

Extended RTS/CTS Control Based on Transmission Request Distribution in Wireless Ad-Hoc Networks

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Abstract. In a wireless ad-hoc network where wireless nodes exchange data messages without help of stationary base stations, collisions of control and data messages are reduced and/or avoided by CSMA/CA and RTS/CTS control of wireless LAN protocols. Random backoff timers for avoidance of collisions among RTS control messages provides equally opportunities to transmit data messages to neighbor wireless nodes since the value of the backoff timer monotonically decreases. In usual wireless ad-hoc networks, wireless nodes are not equally distributed and frequency of transmission requests in wireless nodes is also not the same. Thus, especially in a region with high density of transmissions and receipts requests for data messages, it is not always possible to receive a response CTS control message even though a wireless node has an opportunity to transmit an RTS control message. Hence, the equal opportunities to transmit an RTS control message is not enough to realize the equal opportunities to transmit a data message. In order to solve this problem, this paper proposes a novel RTS/CTS control to equally provide opportunities to transmit data messages whose receiver node is hard to transmit a CTS control message on response to an RTS control message. Here, a transmission of a CTS control message precedes a transmission of an RTS control message in cases that transmissions of a CTS control message fail repeatedly.

Keywords: Wireless ad-hoc communication · Wireless LAN protocol · RTS/CTS control · Feasibility

1 Introduction

In wireless ad-hoc networks, data messages are transmitted between two neighbor wireless nodes which are included in a wireless signal transmission range each other. Since wireless signals are broadcasted in a wireless signal transmission range, they reach all neighbor wireless nodes. That is, all data and control messages transmitted by a sender wireless node N_s reach not only a receiver wireless node N_s but also all neighbor wireless nodes of N_s. When multiple neighbor wireless nodes transmit wireless signals concurrently, their common neighbor wireless

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nodes fail to receive messages carried by the wireless signals since collisions occur at these wireless nodes. In order to reduce or avoid such collisions of wireless signals, CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is introduced in wireless LAN protocols such as IEEE 802.11. Hence, collisions caused by wireless signals transmitted by multiple exposed wireless nodes are reduced or avoided. In addition, RTS/CTS control is also introduced in wireless LAN protocols for reduction or avoidance of collisions of wireless signals concurrently transmitted by hidden wireless nodes. In RTS/CTS control, all neighbor wireless nodes of a sender wireless node N_s and a receiver wireless node N_r suspend their transmissions of any data and control message, collisions of messages at N_s and N_r can be avoided during transmissions of a data message from N_s to N_r and an ACK control message from N_r to N_s.

Here, among multiple neighbor wireless nodes which has requests for data message transmissions, i.e., which has transmission requests of *RTS* control messages, only one of the wireless nodes should transmit an *RTS* control message mutual-exclusively for avoidance of collisions among multiple *RTS* control messages. Hence, a randomly determined backoff timer is introduced in each wireless node. On an expiration of its own backoff timer without receiving any data and control message, a wireless node transmits an *RTS* control message for its mutually exclusive transmission of a data message without collisions. Since the expiration period is determined randomly, chances of transmissions of multiple *RTS* control messages simultaneously by multiple neighbor wireless nodes are reduced, i.e., collisions caused by multiple *RTS* control messages are reduced. In addition, since the rest time duration of a timer for its expiration is carried over without resetting it, the timer value is monotonically decrease and all wireless nodes surely transmit *RTS* control messages at some future time. Hence, each wireless node has equal opportunities to transmit an *RTS* control message for a data message transmissions and various extended method for realize more equal transmission opportunities have been proposed.

