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Recommended Paper

An RSSI-Based Cross Layer Protocol for Directional Ad Hoc Networks and Its Implementation

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Abstract: In this paper, we propose and implement a cross layer protocol for ad hoc networks using directional antennas. In the proposed protocol called RSSI-based MAC and routing protocol using directional antennas (RMRP), RSSI is used for computing the direction of the receiver and also used for controlling backoff time. Moreover, the backoff time is weighted according to number of hops from a source node. In addition, simple routing functions are introduced in the proposed RMRP. We implement the proposed RMRP on a testbed with the electronically steerable passive array radiator (ESPAR) antenna and IEEE 802.15.4. From some experimental results, we confirm some throughput improvement and show the effectiveness of the proposed RMRP. Especially, the proposed RMRP can achieve about 2.1 times higher throughput than a conventional random backoff protocol in a multi-hop communication scenario.

Keywords: ad hoc networks, directional antenna, medium access control (MAC) protocol, routing, implementation

1. Introduction

Wireless ad hoc networks have been intensively studied in recent years because networks can be built only with mobile nodes without any fixed infrastructure. Directional medium access control (directional MAC) protocols are studied in Ref. [1], [2], [3], [4], [5], [6], [7]. Thanks to the spatial reuse, directional MAC protocols control antenna beam forms adaptively depending on the situation of data communication, which improve throughput and reduce delay etc. Most directional MAC protocols are evaluated by computer simulations where antenna beam forms and radio propagations are assumed to be ideal. However, if we use directional antennas in a real environment, we have to consider the effects of actual antenna beam forms and radio propagations. Some works implement directional protocol in real systems [8], [9], [10], [11], [17], [18]. **Table 1** shows the comparison between these works and our proposal RMRP. Reference [8] uses directional antennas for intelligent transport system (ITS). The implementation consists of access points (APs) and vehicles. Each AP has an omni-directional antenna; each vehicle has a directional antenna. A vehicle transmits data to an AP with directional transmission. Reference [9] implements a system with directional antennas for vehicular-to-vehicular networks where omni-directional beam to broadcast for neighbor discovery and directional beam to transmit data for single-hop ITS communication. Reference [11] is a demonstration system which implements omni-directional and directional communication. Reference [10], a directional MAC protocol called SWAMP is implemented on Ref. [11]. Reference [17] is for intelligent transport system (ITS), and uses directional beam to discover neighbors for single-hop communication. Reference [18] is a testbed with ESPAR antenna, and shows that using directional antenna can increase the spatial reuse and improve the throughput of the entire network. This work uses AST table to maintain information of neighbors. However, it just evaluates single-hop communication. It does not effectively uses AST information for routing in outdoor environment. As our design RMRP, each node uses directional beam to discover its neighbors by maintaining its AST table and transmits data for multi-hop communication.

For chipset CC2420, Ref. [12] shows that link quality indicator (LQI) is not better indicator of link quality than receive signal strength indicator (RSSI). So we consider RSSI to design our proposal. Reference [13] implemented a routing protocol based on RSSI through beacon for multi-hop wireless sensor network. But it is not for directional protocol. We use RSSI through data packet to design a directional protocol RMRP. Reference [13] is evaluated by simulation, but we evaluated our proposal RMRP using our implemented testbed.

In this paper, we propose and implement an RSSI-based cross layer protocol for ad hoc networks using directional antennas. In the proposed protocol called RSSI-based MAC and routing protocol using directional antennas (RMRP), RSSI is used for computing the direction of the receiver and also used for controlling backoff time. Moreover, backoff time is weighted according to number of hops from a source node. In addition, simple routing functions are introduced. We implement the proposed protocol

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Table 1 Related studies comparison.

	Beam forming	Hops	Location	Application
[8]	APs: omni directional beam; Each node: directional beam	Single-hop communication	GPS	ITS
[9]	Detect neighbors: omni directional beam; Transmit data: directional beam	Single-hop communication	GPS	ITS
[11]	Omni directional beam; Directional beam	Single-hop communication	GPS	Not specified
[17]	Directional beam	Multi-hop communication	RSSI	ITS
[18]	Directional beam	Single-hop communication	RSSI	Not specified
RMRP	Directional beam	Multi-hop communication	RSSI	Not specified

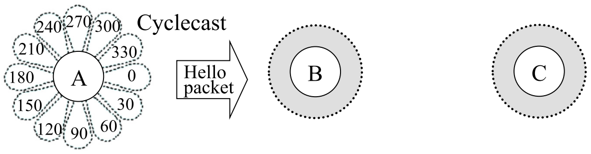


Fig. 1 Cyclecasting from node A.

on a testbed with the electronically steerable passive array radiator (ESPAR) antenna [14] and IEEE 802.15.4 [15].

