Power Controlled RTS/CTS for High Throughput Transmissions along Hop-by-Hop Shortening Wireless Multihop 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 due to the well known hidden terminal problem 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 an 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, IEEE 802.15 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 of data messages in wireless multihop transmissions, this paper proposes RH2SWL (Routing Hop-by-Hop Shortening Wireless Links) with transmission power control...
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 range 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 of 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 a transmission interval of data messages is proposed. Finally, this paper evaluates performance improvement of our proposed method.

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 node for avoidance of collisions with 1-hop neighbor wireless nodes and 2-hop intermediate wireless nodes within the same wireless multihop transmission route. [4, 6] 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, well known CSMA/CA and RTS/CTS control are widely available in various wireless LAN protocols. 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. [1, 5] 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] have proposed 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 in the coverage of $FRTS$ and $FCTS$ control messages and busy tones with enhanced transmission power are 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 tones 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 consist of wireless nodes with the same transmission power and their wireless signal transmission ranges are equal. Hence, in a wireless multihop transmission route \( |N_0 \ldots N_n| \) 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 route, 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, intraroute collisions of data messages in wireless multihop transmissions of a sequence of data messages are avoidable if a wireless multihop transmission route \( |N_0 \ldots N_n| \) 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 \( N_{i-1} \). However, since \( |N_iN_{i+1}| > |N_{i+1}N_{i+2}| \) and \( N_{i+1} \) transmits data messages with the minimum transmission power to reach \( N_{i+2} \), \( N_i \) is out of the wireless signal transmission range of \( N_{i+1} \) and the data messages never reach \( N_i \) 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 messages is expected to be theoretically \( T_n/2 \) which achieves 50% improvement as shown in Figure 3.
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 a route request control message $Rreq$. Different from the original AODV routing protocol, a copy of $Rreq$ control message in RH2SWL carries estimated length of a 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 $|N_{i-2}N_{i-1}N_i| > |N_{i-1}N_i|$ 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, 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 cause 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 $|N_{i-1}N_i| > |N_iN_{i+1}|$, $N_{i-1}$ concurrently transmits a data message with $N_i$ and a collision occurs at $N_i$ where $N_i$ cannot receive the data message transmitted from $N_{i-1}$. 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 an RTS control message from $N_i$ does 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 messages at $N_i$ cannot be avoided.

![Figure 3: End-to-End Throughput in Proposed Wireless Multihop Transmissions.](image1)

![Figure 4: Collisions of Data Messages Transmitted by Successive Intermediate Nodes.](image2)
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.

![Figure 5: CTS Transmission with Higher Transmission Power.](image)

![Figure 6: Possible Collision between RTS and Power-Controlled CTSs.](image)

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 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 contributes to notify requirement for silence of all 1-hop neighbor wireless nodes of a sender wireless nodes in the original RTS/CTS control. That is, in a wireless multihop transmission context, for a 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 \( N_{i+1} \) since the data message has been 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 \( N_i \) only by introduction of enough interval before a transmission of an RTS control message in \( N_{i-1} \) as discussed later. 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 messages are 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 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 an enough and sufficient 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

