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Two-Phase Coding Multichannel MAC Protocol With MAI Mitigation for Mobile Ad Hoc Networks

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Abstract

This letter introduces a novel multichannel medium access control (MAC) protocol for mobile ad hoc networks (MANETs) based on a scalable two-phase coding scheme, which eliminates the hidden terminal problem (HTP) without exchange of neighborhood information. Furthermore, power control is incorporated to mitigate multiple-access interference (MAI). Simulation results show that significant improvement can be achieved by the proposed protocol over IEEE 802.11 DCF.

Index Terms

Medium access control (MAC), mobile ad hoc networks (MANETs), multiple-access interference (MAI), two-phase coding multi-channel MAC protocol (TPCMMP).

1. Introduction

Recently, several multichannel medium access control (MAC) schemes have been proposed for mobile ad hoc networks (MANETs) to increase the network capacity over the single channel MAC protocol such as IEEE 802.11 DCF [2]. The basic idea of the CDMA-based multichannel MAC designs [1], [4] is that the nodes within two hops should adopt different codes, such that the hidden terminal problem (HTP) can be avoided. Such protocols rely on the periodic exchange of neighborhood information, which results in expensive communication overhead. When the mobility of the network is particularly high, it is difficult for each node to obtain its exact neighborhood information in real time. Consequently, HTP cannot be avoided. To date, few CDMA-based multichannel MAC protocols for MANETs have considered multiple-access interference (MAI) due to the near-far problem, which can seriously degrade the network throughput. This letter aims to develop an efficient multichannel MAC protocol by introducing two-phase coding scheme together with power control to relieve MAI.

2. Two-phase Coding Multichannel MAC Protocol (TPCMMP)

Similar to the grid location awareness scheme in [6], the network is subdivided into cells with hexagonal cellular geographic structure [7] and all cells are of the same radius r , which equals to

the transmission range of the nodes. We introduce a two-phase coding scheme, where the first-phase code is used for differentiating cells and the second-phase code is employed for distinguishing nodes in one specific cell. Similar to frequency reuse in cellular communications, seven different first-phase codes are required to cover the whole network. This is easy to calculate that the minimal distance between any two nodes in different cells with the same first-phase codes is $\sqrt{7}r$, which ensures that they are at least two hops away. The reuse of the first-phase codes greatly increases the scalability of TPCMMP.

Assume there exists a set of m PN codes $C_{FC} = \{C_1^i | i = 1, 2, \dots, m\}$ used for the first-phase codes and another set of n PN codes $C_{SC} = \{C_2^j | j = 1, 2, \dots, n\}$ for the second-phase codes. The set of the transmission codes is defined as $C_{TC} = \{(C_1^i, C_2^j) | C_1^i \in C_{FC}, C_2^j \in C_{SC}\}$ with each element being a joint first-phase and second-phase code and any two elements in C_{TC} being quasi-orthogonal.

The wireless channel is divided into a control channel and a data channel. A cell leader, which is elected by its cell members according to the location, remaining power, and stability to stay in the cell, is responsible for maintaining and assigning the second-phase codes to its cell members. Initially, whenever a node cannot acquire its code after three-code acquisition trials, it assumes that no cell leader exists in the current cell and initiates the leader election by broadcasting a packet to declare itself as a cell leader after deferring a random time. If it hears the declaration from its neighbors with the same first-phase code during this random time, it gives up its competition. The first node, which broadcasts the declaration, upgrades itself as the cell leader. If necessary, a cell leader will automatically hand over the leadership and the available second-phase codes set to a more suitable member.

Transmitter-oriented data transmission [5] is adopted. Node i knows its first-phase code C_1^i according to its location from a positioning device such as GPS and acquires its unique second-phase code C_2^i from its cell leader. When a node migrates from one cell to another, it releases its original second-phase code, tunes its first-phase code corresponding to the new cell and obtains its new second-phase code from the cell leader of the new cell. All the operations of obtaining and releasing the codes as well as election and handover of the cell leaders are completed in the control channel.