The results of fundamental evaluation show that the proposed protocol can achieve about 2.4 times higher data arrival ratio than the conventional random backoff method with directional antennas.

In Section 2, the design concept of the proposed RMRP is described. Section 3 describes the implementation of the proposed RMRP. The experimental results in single-hop and multi-hop communications are provided in Section 4. We show the concluding remarks and future work in Section 5.

2. Proposed RMRP

This paper proposes an RSSI-based MAC and routing protocol using directional antennas (RMRP). The proposed RMRP is a simple directional MAC and routing protocol with directional antennas, which uses RSSI for reducing CPU processing. The proposed RMRP has the following three functions:

(1) Detecting neighbors' direction by using angle-signal table (AST): Thanks to directional antenna, each node can record the RSSI from each direction to recognize neighbors' direction,

(2) Routing function embedded in MAC layer: RSSI can indicate the link reliability. So it can be used for routing,

(3) Backoff time calculation using RSSI: RSSI intrinsically fluctuates due to natural turbulence. Therefore we use it for back off time control to avoid packet collision.

We focus on small-scale networks. RSSI is used for the above functions for simple implementations.

2.1 Detecting Neighbors' Direction

Detecting neighbors' direction is necessary for directional MAC/routing because a transmitter needs to know the direction of its receiver. In the proposed RMRP, each node rotates its directional antenna sequentially to all directions to send Hello packets, called cyclecasting as shown in **Fig. 1**. This figure shows an example where Node A transmits twelve Hello packets directionally rotating its antenna direction at 30 degree. Each node has a table called AST table, which includes node ID, angle (direction), RSSI value, node ID of next hop and number of hops. When receiving a Hello packet, a node observes the RSSI value of Hello packets, and records the RSSI value and its direction of the transmitter of the Hello packet in its AST table. An example of AST table is shown in **Table 2**. We show the procedure of updating AST tables of Node B and C using the topology of Fig. 1. At first, Node A sends an Hello packet to direction 0 with directional beam. Node B receives the Hello packet with omnidirectional mode, and records the observed RSSI of the Hello packet. Sequentially, Node A cyclecasts Hello packets to all directions. When receiving Hello packet, Node B records the observed information into its AST table. Table 2 (a) is an example of Node B's AST table after receiving Node A's cyclecast. In this example, Node B receives three Hello packets transmitted by Node A from angle 0, 30 and 330 degrees. Node B detects the Node A's direction as angle 0 degree because the RSSI of the Hello packet from angle 0 is the strongest among these three Hello packets. After that, Node B cyclecasts Hello packets as well. Table 2 (b) shows Node C's AST table after receiving Hello packets from Node B. Since Hello packets from Node B includes the information of Node B's AST table, Node C adds the information of Node B's AST table into its own AST table. As the benefit we record the angle of A, Node C can recognize that there is a path to Node A through B just towards to Node B with angle 0. In that sense, RMRP is suitable for small-sized networks not for large-sized ones. Therefore we design RMRP for small networks.

Periodical cyclecasting of Hello packets is based on a node synchronization with neighbors. Thanks to the synchronization, collisions of Hello packets are avoided. As shown in **Fig. 2**, Hello packets include the synchronization information. Each node has an AST timer. AST timer is set according to the first Hello packet; All Hello packets except the first one are ignored. A node begins to cyclecast Hello packets when the reminder of AstTimer/(MaxNumNodes × AstDuration) is equal to NodeID × AstDuration, where AstTimer is the AST timer; MaxNumNodes is the maximum number of nodes in a network; AstDuration is the time duration for cyclecasting to all directions. The timing

Table 2 AST table.

(a) Node B's AST table

ID	Angle	RSSI	Next	# hops
A	0	−40	-	0
A	30	−45	-	0
A	330	−45	-	0

(b) Node C's AST table

ID	Angle	RSSI	Next	# hops
B	*0*	*−40*	-	*0*
A	0	−40	B	1
A	30	−45	B	1
B	*330*	*−45*	-	*0*
A	330	−45	B	1

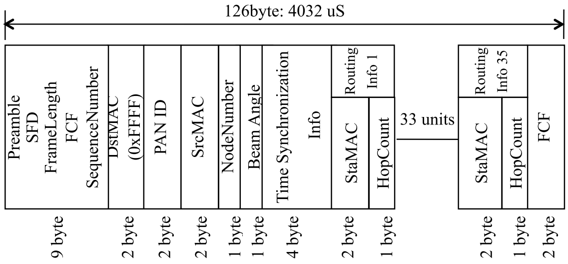


Fig. 2 Format of Hello packet.

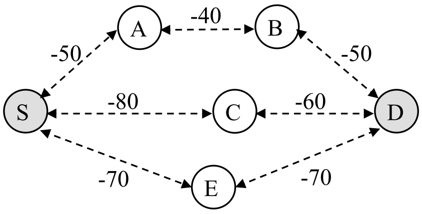


Fig. 3 Topology.

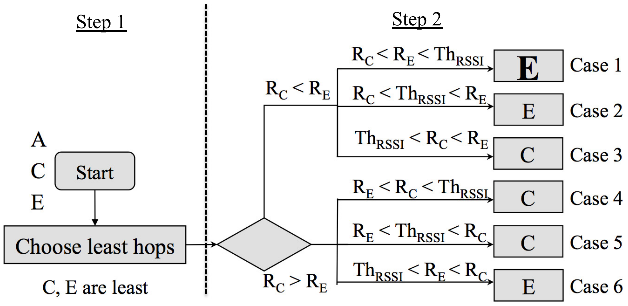


Fig. 4 Routing algorithm.

of Hello cyclecasting of all nodes is differentiated by AstTimer. Therefore, collisions of Hello packets never occur. Actually, the collision avoidance incurs overhead. However, since the proposed protocol assumes small-scale networks, we think that the simplicity is more important for the implementation than some performance degradations.

2.2 Routing Function Embedded in MAC Layer

Since conventional routing protocols such as DSR, AODV and OLSR are exaggerated specifications in some cases, we introduce a simple routing function in MAC layer, which uses only next hop node, RSSI value and number of hops to the destination. By means of the periodical Hello packet exchanges, each node has the information of the direction and the RSSI value to the neighbor. The proposed RMRP sets a threshold of RSSI value called Th_{RSSI}, which means a sufficient RSSI value of successful data transmissions. We set an appropriate Th_{RSSI} based on some experimental results, so the data arrival rate is almost 100% when the RSSI is greater than Th_{RSSI}. The proposed routing is based on a shortest-hop routing for its simplicity. In addition, increase of number of hops to the destination incurs intra-flow interference, which degrades end-to-end throughput. Therefore, we propose a routing protocol based on shortest-hop routing considering link reliability.

We show the routing procedure of the proposed RMRP using **Fig. 3** and **Fig. 4**. Figure 3 is a sample network topology. In the figure, the value near each link indicates the RSSI values. The routing procedure is shown in Fig. 4. In Step 1, the source node S selects the least number of hops to the destinations among all the route candidates. In this example, three routes: S → A → B → D, S → C → D and S → E → D are the candidates. The two routes via S-C and S-E have the least number of hops to the destination. Then go to Step 2. In Step 2, compare the RSSI values to the next hop and Th_{RSSI}. In the example, the RSSI values of link S-C (R_C) and S-E (R_E) are −80 and −70, respectively. In addition, we assume $Th_{RSSI} = -60$. In this case, $R_C < R_E < Th_{RSSI}$ (Case 1 in Fig. 4) holds; The route S → E → D is selected because link S-E seems to be more reliable than link S-C according to the RSSI value. As shown in Cases 1, 2, 4 and 5, more reliable link is selected basically. However, as shown in Cases 3 and 6, the least reliable link among the links which are greater than Th_{RSSI} is selected. In these cases, since the link has a sufficient RSSI value, the least reliable link is selected for the next hop to be more reliable. For example, we assume R_C, R_E and Th_{RSSI} are −40, −50 and −60, respectively. In this case, $Th_{RSSI} < R_E < R_C$ (Case 6 in Fig. 4) holds. As we expected roughly, the next hop C-D is more reliable than E-D.

2.3 Control Backoff Time

Simple backoff time value generation is one of the important issues for system implementations. The proposed RMRP uses RSSI value for backoff time value generation. The observed value of RSSI fluctuate naturally because of signal strength fluctuations. Therefore, the absolute value of RSSI can be used for controlling backoff time.

In the proposed RMRP, RSSI is also used for prioritization of links. The following two factors are considered for setting back off time (BoT) of a node. One is strength of RSSI; The other is number of hops to the destination node. In the proposed RMRP, backoff time of node i (μsec) is given as the following equation,

$$BoT_i = 8\{w_1|RSSI_{ij}| + w_2(h_i - 1)\}, \qquad (1)$$

where $RSSI_{ij}$ is the RSSI value (dBm) between node i and node j; Node j is the next-hop node. w_1 is a weight for RSSI strength; w_2 is a weight for number of hops. In addition, h_i is number of hops to the destination node D from node i.

