# A Multiple Access Collision Avoidance Protocol for Multicast Service in Mobile Ad Hoc Networks

Ki-Ho Lee, *Student Member, IEEE,* and Dong-Ho Cho, *Senior Member, IEEE*

*Abstract*— **In the view of cross-layer optimization, we propose a multiple access collision avoidance protocol for multicast service (MACAM) that combines RTS/CTS with scheduling algorithms to support the multicast routing protocol. We avoid collision by including additional information in the RTS. Proposed MACAM, together with extra benefits, such as power saving, reliable data transmission and higher channel utilization compared with CSMA or multiple unicast, enables the support of multicast service in mobile ad hoc network environments coexisting with conventional unicast and broadcast MAC protocols.**

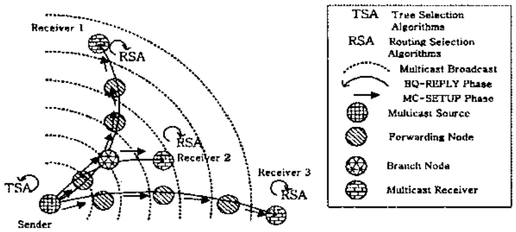

Fig. 1. Multicast routing protocol

## I. INTRODUCTION

MOBILE ad hoc network (MANET) composed of several mobile handsets or laptops is formed without any base stations and must support multi-hop wireless connectivity with each mobile node's relay of data packets to their neighbor nodes. Due to the change of network topology, mobile ad hoc network allows spontaneous formations and deformation of mobile networks. To support many applications in mobile ad hoc networks, there are many protocols for unicast, multicast and broadcast communications. In this paper, we consider MAC protocol for multicast communications.

In mobile ad hoc networks, one important issue is how to increase channel utilization, while taking into account the hidden node problem. In the case of unicast data, IEEE 802.11 MAC [1] uses a collision avoidance scheme with RTS/CTS/ACK to resolve this problem. An RTS can be used by a node to indicate its wish to transmit data. By using a CTS, the receiving node can allow this transmission. Because of the broadcast nature of these messages, the sender and receiver can prevent neighbor nodes from transmitting data while the channel is used. So, they can avoid the collision of data. However, there is, to date, no appropriate MAC protocol that resolves the hidden node problem for multicast data transmission.

The previous approach solving problems associated with multicast for ad hoc networks was to resolve them at the network layer. As a result, there are many multicast routing algorithms based on multicast delivery structure in mobile ad hoc networks. Fig. 1 shows us one of the multicast routing protocols (Associativity-Based Ad Hoc Multicast [2]). To establish a point-to-multipoint ad hoc mobile multicat tree, this protocol uses a three-phase tree setup approach such as a BQ-M (Broadcast Query Multicast) via wave-like broadcast, a BQ-Reply using route selection algorithm (RSA) to derive the best route and an MC-SETUP (MultiCast Setup) using a tree selection algorithm (TSA) to derive the multicast tree. As a result of the above procedure, branch nodes are generated. In [3], a simple multicast MAC protocol for a branch node's transmitting multicast data is proposed, but there is no consideration of the hidden node problem. In this paper, we propose a multiple access collision avoidance protocol for multicast service (MACAM) that resolves the hidden node problem in ad hoc networks.

## II. MULTIPLE ACCESS COLLISION AVOIDANCE PROTOCOL FOR MULTICAST SERVICES (MACAM)

For multicast data transmission of a branch node in ad hoc networks, we must consider hidden nodes, frame length and mutual coexistence with the traditional ad hoc unicast MAC protocol (RTS/CTS). Fig. 2 shows the operation procedure of proposed MACAM. If a multicast frame length is longer than the threshold length, the sender broadcasts an RTS to receivers. The frame format of RTS is shown in Fig. 3. The RA (Receiver Address) list of the RTS frame is the address list of the node that is the intended recipient of the multicast data. The TA (Transmitter Address) is the address of the node transmitting the RTS and the FCS is frame check sequence. The CTS transmission order of receivers is equivalent to the order of identities in the RTS to avoid the collisions of the CTSs. When the node has received an RTS, the receiver corresponding to RA 1 sends a CTS after $\overline{SIFS}$ time. The second node does not send a CTS until $\overline{SIFS}+\overline{CTS}+\overline{SIFS}$ time flows and so on. To receive ACKs from receivers, this scheduling scheme also is applied, and therefore MACAM enables reliable data transmission. The nodes that do not transmit a CTS are able to receive multicast data at the time of the next RTS transmission. Fig. 4 shows the message transmission sequence. In this figure, receiver 2 does not send a CTS because the node is prohibited from transmitting data or under contend state but the others