A data message transmission from a sender wireless node N_s to its neighbor wireless node N_r is allowed only after an *RTS* control message from N_s to N_r and a *CTS* control message from N_r to N_s are successfully transmitted. For transmissions of these messages, both N_s and N_r do not set any NAV (Network Allocation Vector) which represents time duration while they are prohibited to transmit any data and control message, i.e., they do not received any *RTS* and *CTS* control message from their neighbor wireless node. That is, neighboring sender wireless nodes and receiver wireless nodes contend for communication opportunities. However, currently available wireless LAN protocols do not provide equal opportunities for communication to such neighboring sender and receiver wireless nodes. Hence, if the density of communication requests around N_r is high, N_r receives many *RTS* and *CTS* control messages from its neighbor wireless nodes and it does not have equal opportunities to transmit a *CTS* control message in response to an *RTS* control message from N_s since N_r transmits the *CTS* control message passively. In order to solve this problem, this paper proposes an extended RTS/CTS control where N_r transmits a preceding *CTS*

control message to N_s after multiple abandonments of transmissions of a *CTS* control message in response to receipt of an *RTS* control message from N_s and design a novel data message transmission protocol with the receiver-initiated RTS/CTS control.

2 Related Works

In wireless LAN protocols such as IEEE 802.11, for collision-free transmissions of a data message and a corresponding *ACK* control message between neighbor wireless nodes, an *RTS* and a *CTS* control messages are broadcasted by a sender wireless node N_s and a receiver wireless node N_r, respectively, within their wireless signal transmission range in advance. All neighbor wireless nodes receiving one of these control messages should suspend their data and control message transmissions during NAV interval included in these control messages. For transmissions of an *RTS* and a *CTS* control messages by N_s and N_r respectively, N_s and N_r should not set their NAV in response to receipts of other *RTS* or *CTS* control messages from their neighbor wireless nodes. An *RTS* control message from N_s is transmitted after randomly determined backoff time interval without receipt of another *RTS* control message from its neighbor wireless node for avoidance of concurrent transmissions of data messages causing their collisions in CSMA/CA. In addition, even if a backoff timer of another neighbor wireless node expires in advance, the rest time duration of backoff timer for its expiration is carried over without resetting it. In result, the timer value monotonically decreases and the timer surely expires in some future time. This means that each wireless node has transmission opportunities of an *RTS* control message equally (Fig. 1).

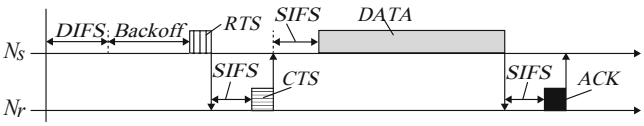

Fig. 1. RTS/CTS control for collision avoidance.

In cases that wireless nodes are not evenly distributed but their distribution is geographically localized and/or that their communication requirements are so frequent, many neighbor wireless nodes simultaneously have their transmission requests of data messages. In such cases, multiple neighbor wireless nodes may have the same randomly determined backoff timer value and transmit their *RTS* control messages simultaneously just after expiration of the timers, which results in a collision of the *RTS* control messages. In the original CSMA/CA control, in order to reduce the probability of the occurrence of such collisions, the range of the randomly determined backoff timer value is expanded. However, each wireless node locally adjusts its backoff timer range without cooperation

among neighbor wireless nodes, that is, a wireless node detecting a collision unilaterally expands its backoff timer range to reduce the probability to cause such collisions for all its neighbor wireless nodes, the opportunities to transmit *RTS* control messages are unevenly provided among neighbor wireless nodes. In [1,2,6,8], various extended methods to improve such uneven provision of opportunities to transmit *RTS* control messages have been proposed. Here, histories of transmissions of *RTS* control messages are exchanged among neighbor wireless nodes to flatten opportunities to transmit *RTS* control messages, i.e., to transmit data messages. In addition, WLPB [7] provides a wireless node with less data message transmissions additional opportunities to transmit data messages by frame bursting. Here, a wireless node continuously transmits data messages by a transmission of an *RTS* control message with a *SIFS* interval after a receipt of an *ACK* control message.

Even if a sender wireless node N_s sends an *RTS* control message on expiration of its own backoff timer, it is not always possible for a receiver wireless node N_r to send back a *CTS* control message. Here, all the neighbor nodes of N_s suspend their data and control message transmissions by setting their NAV due to receipts of the *RTS* control message from N_s. In case with no transmission of a *CTS* control message from N_r to N_s, this suspension does not contribute for avoidance of collisions with an *ACK* control message from N_r to N_s in response to a data message transmitted from N_s to N_r and is only takes away transmission opportunities of data and control messages from the neighbor wireless nodes of N_s. RTS Invalidation [5], NAV Reduction [5] and Cancel RTS (CRTS) [3] have been proposed to solve this problem.

