An approach towards improving Quality of Service in ad hoc networks with ESPAR Antenna

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ABSTRACT- SDMA(Space Division Multiple Access) by directional and adaptive antennas realizes not only the throughput improvement but also the less delay, the simultaneous connections within omni-range, the larger number of link-candidates for multihop routing to improve reliability and the improved scalability. This paper proposes adaptive MAC protocol for SDMA for the improved QoS assurance, which can maintain the direction information of such antennas for transmission and reception in each terminal with less overhead and controls the beams of four-way handshake. In addition, we study the system performance to evaluate the total communication efficiency(i.e. the improved performance by SDMA including the overhead for maintenance) for various beam-widths, velocity and node density.

1. INTRODUCTION

The recent progress of wireless communication and personal computing leads to the research of wireless ad hoc networks[1,2], which are temporally and rapidly deployable without infrastructure. In wireless ad hoc networks, not only the scarcity of radio frequency but also the throughput degradation by multihop limit the QoS(Quality of Service), such as bandwidth(throughput), delay and reliability. Therefore, the enhancements on all OSI layers to increase the spectrum efficiency and to support the required QoS are needed.

When we focus on MAC layer, QoS assurance is very difficult in conventional ad hoc network with omni antenna because of poor media utilization at MAC layer. Whatever may be the routing scheme, if the MAC is inefficient, QoS can not be assured. The approach which is taken in this paper is the utilization of directional and adaptive antennas in order to offer improved medium utilization efficiency for QoS assurance. The SDMA(Space Division Multiple Access) by directional and adaptive antennas realizes not only the throughput improvement but also the less delay, the simultaneous connections within omni-range, the larger number of link-candidates for multihop routing to improve reliability and the improved scalability.

We are working towards implementing Wireless Ad Hoc Community Network (WACNet) testbed[3] and have developed the key technologies to realize the enhancement of throughput through SDMA. The key features of WACNet are i) the use of small, low-cost directional and adaptive antennas, known as ESPAR (Electronically Steerable Passive Array Radiator) antenna, suitable for user terminals[4,5,6] and ii) implementation of adaptive MAC and routing protocol to exploit the capabilities of directional and adaptive antennas. The higher frequency utilization can be achieved with the sharper beam pattern. However, <u>at first</u>, in order to start communication with directional and adaptive beams, it is necessary for each base-station or terminal to know the information(such as node-ID, direction, link quality, etc) of the target nodes, beforehand(The necessity of angle information to start communication with directional antenna is clear. In adaptive antenna, since the beam and null for transmitter cannot be formed without any reception of packet, it's required for the initial packet to be transmitted by directional antenna which directs the beam for the target node). <u>Secondly,</u> this overhead of neighbor information is a serious problem in wireless ad hoc networks, especially which consist of only distributed mobile terminals without base stations. <u>Thirdly, adequate beam control of four-way handshake is required for SDMA under the pre-collected information about the target nodes.</u> <u>Fourthly</u>, in order to maintain the information of moving target terminals, the shorter interval for update is required for the narrower beam-width. Consequently, although the narrower beam can realize the higher frequency utilization, it requires the shorter update interval for maintaining neighborhood information in each user terminal. Therefore, the issues to meet QoS requirements are not only to study MAC protocol with less overhead for maintaining the information of the target nodes, but also to study the total communication efficiency(i.e. the improved performance by SDMA including the overhead for maintenance for various beam-widths, velocity and node density).

<u>Thus, in Section 3 &4,</u> we propose and evaluate adaptive MAC protocol (MAC_2) which controls the beams of four-way handshake and can maintain the direction of information of antennas for transmission and reception with Angle-Signal Table and has much less overhead than our earlier work(MAC_1) using Angle-SINR Table[7]. Also, the relations among communication efficiency, the effective beam-width of directional and adaptive antennas, the overhead for acquiring neighborhood information mobility and node density are analyzed <u>in Section 4.</u>

2. ESPAR ANTENNA

Although the adaptive array antennas are normally digital beamforming (DFB) antennas, ESPAR antenna[3,4,5,6] relies on RF beamforming which drastically reduces the circuit complexity. The ESPAR antenna consists of one center element connected to the source (the main radiator) and several surrounded parasitic elements (typically four to six) in a circle. By adjusting the value of the reactance that terminates the parasitic elements forms the antenna array radiation pattern into different shapes, namely, omni-mode, sector-mode, rotational-sector-mode and adaptive-mode. Rotational-sector-mode is the steerable beam, namely 360 degree sweeping. In adaptive-mode, seven-element ESPAR antenna can steer beam and null in arbitrary directions with a simultaneous 8dBi beam gain and -30dBi [5]. Since the ESPAR antenna would be a low-cost, low-power, small-sized antenna, it would help to reduce the power consumption of the user terminals in WACNet and would be able to deliver all the advantages of directional and adaptive antennas.

3. MAC PROTOCOLS WITH ESPAR ANTENNA IN WACNet

In the proposed scheme(MAC_2), the data communication based on IEE802.11 MAC protocol is performed during the interval of periodic table production phase. Also, a training sequence is added to each frame to enable the receiving and transmitting antennas to steer its beam and nulls and shift into adaptive-mode.

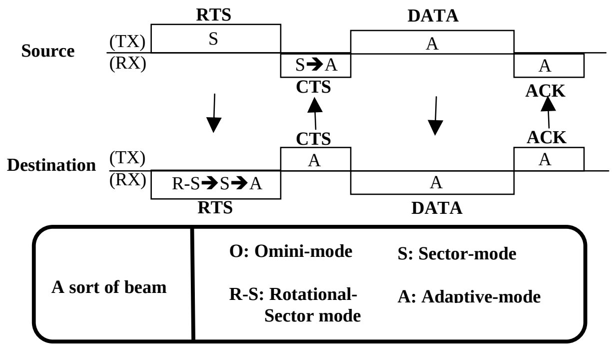

Figure 1: Example of antenna modes of 4-way-handshake in MAC_2

Figure 1 shows example of the usage of antenna modes of 4-way-handshake in MAC_2. Although adaptive antenna can track the moving terminals, the beam and null cannot be formed without reception of a packet. Therefore, sector mode is used in RTS-transmition. Moreover, rotational-sector mode is used at the beginning part in RTS reception, because the waiting node doesn't know from what direction the directional-RTS will come. Also, sector mode is used at the beginning of CTS-reception, because the receiving node doesn't received the training sequence but know the angle of destination from Angle-Signal Table. Note that the duration of RTS is twice of that of RTS in IEE802.11 MAC. The directions of RTS-transmition and CTS-reception can be obtained from the following periodic Angle-Signal Table.

3.1 MAC_1 Scheme with Angle-SINR Table

In order to form Angle-SINR Table, the following steps are performed periodically by any node n asynchronously:

- -Whenever the medium is free, node n sends an omni-directional SETUP packet to its neighbors.
- -Node n steers its directional antenna and sends a directional request(RQ:ReQuest) at each direction in the form of a directional broadcast, sequentially in all directions.
- -After receiving SETUP from n, each node i in the neighborhood of n will wait in receive-mode for a pre-specified amount of time to make sure that the directional broadcasts(sequential RQs) by n in all direction are over.
- -Node i sends this information to node n as a reply-packet (RE:REply). RE is treated as a data packet. After receiving this information from all the neighbors of n, the Angle-SINR Table of n would be complete.

This protocol with Angle-SINR can collect neighborhood information periodically in both indoor and outdoor <u>without the help of GPS.</u> However, since the interfering conditions easily change by the bursty nature of packet, it is not adequate to use SINR for angle estimation. Another problem of MAC_1 is the overhead. In order to build Angle-SINR Table in the transmitting node of SETUP and RQs, all the surrounding nodes always must answer the received SINR values through RE, namely as data packets of four way handshake.

3.2 Proposed MAC_2 scheme with Angle-Signal Table

In the proposed MAC protocol with Angle-Signal Table, each node periodically performs the following steps.

- -Each node n, which has the neighbors, i, j, k, always waits in rotational-sector mode(Node n steers its directional antenna and senses the received signal at each direction in the form of the sequential directional receivings in all directions).
- -Whenever the medium is free, each node sends an omni-directional beacon(two sequential packets) to its neighbors. The first beacon packet helps the receiving node in rotational-sector mode to sense whether a beacon is being transmitted or not. Then the receiver receives and decodes the second beacon packet. The second packet contains the node id. The time to rotate in all directions is less than the duration of one packet.
- -In rotational-sector mode, when node n senses the first packet of a beacon from another node i in one of rotational sector during its rotation, node n stops rotating in that sensed sector in order to receive the second packet of the beacon from i. The signal level of the second packet is measured, node id of i is decoded, and the sensed sector is the angle of the neighbor i which transmitted that beacon.
- -Node n fills the column of Angle-Signal Table of node n for node i. ANGLE n,i (t) is the direction of received sector from node i to node n, and SIGNALn,i (t) is the received

signal level from node i in that sector of node n, at that instance of time t.