Suppose the transmission codes of nodes A and B are $C^a = (C_1^a, C_2^a) \in C_{TC}$ and $C^b = (C_1^b, C_2^b) \in C_{TC}$, respectively. Actually, when A and B are within two hops and transmitting simultaneously to the same receiver, there are two cases that HTP may happen: 1) A and B are in the same cell, then $C_1^a = C_1^b$ and $C_2^a \neq C_2^b$, thus $C^a \neq C^b$. 2) A and B are in different cells, then the maximum distance between A and B is $2r$. Since the minimal distance between any two nodes in different cells with the same first-phase codes is $\sqrt{7}r$ and $2r < \sqrt{7}r$, one has $C_1^a \neq C_1^b$. Thereby, no matter what second-phase codes do nodes A and B use, one always has $C^a \neq C^b$. In both cases, C^a and C^b are always quasi-orthogonal. Therefore, with this assignment of codes, HTP is eliminated in TPCMMP.

Moreover, there is a substantial reduction of control overhead in TPCMMP. Several control packets are exchanged respectively in code acquisition and release for each node, only one declaration message is required for the initial leader election, and the handover of the cell leader requires the responses from its one-hop neighbors with the same first-phase code. Thereby, given d as the network degree, N as the set of the cells and V as the set of the nodes, the complexity of the overhead in TPCMMP is $O(|N|d)$. However, in the classic CDMA-based MAC design [1], [4], the code change of one node might incur the corresponding codes change of the nodes in the whole network. Consequently, the communication overhead is $O(|V|d^2)$. When the network is full-connected and there is at least one node in a cell, one always has $|N| < |V|$. Therefore, TPCMMP brings significantly less communication overhead.

3. Power Control for MAI Mitigation

Since TPCMMP is based on CDMA, one problem that seriously degrades the performance is MAI. We incorporate the power control strategy in TPCMMP to combat MAI. Assume a general channel propagation model is given by

$$P_r^k = \alpha \cdot P_t^h \quad (1)$$

where P_t^h and P_r^k are, respectively, the transmission power at transmitter h and the receiving signal strength at receiver k , and α is the propagation attenuation from h to k .

A. Criterion 1

Given the reception threshold P_{r_thresh} , it requires that

$$P_t^h \geq \frac{P_{r_thresh}}{\alpha} = P_{r_thresh} \cdot \frac{P_{t0}}{P_{r0}^k} \quad (2)$$

holds for a successful transmission from h to k , where P_{r0}^k is the receiving signal strength at receiver k under the default transmission power P_{t0} .

B. Criterion 2

Given the current MAI signal strength P_{MAI}^k , the internal noise N_0 , the processing gain L and the minimum signal-to-interference-plus-noise ratio (SINR) requirement γ_0 , a successful reception at receiver k should satisfy

$$\frac{\alpha P_t^h}{N_0 + \frac{P_{MAI}^k}{L}} \geq \gamma_0 \quad (3)$$

i.e.,

$$P_t^h \geq \gamma_0 \cdot \left(N_0 + \frac{P_{MAI}^k}{L} \right) \cdot \frac{P_{t0}}{P_{r0}^k}. \quad (4)$$

To ensure the communication invulnerable to the mobility, we provide guard bands δ_1 and δ_2 for the receiving signal strength and SINR, respectively. Therefore, according to criteria 1 and 2, the desired transmission power $P_{t_desired}^h$ is calculated as

$$P_{t_desired}^h = \max \left\{ (P_{threshold} + \delta_1) \cdot \frac{P_{t0}}{P_{r0}^k}, \right. \\ \left. (\gamma_0 + \delta_2) \cdot \left(N_0 + \frac{P_{MAI}^k}{L} \right) \cdot \frac{P_{t0}}{P_{r0}^k} \right\}. \quad (5)$$

Let $H_1(h)$ be the set of all the neighboring nodes of transmitter h . For $\forall i \in H_1(h)$, the upcoming transmission from node h to k will cause MAI to the ongoing receptions at i . Since the allowed MAI $P_{MAI_allowed}^i$ at receiver i should satisfy

$$\frac{P_r^i}{N_0 + \frac{(P_{MAI}^i + P_{MAI_allowed}^i)}{L}} \geq \gamma_0 \quad (6)$$

i.e.,

$$P_{MAI_allowed}^i \leq L \cdot \left(\frac{P_r^i}{\gamma_0} - N_0 \right) - P_{MAI}^i \quad (7)$$

and transmitter h overhears the beacon packets sent by receiver i with the transmission power P_{t0} and the receiving signal strength $P_{r0}^{(i,h)}$, the upper bound of the allowed transmission power $P_{t_allowed}^h$ at transmitter h can be calculated as

$$P_{t_desired}^h = \min_{i \in H_1(h)} \left\{ P_{MAI_allowed}^i \cdot \frac{P_{t0}}{P_{r0}^{(i,h)}} \right\}. \quad (8)$$

C. Criterion 3

Transmitter h can initiate its communication with acceptable MAI to any ongoing transmission only if $P_{t_desired}^h$ satisfies

$$P_{t_desired}^h \leq P_{t_allowed}^h. \quad (9)$$

Power control is implemented in TPCMMP according to the above three criteria. Communication pair negotiates $P_{t_desired}$ through exchanging the control packets in control channel with the transmission power P_{t0} . For transmission from h to k , transmitter h sends probing

signal to k , then receiver k calculates $P_{t_desired}^h$ according to (5), and feeds back this information to h . As each receiver i will periodically broadcast its $P_{MAI_allowed}^i$ beacons in control channel, transmitter h obtains $P_{t_allowed}^h$ by (8). According to the constraint in criterion 3, transmitter h determines if it can initiate its transmission with the acceptable interference to the ongoing transmissions. The transmission power can be dynamically adjusted to ensure $\gamma_0 \leq \gamma \leq \gamma_0 + \delta_2$.

4. Simulation Results

The simulation model is set up as shown in Table I. The simulation results are averaged ten runs with different movement patterns for each value of the packet arrival rate.

As shown in Fig. 1, we observe that TPCMMP outperforms IEEE 802.11 in throughput performance, which is expected because with two-phase coding concurrent transmissions are possible and HTP is eliminated. Furthermore, through access control considering the upcoming SINR, the throughput is twice over that of TPCMMP when the packet arrival rate exceeds 80 packets/s because MAI is effectively mitigated.

Fig. 2 shows the average latency performance. As the offered load increases, we observe the significantly less latency in TPCMMP. When the packet arrival rate is 50 packets/s, the average latency is 0.17 s in TPCMMP. However, in 802.11 the larger average latency is typically 0.9 s because of frequent collisions and retransmissions. There is a minimal increase of latency in TPCMMP with power control since communication pair has to negotiate the appropriate transmission power and adjust it in real time according to SINRs.

5. Conclusion

An efficient multichannel MAC protocol named as TPCMMP is proposed, which eliminates the HTP in MANETs without periodical exchange of neighborhood information and outperforms the conventional single channel MAC protocol. Furthermore, the performance is improved by effectively reducing MAI.

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Figure 1 Throughput versus packet arrival rate per flow.

Figure 2 Average latency versus packet arrival rate per flow.

Table I

Parameters	Values
Platform	Ns2 [3] with CMU wireless extensions
Propagation Model	Two-ray ground model
Channel rate	2Mbps
Scenario	50 nodes and 20 traffic flows in 800m*700m with 32 cells
Mobility model	Random way point mobility model
Speed	Up to 5m/s with 0 pause time
Simulation time	200sec
Traffic type	CBR UDP with packet size 512bytes
Control channel rate	0.3Mbps
L	11
r	100m
γ_0	10dB
P_{t0}	7.214mw
P_{r_thresh}	3.652e-10w
Δ_1 and Δ_2	1.826e-10w and 5dB
Beacon period	1sec

Figure 1

Figure 2