also, because there is no exchanging beacon messages, sensors are not aware of existence of each other. Therefore, a sender broadcasts data and a next forwarder acquires transmission permission through contention process in the receiver-based schemes. Waiting time is consumed for the contention so it should be considered that this time is included. Thus, we need to redesign delay estimation principle to adapt beaconless-routing. In this section, we describe delay estimation method on receiver-based scheme and explain how data is delivered by utilizing this method.

## 3.1 Spatiotemporal Approach for Real-time Services

The conventional schemes (T. He and Abdelzaher, 2005) for real-time data dissemination mainly exploit the spatiotemporal approach in order to deliver data from a source to a static sink within a desired time deadline $T_{setdeadline}$. While in multi-hop wireless sensor network, since communication is physically bounded, the end-to-end delay depends not only on single hop delay (temporal), but also on the distance a packet travels (spatial). To achieve this, source nodes initially calculate a desired delivery speed $S_{setspeed}$ with the time deadline and the end-to-end distance d(source, sink) from the source to the sink as follows:

$$S_{setspeed} = \frac{D(source, sink)}{T_{setdeadline}} \quad (1)$$

In the protocols, each node on the dissemination route selects a node as its next-hop node which is nearer to the sink and provides a better relay speed than the desired delivery speed $S_{setspeed}$. The relay speed means the advance in distance to each next node dividing by the delay to forward a packet to the each next node. The end-to-end real-time data dissemination is achieved by maintaining the desired delivery speed from sources to the sink.

## 3.2 Delay Estimation

In order to calculate relay speed discussed above at each hop, we need to be aware of the single hop delay between a sender and a receiver, and the distance between them. Single hop delay means hold-up time in a hop. In RBRR, we define single hop delay as the time for that data from a current forwarder is broadcasted and a next forwarder is determined among neighbors receiving the data. Therefore, single hop delay includes *processing delay* due to buffering, MAC protocols and so on such backoff, and *waiting delay* for contention.

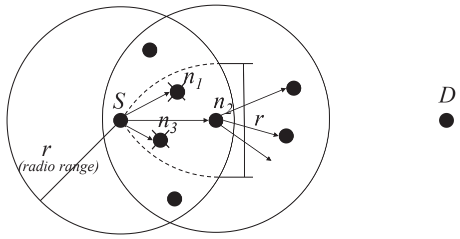


Figure 3: Basic principle of data forwarding in RBRR.

Existing single hop delay estimation is computed by a sender because next forwarder selection is performed on sender side. However, since a next forwarder is determined by neighbors after receiving data in RBRR, it should provide single hop delay information for receivers. Conventional single hop delay estimation principle could not be directly adapted.

When a sender broadcasts data, it includes average processing delay of the sender into the data packet header. Calculation of the processing delay is obtained by difference between the entering time into output queue of a data packet ($T_{arr}$) and the actual sending time of last bit of the data ($T_{dprt}$) as well as the conventional real-time schemes. This time is accumulated to previous average processing delay and then the average processing delay is updated as follows.

$$Delay_{new} = \varepsilon \cdot (T_{dprt} - T_{arr}) + (1 - \varepsilon) \cdot Delay_{prev} \quad (2)$$

As shown in Fig. 1, when a candidate node wakes up after certain waiting time, this node adds average processing delay of the sender to consumed time for waiting (waiting delay) and decides to satisfy desired speed.

## 3.3 Forwarding in RBRR

Since communication is physically bounded in wireless networks, minimizing the number of hops brings better performance in terms of delivery deadline success ratio. Therefore, the closer node is to a destination, the shorter waiting time becomes in contention process for beaconless routing. Waiting time is assigned according to distance to a destination between

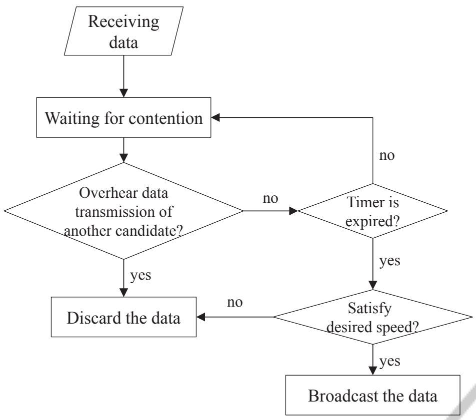


Figure 4: Decision flow of becoming a next forwarder.

0 and $D_{MAX}$. $D_{MAX}$ represents maximum time given by an application to wait for contention.

For contention process, each candidate must have unique waiting time to avoid collision with the others. It can be assigned according to progress toward a destination. However, some nodes might have same progress. Also, adding simply random values incurs duplicate wait time as well in case of some nodes having distance differences as much as a random value. To deal with this, we divide forwarding area into sub-time zones (J. A. Sanchez and Ruiz, 2007). Each sub-time zone has mutually different waiting time. In a same sub-time zone, each candidate has random time respectively. Therefore, all candidates could avoid transmission collision. To construct sub-time zones, a forwarding area is divided into the number of sub-time zones ($N_{tz}$) given according to applications. A zone index affiliated candidate neighbor $n$ is obtained as follows:

$$Z_n = \left\lfloor N_{tz} \times \left(1 - \frac{d(s,d) - d(s,n)}{r}\right) \right\rfloor \quad (3)$$

where $s$ and $d$ are the current forwarding node and the destination. The function $d(c,d)$ represents the Euclidean distance between the positions of the nodes $c$ and $d$. In order to give shortest waiting time to the closest node toward the destination, it reversely assign the time in proportion to radio range $r$.

Each sub-time zone could wait until for time ($D_{MAX}$ / $N_{tz}$). Thus, we could compute delay of each candidate neighbor as follows:

$$T_{wait} = \left(Z_n \times \frac{D_{MAX}}{N_{tz}}\right) + rand\left(\frac{D_{MAX}}{N_{tz}}\right) \quad (4)$$

here, the function $rand(x)$ returns a random value between 0 and $x$. Therefore, a node in the farthest group from a sender node starts wake up in order. If there is no qualified node, chance passes to the next group by equation (4). Fig. 2 shows an example of the sub-time zone.

Movement speed could be calculated by single hop delay and progressed distance. Satisfying this speed represents that real-time data is successfully delivered within desired time. Thus, data is re-broadcasted by the receiver and this means namely relaying data is successfully fulfilled. This procedure is continuously repeated until data reach to a destination. Fig. 3 shows data delivery process described above. Sender $S$ broadcasts data. Then candidate neighbor $n_1$, $n_2$ and $n_3$ receive data and wait for assigned time respectively. Since $n_2$ is the closest to destination $D$, $n_2$ wakes up first and decides whether to be able to satisfy desired speed. If $n_2$ satisfies the desired speed, $n_2$ broadcasts data as the next relay node. Other candidates overhear the broadcasting of $n_2$ and cancel its own waiting timer.

When the first node finished waiting time transmits data as a relay node, other candidates give up the contention by overhearing the transmission. However, some nodes might not be included within radio range of the relay node. This may cause duplicate transmission. To avoid the duplications, we bring *Reuleaux Triangle* described in BLR. All nodes within the area can overhear each other. Basic process of next forwarder decision is described in Fig. 4.

# 4 EXPERIMENTAL RESULTS

We compare the performance of RBRR with that of the representative real-time routing scheme in WSNs, SPEED (T. He and Abdelzaher, 2005). We implemented three protocols in Network Simulator Qualnet 4.0 (QUALNET, 2008). Sensor nodes follow the specification of MICA2 (Hill and Culler, 2002) and their transmission range is about 50m. IEEE 802.11b was used as the MAC layer protocol. The size of the sensor network is set to 250m 250m where 2500 nodes are randomly distributed. For all simulations, we use one source-sink pair for performance evaluation. We use the following metrics for performance analysis and evaluations: the success delivery ratio is defined as the ratio of the number of data packet successfully received within desired time by the sink to the number of data packets generated by the source. The control overhead is defined as the total number of control packets. The average energy consumption is defined as average consumption of twenty times of transmission. Transmitting and receiving power consumption rates of the sensors are 21mW and 15mW, respectively. The beacon interval is set to 1.5s and ac-

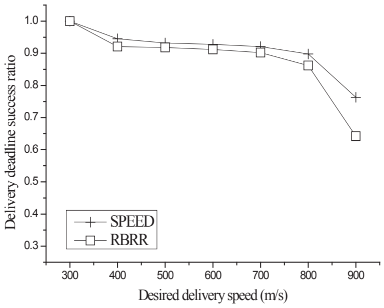


Figure 5: Success delivery ratio impacted by sink speed.

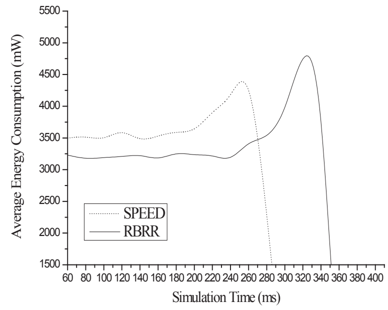


Figure 6: Average energy consumption according to elapsed simulation time.

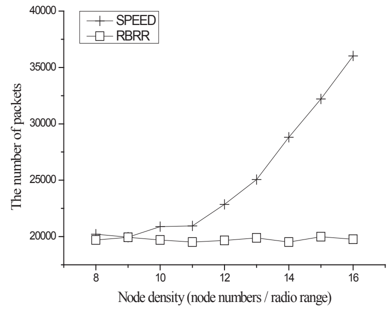


Figure 7: The number of total packets impacted by node density.

cordingly the time-out interval to 4.5  1.5s = 6.75s after which a node is deleted from the neighbor table if no beacon is received. We use constant bit rate (CBR) traffic. To test performance at one time, a node is randomly chosen from left side of the terrain and sends periodic data to the right side of the terrain. The node generates 1 CBR flow with a rate of 1 packet/second.

The results in Fig. 5 show network lifetime according to elapsed simulation time. For comparing network lifetime, we estimate the energy consumption of the whole sensor nodes based on MICA2 mote energy model. We set battery capacity of a sensor node to 3000mW. In SPEED, since each sensor node periodically exchanges beacon messages, depletion time of a node is shorter than one of RBRR.

In Fig. 6, deadline delivery success ratio due to desired delivery speed is depicted. We vary a desired delivery speeds between 400m/s and 1000m/s to compare an effect on the deadline delivery success ratio against different speeds. In this simulation, we set that SPEED is so operated that the fastest path is selected for transmission. Also, we do not consider traffic distribution. SPEED has no delay for selection relay nodes so delivery deadline success ratio is relatively higher than one of RBRR. However, since success ratio keeps over 0.9 to desired speed 700m/s, it could say that RBRR is effective.

Fig. 7 shows communication overhead according to density. Packet overhead means total number of packets sent at the radio layer. In SPEED, packet overhead rapidly increases due to congestion caused by beacons to update neighbor table. Therefore, retransmission or additional control is more required according to be dense. However, in RBRR, the density does not affect the communication overhead. Since RBRR does not require beaconing, congestion probability is almost constant. So, RBRR has advantage in terms of scalability.

Fig. 8 shows the number of node alive according to elapsed simulation time. Periodic beacon messages in SPEED quicken dissipation of node. Therefore, the number of node alive dramatically decreases in the middle of simulation time. At the end of the simulation time, since many nodes are dissipated, the number of beacons decreases and then nodes dissipation speed shows a decreasing trend. On the other hand, since RBRR extremely reduces control messages, nodes endure long time in comparison with SPEED.

Fig. 9 plots delivery deadline success ratio in network dynamics. In this experiment, we set desired delivery speed to 500m/s. As simulation time passes, network topology frequently changes due to dissipated sensor nodes. In the middle of the simulation time between 140s and 240s, sensor nodes are rapidly dissipated and then topology of the network varies fast. In SPEED, since forwarder selection relies on the neighbor table, information about some nodes might not valid anymore on the situation. Thus, transmission failure might occur frequently until the tables are updated by beacons. However, RBRR needs not to maintain neighbor tables. It always operates among actually existent nodes. RBRR is tolerant of network dynamics in comparison with conventional real-time scheme based on beacon messages.

Fig. 10 shows end-to-end delay according to network dynamics. As we discussed above experiment, frequent topology changes might cause retransmission or additional control. It affects to end-to-end packet delivery delay. In SPEED, delay rapidly increases due to the reason. As simulation time passes, many nodes are dissipated. Therefore, end-to-end path is longer so that the delay proportionally increases. Although RBRR has typically larger delay than that of SPEED, it shows stable delay in high dynamics of networks.

## 5 CONCLUSIONS

In this paper, we propose a receiver-based beaconless

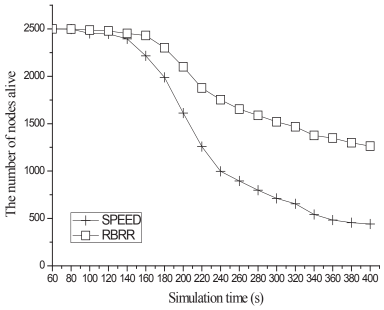


Figure 8: The number of nodes alive according to elapsed simulation time.

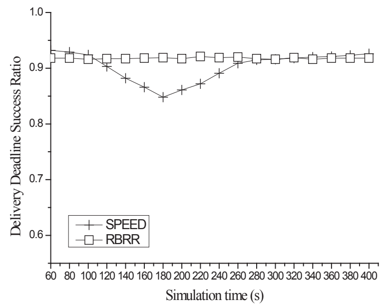


Figure 9: Delivery deadline success ratio according to elapsed simulation time.

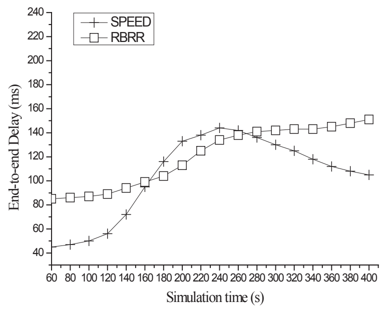


Figure 10: End-to-end delay according to elapsed simulation time.

real-time routing scheme. Beaconless routing without periodic exchanging beacon messages is attractive approach. For providing real-time services with receiver-based beaconless, delay estimation principle should be renovated focusing on receivers. To do that, we propose new delay estimation principle, called RBRR. A sender includes its own single hop delay into data for receiver to receive. Also, it adds waiting time for contention to single hop delay. Experimental results for performance evaluation show that RBRR well provides real-time services while achieves high energy efficiency.

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