Multi-Lobe Multicast using Directional Antenna for Network Coding in Multi-Rate Ad Hoc Networks

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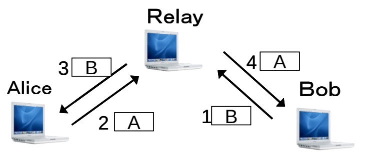
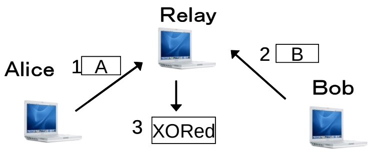
In this paper, we propose a multi-lobe directional transmission for network coding in multi-rate ad hoc networks to improve throughput performance of XOR-based WNC. The proposed scheme uses directional antennas that can make antenna beam forms with multiple main lobes. In the proposed scheme, a node transmits native packets with a beam form of one or multiple main lobe for realizing high-rate unicast transmissions. In addition, a node transmits XORed packets and native packets with a beam form of multiple main lobes with directional antenna to realize high-rate multicast transmissions. We evaluate and investigate the performance of the proposed scheme in terms of throughput via intensive computer simulations. The simulated results show that the proposed scheme can improve throughput performance of XOR-based WNC in some simple topologies such as 5 nodes straight line topology and X topology. In a fundamental evaluation, we have confirmed that the proposed scheme can achieve higher throughput than the conventional XOR-based WNC without using directional antennas in simple topologies. The proposed scheme is also applicable for other smart/directional antennas.

1. Introduction

Recently, the rapid progress in wireless technologies realizes wireless ad hoc networks, which have an advantage that they need no specific predefined infrastructure. Wireless ad hoc networks are applicable to a wide variety of fields such as transport systems, industry and agriculture. In wireless ad hoc networks, one of the current trends is to provide the physical layer multi-rate capability. Many wireless networking standards such as IEEE 802.11a, 802.11b and 802.11g support the multi-rate capability. For example, IEEE 802.11g supports the transmission rates of 1 to 54 Mb/s. Various medium access control (MAC) and routing protocols for ad hoc networks with rate adaptations have been presented; the multi-rate ad hoc networks work well in unicast transmission.



(a) Unicast Transmission



(b) WNC

Fig. 1 Formal unicast transmission and and WNC

On the other hand, wireless network coding (WNC) offers throughput improvement in wireless multihop networks. Among the techniques of WNC, XOR-based WNC is the basic and a promising technique for improving throughput in multihop networks[7]. A general process of XOR-based WNC includes transmissions. For example, we consider the well-known Alice-Bob topology in FIg. 1, in which *Alice* and *Bob* are connected with an intermediate node *R*. There are two bidirectional flows: *Alice-R-Bob* and *Bob-R-Alice* in the network. At first, *Alice* and *Bob* unicast packets to *R*, respectively. After that, *R* XORs two packets from *Alice* and *Bob*. After XORed the packets, *R* multicasts the XORed packet to *Alice* and *Bob* simultaneously. Fig. 1 shows the conventional unicast transmission and XORed based WNC. In Fig. 1, Alice have packet A to Bob, and node Bob have packet B to Alice. In Fig. 1(a), number of transmitted packets is four, while in Fig.1(b) shows that XOR-based WNC proceeding transmit only three because of

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coding two packets into XORed one packet. The multicast transmission rate is limited to the lowest link rate. For example, 5.5 Mb/s is selected as the multicast transmission rate when the rate of the link *R-Alice* is 5.5 Mb/s and that of *R-Bob* is 54 Mbps.

In this paper, we propose a multi-lobe directional transmission scheme for network coding in multi-rate ad hoc networks to improve throughput performance of XOR-based WNC. The proposed scheme uses directional antennas that can make antenna beam forms with multiple main lobes. In the proposed scheme, a node transmits native packets with a beam form of single lobe for realizing high-rate unicast transmissions. In addition, a node transmits XORed packets with a beam form of multiple main lobes with directional antenna to realize high-rate multicast transmissions. In general, the transmission of XORed packets is a bottleneck for performance improvement in XOR-based WNC. In the proposed scheme, the multi-lobe directional multicast is introduced to reduce this bottleneck; the rate of multicast transmissions (the minimum transmission rate among all the links between the source and its each neighbor node). We show the result of evaluation via computer simulation. This paper is organized as follows.

We introduce existing work related to the directional antenna and the wireless network coding in section 2. ESPAR antenna which is assumed as the actual directional antenna is introduced in section 3. We explain the detail of the proposed scheme in section 4. Section 5 presents the performance evaluation of the proposed scheme compared with the conventional unicast transmission in omnidirectional and XOR-based WNC in multilobe beam. Finally the section 6 is conclusion.

2. Related Work

Many conventional directional MAC and Routing protocols consider single lobe beam form1)2)3). Recently, the multi-lobe with high-gain multicasts that uses the directional antenna attracts attention. In multicasting of link-layer(MAC), low-gain omnidirectional transmission have the advantage that it is possible to transmit to a lot of neighbor nodes at the same time . On the other hand, a directional antenna which make a single lobe beam pattern transmits data with high-gain but its transmission is spatially restricted. In 4), the authors employ both omni and single lobe beamformed multicast to reduce multicast communication delay. It is enabled by combining single lobe directional transmission with high transmission rate and omnidirectional transmission with low transmission rate. In 5), the authors consider multi-lobe beam patterns to muticast data in wireless ad hoc network. The authors propose an efficient greedy algorithm that provides good performance better than the work4). As a research on other multi-lobe transmission, in 10), the authors consider twin lobes beam patterns to solve the deafness problem in using the directional antenna. In the work, a source node transmits RTS to two directions at the same time to solve the deafness problem and then improves throughput in unicast session. In this paper, we employ not only multi-lobe directional multicast but also wireless network coding to improve throughput in unicast session.

WNC offers throughput improvement and attracts attention in wireles multihop networks. The concept of network coding was introduced by Ahlswede et al. in their seminar paper6). COPE7) made the application of network coding popular to unicast sessions in wireless multihop networks. COPE was implemented in a real testbed and evaluated experimentally. BFLY8) was proposed based on COPE and was evaluated in computer simulation. Many methods concerning network coding have been presented. But those proposed schemes related WNC use the omnidirectional antenna . WNC with a directional antenna is not considered. Because it is difficult to multicast at a same time by a single lobe directional antenna. In this paper, the throughput of WNC is improved further by the multi-lobe directional high transmission rate multicast.

3. Directional antenna

In the proposed scheme, the multi-lobe directional multicast is introduced for reducing the bottleneck; the rate of multicast transmissions (the minimum transmission rate among all the links between the source and its each neighbor node) increases. We simulate the proposed scheme according to the actual antenna beam forms of the electronically steerable passive array radiator (ESPAR) antenna9), which is a representative smart antenna developed by ATR. ESPAR antenna is composed by seven antenna element, and it sends and receives signal by supplying the electric power to the element at the center. The beam form of the antenna is changed by the arrangement of the elements and controlling the voltage. The beam form of the ESPAR antenna is calculated by changing the parameter. We evaluate the proposed scheme using beam patterns of the ESPAR antenna calculated by computer simulations.

ESPAR antenna can make omnidirectional beam form as shown in Fig. 2 from the calculation of the computer simulations. The antenna gain is 3.6 dBi to all the directions when omnidirectional beam form is adopted. Also, ESPAR antenna can make various beam forms not only single lobe but also multiple beam forms. Fig. 3 shows the single lobe beam form of ESPAR antenna where the direction of the main lobe is 0 degree. Gains more than 0 dBi are plotted in the figure. The antenna gains are about 9 dBi when single-lobe is adopted. The antenna gains are about 7 dBi when twin-lobes is adopted. Fig. 4 shows the twin lobes form whose main lobes are toward 0 and 180 degrees. The antenna gains are about 7 dBi or 6 dbi when triple-lobe is adopted. Fig. 5 shows the triple-lobes whose main lobes are toward 0, 120 and 240 degrees. In the calculated beam form of ESPAR antenna, twin lobes and triple lobes beam forms are higher than omnidirectional beam form. However, the beam patten becomes nearly omnidirectional beam when becoming more than four lobes.

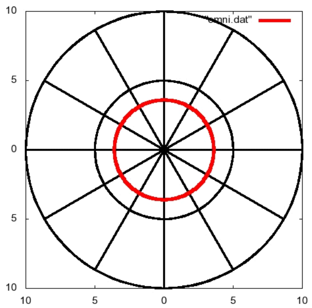


Fig. 2 Omni beam

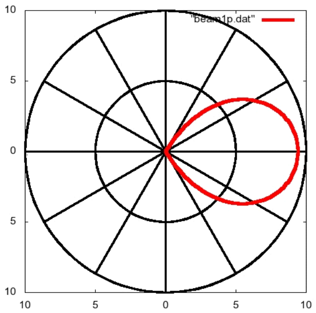


Fig. 3 Single lobe beam

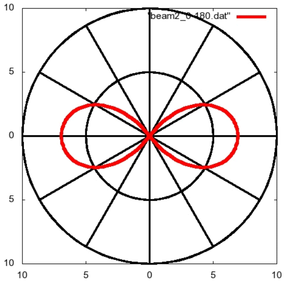


Fig. 4 Twin lobes beam

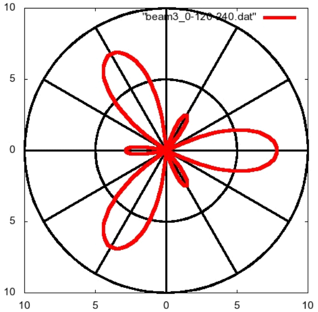
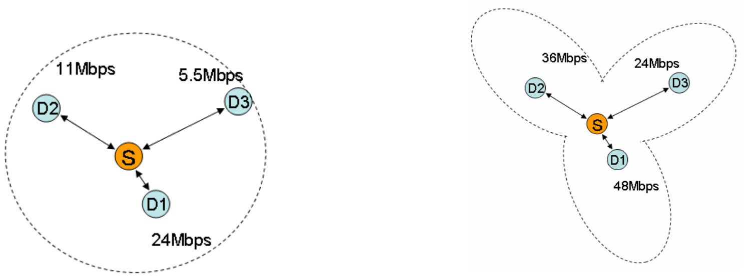


Fig. 5 Trile lobes beam



(a) Omnidirectional multicast

(a) Multi-lobe directional multicast

Fig. 6 Omnidirectional and multi-lo11be directional multicast

There is a problem in multicast/broadcast transmissions, in which a node transmits a packet to some neighbor nodes simultaneously (MAC level multicast/broadcast). When a node tries to multicast data to its neighbor nodes, the transmission rate is limited to the minimum rate. For instance, we assume a situation as Fig. 6a where a source node S and its three neighbor nodes $D1$, $D2$ and $D3$ exist. We also assume that the transmission rates of each link are the following: $S\text{-}D1 = 5.5$ Mb/s, $S\text{-}D2 = 11$ Mb/s and $S\text{-}D3 = 24$ Mb/s, respectively. The difference of the transmission rate is due to the distance, the radio propagation environment and so on. In this case, S has to transmit multicast packets at 5.5 Mb/s, which is the minimum rate available among the neighbors, so that all the neighbors receive packets reliably. To solve the rate limitation, a multicast

Table 1 Relation of the transmission rate and reception power

1 Mbps	-94 dbm
2 Mbps	-93 dbm
5.5Mbps	-92 dbm
6 Mbps	-86 dbm
9 Mbps	-86 dbm
11 Mbps	-90 dbm
12 Mbps	-86 dbm
18 Mbps	-86 dbm
24 Mbps	-84 dbm
36 Mbps	-80 dbm
48Mbps	-75 dbm
54 Mbps	-71 dbm

transmission with directional antennas has been presented for multi-rate ad hoc networks. The directional multicast transmission uses the smart antenna that can make a beam form with multiple main lobes. In the multi-lobe directional transmission, a high antenna gain toward the direction of the neighbor node with the minimum transmission rate, *D1* in the previous example, pushes up the minimum transmission rate. This scheme can push up the rate of multicast/broadcast transmissions. Fig. 6(b) shows transmission rate of each links pushed up by directional antenna that make a multi-lobe beam form. In Fig. 6 case, pushed up transmission rate of each links are the following: *S-D1* = 24 Mb/s, *S-D2* = 36 Mb/s and *S-D3* = 48 Mb/s. So, *S* can transmission multicast packets at 24 Mb/s.

On the other hand, WNC delivers a packet to two or more neighbor nodes by a transmission. We expect that the use of multiple lobes improves the throughput performance in multicast transmissions. So, if each node can make multiple lobes, WNC will improve throughput.

On the other hand, WNC approach delivers a packet to two or more neighbor nodes by a transmission once. High transmission rate multicast using the multi-lobe directional beam can improve thorughput more than in omnidirectional.

4. Multi-Lobe Multicasting for network coding

In this section, we explain about the proposed scheme in X topology as shown in Fig. 7. The proposed scheme is applied in X topology. In X topology, two source nodes S1 and S2, and two destination nodes D1 and D2 and one relay node R exist. Source node S1 has packets to node D1 and source node S2 has packets to node D2. These two flows need relay node R to deliver packets to the destination node. In this topology, If each node uses omnidirectional antenna, transmission range is limited. For example, node S1 transmission range is within node S2 and node R and node D2, node D2 is out of the node S1's transmission range. All nodes are in Fig. 7 within the Node R's transmission range. The proposed scheme uses the following procedures to multicast for that source node makes multi-lobe beam. We assume that each node knows the position of neighbor nodes beforehand, and sets the beam form beforehand.

- At first, each node in the network exchanges Hello packets in omnidirectional antennas periodically to know the neighbor nodes' locations for controlling the direction of multiple main lobes before source nodes transmit data.
- Secondly, each node discovers the topology that makes X type as shown in Fig. 7. In Fig. 7, node R can know that R is at the center of the X topology.
- Next, node R discovers the flows of X type from transmission of packets.
- Node R asks a source node S1 to multicast to the node R and node D, and asks a source node S2 to multicast to node R and node D1. In X topology, node R XORs the packets and transmits to node D1 and node D2. Node D1 and node D2 decode XORed packets to native packets. So, node S1 and node S2 multicast native packets to node D2 and node D1 for decoding the XORed packets.
- Source nodes and a relay node calculate the transmission rate for each link, then decide minimum transmission rate for its destinations to receive the packet. In X-topology, two source nodes and node R multicast with multi-lobes directional beam. For instance, source node S2 make a twin lobe beam as shown in Fig. 7.
- If each node decides the transmission rate for muticasting, a suitable beam is formed to start trasmission.

In this paper, we consider the physical layer of the IEEE 802.11g. IEEE 802.11g supports multiple transmission rates from 1 to 54 Mb/s. The most suitable transmission rate is chosen by calculating the reception power *Pr*. In Table 1, we show the relationship between the transmission rate and reception power in

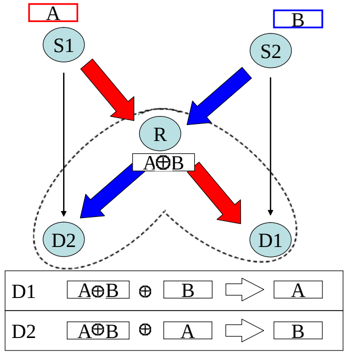


Fig. 7 Performance of WNC in X-topology

IEEE 802.11g. For example, if the reception power is -85 dBm, the transmission rate is 18 Mbps .

In this paper, we apply XOR-based simple network coding. XOR is performed with 2.5 layer between the routing layer and MAC layer. The XORed packet is generated by two different native packets of the next-hop address. The XORed packet is transmitted in 1way whereas the native packet is 4way in CSMA/CA. Even if a packet disappears by a collision in the transmission of the XORed packet on the way, it needs not to be retransmitted. In this evaluation, loss of the packet must not happen. Then, all XORed packets are assumed to be able to decode. We assume each node outputs queue is bounded at 100 packets.

5. Evaluation

In this section, we evaluated the performance of the proposed multi-lobe multicast for network coding. We evaluate throughput with two different topologies, 5 nodes straight line topology and X-topology. We compare the throughput with proposed scheme, CSMA/CA and also, CSMA/CA with network coding. In these topologies, we set the route that is from a source node to a destination node, and the multi lobe beam patterns of each node is set beforehand.

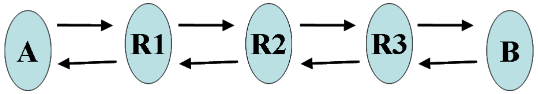


Fig. 8 5 nodes straight line topology

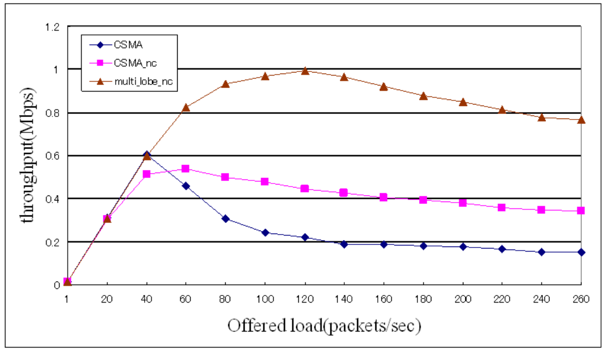


Fig. 9 Result of the straight line topology

5.1 Evaluation in 5 nodes straight line topology

We assume 5 nodes straight topology as shown in Fig. 8. In the topology, the existing flows are two that node A has packet A to node B, and also node B has packet B to node A. Each packet must multi-hop to deliver destination node. The distance between the nodes is 140m and omnidirectional transmission range is 150m in radius. The proposal scheme can be applied even in this topology. Since two different source nodes and two different destinations exist. However, because it is not X topology, it need not be a multicast as for native packet to decode. In this topology, 2 Mb/s is selected as each omnidirectional transmission. On the other hand, the proposed scheme uses the single lobe beam form and the twin lobes beam form. Node A and node B's neighbor is one, so nodes A and B uses the single lobe toward its neighbor node, respectively. On the other hand, evaluation of the proposed scheme uses a single lobe beam form and twin lobe

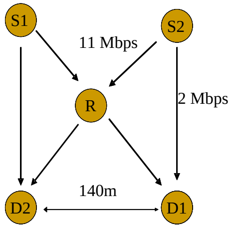


Fig. 10 X-topology in omnidirectional.

beam forms. Node A and node B's neighbor node is only one. So, the two nodes make a single lobe toward its neighbor node. However three relay nodes node R1, R2 and R3 select a twin lobe beam form. because the three relay nodes need to multicast the XORed packets toward neighbors. In this case, if a single lobe beam form is adopted, the transmission rate is 18 Mbps. And if twin lobe beam form is adopted, the transmission rate is 11 Mbps. We show the simulated result where five nodes are arranged in a straight line in Fig. 9. XORed packets are transmitted by CSMA/CA without ACK (one way), so DATA packets are lost due to data collisions. The performance of CSMA/CA with network coding is worse than that of CSMA/CA. This is because the packet loss occurs frequently because of the data collision in CSMA/CA with network coding. In CSMA/CA, the data collision does not happen easily because nodes turn waiting status until the communication of neighbor nodes end by using the control packet of a small size. In addition, in Fig. 9, throughput of the proposed multi-lobe transmission is about two times higher than CSMA/CA which uses omnidirectional communications.

5.2 Evaluation in X-topology

We evaluate the proposed scheme in X-topology as shown in Fig. 10. In this evaluation, we also evaluate the proposed scheme changed packets loss rate. In this topology, the link between S2 and D1 is 2 Mb/s; the link between S2 and R is 11 Mb/s. So, when we apply WNC, node S1 and S2 select 2 Mbps to multicast the packet in omnidirectional. When we apply conventional multi-hop approach, each source node transmits the packets at 11 Mbps.

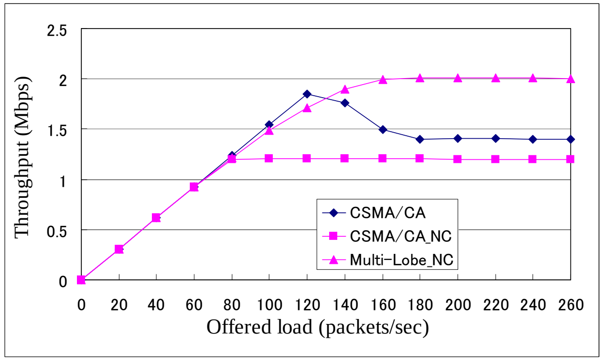


Fig. 11 Result of X-topology.

In this topology, two source nodes S1 and S2 exist. S1 has packets to D1; S2 has packets to D2. These two flows need relay node R to deliver packets to their destination. In the omnidirectional transmission, the transmission range is limited only to its neighbor nodes. For example, S2, R and D2 are within the transmission range of S1.

We compare with evaluation of CSMA/CA , CSMA/CA with WNC, and proposed scheme. We suppose that the packet loss does not happen in this evaluation. We show the result of CSMA/CA, CSMA/CA with network coding, and proposed scheme in Fig. 11. When CSMA/CA and CSMA/CA are compared, we found that throughput in multi-hop communication at 11Mbps is higher than WNC at 2 Mbps. As shown in Fig. 11, CSMA/CA with network coding is not always good choice in comparison with CSMA/CA. This is because the transmission rate in CSMA/CA with network coding is much lower than the transmission rate in CSMA/CA. The network coding improves throughput of the network. But WNC at 2 Mbps is much low transmission rate to improve throughput in the multi-hop communication at 11 Mbps. On the other hand, As shown in Fig. 11, proposed scheme achieves throughput that is higher than CSMA/CA and CSMA/CA with network coding. This is because the transmission rate that is higher than omnidirectional is selected by the multi lobe multicast.

Next, we evaluate the proposed scheme changed packets loss rate in various ways. We show the result in Fig. 12. In this graph, *p_ loss* means the packet

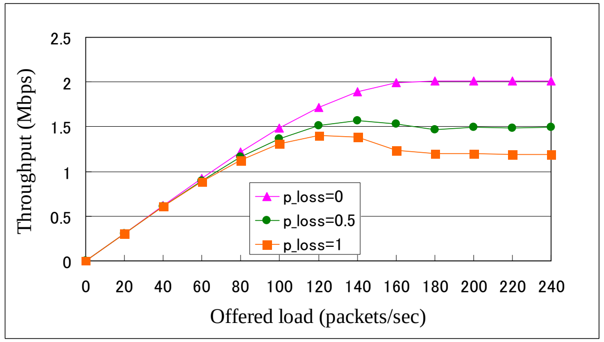


Fig. 12 Throughput performance in various packets loss rates

loss rate.In this evaluation, we assume that packet lost rate is fixed 0 in the link of node R and node S1, node R and node S2, node R and node D1, node R and node D2. *p_loss* changes in link of S1 and D2, link of S2 and D1. As shown in Fig. 12, if *p_loss* is 0.5 , the throughput falls by almost 25%. And if *p_loss* is 1, compared with the case of *p_loss* is 0, the throughput falls by almost 40%. The reason that throughput does not fall to almost 0 is node D1 and node D2 receive a a lot of native packets from node R. The frequency in which the node R transmits native packets increases by the deafness problem. If the deafness problem can be solved, the ratio of the XORed packets can be increased.

6. Conclusion

In this paper, we proposed multi-lobe multicast in multi-rate for network coding. The proposed scheme uses directional antennas that can make antenna beam forms with multiple main lobes. We evaluated and investigated the performance of the proposed scheme in terms of throughput via intensive computer simulations. We showed the evaluation of the proposed scheme that has higher throughput than CSMA/CA of omnidirectional beam. The proposed scheme is also applicable for other smart/directional antennas. We will consider the detail of proposed scheme for more complicated topology, grid topology and so on in the future. We confirmed the deafness problem in the directional antenna decreased the coding probability. It is necessary for us to consider the coping process.

7. Acknowledgments

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