High Throughput Wireless Multihop Transmissions by Power Controlled Transmissions along Hop-by-Hop Shortening Route

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Abstract: In data message transmissions in wireless multihop networks, intra-route collisions of data messages and control messages are required to be reduced or avoided for shorter transmission delay and higher end-to-end throughput of data messages. RH2SWL (Routing with Hop-by-Hop Shortening Wireless Links) avoids collisions between 2-hop neighbor intermediate wireless nodes and provides them more opportunities to forward data messages; however, 1-hop neighbor intermediate wireless nodes might forward data messages simultaneously, which causes collisions of data messages. This paper proposes an extension of RH2SWL introducing transmission power control of RTS/CTS control messages and intentional transmission interval of data messages in order to reduce collisions between data messages and control messages transmitted by 1-hop neighbor intermediate wireless nodes.

Key Words: Wireless Multihop Networks, Sequence of Hop by Hop Shortening Wireless Links, Wireless Signal Transmission Power Control, RTS/CTS Control, Collision Avoidance.

1 Introduction

In wireless multihop transmissions of data messages in wireless ad-hoc networks, wireless sensor networks and wireless mesh networks, end-to-end data message transmission throughput decreases due to collisions between data messages, between a data message and a control message, and between control messages when a sequence of data messages are transmitted along a wireless multihop transmission route from a source wireless node to a destination one. In order to solve this problem, reduction or avoidance of these collisions especially between data messages is most efficient. Collisions between data messages transmitted along the same wireless multihop transmission route are called *intra-route collisions* which are caused by simultaneous data message transmissions by 1-hop neighbor intermediate wireless nodes, i.e., by successive intermediate wireless nodes in the wireless transmission route being exposed wireless nodes each other and by 2-hop neighbor intermediate wireless nodes being hidden nodes each other. The latter collisions are caused by the well known hidden terminal problem which is believed to be intrinsically difficult to avoid in wireless multihop transmissions since each intermediate wireless node is included in wireless transmission ranges of both its previous- and next-hop intermediate wireless nodes. In most of the currently widely available wireless LAN protocols such as IEEE 802.11, IEEE802.15 and so on, CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is applied for avoidance of collisions of data messages transmitted by exposed wireless nodes each other, and RTS/CTS (Request to Send / Clear to Send) control is introduced for avoidance of collisions of data messages transmitted by hidden wireless nodes each other. Here, during a transmission of a data message by an intermediate wireless node in a wireless multihop transmission route, some other intermediate wireless nodes are required to suspend their data message transmissions, which are called contentions. While an intermediate wireless node transmits a data message to its next-hop intermediate wireless node, not only its 1-hop neighbor intermediate wireless nodes, i.e., its previous- and next-hop intermediate wireless nodes but also its 2-hop neighbor intermediate wireless nodes are required to suspend their data message transmissions for avoidance of collisions between data messages. Due to these transmission suspensions of data messages, though intra-route collisions are avoided, improvement of throughput of data message transmissions is limited.

In order to improve end-to-end data message throughput by avoidance of intra-route collisions among data messages in wireless multihop transmissions, this paper proposes RH2SWL (Routing Hop-by-Hop Shortening Wireless Links) with transmission power controlled RTS/CTS. Here, a wireless multihop transmission route consists of a sequence of hop-by-hop shortening wireless links and each intermediate wireless node transmits data messages to its next-hop intermediate wireless node with the minimum transmission power to reach a data message to its next-hop intermediate wireless node. Each intermediate wireless node is not included in a wireless signal transmission range of its next-hop intermediate wireless node but included in a wireless signal transmission rage of its previous-hop intermediate wireless node. Hence, though it receives data messages from its previous-hop node but these data messages never collide with other messages transmitted by its next-hop node. Hence, while an intermediate wireless node transmits a data message to its next-hop intermediate wireless node, only its 1-hop neighbor intermediate wireless node, i.e., its previous- and next-hop intermediate wireless nodes are required to suspend their data message transmissions for collision avoidance. Instead of avoidance collisions of data messages caused by 2-hop neighbor hidden intermediate wireless nodes, it becomes difficult for intermediate wireless nodes to avoid collisions of data messages caused by 1-hop neighbor exposed intermediate wireless nodes since it cannot overhear data message transmissions of its next-hop intermediate wireless node due to its transmission power control of data messages. In order for avoidance or reduction of such collisions, this paper proposes power controlled RTS/CTS control message exchanges. For avoidance or reduction of collisions not only between data messages but also between control messages, combination of power controlled RTS/CTS and transmission interval of data messages is proposed. Finally, this paper evaluate performance improvement of our proposed method is estimated and evaluated in simulation experiments.

2 Related Works

Various methods have been proposed for collision avoidance or reduction in wireless multihop networks. [7, 8]have proposed TDMA (Time Division Multiple Access) approaches where time slots for data message transmissions are assigned to each intermediate wireless nodes for avoidance of collisions with 1-hop neighbor wireless nodes and 2-hop intermediate wireless nodes within the same wireless multihop transmission route. [6, 4] have proposed methods for channel assignment to wireless nodes where wireless signals transmitted through different wireless channels never collide even their transmission ranges are overlapped.

Under an assumption of single wireless channel and asynchronous, i.e., no closely synchronized local clocks in wireless nodes, environments, well known CSMA/CA and RTS/CTS control are widely available in various wireless LAN protocol. In CSMA/CA, each wireless node senses wireless carrier signal transmissions and then transmits its wireless signal if it detects no wireless signal transmissions, which results in avoidance of collisions between exposed 1-hop neighbor wireless nodes. In RTS/CTS control, a sender wireless node N_s broadcasts an RTS control message and then a receiver wireless node N_r broadcasts a CTS control message. A data message is transmitted from N_s to N_r after this handshake. Since all their 1-hop neighbor wireless nodes receiving the RTS or the CTS control messages postpone their own data message transmissions, collisions between hidden 2-hop neighbor wireless nodes are avoided. In addition to the conventional CSMA/CA and RTS/CTS control, transmission power control has also been proposed for power efficient and collision avoiding ad-hoc data message transmissions. Here, a sender wireless node transmits data messages with the minimum transmission power to reach a receiver wireless node. [5, 1] have proposed wireless multihop transmissions of data messages with transmission power control for avoidance of inter-route collisions, i.e. collisions of data messages transmitted along different wireless multihop transmission routes. However, transmission power control of data messages have not yet applied for avoidance of intra-route collisions.

Some collision avoidance methods for wireless networks consisting of different transmission power have also been proposed. [2, 3] proposes two different methods for avoidance of collisions of data messages caused by 2-hop neighbor hidden nodes with different transmission power. In [2], 1-hop neighbor wireless nodes of a sender wireless node receiving an RTS control message and 1-hop neighbor wireless nodes of a receiver node receiving a CTS control message broadcast $FRTS$ and $FCTS$, respectively, to make enough neighbor wireless nodes silent in order for avoidance of collisions with a data message. In [3], by using busy tones with different transmission power, collisions of data messages transmitted by sender nodes with different transmission power at a common receiver wireless node are tried to be avoided. However, it is not always the coverage of $FRTS$ and $FCTS$ control messages and busy tone with enhanced transmission power is not enough to avoid collisions of data messages. In addition, these methods are power inefficient since transmissions of the additional control messages and higher powered busy tone are always required independently of the existence of multiple sender nodes with different transmission power transmitting data messages simultaneously. Furthermore, there have been no proposal for supporting wireless multihop transmissions of data messages along a wireless multihop transmission route of intermediate wireless nodes with different transmission power.

3 Proposal

3.1 Routing with Hop-by-Hop Shortening Links

Usually, wireless multihop networks such as wireless ad-hoc networks, wireless sensor networks, wireless mesh networks and so on are assumed to consists of wireless nodes with the same transmission power and their wireless signal transmission ranges are equal. Hence, in a wireless multihop transmission route $|N_0 \ldots N_n\rangle$ from a source wireless node N_0 to a destination one N_n, a wireless transmission range of an intermediate wireless node N_i contains both its previous- and next-hop intermediate wireless nodes N_{i-1} and N_{i+1}. That is, an intermediate wireless node N_i is contained in wireless transmission ranges of its previous- and next-hop intermediate wireless nodes N_{i-1} and N_{i+1} which are hidden wireless nodes each other and may cause collisions of data messages at N_i. In cases that a sequence of data messages are transmitted along the wireless multihop transmission routes, a collision of data messages occurs at N_i if both N_{i-1} and N_{i+1} forward data messages simultaneously. Since such collisions cause retransmissions with a longer random back-off interval in wireless LAN protocols, end-to-end transmission delay of data messages gets longer and their throughput gets lower. However, it is considered impossible for wireless multihop transmissions of data messages to avoid such collisions caused by hidden wireless nodes without temporarily suspensions of data message transmissions in either N_{i-1} or N_{i+1} by using RTS/CTS control. As a result, the upper bound of end-to-end throughput of data messages is theoretically $T_n/3$ where T_n is data message transmission throughput of wireless module in wireless nodes as shown in Figure 1.

Recently, wireless modules in wireless nodes support transmission power control[9]. Hence, intra-route collisions of data messages in wireless multihop transmissions of a sequence of data messages are avoidable if a wireless multihop transmission route $|N_0 \ldots N_n\rangle$ consists of a sequence of hop-by-hop shortening wireless links and data message transmissions with the minimum transmission power to reach a next-hop intermediate wireless node in each intermediate wireless node. Since N_{i-1} transmits data messages with the minimum transmission power to reach N_i, N_i is in a wireless transmission range of

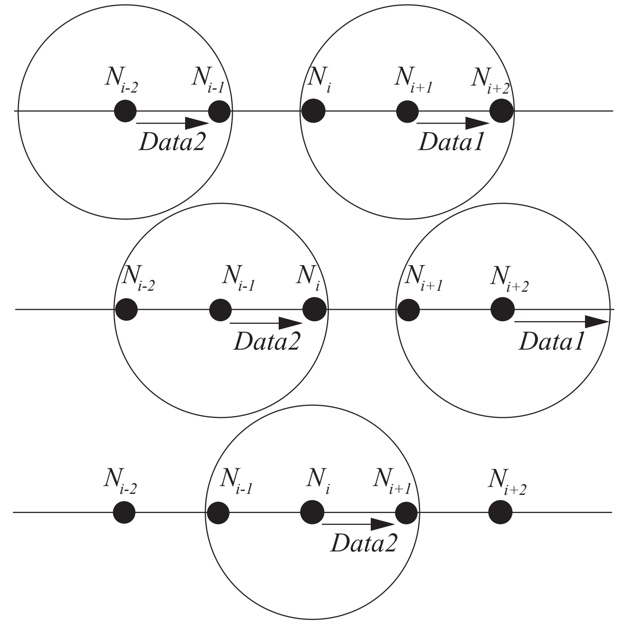

Figure 1: End-to-End Throughput in Conventional Wireless Multihop Transmissions.

N_{i-1}. However, since $|N_i N_{i+1}\rangle > |N_{i+1} N_{i+2}\rangle$ and N_{i+1} transmits data messages with the minimum transmission power to reach N_{i+2}, N_{i+1} is out of the wireless signal transmission range of N_{i+2} and the data messages never reach N_{i+1} as shown in Figure 2. Hence, N_{i-1} and N_{i+1} are not hidden wireless nodes in accordance with N_i and no collisions occur at N_i between the data messages forwarded by N_{i-1} and N_{i+1} even though they are transmitted simultaneously. Thus, the upper bound of end-to-end throughput of data message is expected to be theoretically $T_n/2$ which achieves 50% improvement as shown in Figure 3.

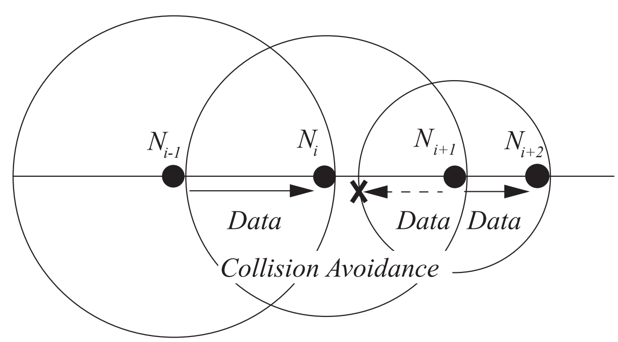

Figure 2: Collision Avoidance with Hop-by-Hop Shortening Multihop Transmission Route.