3 Proposal

3.1 Problem

In a wireless ad-hoc network, a wireless node communicates with any neighbor wireless node within its wireless signal transmission range without help of a stationary wireless base station. Wireless nodes are not always distributed evenly as in Fig. 2 (a) but are localized usually as in Fig. 2 (b) due to geographical features, existence of roads and buildings, various environmental conditions and requirements for node locations by applications. Especially, in wireless ad-hoc networks with mobile wireless nodes, node distribution is not stable but time-variable due to their mobility. In addition, communication requests are also not distributed evenly and frequency of transmission requests of data messages are different in every pair of neighbor wireless nodes. For example, in wireless sensor networks, sensor nodes located in an area with frequent event occurrences have much more transmission requests of sensor data messages carrying observation data, i.e., communication requests are unevenly distributed geographically. In addition, in wireless multihop networks, some wireless nodes are required to serve a role of intermediate wireless nodes of a lot of wireless multihop transmission routes and these wireless nodes have so frequent transmission requests of data messages as a result.

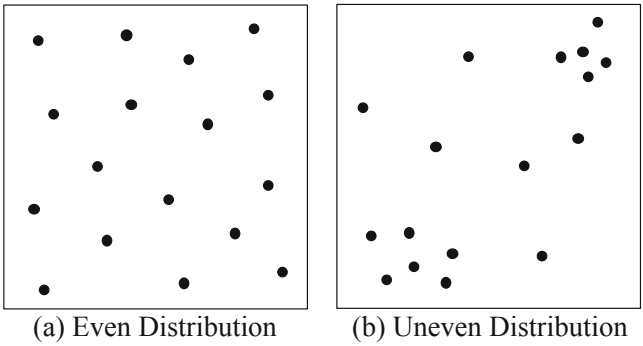

Fig. 2. Wireless node distribution.

For transmissions of data messages from a sender wireless node N_s to a neighbor receiver wireless node N_r, a data message from N_s to N_r and a corresponding ACK control message from N_r to N_s are required to be transmitted without collisions with any data and control messages at N_r and N_s, respectively. This is realized by RTS/CTS collision avoidance control in wireless LAN protocols such as IEEE 802.11. For avoidance of collisions with the ACK control message at N_s, N_r should transmits the ACK control message mutually exclusively among the neighbor wireless nodes of N_s. Hence, N_s broadcasts an RTS control message to all neighbor wireless nodes within a wireless signal transmission range of N_s and all the neighbor wireless nodes of N_s receiving the RTS control message are required to suspend their transmissions of data and control messages during NAV interval specified by the RTS control message. Even opportunities to transmit RTS control messages among neighbor wireless nodes are realized by monotonically decreasing backoff timer values. Initial backoff timer value which represents a waiting interval for a transmission of an RTS control message is determined randomly for collision avoidance and the rese backoff timer value is carried over even if backoff timer of another neighbor wireless node expires earlier. Hence, all the backoff timer values monotonically decrease to zero, i.e., they surely expire, and all the wireless nodes have opportunities to transmit RTS control messages at some future time.

On the other hand, in order to avoid collisions with a data message at N_r, N_s should also transmit the data message mutually exclusively among the neighbor wireless nodes of N_r. Hence, N_r broadcasts a CTS control message to all neighbor wireless nodes within a wireless signal transmission range of N_r and all the neighbor wireless nodes of N_r receiving the RTS control message are required to suspend their transmissions of data and control messages during NAV interval specified by the CTS control message. Different from RTS control messages, even opportunities to transmit CTS control messages are not provided to a wireless node among neighbor wireless nodes contending for communication requirements. In order for N_r to transmit a CTS control message to N_s, N_r should not have set its NAV interval due to receipt of an RTS or a CTS

