Cross-Layer Transmission Scheme with QoS Considerations for Wireless Mesh Networks

Chin-Fu Kuo
Department of Computer Science and Information Engineering
National University of Kaohsiung
Kaohsiung, Taiwan, R.O.C.
Email: chinfuko2006@nuk.edu.tw

Hsueh-Wen Tseng
and Ai-Chun Pang
Department of Computer Science and Information Engineering
National Taiwan University
Taipei, Taiwan, R.O.C.
Email: d92005@csie.ntu.edu.tw
acpang@csie.ntu.edu.tw

Abstract—IEEE 802.11 wireless networks utilizes a hard handoff scheme when a station is travelling from one area of coverage to another one within a transmission duration. In IEEE 802.11s wireless mesh networks, the handoff procedure the transmitted data will first be buffered in the source MAP and be not relayed to the target MAP until the handoff procedure is finished. Besides, there are multi-hop in the path between the source station and the destination station. In each pair of neighboring MAPs, contention is needed to transmit data. The latency for successfully transmitting data is seriously lengthened so that the deadlines of data frames are missed with high probabilities. In this paper, we propose a cross-layer transmission (CLT) scheme with QoS considerations for IEEE 802.11 mesh wireless networks. By utilizing CLT, the ratios of missing deadlines will be significantly improved to conform strict time requirements for real-time multimedia applications. We develop a simulation model to investigate the performance of CLT. The capability of the proposed scheme is evaluated by a series of experiments, for which we have encouraging results.

I. INTRODUCTION

The IEEE 802.11 infrastructure basic service set (BSS) consists of an access point (AP) and the associated stations (STA) which are used for communication within the BSS even if the STAs reside within the same area. This infrastructure mode is the most widely used wireless LAN (WLAN) system. There is a growing need for interconnecting some APs of BSSs to form an extended service set (ESS) in wireless mesh networks (WMN)[5]. In WMN, an AP is referenced as a mesh access point (MAP). MAPs deliver data packets by means of multihop relaying from a source MAP to its corresponding target MAP. Each MAP has its corresponding BSS in the ESS and meshes with the other MAPs, while an STA is just associated to only an AP.

IEEE 802.11 medium access control (MAC) protocol defines two access methods: distributed coordination function (DCF) and point coordination function (PCF) [9]. PCF supports QoS guaranteed polling-based access, but the current products hardly provide the PCF mechanism due to its high implementation cost. IEEE 802.11 can not support QoS for real time applications. The emerging of QoS demands pushes the amendment of IEEE 802.11e QoS enhancement standard [10] for multimedia applications over WLANs. The IEEE 802.11e specification introduces the hybrid coordination function (HCF), which is backward compatible with DCF and PCF. By using parameterized QoS information, the HCF makes STAs to access wireless mediums with different priority levels. However, PCF and HCCA are designed only for single-hop networks.

In the WMN, for interconnecting APs to form an efficient multihop network supporting QoS is a challenge[15]. Further, QoS requirements including throughput, delay, jitter, and packet loss ratio impose a great challenge for achieving the goal in a multihop environment. On the side, WMN is expected to handle real-time applications with diverse QoS requirements like VoIP, VoD, and online gaming [8]. In WMN, an STA can any randomly move with some speed. If the STA is receiving real-time data from the WMN and moves out the coverage of the original MAP, then the handoff process will be started.

A handoff is the process in which an STA is handed from one BSS to the next in order to maintain a radio connection with the network. When an STA move to the BSS of the target MAP from the BSS of the source MAP, the STA must trigger a handoff procedure to make data packets transmitted to the target MAP. The handoff process can be divided into two types: soft handoff and hard handoff. The hard handoff is defined service with the target AP to start after a disconnection with the previous serving AP. The soft handoff is defined service with the target AP to start before disconnecting to the previous serving AP. We find that the soft handoff provides the seamless data transmission. But, the soft
handoff needs extra cost. The soft handoff scheme is not supported and defined in the IEEE 802.11 standard. For resource limitation, IEEE 802.11 wireless networks almost uses hard handoff.

In IEEE 802.16[6] and 3G[1][2][3], the soft handoff scheme is utilized when mobile subscriber station (MSS) moves out the base station (BS) coverage. When an MSS receives the real time data in IEEE 802.16 or 3G, the QoS requirements can be guaranteed. In addition, the BS coverage is greatly larger than that of an AP so that a mobile device does not have frequent handoff processes. In IEEE 802.16 and 3G, the powerful BS can fast process handoff procedures in a short period.

IEEE 802.11f inter access point protocol (IAPP) provided session continuity for handoffs between APs in a WLAN distributed system[4]. However, IEEE 802.11f is not implemented in IEEE 802.11 wireless device currently so the association procedure of IEEE 802.11 standard resumes in handoff situations. However, the handoff of IEEE 802.11s WMNs is very important and a serious problem due to the small coverage of an AP, contention basis for channel access and the slow process speed. In IEEE 802.11, an STA utilizes a soft handoff scheme. The data transmission will be suspended in the duration in which the STA leaves the BSS of the source AP and will not be resumed until the handoff procedure is finished. But, the suspended data transmission is a critical issue especially for real-time applications. When the real-time data is transmitted between MAPs in WMN, because of a random process of selecting backoff window, and multi-hop in the path between the source MAP and the target MAP, the QoS of a high priority multimedia stream could be temporarily unsatisfactory, especially when the system load is heavy. This is because that generally the data packets tend to have a large transmission delay and the QoS violation for real-time applications can be caused. Some work propose handoff schemes on MAC layer or the linker layer to improve transmission QoS [7][11][12]. However, if only the information of a layer is considered, it is not enough to make accurate decision for handoff. For example, due to wireless channel characters, the handoff schemes only use the information of MAC layer which do not consider wireless channel environment. When a device processes the handoff procedure in a dirty wireless channel, the control messages are not handshake successfully. In other words, the latency of handoff will be increased so QoS violation for real-time applications is more serious.

In this paper, we propose the cross-layer transmission (CLT) scheme with QoS considerations for WMN. We utilize contention window (CW) and received signal strength indication (RSSI) to decide the ratio of relayed real-time data frames between two MAPs when an STA is moving through MAPs in WMN. We utilize the cross-layer layer information to more accurate decide the ratio of real time stream for MAPs of the WMN. Therefore, STAs in the WMN can meet the QoS requirements without extra overheads.

The rest of this paper is organized as follows: Section II represents the handoff problem in WMN clearly. In Section III, we describes our CLT. In Section IV, a simulation model for CLT is presented. Based on the simulation experiments, we compare the performance of CLT with that of IEEE 802.11 standard. Finally, the conclusion is given in Section V.

II. Motivation

In this section, we will define the QoS problem in the handoff procedure. In IEEE 802.11, an STA utilizes a hard handoff scheme when the STA is roaming between a source MAP and the corresponding target MAP. In addition, when the real-time data is transmitted between MAPs in WMN, because of a random process of selecting backoff window, and multi-hop in the path between the source MAP and the target MAP, the QoS of a high priority multimedia stream could be temporarily unsatisfactory, especially when the system load is heavy. The QoS consideration is an important issue in WMN especially for roaming situation.

When a station STA is in the BSS of an MAP, we define the MAP is the “source” MAP. On the other hand, when the STA moves to the BSS of another MAP, the MAP is defined as the “target” MAP. We use an example to illustrate the hard handoff scenario of IEEE WMN, shown in Figure 1.(a). In this example, STA1 runs a multimedia application and receives the video stream from STA2. The transmitted data between the two stations are delayed by some MAPs. STA1 is first serviced in the BSS of the MAP1. We assume that STA1, as shown in Figure 1.(b)[4]. In IEEE 802.11, the hard handoff procedure needs to take some time in which data frames must be buffered in MAP1. The data frames are relayed to MAP2 after the handoff is finished.

In some worse case, if the station moves with a high speed, it can move through more than one BSS in a short interval. The previous handoff procedure is not finished but a new handoff procedure is started. During the handoff procedure, the routing tables in related MAPs will be updated and the data transmission between the source station and destination station is suspended [4]. In addition, the MAPs transmit data to utilize contention schemes in WMN so the transmission delay is very large. If the applications on STA1 has the QoS guarantee requirement, the requirement will not be satisfied. The QoS problem becomes more serious. Furthermore, there are multi-hop in the path between the source MAP and the target MAP. When the handoff is complete, the
buffered packets will be relayed from source MAP to the target MAP.

Based on the above discussions, the interval between the source station starting to transmit a data frame and the destination station receiving the frame successfully can be too long. The deadline of real-time frame cannot be met. We will investigate such a problem to propose a scheme to improve the delays for real-time data frames.

III. CROSS-LAYER TRANSMISSION SCHEME

We will propose a cross-layer transmission (CLT) scheme to improve the QoS of applications for wireless mesh networks. The approach consists of two phases: in the off-line phase, the scheme computes the ratios for few combinations of the CW value and the RSSI value and save them in each MAP of WMS for run-time usage; in the on-line phase, the scheme derives a feasible ratio from the saved ratios computed in the off-line phase based on the CW value and the RSSI value.

A. Off-line Fashion: Ratio Computation

In wireless networks, the data from a source station will be relayed to its corresponding destination station with the only one MAP whose BSS the destination station is currently in. In the proposed CLT scheme, during the handoff procedure some data frames will be relayed to the target MAP(s), such as MPi in Figure 2. An anchor node is defined as the MAP which can relay data to the source MAP and the target MAP(s), such as MPi in Figure 2. To avoid that the load increasing affects the data sending and receiving of other stations in the BSSs of the MAPs. We adopt the CW size and the RSSI value between the anchor node and the target MAP to compute the suitable ratio of data frames relayed to the target MAP. The CW size is controlled in the MAC layer and the RSSI is estimated in the physical (PHY) layer. The CW is an implicit indicator of the degree of channel congestion. The RSSI is a simple way to roughly estimate the transmission distance from the source node to its corresponding destination node in a link. IEEE 802.11 has the ability to provide many different modulation schemes (e.g., Complementary Code Keying (CCK), Packet Binary Convolutional Code (PBCC), and so on). When the high signal-to-noise ratio (SNR) is detected between a transmission device and the corresponding received device, the received device has the ability to select a high-level modulation scheme for data transmission. In other words, a higher-level modulation scheme represents that the higher data rate is utilized in transmission duration. Further, if the RSSI value is high, the high data rate will be utilized in transmission duration.

Assume that $CW_{max}$ and $CW_{min}$ are the maximum value and the default minimum value of CW, respectively. There is $M$ possible CW values between $CW_{min}$ and $CW_{max}$ and $2^{M-1} = \frac{CW_{max}}{CW_{min}}$. In IEEE 802.11 wireless networks, if the channel has been occupied by some other device, the size of CW for a specific device will doubled until the maximum value $CW_{max}$ is reached. Let $RSSI_{max}$ and $RSSI_{min}$ be the maximum value and the minimum value of RSSI, respectively. We divide the range between $RSSI_{max}$ and $RSSI_{min}$ into $N$ regions. Each $j$th region of RSSI has the boundary $(RSSI_{min} + (j-1) \cdot \frac{RSSI_{max}-RSSI_{min}}{N}, RSSI_{min} + j \cdot \frac{RSSI_{max}-RSSI_{min}}{N})$, where $0 \leq j \leq (N-1)$. The $N$ value is a user-defined variable and is set according to the granularity of the saved ratios. The transmission-ratio table, denoted by $T$, is an $M \times N$ table of non-negative real numbers, and each element $t_{m,n}$ in $T$, where $1 \leq m \leq M$ and $1 \leq n \leq N$, denotes the ratio with which the anchor node should transmit data frames to the target MAP. Most multimedia applications, such
as voice or video, use encoding mechanisms to compress the transmission data, such as MPEG1 [14]. The derived ratio between the anchor node and the target MAP must be larger than the minimum ratio which can be used to uncompress the received data frames by applications in the application layer. Assume that the minimum ratio is $\gamma$. Therefore, the minimum value in the table is equal to the ratio $\gamma$ while the maximal value is equal to 100%.

Each element $e_{m,n}$ in $\mathbb{T}$, where $1 \leq m \leq M$ and $1 \leq n \leq N$, should reflect the corresponding CW value $CW_{min} \ast 2^{m-1}$, and the corresponding RSSI value range $(RSSI_{min} + \frac{(n-1) \ast RSSI_{max} - RSSI_{min}}{N} \ast n \ast \frac{RSSI_{max} - RSSI_{min}}{N})$. We propose a weighted equation to derive the value of the element $e_{m,n}$, as shown in the following: $e_{m,n} = \gamma + (100\% - \gamma) \ast \left[\left((M-1)\ast\omega + (N-1)\ast(1-\omega)\right) - \left[m\ast\omega + n\ast(1-\omega)\right]\right]$, where $\omega$ is the weight of CW and $0 \leq \omega \leq 1$. In contract, the weight of RSSI is $(1 - \omega)$. The table will be constructed in an off-line fashion and saved in the MAPs of WMN and used in run time. Such the off-line phase can improve time for computing ratios in run time.

B. On-line Fashion: Ratio Usage for Run-time States

In this section, we present the approach for searching the transmission ratio based on the run-time CW value and the RSSI value when an STA starts a handoff procedure. The ratio will be used by the anchor node to control data relay in the network layer. Assume that at some time instance $t$ an STA reaches a target BSS from the source BSS and starts a handoff procedure. During the handoff procedure, real-time data frames should be guaranteed to meet their deadlines. Therefore, an anchor node should start to relay data frames to the target MAP(s). Then the target MAP relays the data frames to the destination STA. Besides, if the STA moves with a high speed, it can start more than one handoff procedure. Therefore, the anchor node need to relay data frames to more than one MAP. To improve the QoS of multimedia applications in the STA, during the handoff procedure the anchor node will start to transmit some data frames to the target MAPs, such as MAP2 and MAP3 in Figure 1. Simultaneously the anchor node continually relays data frames to the source MAP. To avoid to affect the transmission of data frames of STAs in the BSS of the target MAPs, the anchor node may not relay all the same data frames which are relayed to the source MAP to the target MAPs.

The proposed CLT scheme proposes to compute a reasonable transmission ratio to relay data frames. The ratio will be searched based on the CW value, $CW_t$, and the RSSI value, $RSSI_t$, at time instance $t$. We will derive the ratio from the transmission-ratio table constructed in the off-line fashion. Let $(x, y)$ be the position of the goal ratio in the transmission-ratio table $\mathbb{T}$, where $x$ and $y$ are the indexes of the CW value and the RSSI range, respectively, and they are integers

not less than 0. $x$ and $y$ are derived by the following equations:

$$2^x = \frac{CW_t}{CW_{min}}$$

and

$$y = \left\lfloor \frac{RSSI_t - RSSI_{min}}{RSSI_{max} - RSSI_{min}} \right\rfloor \mod N.$$
second. STA1 is first in the BSS of MAP1 and will move to MAP2 and then go to MAP3. Then STA1 will go back the BSS of MAP1 through the BSS of MAP2. The simulation model follows the IEEE 802.11 specification and simulates a frequently interactive communication environment, as shown in Table I. We assume that the data arrival rate at an STA follows a Poisson distribution with the arrival rate \( \lambda \), and the length of data frames is exponentially distributed with a mean 1024, where the unit is in bytes. The default relative deadline and the length of each real-time data frame is 30 ms and 2048 bytes, respectively [13]. In the simulations, the CLT scheme with the weight value \( \omega \) of CW equal to 0.1, 0.5, and 0.9 are evaluated. Each simulation run proceeds for 1,000,000 time slots and each simulation result is an average over ten independent simulation runs. Additionally, there are some assumptions described as follows:

- The position of the ten MAPs are fixed and each MAP has ten STAs and the STAs are randomly located in the BSS of the MAP.
- The control frames of RTS/CTS are used for channel contention.
- Channel is noiseless and error-free.
- Propagation delay between STA and MAP or MAP and MAP is ignored.