In order to configure a wireless multihop trans-

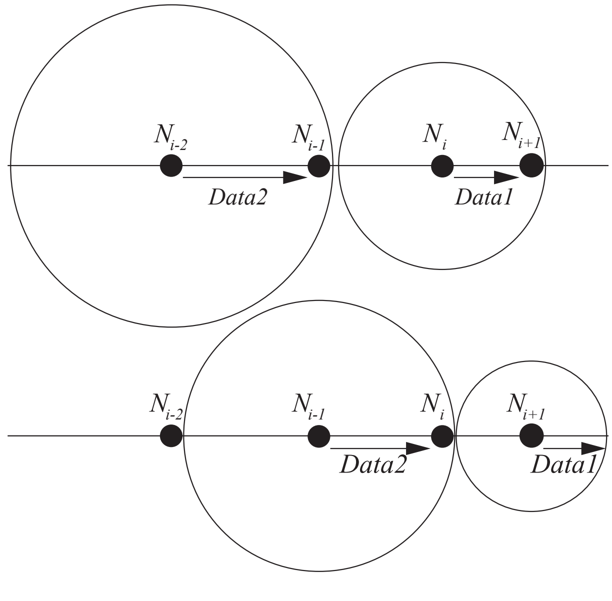

Figure 3: End-to-End Throughput in Proposed Wireless Multihop Transmissions.

mission route with a sequence of hop-by-hop shortening wireless links, an well known on demand routing protocol AODV is extended. RH2SWL is an extended routing protocol based on a flooding of route request control message $Rreq$. Different from the original AODV routing protocol, a copy of $Rreq$ control message in RH2SWL carries estimated length of previous-hop wireless communication link, i.e., an $Rreq$ message from N_{i-1} carries an estimated distance $|N_{i-2}N_{i-1}|$. On receipt of the $Rreq$ message, N_i estimates $|N_{i-1}N_i|$ by receipt wireless signal power and broadcasts a copy of the $Rreq$ message only when $|N_{i-2}Ni-1| > |N_{i-1}N_i|$ is satisfied.

3.2 Power Controlled RTS/CTS

By power controlled transmissions of a sequence of data messages along a hop-by-hop shortening wireless multihop transmission route detected by RH2SWL routing protocol, no collisions of data messages caused by simultaneous data message transmissions by 2-hop neighbor hidden wireless nodes can be avoided and 50% improvement of end-to-end throughput is theoretically expected. However, due to introduction of transmission power control of data message transmissions, CSMA/CA does not work and 1-hop neighbor exposed intermediate wireless nodes causes collisions. As shown in Figure 4, since an intermediate wireless node N_{i-1} cannot detect data message transmission from N_i to N_{i+1} due to $|N_{i-1}N_i| > |N_iN_{i+1}|$, N_i concurrently transmits a data message with N_{i+1} and a collision occurs at N_i where N_i cannot receive the data message transmitted from N_i. In order for avoidance collisions between data messages transmitted by two successive intermediate wireless nodes, certain synchronization method has to be introduced. Even if RTS/CTS control is introduced where RTS and CTS control messages are transmitted with the same transmission power as data messages, N_{i-1} cannot find that N_i is transmitting a data message to N_{i+1} since a CTS message from N_i dose not reach N_{i-1} and N_{i-1} transmits a data message independently of the state of N_i. Hence, the collision of data message at N_i cannot be avoided.