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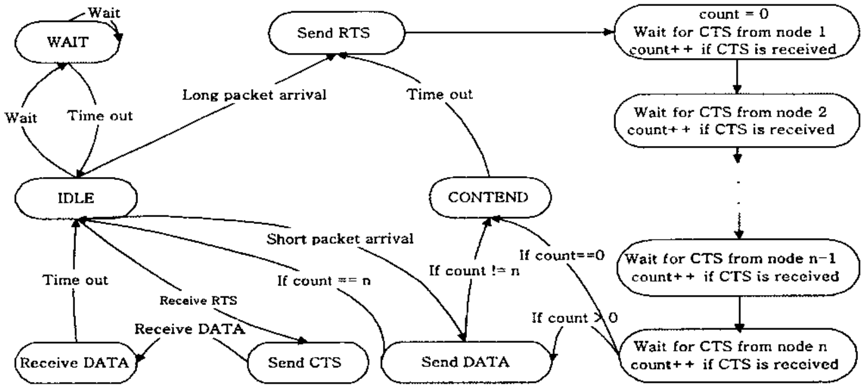

Fig. 2. State diagram of MACAM protocol

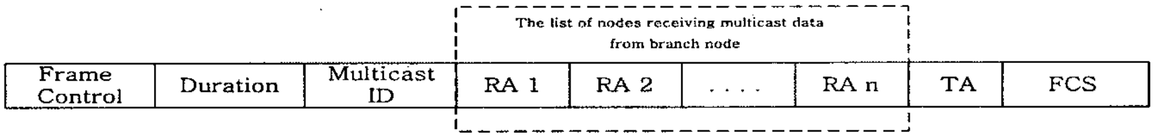

Fig. 3. RTS frame format

except receiver 2 send CTSs sequentially, and thus can receive multicast data from the sender.

When the RTS has a unique identity, the procedure is equal to the conventional RTS/CTS scheme. If the number of the nodes receiving multicast data from the branch node is higher than the threshold, the RTS includes the threshold number of RAs determined according to packet length, node density, channel condition, etc. So, the remnant nodes excluded from the RA list in the RTS are able to receive multicast data when multicast data is next transmitted. The threshold number of RAs is beyond the scope of this paper.

## III. PERFORMANCE ANALYSIS

We assume that the traffic source is modelled as a Poisson process. Each node generates channel traffic to neighbor nodes at an infinitesimally small rate and has the same transmission radius. All source-destination pairs are assumed to have no propagation delay, constant packet transmission time (L sec), and a noiseless channel. In addition, we use a hybrid of unicast traffic and multicast traffic to analyze our new MAC protocol in multi-hop ad hoc networks. To evaluate the performance of proposed MACAM protocol, RTS-CTS scheme with carrier sensing is used for unicast traffic and MACAM protocol is compared with non-persistent CSMA protocol for multicast traffic. We use the following definitions and variables.

- $S_i$ :the set of nodes in the cluster centered at node i
- $R_i$ : the set of nodes within one hop, receiving multicast data from node i
- $\rho_u(i,j)$ : offered load - the unicast traffic rate from node i to node j in L sec
- $\rho_m(i,R_i)$ : the average multicast traffic rate from node i to nodes $\in R_i$ in L sec
- $\rho_{S_i}$ : the sum of the unicast packet arrival rate within the cluster centered at node i and the RTS arrival rate from the nodes outside the cluster
- $\rho_{(S_j,S_i)}$ : $\rho_{S_j}$ in the case that nodes $\in S_i$ do not transmit packets.
- $T_i$ : throughput which is the number of multicast data received from branch node i successfully in L sec

From the above definitions, the following equations are obtained.

$$\begin{aligned}\rho_{S_i} &= \sum_{j\in S_i}\sum_{k\in S_j}\rho_u(j,k)\\ &\quad+\sum_{j\in S_i}\sum_{k\in(S_j-S_i)}\rho_u(k,j)\cdot\frac{1}{1+\rho_{S_k}} \qquad (1)\\ \rho_{(S_j,S_i)} &= \sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_i)}\rho_u(k,l)\\ &\quad+\sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_i-S_j)}\rho_u(l,k)\cdot\frac{1}{1+\rho_{(S_l,S_i)}} \qquad (2)\end{aligned}$$