As the first factor, we introduce the RSSI value to determine

BoT in the proposed RMRP. Each node has AST table (See Table 2), which includes RSSI value from neighbor nodes. According to the AST table, the backoff time for a node with strong RSSI is shortened. So these nodes have a high priority and can complete communication earlier, which can prevent the interference to the other nodes. In contrast, a long distance node with weak RSSI has a long backoff time, so the priorities become lower.

As the second factor, we introduce number of hops to determine BoT to make multihop communication smoothly. The backoff time of each node is set according to the distance (number of hops) from the source node. In other words, the backoff time of each node uses the number of hops in routing table. The backoff time for a link near destination is set shorter, and the backoff time near the source is set longer.

In general, directional antenna can mitigate interference to other communications because antenna gain for un-specified direction is quite small. Therefore, data contention occurs less frequently than omni-directional protocol. The total backoff time can be reduced due to less interference. Furthermore, if the backoff time of nodes with strong RSSI can be shortened, they can complete communication earlier, and mitigate the interference to the other nodes. Based on the observation, the backoff time should be used for prioritization of links rather than avoiding contentions in directional MAC protocol.

The range of backoff time of 8-bit random is $8 \times [0, 127]$ (μsec). We select a random value in [0, 127] (7-bit value, 1 bit is used for sign). As shown in Eq. (1), backoff time (BoT) should be a multiple of eight. Therefore, the range is $8 \times [0, 127]$ (μsec). The range of backoff time of RSSI is also $8 \times [0, 127]$ (μsec). In our testbed, RSSI is quantized to signed 7-bit integer $[-127, 127]$. Therefore, the absolute value $|\mathrm{RSSI}|$ is in the range of [0, 127]. Also in this case, BoT is a multiple of eight, so the range is $8 \times [0, 127]$ (μsec). On the other hand, the range of backoff time of the proposed RMRP is not a constant value. It depends on h_i, w_1, and w_2. For example, when $h_i = 5$ and $w_1 = 1$ and $w_2 = 25$, BoT is $8 \times \{[0, 127] + 25 \times (5 - 1)\} = 8 \times [100, 227]$ (μsec).

2.4 Other Detailed Features

The other detailed features such as the data frame structure and the carrier sense procedure are described as the following.

2.4.1 Data Frame Structure

We use DATA/ACK of IEEE802.15.4/Zigbee to perform handshaking for data communication. The data frame structure is shown in **Fig. 5**. The fields of the DATA are the following:

- DstMAC: Receiver MAC address
- SrcMAC: Transmitter MAC address
- StaMAC: Destination MAC address (Final recipient for multihop)
- BsrcMAC: Source MAC address
- TimeExceed: Lifetime of this packet
- Packet Type
  - 0: Data
  - 1: Time Exceed Error
  - 2: Routing Error
  - 3: Retry Error
  - 4: Queue Overflow

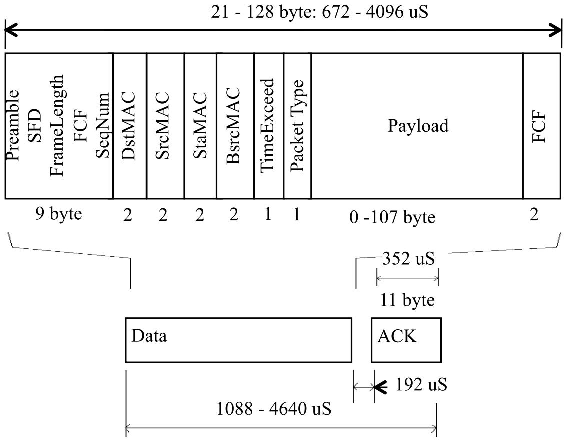
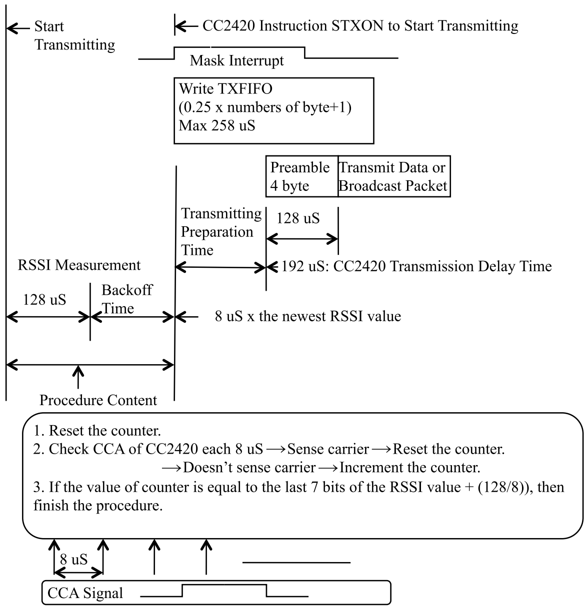


Fig. 5 Data structure.