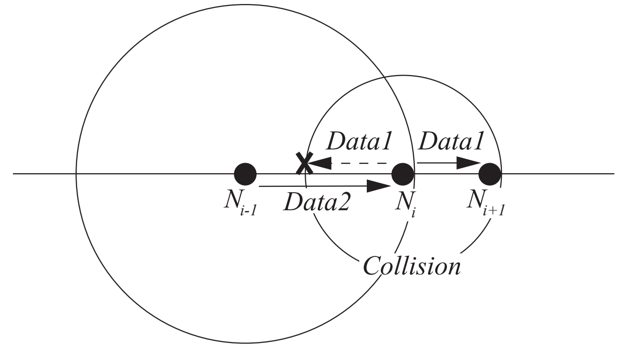

Figure 4: Collisions of Data Messages Transmitted by Successive Intermediate Nodes.

In order to solve this problem, this paper proposes power-controlled transmission of data messages. Here, for realizing reasonable RTS/CTS control, RTS and CTS control messages are transmitted with an adequate transmission power control. In order to notify that an intermediate wireless node N_i is ready for receiving a data message from its previous-hop intermediate wireless node N_{i-1}, N_i sends back a CTS control message to N_{i-1} with the minimum transmission power to reach N_{i-1} in response to the receipt of an RTS control message from N_{i-1}. Since N_i usually transmits data messages with the minimum transmission power to reach N_{i+1} where $|N_{i-1}N_i| > |N_iN_{i+1}|$, N_i transmits a CTS control message to N_{i-1} with higher transmission power than a data message to N_{i+1} as shown in Figure 5. Since a data message is transmitted only after an exchange of an RTS and a CTS control messages between 1-hop neighbor intermediate wireless nodes and N_i receives an RTS control message from N_{i-1}, a CTS control message with controlled transmission power to reach N_{i-1} never collide with a data message at N_{i-1}. In addition, since N_i sends back a CTS control message to N_{i-1} only when N_i does not transmit a data message to N_{i+1}, the CTS control message never collide with a data message at N_{i+1}. Hence, even with highly controlled transmission power, a CTS control message does not collide with a data message. It is possible for the CTS control message to collide with an RTS control message at N_{i-1} and with a CTS control message at N_{i+1} as shown in Figures 6 and 7. The former becomes fewer by the introduction of a transmission interval of RTS control messages as discussed in the next paragraph. The latter is difficult to be avoided; however, CTS control messages are small ones and there may be few chances to collide. The probability is evaluated in simulation experiments.

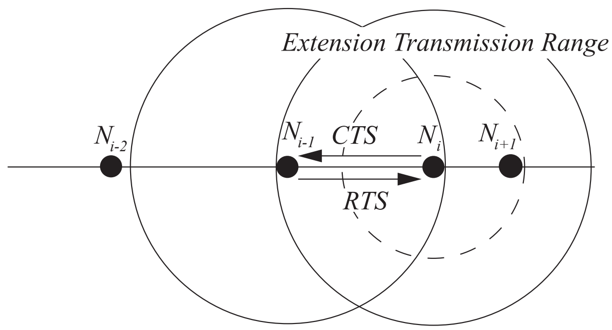

Figure 5: CTS Transmission with Higher Transmission Power.

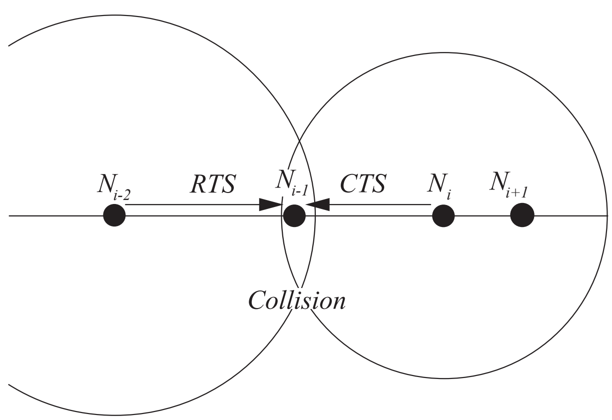

Figure 6: Possible Collision between RTS and Power-Controlled CTS.