Also, for the performance analysis of conventional and proposed schemes, we use the following abbreviations:

- *Pkt: packet,*
- *DAT: DATA,*
- *arr: arrival*
- *Pr: probability,*
- *Tx: transmit,*
- *Rx: receive*

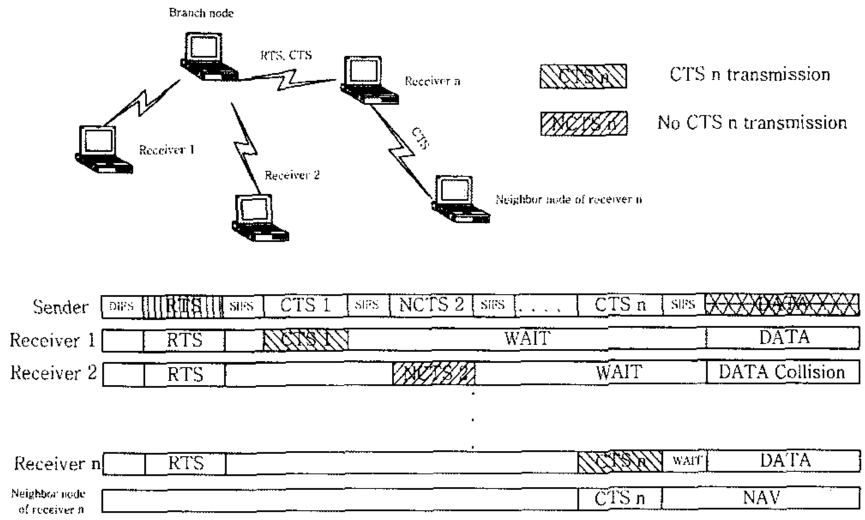

Fig. 4. Message transmission sequence

### A. MACAM Protocol

The probability that a packet transmission is successful, $Pr(DAT\ Rx|Pkt\ arr)$ can be expressed as

$$\begin{aligned} Pr(DAT\ Rx|Pkt\ arr) = \\ & Pr(RTS\ Tx|Pkt\ arr) \\ & \cdot Pr(RTS\ Rx|RTS\ Tx) \\ & \cdot Pr(CTS\ Tx|RTS\ Rx) \\ & \cdot Pr(CTS\ Rx|CTS\ Tx) \\ & \cdot Pr(DAT\ Tx|CTS\ Rx) \\ & \cdot Pr(DAT\ Rx|DAT\ Tx) \end{aligned} \tag{3}$$

$Pr(RTS\ Tx|Pkt\ arr)$ in (3) is the probability that the channel is idle, and thus can be obtained approximately by using the ratio of busy period and idle period as follows if we neglect the length of control message.

$$Pr(RTS\ Tx|Pkt\ arr) \simeq \frac{1}{1+\rho_{S_i}+\rho_m(i,R_i)} \tag{4}$$

If a collision occurs in a node and the node waits for a time long enough to guarantee the successful data transmission of other nodes, we can obtain equations as follows.

$$Pr(CTS\ Rx|CTS\ Tx) = 1 \tag{5}$$

$$Pr(DAT\ Tx|CTS\ Rx) = 1 \tag{6}$$

$$Pr(DAT\ Rx|DAT\ Tx) = 1 \tag{7}$$

In addition, when a node receives RTS, the probability of receiving RTS successfully can be obtained as

$$Pr(RTS\ Rx|RTS\ Tx) \simeq 1 \tag{8}$$

When a node receives an RTS successfully, the probability of transmitting CTS can be calculated as

$$Pr(CTS\ Tx|RTS\ Rx) \simeq \frac{1}{1+\rho_{(S_j,S_i)}} \tag{9}$$

By substituting (5), (6), (7), (8) and (9) for (3), we obtain

$$\begin{aligned} Pr(DAT\ Rx|Pkt\ arr) &= \frac{1}{1+\rho_{S_i}+\rho_m(i,R_i)} \\ & \cdot Pr(CTS\ Tx|RTS\ Rx) \end{aligned} \tag{10}$$

So, $T_i$ can be calculated approximately as follows.

$$\begin{aligned} T_i &= \rho_m(i,R_i)\cdot Pr(RTS\ Tx|Pkt\ arr) \\ & \cdot \sum_{j\in R_i} Pr(\ j\ CTS\ Tx|j\ RTS\ Rx) \end{aligned} \tag{11}$$