-Node n accumulates the entire column of the Angle-Signal Table of n for node i, j, k, by receiving beacon from node i, j, k, one after another (Table I).

Table I: Angle-Signal table for node n

Neighbors of node n	**Azimuth Angle(degree)**	**Signal level**
i	$ANGLE_{n,i}$ (t)	$SIGNAL_{n,i}$ (t)
j	$ANGLE_{n,j}$ (t)	$SIGNAL_{n,j}$ (t)
k	$ANGLE_{n,k}$ (t)	$SIGNAL_{n,k}$ (t)

In this MAC_2 with Angle-Signal Table, it is enough to send only two packets as beacon without many directional-RQs nor RE. Moreover, this MAC_2 can avoid the problem of the interference in Angle-SINR Table of the MAC_1 protocol, because the proposed MAC uses as link quality parameter not SINR but signal level in order for each node to estimate the angle of the neighbors.

Thus, here proposed adaptive MAC_2 protocol with Angle-Signal Table, realizes for each node to keep the angle information in indoor and outdoor with less overhead than before and without the influences of the interference. This angle information is not only necessary to start communication with directional and adaptive beams, but also useful for effective routing protocols in SDMA. Also signal information can be used for link-state routing.

4. EVALUATION

4.1 Angle-Signal Table

In order to compare Angle-SINR Table and Angle-Signal Table, let us assume that packet transmissions from each node for these tables don't collide and that the packet lengths of SETUP, RQ, RTS, CTS, DATA and ACK are same. When each node with range of R[m] moves with V=2R, R, R/2, R/4[m/s] and one neighbor locates R/2[m] away in the center of the beam, the effective angular width of sector beam is 60 degree, we can assume, as example, (3R/8)/V[sec] interval for the update of Angle-SINR or -Signal Table in order for node A to track node B by one sector beam among six 60°-sectors. For approximately 220usec per packet (IEEE802.11b based), the occupied times and ratios for each node by Angle-SINR and -Signal Table among (3R/8)/V[sec] interval is shown in Table II & Figure 2. It is clear that Angle-Signal Table is effective for the reduction of overhead, especially for 12 neighbors, because of the deletion of RE packets. Since the overhead of Angle-Signal Table is reduced to 14.9% (four neighbors) and 10.0% (twelve neighbors) from those of Angle-SINR Table, the occupied ratio of Angle-Signal Table is always less than 15% among for all table update intervals.

Table II: Occupied time by Table update

	4 neighbors	12 neighbors
Angle-SINR Table	14.74ms	56.98msec
Angle-Signal Table	2.2ms	5.72ms

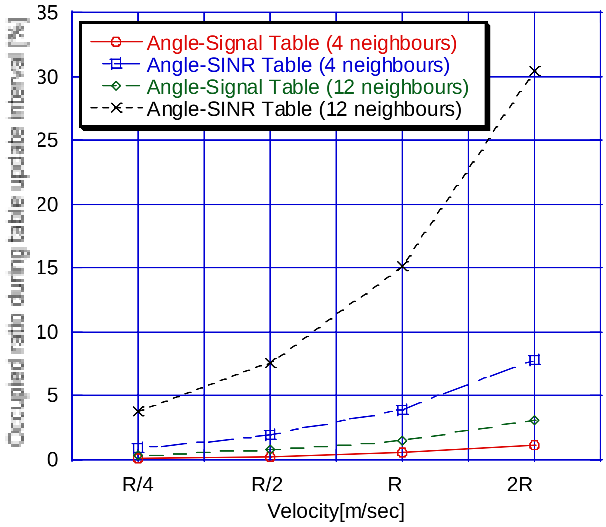

Fig. 2: Occupied ratio during table update interval

4.2 Communication Efficiency

We present simulation results for ad hoc networks with 100 and 200 and 400 mobile hosts, operating at a transmission range of R[m]. The environment is assumed to be a closed area of 8R x 8R square meters in which mobile nodes are distributed randomly. The speed of movement of individual node ranges from 2R[m/sec] to R, R/2 and R/4[m/sec]. Each node starts from a home location, selects a random location as its destination and moves with a uniform, predetermined velocity towards the destination. Once it reaches the destination, it waits there for a pre-specified amount of time, selects randomly another location and moves towards that. However, in the present study, we have assumed zero waiting time to analyze worst-case scenario. For simplicity, we assume that $SIGNAL_{nm}(t)$ to be equal to $SIGNAL_{mn}(t)$ and the transmission range R for all the nodes are equal. The effective width of directional beam changes from 2º to 10º, 20º, 30º and 60º. In the simulation, 30000 runs are done with 1msec interval.