A CTS control message transmitted by an intermediate wireless node N_i reaches not only its previous-hop intermediate wireless node N_{i-1} but also its next-hop one N_{i+1}. The CTS control message to N_{i-1} notifies that N_i receives the RTS control message from N_{i-1} and N_i is ready to receive a data message from N_{i-1}. In the conventional RTS/CTS control, the receipt of the CTS control message by N_{i+1} is useful for N_{i+1} to refrain from transmitting data messages to its next-hop intermediate wireless node N_{i+2} in order to avoid collisions of data messages at N_i. However, in our proposed method, data messages

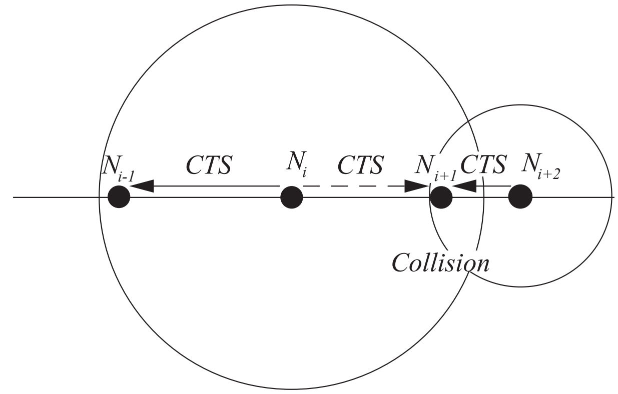

Figure 7: Possible Collision between Power-Controlled CTSs.

from N_{i-1} to N_i and from N_{i+1} to N_{i+2} never collide at N_i since the latter does not reach N_i due to transmission power control of data messages along wireless multihop transmission route with a sequence of hop-by-hop shortening wireless links. Hence, though N_{i+1} receives a CTS control message from N_i, N_{i+1} only ignores it.

Same as a CTS control message, an RTS control message also contribute for notify requirement for silence of all 1-hop neighbor wireless nodes of a sender and a receiver wireless nodes in the original RTS/CTS control. That is, in a wireless multihop transmission context, for data message transmission from N_i to N_{i+1}, an RTS control message broadcasted by N_i makes N_{i-1} silent for avoidance of collisions at N_i. Hence, the RTS control message transmitted by N_i seems to be required to reach N_{i-1}. That is, RTS control messages are also required to be transmitted with higher transmission power enough to reach the previous-hop intermediate wireless nodes. However, without receipt of an RTS control message from N_i, N_{i-1} knows that N_i tries to transmit a data message to its next-hop intermediate wireless node N_{i+2} since the data message is transmitted from N_{i-1} to N_i. Therefore, without higher power transmissions of an RTS control message from N_i, there are no collisions between RTS control messages from N_{i-1} and N_i at N_i. Hence, RTS control messages are transmitted with the same transmission power as data messages discussed in the previous subsection.

ACK control messages in response for receipt of a data message has almost the same properties of CTS control messages. Therefore, in our proposal, RTS control message is broadcasted with the same power as data messages, i.e., with the minimum transmission power to reach its next-hop intermediate wireless node, and CTS and ACK control messages are broadcasted with higher transmission power than data

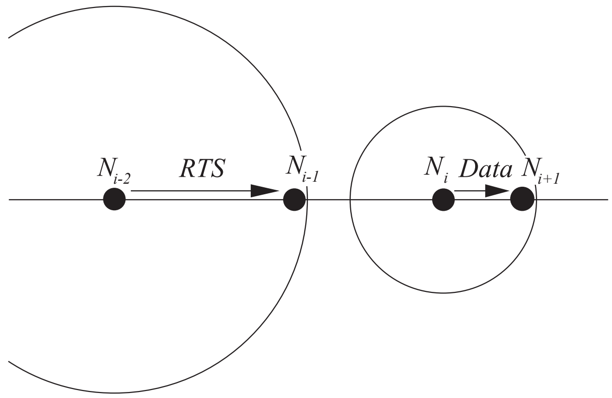

Figure 8: RTS Transmission with Same Power as Data Message.

messages, i.e., with the minimum transmission power to reach its previous-hop intermediate wireless node.

As discussed in this subsection, an intermediate wireless node N_i knows that its next-hop intermediate wireless node N_{i+1} tries to transmit the data message received from N_i to its next-hop intermediate wireless node N_{i+2}. Hence, after receipt of an ACK control message from N_{i+1}, N_i refrains to transmit the next data message to N_{i+1} for a certain interval. If this interval is too short, N_i initiates its data message transmission to N_{i+1} even while N_{i+1} is transmitting a data message to N_{i+2} which may cause collisions at N_{i+1}. On the other hand, if this interval is too long, N_i needlessly suspends its data message transmission which causes lower end-to-end throughput and longer end-to-end transmission delay. Hence, this interval is required to be controlled adequately.

Now, our power controlled RTS/CTS synchronization for collision avoidance between 1-hop neighbor intermediate wireless nodes is summarized as follows:

1) For data message transmission from N_i to N_{i+1}, after a required interval between two successive data message transmissions, N_i broadcasts an RTS control message with the same transmission power as data messages.

2) On receipt of the RTS control message, N_{i+1} broadcasts a CTS control message with higher transmission power than data messages enough to reach N_i if N_{i+1} is not engaged in its data message transmission to N_{i+2}.

3) On receipt of the CTS control message, N_i transmits a data message to N_{i+1} to the minimum transmission power to reach N_{i+1}.

4) On receipt of the data message, N_{i+1} sends back an ACK control message to N_i with higher transmission power than data messages enough to reach N_i.

5) After receipt of the ACK control message, N_i suspends its data message transmission to N_{i+1} for an interval enough for N_{i+1} to forward the data message to N_{i+2}. □

4 Evaluation

This section estimates the end-to-end throughput of data messages in wireless multihop transmissions. Table 1 shows primary parameters of IEEE802.11 wireless LAN protocol.

Table 1: Parameters of IEEE802.11.

Parameters	length	transmission time(μs)
PHY_{hdr}	144bit+48bit=192bit	192
MAC_{hdr_data}	24byte=192bit	-
LLC_{hdr}	8byte=64bit	-
$MAC_{Payload}$	20byte+8byte+1472byte=12000bit	-
MAC_{hdr_RTS}	16byte=128bit	-
$MAC_{hdr\_CTS/ACK}$	10byte=80bit	-
FCS	4byte=32bit	-
$T_{Payload}$	1472byte	1071
T_{DATA}	PHY_{hdr}+MAC_{hdr_data}+LLC_{hdr}+$MAC_{Payload}$+FCS	1309
T_{RTS}	PHY_{hdr}+MAC_{hdr_RTS}+FCS	352
$T_{CTS/ACK}$	PHY_{hdr}+$MAC_{hdr\_CTS/ACK}$+FCS	304
$DIFS$	-	50
$SIFS$	-	10
$Slot\_time$	-	20
CW_{min}	Size: 31	-

According to the values in Table 1, 1-hop wireless transmission throughput is estimated as follows:

$$T_n = \frac{T_{Payload} \times 11Mbps}{DIFS + \frac{CW_{min}}{2} \times Slot\_time + T_{RTS} + T_{CTS} + T_{DATA} + T_{ACK} + 3 \times SIFS}$$

As discussed in the previous section, in the original wireless multihop transmission with RTS/CTS control, the estimated end-to-end throughput is $T_n/3$ =1.48Mbps. However in our proposal, since simultaneous data message transmissions by 2-hop neighbor intermediate wireless nodes are allowed without collisions of data messages, the estimated end-to-end throughput is $T_n/2$ =2.22Mbps.

5 Conclusion

This paper proposes a novel high throughput data message transmission method for wireless multihop networks. Data message transmission along a wireless multihop transmission route consisting of a sequence of hop-by-hop shortening wireless communication links and with the minimum transmission power to reach next-hop intermediate wireless nodes are free from data message collisions caused by 2-hop neighbor hidden intermediate nodes. In addition, by introduction of power controlled transmissions of RTS/CTS control messages, i.e., RTS control message transmissions with the minimum power to reach next-hop intermediate wireless nodes and CTS control message transmissions with the minimum power to reach previous-hop intermediate wireless nodes results in data message transmissions without collisions caused by 1-hop neighbor exposed intermediate nodes. In future work, the authors evaluated the performance of our proposed method in simulation experiments.

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