4.1 Theoretical End-to-End Throughput Improvement

This subsection 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>
<thead>
<tr>
<th>Parameters</th>
<th>Length</th>
<th>Transmission Time (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTS</td>
<td>144bytes+80bit=152bit</td>
<td>152</td>
</tr>
<tr>
<td>LLC</td>
<td>4bytes=32bit</td>
<td>-</td>
</tr>
<tr>
<td>MACframe</td>
<td>24bytes=192bit</td>
<td>-</td>
</tr>
<tr>
<td>MACframe</td>
<td>24bytes=192bit+1472bytes=1596bit</td>
<td>-</td>
</tr>
<tr>
<td>MACframe</td>
<td>10bytes=80bit</td>
<td>-</td>
</tr>
<tr>
<td>MACframe</td>
<td>3bytes=24bit</td>
<td>-</td>
</tr>
<tr>
<td>FCS</td>
<td>4bytes=32bit</td>
<td>-</td>
</tr>
<tr>
<td>T_DIFS</td>
<td>1472µs</td>
<td>1071</td>
</tr>
<tr>
<td>T_DATA</td>
<td>PHYframe+MACframe+MACframe+MACframe+MACframe+FCS</td>
<td>1300</td>
</tr>
<tr>
<td>T_CTS</td>
<td>PHYframe+MACframe+MACframe+MACframe+FCS</td>
<td>352</td>
</tr>
<tr>
<td>T_ACK</td>
<td>PHYframe+MACframe+MACframe+MACframe+FCS</td>
<td>306</td>
</tr>
<tr>
<td>DIFS</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>SIFS</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>SlotTime</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>CWmin</td>
<td>Stps: 31</td>
<td></td>
</tr>
</tbody>
</table>

According to the values in Table 1, 1-hop wireless transmission throughput in conventional wireless multihop transmission with RTS/CTS control is estimated as follows:

$$T_{\text{thcon}} = \frac{T_{\text{DIFS}} + \frac{80}{11} T_{\text{SlotTime}} + T_{\text{RTS}} + T_{\text{CTS}} + T_{\text{DATA}} + T_{\text{ACK}}}{3} + 3 SIFS$$

The estimated 1-hop wireless transmission throughput in conventional wireless multihop transmission is $T_{\text{con}}=4.43$Mbps. As discussed in the previous chapter, in the conventional wireless multihop transmission with RTS/CTS control, since it is necessary that 2-hop neighbor intermediate wireless node from transmitter one defers own data message transmission for data message transmission of transmitter wireless node, the estimated end-to-end throughput is $T_{\text{con}}/3=1.48$Mbps. Note that, since random backoff time is calculated as average in equation of $T_{\text{con}}$, the possible value of $T_{\text{con}}$ is $3.97$Mbps $\leq T_{\text{con}} \leq 5.01$Mbps.

On the other hand, 1-hop wireless transmission throughput in our proposal without ACK control message is estimated as follows:

$$T_{\text{thcon}} = \frac{T_{\text{DIFS}} + \frac{80}{11} T_{\text{SlotTime}} + T_{\text{RTS}} + T_{\text{CTS}} + T_{\text{DATA}} + 2 SIFS}{2}$$

"Figure 8: RTS Transmission with Same Power as Data Message."
The estimated 1-hop wireless transmission throughput in conventional wireless multihop transmission is $T_{pro}=5.02\text{Mbps}$. As discussed in the previous chapter, 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 $T_{pro}/2=2.51\text{Mbps}$. Note that, since random backoff time is calculated as average in equation of $T_{pro}$, the possible value of $T_{pro}$ is $4.44\text{Mbps} \leq T_{pro} \leq 5.79\text{Mbps}$.

These results of calculation shows that our proposal without ACK control message improves end-to-end throughput 70% in comparison with the conventional wireless multihop transmissions of data messages with RTS/CTS control.

4.2 Evaluation of End-to-End Throughput in Simulation Experiments

In our proposal, it is necessary that each intermediate wireless node transmit a data message with proper transmission interval that is, the proper data transmission rate for avoidance of collision between messages including control messages. Hence, in case that the source wireless node $N_0$ sends data messages with a proper data message transmission rate, no collisions occur between the RTS control message sent from an intermediate wireless node $N_i$ and the data message sent from its next-hop one $N_{i+1}$ because when $N_i$ initiate communication to $N_{i+1}$, the data message transmission of $N_{i+1}$ is completed. This subsection evaluates the performance of the proposed method in simulation experiments to make clear whether the proposed method improves the end-to-end throughput and to make clear the proper data transmission rate in comparison with the original wireless multihop transmission. Here, 2-11 wireless nodes with 100m wireless signal transmission ranges are randomly distributed and configure 1-10hop wireless multihop transmission routes that hop-by-hop shortening wireless links in a $1,000m \times 1,000m$ square field. Data packet size is 1,472 bytes each wireless nodes transmit data messages according to the protocol, CBR(Constant Bit Rate). Table 2 shows all parameter of this experiment environment.