control message from another neighbor wireless node for collision avoidance at the instance when it receives an *RTS* control message from N_s. Hence, if the neighbor wireless nodes of N_r often transmits *RTS* and *CTS* control messages due to high density of wireless node distribution and their highly frequent communication requests, N_r should set its NAV for collision avoidance so frequently. As a result, as shown in Fig. 3, time duration for suspension of data and control messages including *CTS* control messages determined by the NAV becomes longer and the opportunities to send back a *CTS* control message to N_s in response to receipt of an *RTS* control message from N_s decrease. Since times when N_r receives an *RTS* control message from N_s are independent of NAV intervals set in N_r determined by receipts of *RTS* and *CTS* control messages from its neighbor wireless nodes, opportunities of transmissions of the *CTS* control message from N_r is not even with opportunities of transmissions of *RTS* and *CTS* control messages from the neighbor wireless nodes of N_r different from colliding transmission requests of *RTS* control messages regulated by CSMA/CA collision avoidance control. Therefore, N_s does not have equal opportunities to transmit data messages to N_r and the waiting time duration for data message transmission is postponed in N_s irrationally.

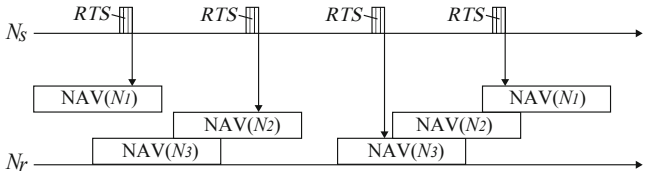

Fig. 3. Unequal transmission opportunities for CTS due to high density transmission/receipt requests.

It is considerable that N_r notifies its NAV interval to N_s in advance in order for N_s to send an *RTS* control message to N_r when N_r can send back a *CTS* control message to N_s. However, since its NAV interval is set just after receipt of an *RTS* or a *CTS* control message from its neighbor wireless node, it is impossible for N_r to transmit a control message for the notification; this is contradiction. If the NAV interval is delayed for the transmission of the additional control message for the notification, additional time overhead is required, i.e., the additional interval for RTS/CTS collision avoidance control before transmission of a data message becomes longer, and the performance of the data message transmission should become lower. On the other hand, just after the expiration of a NAV interval, N_r may send a *CTS* control message to N_s in response to the *RTS* control message which N_r receives during its NAV interval. However, the NAV interval set in the other neighbor wireless nodes of N_s has already been consumed before the transmission of delayed *CTS* control message and this may cause collisions of an *ACK* control message from N_r to N_s and another message at N_s.

3.2 Receiver-Initiated RTS/CTS Control

In order to solve the problem discussed in the previous subsection, i.e., the problem that a receiver wireless node has less opportunities to send back a *CTS* control message to a sender wireless node N_s, this paper proposes a novel receiver-initiated RTS/CTS collision avoidance control which works supplementary.

In cases that in spite of receipt of an *RTS* control message from N_s, N_r suspends transmissions of data and control messages due to its NAV interval set by receipt of a preceding *RTS* or *CTS* control message from its neighbor wireless node, N_r cannot send back a *CTS* control message to N_s. As a result, a timeout interval expires in N_s and it is impossible for N_s to send a data message to N_r. In order to solve this problem, this paper proposes a receiver-initiated RTS/CTS collision avoidance control. Here, if N_r fails to send back a *CTS* control message to N_s due to its NAV interval repeatedly more times than predetermined threshold, N_r sends a *CTS* control message to N_s antecedently to an *RTS* control message from N_s to N_r. That is, an *RTS* and a *CTS* control messages are exchanged between N_s and N_r in a reverse order to the original RTS/CTS control. As mentioned in the previous subsection, though N_r has less opportunities to send back a *CTS* control message to N_s due to higher distribution density of wireless nodes and higher frequency of communication requests for data message transmissions, N_r passively sends back a *CTS* control message in response to an *RTS* control message from N_s in the original RTS/CTS control. This is the reason of uneven distribution of transmission opportunities to send the control messages, i.e., *RTS* and *CTS* control messages among the neighbor wireless nodes of N_r. As shown in Fig. 4, in our proposal, after some continuous receipt of *RTS* control messages from N_s to which N_r fails to send back a corresponding *CTS* control message, N_r sends a *CTS* control message to N_s precedingly to an *RTS* control message from N_s. That is, just after all its NAV intervals expire, N_r sends a *CTS* control message to N_s. After receipt of the *CTS* control message, N_s sends an *RTS* control message with *SIFS* interval to all its neighbor wireless nodes including N_r for notification of receipt of the *CTS* control message to N_r and mutually exclusive transmissions of a data message to N_r and of an *ACK* control message from N_r to N_s. Same as the original RTS/CTS control, if a NAV interval has already been set by N_s due to receipt of another *RTS* or *CTS* control message from its neighbor wireless node, N_s does not send the *RTS* control message in response to the *CTS* control message from N_r. By receipt of the *RTS* control message, N_r is notified that N_s sends a data message to N_r and all neighbor wireless nodes of N_s suspends their transmissions of data and control messages to avoid collisions at N_s with an *ACK* control message from N_r. Therefore, collision-free transmissions of a data message and a corresponding *ACK* control message are realized between N_s and N_r.

In our proposed method, on expiration of all NAV intervals set by N_r due to receipts of *RTS* or *CTS* control messages from its neighbor wireless nodes, N_r should immediately send a *CTS* control message to N_s not to lose the

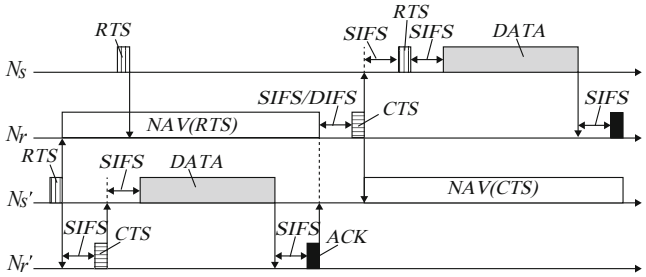

Fig. 4. Receiver-initiated RTS/CTS control.

opportunity to transmit it. That is, before a receipt of any *RTS* or *CTS* control message from its neighbor wireless nodes, N_r should send the preceding *CTS* control message to N_s. Though the *CTS* control message should be sent with a *DIFS* interval after expiration of all the NAV intervals, it is sent with a *SIFS* interval [7] or with a *DIFS* interval with zero backoff timer value [4] in our proposal. In either method of them, the transmission of the *CTS* control message from N_r to N_s precedes other *RTS* or *CTS* control messages transmitted from neighbor wireless nodes of N_r.

In our proposal, since a *CTS* control message is transmitted preceding to an *RTS* control message, different NAV values are carried by these control messages from the original RTS/CTS control. In the original RTS/CTS control, as shown in Fig. 5, the NAV interval value carried by an *RTS* control message is a summation of required time durations for a *CTS* control message transmission, a data message transmission, an *ACK* control message transmission and triple of a *SIFS* interval. The NAV interval carried by a *CTS* control message is a summation of required time durations for a data message transmission, an *ACK* control message transmission and double of a *SIFS* interval. Here, a data message transmission time depends on its size that only N_s can calculate. However, the transmission time duration of each control message and a *SIFS* interval are constant. Hence, the NAV interval carried by the *CTS* control message is calculated by N_r by subtracting the required time durations for an *RTS* control message transmission and single *SIFS* interval from that carried by an *RTS* control message.