1. Reset the counter.
2. Check CCA of CC2420 each 8 uS ⟶Sense carrier⟶Reset the counter.
⟶Doesn't sense carrier⟶Increment the counter.
3. If the value of counter is equal to the last 7 bits of the RSSI value + (128/8)), then finish the procedure.

Fig. 6 Event handling procedure.

2.4.2 Carrier Sense Procedure

Carrier sense is performed before transmitting data or cycle-casting Hello packet. The procedure is shown in **Fig. 6**. The granularity of carrier sense is 0.5 symbol (8 μsec) to know whether a signal is detected. As shown in Section 2.3, RSSI value of received packet is used to calculate the backoff time. RSSI is quantized to 7-bit value, so the maximum backoff time is $8\,\mu\mathrm{sec} \times 2^7 = 1.016\,\mu$ sec. Using ZigBee chip TI/Chipcon-CC2420 [16], an RSSI measurement needs $128\,\mu$sec to perform carrier sense, and transmitting preparation time needs $192\,\mu$sec.

3. Implementation

We implement the proposed RMRP on a testbed called UNAGI/ESPAR (UNAGI is a Japanese word meaning "eels"/Electronically Steerable Parasitic Array Radiator). The testbed uses the physical layer of IEEE 802.15.4, and ESPAR antenna as the directional antenna. The overview of testbed and the device list are shown in **Fig. 7** and **Table 3**, respectively.

As shown in Fig. 7, the testbed consists of the following four subsystems:

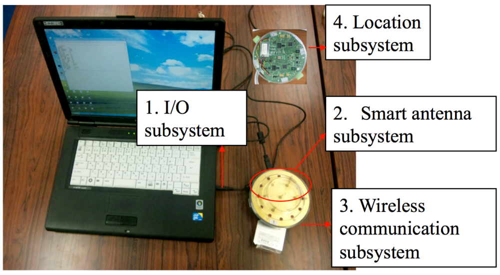


Fig. 7 Overview of testbed.

Table 3 Devices and specifications of testbed.

RF module	Chipcon CC2420 IEEE 802.15.4 2.4 GHz
Micro controller	ATMEL ATmega128L 8 MHz Flash memory 128 kbyte
GPS	FURUNO GN-80B1M
Gyroscope	Analog Device ADXRS401
Writer	ATMEL AVR ISP

(1) I/O subsystem,
(2) Smart antenna subsystem,
(3) Wireless communication subsystem,
(4) Location subsystem.

We use a laptop PC as an I/O subsystem to issue commands to control the experiments, and to collect logs and statistics. In the smart antenna subsystem, ESPAR antenna developed by ATR is used to form not only an omni-directional beam, but also a directional beam. In wireless communication subsystem, we use IEEE 802.15.4 and adopt all the frames of MAC protocol without 802.15.4 control frames. The frame structure is shown in Section 2. In the location subsystem, the micro controller of the wireless communication subsystem can acquire the location and angle information with GPS and gyroscope. More details are available in Ref. [11].

4. Experimental results and evaluations

We evaluate the proposed RMRP with some experiments using testbed implementation with ESPAR antenna and IEEE 802.15.4. We evaluate the following three situations: single-hop communication, single-flow multi-hop communication and multi-flow multi-hop communication. The initial parameters are set as the following:

(1) MaxNumNodes is eight,
(2) Th_{RSSI} is −40 dbm,
(3) AST timer is 1,000 msec,
(4) Transmission Power is 0 dbm.

The MaxNumNode is set beforehand as a system parameter. The proposed protocol is for relatively small networks. As shown in Fig. 2, the greatest value of MaxNumNode is 35 because of the packet format of Hello packets.

When we evaluate the following situation: single-flow multi-hop communication and multi-flow multi-hop communication in indoor environment, we placed the nodes in linear topology as shown in Fig. 14. The distance is set to 10 cm for each adjacent node.

4.1 Single-hop Communication

4.1.1 Fundamental Calculation

Before starting the experiment, we tune the parameter w_1 via a simple calculation. We calculate the throughput performance of the proposed RMRP in the case where two nodes exist in a single-hop communication to investigate how w_1 affects the performance. The calculation considers the overhead of MAC header, PHY preamble, FCS and inter frame duration such as SIFS. Channel rate is 250 kbps. **Figure 8** shows the throughput performance for various values of w_1. As shown in Section 2.4.2, a symbol duration is 16 μsec; Carrier sense granularity is 8 μsec. Due to hardware limitations, w_1 should be greater than 1. As shown in Fig. 8, the smaller w_1 makes the better throughput. Since throughput decreases quickly in smaller w_1, we set $w_1 = 1$ hereinafter.

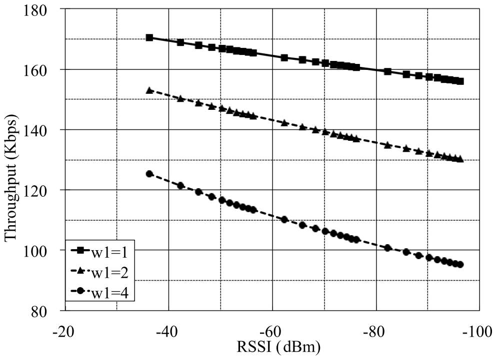


Fig. 8 Calculated throughput of single-hop communication.

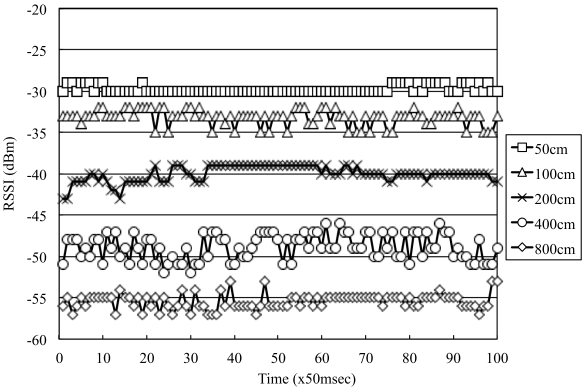


Fig. 9 RSSI fluctuation.

4.1.2 Experiment

We evaluate the proposed RMRP in the case where two nodes exist (single-hop communication).

The proposed RMRP uses the fluctuations feature of RSSI for controlling backoff time to avoid collision. The fluctuations occur even when nodes are static. We measure the RSSI fluctuation for various distances between these two nodes. **Figure 9** shows the experimental results of RSSI fluctuation for various distances between two nodes. In this figure, even nodes are static, RSSI fluctuation occurs. We also find that RSSI is almost a linear relation to the distance of these node. **Table 4** shows the average and standard deviation of RSSI. The results are calculated by 910 samples. In this table, we find that relative RSSI fluctuation is smaller in a long distance. From these results, we confirm that RSSI can be used for controlling backoff time in a real system.

4.2 Single-flow Multi-hop Communication

We evaluate the proposed RMRP in the case where six nodes exist (multi-hop communication) as shown in **Fig. 10**. In this case, a single flow from Node 6 to Node 1 exists; Nodes 5, 4, 3 and 2 relay data in a multi-hop manner. We use DATA/ACK handshaking of IEEE802.15.4/Zigbee. **Figure 11** shows packet arrival rate of each link versus average received power. In this figure, we observe that packet arrival rate between two nodes becomes almost zero when RSSI is greater than −60 dBm. Therefore, we select −60 dBm as Th_{RSSI}.

Figure 12 shows the throughput of each link of the proposed RMRP in the single-flow multi-hop communication. 8-bit random method means the conventional backoff time of IEEE 802.15.4. RSSI method means that only RSSI is used for controlling backoff time, that is $w_2 = 0$ in Eq. (1). As shown in this figure, the proposed RMPR achieves higher throughput than 8-bit Random and RSSI methods near the destination (Link 2→1).

Table 4 Average and standard deviation of RSSI.

	50 cm	100 cm	200 cm	400 cm	800 cm
Average (−dBm)	−30.80	−33.53	−41.02	−49.16	−54.42
Std deviation (−dBm)	0.51	0.97	1.46	1.62	1.12

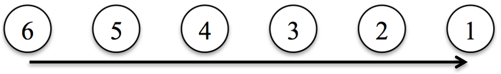


Fig. 10 Single-flow multi-hop communication.

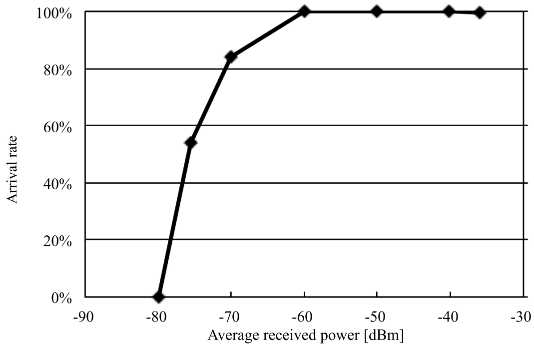


Fig. 11 Single-flow multi-hop arrival rate.

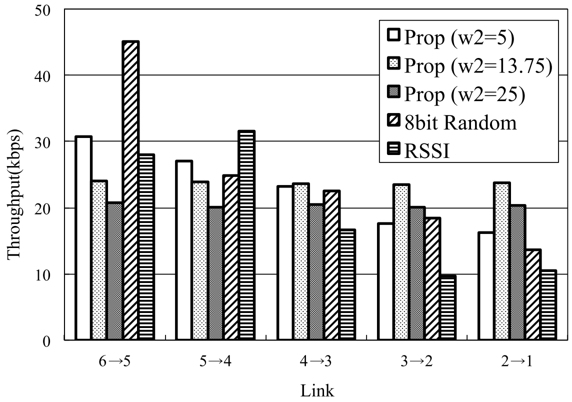


Fig. 12 Throughput of each link (single flow).

When w_2 is large, communication near the destination is more prioritized. In other words, in order to make the data stream of multihop communication smoothly, the backoff time for a link near destination should be set larger for throughput improvement. In this figure, the throughput improves gradually from $w_2 = 5$ to $w_2 = 13.75$. However, when $w_2 = 25$ is set, throughput gets worse than $w_2 = 13.75$. Therefore, too large value of w_2 incurs performance degradations. As shown in this figure, throughput of each link in $w_2 = 25$ is almost the same. This phenomenon means the occurrence of the bottleneck link near the source node (Link 6→5). Throughput degrades because of the bottleneck link, so we should set middle value of w_2 such as $w_2 = 13.75$.

Figure 13 shows the end-to-end throughput of the proposed RMRP in the same topology of Fig. 12. As well as Fig. 12, when $w_2 = 13.5$ is set, we can obtain the best end-to-end throughput achievement. Here, comparing Fig. 12 and Fig. 13, we find that the throughput of link 2→1 in Fig. 12 is quite similar to the end-to-end throughput in Fig. 13. For example, the throughput of link 2→1 of $w_2 = 5$, $w_2 = 13.75$ and $w_2 = 25$ in Fig. 12 are 16, 24 and 21 kbps, respectively. These values of throughput are almost the same in Fig. 13. Therefore, comparing the link throughput (Link 2→1) of the conventional 8-bit Random and the proposed RMRP ($w_2 = 13.75$) in Fig. 12, we confirm that the proposed RMRP can achieve almost 2.1 times (=24 kbps/11 kbps) of throughput. Because of the same reason of Fig. 12, w_2 has a peak in Fig. 13.

4.3 Multi-flow Multi-hop Communication

We evaluate the performance of the proposed RMRP in multi-flow multi-hop communications as illustrated in **Fig. 14**. In both cases, two flows: Flow 1 and 2 exist. **Figure 15** shows the aggregated end-to-end throughput of Flow 1 and 2 in Case 1. We find that both performances of these two flows have a peak when w_2 is almost 14. The reason of having the peak is the same as that of Fig. 12 and Fig. 13. In addition, we also find that throughput of Flow 2 is better than that of Flow 1. This is because the number of hops from the source and destination of Flow 2 is smaller than that of Flow 1. However, if we set appropriate value of w_2 such

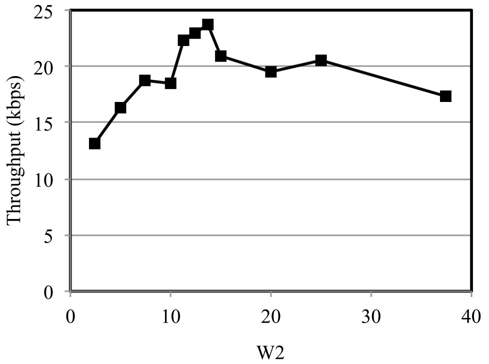
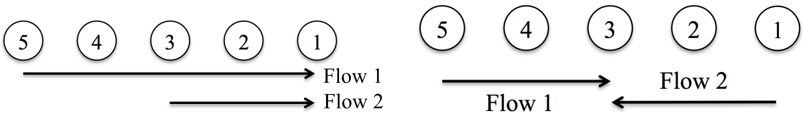


Fig. 13 End-to-end throughput (single flow).



(a) Case 1 (b) Case 2

Fig. 14 Multi-flow multihop communications.

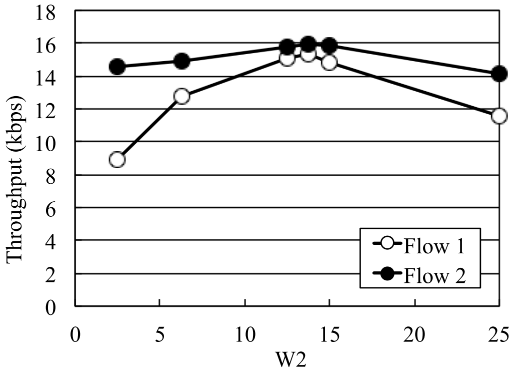


Fig. 15 Aggregated end-to-end throughput (Case 1).

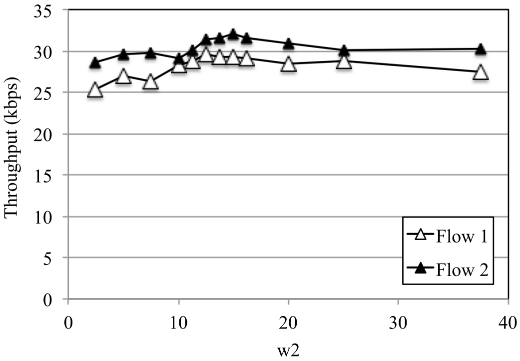


Fig. 16 Aggregated end-to-end throughput (Case 2).

as 14, the performances of these two flows are almost the same. From this result, we can show the effectiveness of the proposed RMRP with setting an appropriate value of w_2. Because of the same reason of Fig. 12, w_2 has a peak in Fig. 15.

We evaluate the uniform random number back off (8-bit random) in the multi-flow multihop communications shown in Fig. 14. The experimental results are shown below. The results are the average of two experiments.

- Flow 1: 11.8 kbps, Flow 2: 6.7 kbps, Total: 18.6 kbps

From these results, 8-bit random has 59 percent throughput of RMRP.

Figure 16 shows the aggregated end-to-end throughput of Flow 1 and 2 in Case 2. Also in this case, we find that these two flows can achieve maximum throughput with a middle value of w_2. In addition, the throughput of these two flows are almost the same for all values of w_2, so we can say that the proposed RMRP can share bandwidth fairly.

We evaluate the uniform random number back off (8-bit random) in the multi-flow multihop communications shown in Fig. 14. The experimental results are shown below. The results are the average of two experiments.

- Flow 1: 25.6 kbps, Flow 2: 31.1 kbps, Total: 56.7 kbps

From these results, 8-bit random has 93 percent throughput of RMRP. Since w2 does not affect when number of hop is always one in this case.

These experiments show the effectiveness of the proposed backoff method in both single-hop and multi-hop environments. The proposed backoff method is easily implemented in resource-restricted systems because it can handle MAC and routing functions without using much memory and CPU processing. We believe this work can contribute the use of directional antennas in ad hoc networks.

5. Concluding Remarks

In this paper, we have proposed and implemented a cross layer protocol for ad hoc networks using directional antennas. In the proposed protocol called RMRP, RSSI is used for computing the direction of the receiver and also used for controlling backoff time. Moreover, the backoff time is weighted according to number of hops from a source node. In addition, simple routing functions are introduced in the proposed RMRP. We have implemented the proposed RMRP on a testbed with ESPAR antenna and IEEE 802.15.4. From some experimental results, we have confirmed some throughput improvement and shown the effectiveness of the proposed RMRP. Especially, the proposed RMRP can achieve about 2.1 times higher throughput than a conventional random backoff protocol in a multi-hop communication scenario. As our future work, we evaluate more detailed performance of the proposed RMRP in more complicated network topologies. In addition, we have a plan to set backoff time adaptively according to a situation such as network congestions.

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Editor's Recommendation

This paper proposes a cross-layer protocol for ad hoc networks consisting of mobile nodes with directional antennas. The novelty of the proposed protocol is in the use of RSSI for computing the direction of the peer node and the backoff time for collision avoidance. Moreover, the proposed protocol realizes multihop communication by its built-in routing function. The authors implemented the proposed protocol with ESPAR antenna and showed that the packet delivery ratio of the proposed protocol is more than twice compared with existing methods in a testbed using actual devices. This protocol will contribute the advance of ad hoc networking with directional antennas.

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