### B. Multicast MAC protocol using the non-persistant CSMA protocol

The probability that a packet transmission is successful, $Pr(DAT\ Rx|Pkt\ arr)$ can be expressed as

$$\begin{aligned} Pr(DAT\ Rx|Pkt\ arr) &= Pr(DATA\ Tx|Pkt\ arr) \\ & \cdot p_{ht} \end{aligned} \tag{12}$$

where $p_{ht}$ is the probability that hidden nodes do not transmit a packet in the vulnerable period. In (12), $Pr(DAT\ Tx|Pkt\ arr)$ can be calculated approximately considering the ratio of busy period and idle period in the CSMA scheme.

$$Pr(DAT\ Tx|Pkt\ arr) \simeq \frac{1}{1+\rho_{S_i}+\rho_m(i,R_i)} \tag{13}$$

When node i transmits multicast data to node j, the rate at which hidden nodes transmit a packet (RTS, CTS, DATA) can be calculated by multiplying the offered load by $Pr(RTS\ Tx|Pkt\ arr)$ and $Pr(CTS\ Tx|RTS\ Rx)$ respectively as follows.

- the rate that hidden nodes are transmitting the only RTS.

$$\begin{aligned}\rho_{RTS} &= \sum_{k\in(S_j-S_i)}\sum_{l\in S_i}\{\rho_u(k,l)\\ &\quad\cdot Pr(k\ RTS\ Tx|k\ Pkt\ arr)\}\\ &\quad+\sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_i)}\{\rho_u(k,l)\\ &\quad\cdot Pr(k\ RTS\ Tx|k\ Pkt\ arr)\\ &\quad\cdot(1-Pr(l\ CTSTx|l\ RTS\ Rx))\}\\ &\simeq \sum_{k\in(S_j-S_i)}\sum_{l\in S_i}\rho_u(k,l)\cdot\frac{1}{1+\rho_{(S_k,S_i)}}\\ &\quad+\sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_i)}\rho_u(k,l)\cdot\frac{1}{1+\rho_{(S_k,S_i)}}\\ &\quad\cdot\frac{\rho_{(S_l,(S_k\cup S_i))}}{1+\rho_{(S_l,(S_k\cup S_i))}} \qquad (14)\end{aligned}$$

- the rate that hidden nodes are transmitting DATA.

$$\begin{aligned}\rho_{DAT} &= \sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_i)}\{\rho_u(k,l)\\ &\quad\cdot Pr(k\ RTS\ Tx|k\ Pkt\ arr)\\ &\quad\cdot Pr(l\ CTS\ Tx|l\ RTS\ Rx)\}\\ &\simeq \sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_i)}\rho_u(k,l)\cdot\frac{1}{1+\rho_{(S_k,S_i)}}\\ &\quad\cdot\frac{1}{1+\rho_{(S_l,(S_k\cup S_i))}} \qquad (15)\end{aligned}$$

- the rate that hidden nodes are transmitting CTS to receive DATA from nodes $\in (S_j \cup S_i)^c$.

$$\begin{aligned}\rho_{CTS} &= \sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_j-S_i)}\{\rho_u(l,k)\\ &\quad\cdot Pr(l\ RTS\ Tx|l\ Pkt\ arr)\\ &\quad\cdot Pr(k\ CTS\ Tx|k\ RTS\ Rx)\}\\ &\simeq \sum_{k\in(S_j-S_i)}\sum_{l\in(S_k-S_j-S_i)}\rho_u(l,k)\cdot\frac{1}{1+\rho_{S_i}}\\ &\quad\cdot\frac{1}{1+\rho_{(S_k,S_l\cup S_i)}} \qquad (16)\end{aligned}$$

We can assume that hidden nodes transmit packets with a Poisson distribution, of which mean rate is $\rho_{RTS} + \rho_{CTS} + \rho_{DAT}$. So, $p_{ht}$ can be calculated as

$$p_{ht} \simeq e^{-(\rho_{RTS}+\rho_{CTS})}\cdot e^{-2\cdot\rho_{DAT}} \qquad (17)$$

So, the throughput of multicast traffic can be obtained as

$$\begin{aligned}T_i &= \sum_{j\in R_i}\rho_m(i,j)\cdot Pr(DAT\ Tx|Pkt\ arr)\cdot p_{ht}(i,j)\\ &\simeq \sum_{j\in R_i}\rho_m(i,j)\cdot\frac{1}{1+\rho_{S_i}+\rho_m(i,R_i)}\cdot p_{ht}(i,j) \qquad (18)\end{aligned}$$

## IV. NUMERICAL AND SIMULATION RESULTS

We assume that the network topology is a grid [4] where nodes are only within the radio range of their immediate four neighbors. We further assume that in the static state, all nodes have the same packet arrival rate, and thus $\rho_u(i,j) = \rho_u(j,i) = \rho_u\ \forall i,j$. Table I shows the simulation parameters. The number of nodes receiving multicast data from a branch node, $n(R_i)$ is 2.