On the other hand, as shown in Fig. 6, in our proposed receiver-initiated RTS/CTS control, the NAV interval carried by a preceding *CTS* control message is a summation of required time durations of an *RTS* control message transmission, a data message transmission, an *ACK* control message transmission and triple of a *SIFS* interval. The NAV interval carried by a corresponding *RTS* control message is a summation of required time durations for a data message transmission, an *ACK* control message transmission and double of a *SIFS* interval. Since the data message is going to be transmitted not by N_r but by N_s, N_r does not know the size of the data message. However, N_r has surely received an *RTS* control message for the same data message from N_s before this

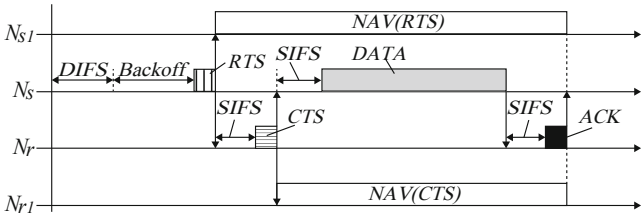

Fig. 5. NAV values in RTS/CTS control.

transmission of a preceding *CTS* control message, the required time duration for the data message transmission can be calculated by N_r even though it does not know the message size. That is, the NAV interval carried by a preceding *CTS* control message is achieved by subtracting required transmission time duration for a *CTS* control message from the NAV interval carried by an already received *RTS* control message from N_s and adding required transmission time duration for an *RTS* control message. In addition, the NAV interval carried by an *RTS* control message transmitted in response to the preceding *CTS* control message is achieved by subtracting required transmission time duration for a *CTS* control message and a *SIFS* interval from that carried by the *CTS* control message.

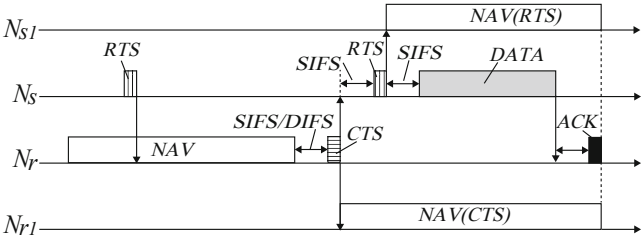

Fig. 6. NAV values in receiver-initiated RTS/CTS control.

4 Concluding Remarks

This paper pointed out the problem that *CTS* control messages are not transmitted evenly due to lack of contention mechanism with *RTS* control message transmissions. In order to solve this problem, this paper proposed the receiver-initiated RTS/CTS control where a receiver wireless node actively transmits a preceding *CTS* control message to an *RTS* control message from a sender wireless node. In future work, the authors evaluate the performance improvement in simulation experiments.

References

1. Cali, F., Conti, M., Gregori, E.: Dynamic turning of the IEEE 802.11 protocol to achieve a theoretical throughput limit. IEEE/ACM Trans. Netw. **8**, 785–799 (2000)
2. Crow, B., Widjaja, I., Kim, J., Sakai, P.: IEEE 802.11 wireless local area network. IEEE Commun. Mag. **35**(9), 116–126 (1997)
3. Harada, T., Ohta, C., Morii, M.: Improvement of TCP throughput for IEEE 802.11 DCF in wireless multi-hop networks. IEICE Trans. **85**(12), 2198–2208 (2002)
4. Ikuma, S., Li, Z., Pei, T., Choi, Y., Sekiya, H.: Rigorous analytical model of saturated throughput for the IEEE 802.11p EDCA. IEICE Trans. Commun. **E102-B**(4), 669–707 (2019)
5. Inoue, D., Shigeyasu, T., Matsuno, H., Morinaga, N.: A Proposal of IEEE802.11DCF with cancel CTS for avoiding unnecessary transmission deferment. In: Proceedings of the 18th IPSJ DPS Workshop, pp. 129–134 (2007)
6. Kwon, Y., Fang, Y., Latchman, H.: A Novel MAC protocol with fast collision resolution for wireless LANs. In: Proceedings of IEEE INFOCOM, vol. 2, pp. 853–862 (2003)
7. Shigeyasu, T., Matsuno, H., Morinaga, N.: Proposal of a method for improving mac level fairness in the coexisting environment with legacy IEEE802.11DCF terminals. IPSJ J. **50**(3), 1156–1169 (2009)
8. Tian, X., Chen, X., Ideguchi, T., Fang, Y.: Improving throughput and fairness in WLANs through dynamically optimizing backoff. IEICE Trans. Commun. **E88–B**(11), 4328–4338 (2005)