In order to evaluate the improvement in one-hop communication efficiency, each node is assumed to establish a connection and communicate with one of its neighbors (randomly selected) for 1msec at 4msec interval. The ratios of number of successful communication events per minute and the number of intended communication per minute, which will be the single-hop communication efficiency of the system without overhead, are shown in Figure 3. Communication efficiency depends not on velocity but on beamwidth and node density. The performance improvement by the narrower beam is significant in higher offered load, because the sharper beam occupies the smaller area. The beamwidth reduction from 60º to 2º produce 10.6%(n=100), 22.3%(n=200) and 36.6%(n=400) improvement of communication efficiency. Since 6.1 /12.9/26.3 average nodes within the omni range in n=100/200/400 correspond to 59º/27.9º/13.7º beamwidths, the sharper beams contribute to the 10% improvement of communication efficiency in all cases. This means that the narrower beams of n=100 costs more than those of n=200/400. Meanwhile, since 80% communication efficiency is achieved by 60º in n=100, power control to keep low the number of nodes within the range is equally important as is the case with SDMA by sharper beam, in order for the higher communication efficiency without overhead where there is no influence of velocity. Communication efficiency saturates at 87-90%, because 13-10% neighbors are under communication.

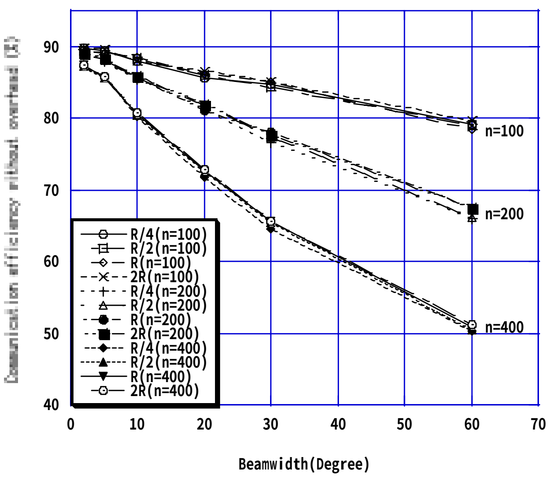

Fig.3: Communication efficiency without overhead

The communication efficiency with the overhead of Angle-Signal Table is evaluated for given beamwidth, velocity and the number of nodes(Figure 4&5&6). This efficiency including overhead is the ratio of {Number of successful communication events per minute) × [1-(overhead of Angle-signal Table[%])/100] } and the number of intended communication per minute. And the following formula is used for the overhead calculation.

(Overhead percentage of Angle-Signal Table among update interval[%])

={(Two packet length for beacon)

× (Average number of nodes within the omni range)}

/ (Average time within the directional beam)

This communication efficiency with overhead is the total performance of communication efficiency without overhead and the overhead by Angle-Signal Table. In case of 100 nodes, since overhead is only few percentage from 60º to 20, the impact on overhead by the narrower beam is not visible, but it's obvious from 10º to 2º(Figure 4). As the number of nodes increases, the efficiency with overhead degrades according to the mobility(Figure 5&6) especially in narrower beam. For example, 7.7% degradation for 5º in n=100 gets 32.8% in n=400.

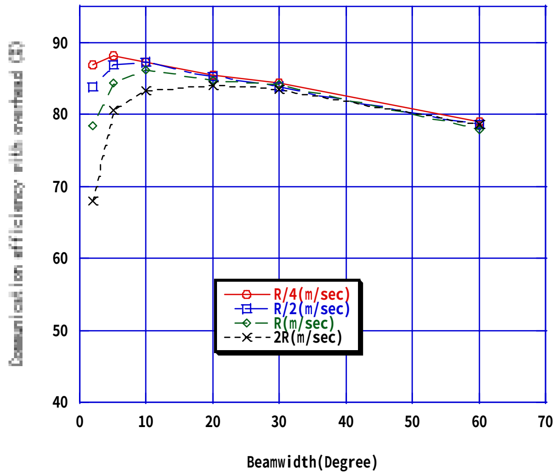

Fig.4: Communication efficiency with overhead (n=100)

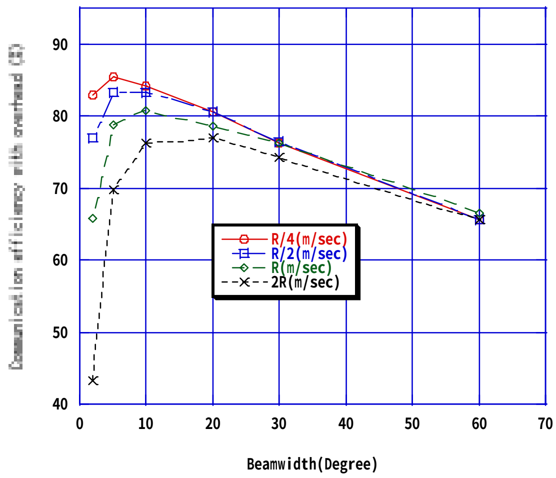

Fig.5: Communication efficiency with overhead (n=200)

The best beamwidths for each velocity and the number of nodes(of which efficiency is the maximum), and its efficiencies including overhead are presented in Table III. The best beamwidth depends not on the number of nodes but on the velocity and the sharper beam is not desirable in high mobility(5°[V=R/4], 5-10°[V=R/2], 10°[V=R], 20°[V=2R]). From this table, we can learn that, under the condition with overhead where the velocity has the influence on the performance, the range decrease by power control with wider beam is essential for the higher communication efficiency, because the reduction of the overhead for Table maintenance is greater than the SDMA degradation. For example, since the range reduction to the half length corresponds to the quarter node density and the double speed, 71.0% efficiency with 10° in n=400 increases to 84.0% with 20° in n=100. Note that the range increase with sharper beam doesn't help the performance, because the overhead volume is larger than the SDMA improvement(For instance, since range increase to the twice length corresponds to the mobility reduction to the half speed and the node density to four times, 86.1% with 10° in n=100 degrades to 75.9% with 5° in n=400).

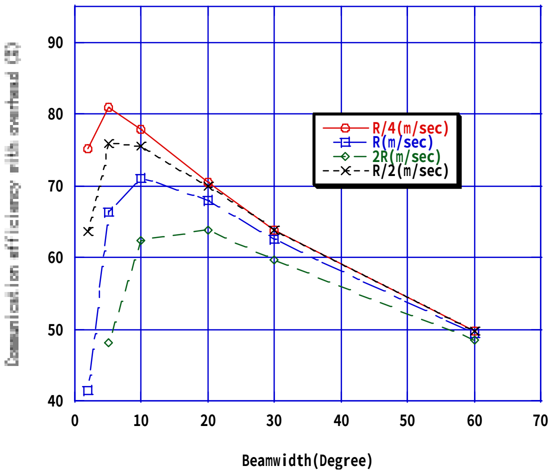

Fig.6: Communication efficiency with overhead (n=400)

Table III
Best beamwidth and its communication efficiency including overhead

	Best beamwidth [Degree] (Communication efficiency with overhead [%])			
	V=R/4	V=R/2	V=R	V=2R
n=100	5° (88.2)	10° (87.2)	10° (86.1)	20° (84.0)
n=200	5° (85.6)	5°&10° (83.2)	10° (80.7)	20° (77.0)
n=400	5° (81.0)	5° (75.9)	10° (71.0)	20° (63.9)

5. SUMMARY

Adaptive MAC protocol for seamless SDMA ad hoc services, where each node periodically collects its neighborhood information and forms Angle-Signal Table with less than 15% overhead of Angle-SINR Table, and where the beams of four-way handshake are controlled adequately, is presented and evaluated. The system performance of this MAC protocol is analyzed in terms of the communication efficiency, considering the effective beamwidth of directional antenna, the overhaed for updating Angle-Signal Table and mobility. Simulation results show that

i) the narrower beams of n=100 is costlier than those of n=200 and 400,

ii) power control to keep low the number of nodes within the range is equally important as is the case with SDMA by sharper beam, in order for the higher communication efficiency without overhead where there is no influence of velocity,

iii)the best beamwidth for the higher communication efficiency including overhead depends not on the number of nodes but on the velocity and the sharper beam is not desirable in high mobility (5° for V=R/4, 5-10° for V=R/2, 10° for V=R, 20° for V=2R),

iv)under the condition with overhead where the velocity has the influence on the performance, the range decrease by power control with wider beam is essential for the higher communication efficiency, and the range increase with sharper beam doesn't help the performance.

The increased hop number(longer delay) by the decreased range(i.e. power control and higher frequencies) is the issue to be investigated. Also, the overhead and convergence speed for adaptive beam training and routing would be included into the system performance in the future.

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