Besides, other related parameters of layer-2 handoff procedure are defined based on the parameter setup in [12]. The minimum ratio \( \gamma \) of video frames is equal to 40% [14]. In experiments, because \( CW_{min} \) and \( CW_{max} \) are equal to 32 and 1024 [9], respectively, the \( M \) value is set as 6. There are two kinds of data frame rates, i.e., 11 and 5.5 Mbps. Therefore, the \( N \) value is equal to 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data frame rate</td>
<td>11, 5.5 Mbps</td>
</tr>
<tr>
<td>Control frame rate</td>
<td>2 Mbps</td>
</tr>
<tr>
<td>A time slot ( (\alpha) )</td>
<td>20 ( \mu s )</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 ( \mu s )</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 ( \mu s )</td>
</tr>
<tr>
<td>RTS frame length</td>
<td>13.6 time slots (68 bytes)</td>
</tr>
<tr>
<td>CTS frame length</td>
<td>12.4 time slots (62 bytes)</td>
</tr>
<tr>
<td>ACK frame length</td>
<td>12.4 time slots (62 bytes)</td>
</tr>
<tr>
<td>( CW_{min} )</td>
<td>32 time slots (32 ( \alpha ))</td>
</tr>
<tr>
<td>( CW_{max} )</td>
<td>1024 time slots (1024 ( \alpha ))</td>
</tr>
</tbody>
</table>

The primary performance metrics are the missing rate \( (MR) \) and the delay \( (D) \). The \( MR \) is defined as the ratio of the number of data frames missing their deadlines to the number of total real-time data frames. The \( D \) is defined as the average interval between the time that the source station transmits the non-real-time frame and the time that the frame is successfully received by the destination station.

![Fig. 4. Effects of arrival rates on missing rate \( MR \) for the CLT scheme with different weight setting and the IEEE 802.11 standard.](image)

![Fig. 5. Effects of arrival rates on delay \( D \) for the CLT scheme with different weight setting and the IEEE 802.11 standard.](image)

**B. Experimental Results**

Figure 4 shows the \( MR \) values of IEEE 802.11 standard and the proposed scheme with different weight values of CW, i.e., 0.9, 0.5, and 0.1. This figure intuitively shows that the \( MR \) values for the scheme with different weights and IEEE 802.11 standard increase as the arrival rate increases. The reason is that real-time data frames are blocked by non-real-time data frames. Due to contention, if there are more non-real-time data frames, the probability that non-real-time data frames block real-time data frames is high. Therefore, the real-time data frames easily miss their deadlines. When the arrival rate is less or equal to 10, the performance difference between the proposed scheme and IEEE 802.11 standard is similar. The proposed scheme with different weight values can almost meet the deadlines of real-time data frames. The reason is that the traffic load in the network is light. However, when the arrival rate is greater than or equal to 15, the difference increases progressively. The less the weight value, the smaller the \( MR \) values. The reason is that the CLT scheme with a high weight value will reflect the busy status of the MAP. Hence, the CLT scheme with a higher weight value uses a lower transmission ratio. Less real-time data frames are relayed to the destination MAP and the data frames have a higher probability to meet their deadlines. Note that the used transmission ratio is still higher than the minimum ratio \( \gamma \), i.e., 40%.

Figure 5 shows the delay \( D \) of the CLT scheme
with different weight values, i.e., 0.9, 0.5, and 0.1, and IEEE 802.11 standard. This figure intuitively shows that for all schemes under investigation, the $D$ value increases as the arrival rate increases. From the results, we can observe that the CLT scheme has smaller $D$ values than that of IEEE 802.11 standard. The reason is that IEEE 802.11 must relay buffered data frames after the handoff procedure is complete. Averagely in IEEE 802.11 standard transmitting a real-time data frame need more contention. The CLT scheme with a higher weight value has larger $D$ values than that of smaller weight values. The reason is that the CLT scheme with a higher weight value uses a lower transmission ratio. Less real-time data frames contend for channels with non-real-time data frames. Hence, non-real-time data frames have smaller $D$ values. From the experimental results, our CLT significantly outperforms IEEE 802.11 standard.

V. Conclusion

This paper proposed a cross-layer transmission (CLT) scheme with QoS considerations for IEEE 802.11s wireless mesh networks. With our proposed CLT scheme, some portion of data frames are relayed to more than one MAP from the anchor node. A simulation model was developed to investigate the performance of CLT. The capability of the proposed scheme was evaluated by a series of experiments, compared to standard IEEE 802.11 wireless networks. From the experimental results, our CLT significantly outperforms the standard of IEEE 802.11. The CLT scheme can reduce the number of real-time data frames missing their deadlines and improve the delay of non-real-time data frames. For future research, we will extend our work to consider the situation in which there are errors and noise during data transmission.

References