TABLE I

SIMULATION PARAMETERS

| | Unicast traffic | Multicast traffic | |
|---|---|---|---|
| | | Proposed | CSMA |
| $\overline{RTS(CTS)}/\overline{DATA}$ | 0.025 ~ 0.3 | | X |
| $\overline{SIFS}/\overline{DATA}$ | 0.02 | | X |
| $\overline{DIFS}/\overline{DATA}$ | 0.03 | | |
| $\overline{Time\ out}/\overline{DATA}$ | 0.05 | | X |
| $Propagation\ delay$ | 0 | | |
| $n(R_i)$ | 1 | 2 | |

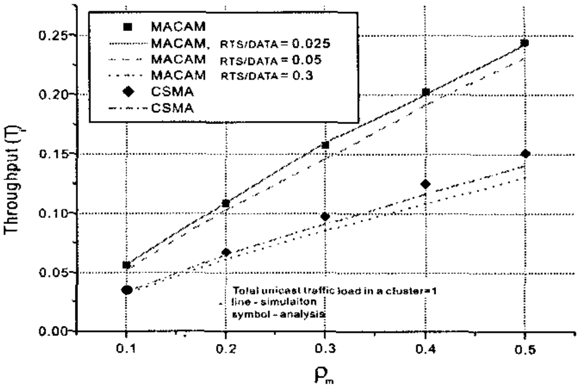

Fig. 5. Throughput of multicast traffic vs. multicast traffic load

Fig. 5 shows the throughput of multicast traffic as the rate of multicast traffic increases in the case that the total offered load of unicast traffic within a cluster centered at branch node is 1. As expected, proposed MACAM shows higher throughput compared with the conventional protocol, because collision avoidance is acquired by using RTS/CTS. In this analysis, we assume that the transmission time of $\overline{RTS}$ and $\overline{CTS}$ is negligible. As the length of RTS/CTS increases, the throughput decreases because the probability of collision of RTS or CTS increases. In this figure, if $\frac{\overline{RTS}}{\overline{DATA}}$ is equal to 0.3, the performance of proposed scheme is degraded to that of the multicast protocol using non-persistent CSMA protocol.

Fig. 6 shows the multicast traffic throughput as the total offered load of unicast traffic within a cluster centered at branch node increases. In the case of CSMA, the throughput degradation is more severe compared with MACAM as the unicast traffic load increases, but MACAM performs well, in spite of a high load of unicast traffic.

## V. CONCLUSIONS

In mobile ad hoc networks, there exists no useful research on multicast data communication. and there is no mathematical research to analyze the throughput in multi-hop ad hoc networks. So, in this paper, we examined the advantages of proposed MACAM shcheme for multicast service in ad

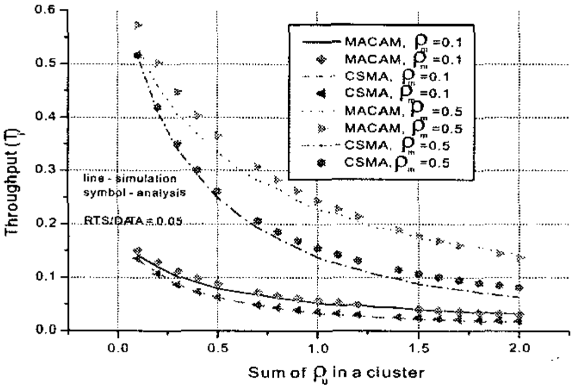

Fig. 6. Throughput of multicast traffic vs. unicast traffic load

hoc networks through analysis and simulations. MACAM, together with extra benefits such as power saving, reliable data transmission and higher channel utilization compared with CSMA/CA or multiple unicast, enables the support of multicast service in mobile ad hoc networks coexisting with conventional unicast and broadcast medium access control protocols.

In the future, the analysis of control message overhead and the maximum number of RA included in RTS by accounting for channel status, is required. Also, for realtime traffic, the research on delay bound is needed.

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