![Figure 9: Average of throughput for data message transmission rate(6-hop wireless transmission route).](image)

Table 2: Environment of end-to-end throughput evaluation experiment.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Simulator</td>
<td>NS2</td>
</tr>
<tr>
<td>Field Size</td>
<td>$1,000m \times 1,000m$</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>2-11</td>
</tr>
<tr>
<td>Length of Wireless Transmission Route</td>
<td>1-10hop</td>
</tr>
<tr>
<td>Wireless LAN Protocol</td>
<td>IEEE802.11b</td>
</tr>
<tr>
<td>Data Packets Size</td>
<td>1,472Bytes</td>
</tr>
<tr>
<td>Application</td>
<td>CBR</td>
</tr>
<tr>
<td>Data Transmission Rate</td>
<td>1.0-6.0Mbps</td>
</tr>
<tr>
<td>Communication Time</td>
<td>100s</td>
</tr>
<tr>
<td>Number of Trials</td>
<td>500</td>
</tr>
</tbody>
</table>

Figure 9 shows the results of end-to-end throughput for 6-hop wireless transmission route.

In low data message transmission rate range, as data message transmission rate increase that is, data message transmission interval shorten, end-to-end throughput decreases. This means that since enough data message transmission intervals are not given for each intermediate wireless nodes, a frequency of packet loss caused by the collisions between an RTS control and a data message or data messages is high as data message transmission interval shortens. It is assumed that the increasing packet loss rate leads to decreasing end-to-end throughput.

Figure 10 shows the enlarged view of the peak of throughput that is, data message transmission rate $1.56-1.70\text{Mbps}$ in Figure 9.

Average of data packets arrival rate monotonically decrease as data message transmission rate increases differently from average of end-to-end throughput. Here, the proper data message transmission rate defines as a one that makes end-to-end throughput maximum with more than 99.0% data packets arrival rate. Hence, in Figure 10 the data message transmission rate $1.66\text{Mbps}$ is the proper one for 6-hop wireless transmission route. Figure 11 shows the results of the end-to-end throughput with proper
Figure 10: Average of throughput and data packets arrival rate for data message transmission rate(6-hop wireless transmission route).

Figure 11: End-to-end throughput with proper data message transmission rate for wireless multihop transmission route.

Note that Figure 11 compare with our proposal without ACK control messages and the conventional wireless multihop transmission with ACK control messages. Both end-to-end throughput of proposal and conventional method monotonically decrease as a wireless multihop transmission route long. However, the influence of a wireless multihop transmission route to end-to-end throughput is very small in any routes more than 4-hop wireless multihop transmissions. Moreover, our proposal achieved improving average of end-to-end throughput 22% in comparison with conventional wireless multihop transmission in any wireless multihop transmission route more than 4-hop. Table 3 shows a comparison with theoretical and experimental value of end-to-end throughput in 1- and 6-hop wireless transmission route.

Table 3: Comparison with theoretical and experimental value

<table>
<thead>
<tr>
<th></th>
<th>1-hop</th>
<th>6-hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal</td>
<td>Theoretical</td>
<td>5.02Mbps</td>
</tr>
<tr>
<td>Conventional</td>
<td>4.43Mbps</td>
<td>4.46Mbps</td>
</tr>
</tbody>
</table>

In 1-hop wireless transmission route, the experimental value achieved theoretical one roughly. However, in 6-hop wireless transmission route, the experimental value achieved only 65.7% of theoretical one. It is assumed that this decreasing end-to-end throughput is caused by collisions with control messages.

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. Finally, the results of simulation experiments show that the proposed method achieves higher end-to-end throughput of data messages due to our proposed power controlled transmissions of RTS/CTS control messages.

References:


