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Abstract

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A Dynamic QoS Algorithm for Wireless AV Home Networks

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***Abstract* - Due to the high bandwidth demanding and the variability of wireless link quality, AV transmission has presented challenges to wireless networks. Traditional technologies have achieved little success. IEEE 802.11e Standard [1] has introduced dedicated bandwidth in combination with prioritization techniques at MAC layer to enhance QoS capability of wireless networks. However, the QoS mechanisms provided in IEEE 802.11e Standard face challenges if required bandwidth is greater than available bandwidth [2]. Therefore, new QoS technologies beyond MAC layer need to be deployed for a complete QoS solution. This paper presents a dynamic QoS algorithm at LLC layer for wireless AV networks.**

***Keywords* – Dynamic QoS, AV transmission, wireless networks.**

1. Introduction

To deliver bandwidth demanding and time-sensitive AV streams over wireless networks, QoS plays such a crucial role that a lost packet can cause a stream transfer to break down. A High Definition TV (HDTV) decoder may discard the received packets if some packets get lost during the transmission. IEEE 802.11e Standard has accomplished the Enhanced Distributed Channel Access (EDCA) and HCF Controlled Channel Access (HCCA) mechanisms to provide QoS solutions for AV streaming over 802.11 wireless networks. The EDCA and HCCA are respectively prioritized mechanism and parameterized mechanism at the MAC layer. Research has shown that due to the non-deterministic nature, EDCA will not guarantee bandwidth except in a very lightly loaded network. HCCA mechanism must be used to ensure consumer acceptance of wireless connectivity for use with AV streaming application [3]. Due to the lack of HCCA mechanism, ad-hoc networks still face challenges in providing adequate QoS for AV streaming applications. Even in infrastructure networks with HCCA mechanism, QoS problems remain exist when bandwidth is in shortage, which can be caused by either fading channel condition or overloaded network traffic. For a wireless AV network with IEEE 802.11e mechanisms, the quality of AV streams may still become unacceptable when bandwidth is over demanding. Some AV streams may have to sacrifice in order to guarantee the quality of other AV streams. The question is which AV stream should be the victim? How much does victim need to sacrifice? The new QoS technologies presented in this paper provides the efficient solutions for those questions.

The proposed QoS algorithm works on top of the IEEE 802.11e standard. It complements and enhances IEEE 802.11e QoS mechanisms. It provides an efficient bandwidth management solution in the case of bandwidth shortage. The proposed QoS algorithm dynamically senses total required bandwidth and total available bandwidth, and dynamically adjusts bandwidth allocation to guarantee the required bandwidth for the higher priority AV traffic streams. The proposed QoS algorithm fully utilizes existing information required by IEEE 802.11e mechanisms as input data to provide new QoS capabilities. This QoS algorithm has been implemented and extensively tested. It provides new QoS functions lacking in IEEE 802.11e QoS mechanisms.

According to IEEE 802.11e standard, all AV streams have same priority in terms of channel access. This makes it difficult to select victim stream. The QoS algorithm presented in this paper defines a new type of the priority for AV streams. This new priority is different from the user priority used in IEEE 802.11e standard. The determination of this new priority is application specific. One way to define the new priority is to use the AV stream bitrate. This definition is used in the implementation presented in this paper with higher bitrate AV stream having higher priority, and lower bitrate AV stream having lower priority. With this type of priority being defined, the QoS algorithm selects victim based on the AV stream priority. Once a stream is selected to be the victim, the bandwidth allocation for this stream shall be reduced. The specific procedure to reduce the bandwidth depends on if the stream is transmitted using EDCA mechanism or HCCA mechanism. The transmitter may perform bitrate reduction of the victim stream in order to use limited bandwidth to transmit all victim stream packets. This will increase bandwidth efficiency and packet usability. The proposed QoS algorithm guarantees bandwidth for the higher priority AV streams by sacrificing the lower priority AV streams when network is overloaded or channel condition worsens. Together with IEEE 802.11e, this QoS algorithm provides a better QoS solution for 802.11 wireless AV networks.

2. The QoS algorithm

The proposed QoS algorithm runs mainly on a QoS access point (QAP) with the cooperation of the QoS stations (QSTAs) within the network. The hybrid coordinator (HC) defined in IEEE 802.11e standard also operates on QAP. The HC performs the bandwidth management functions defined in IEEE 802.11e standard. Therefore, QAP has a complete knowledge of the entire network such as network traffic information and wireless channel condition. The proposed QoS algorithm fully utilizes the HC's existing information of the traffic streams (TSs) such as bitrate, PHY rate, packet size, and medium access method (EDCA or HCCA) used for transmitting the TSs to efficiently manage bandwidth whenever the bandwidth shortage occurs. All the input information to the QoS algorithm is obtained from existing HC data base. No new information is needed.

One of the major differences between IEEE 802.11e MAC and conventional IEEE 802.11 MAC [4] is the transmission opportunity (TXOP) introduced by IEEE 802.11e MAC. A TXOP is an interval of time when a particular QSTA has the right to initiate frame exchange sequences onto the wireless medium. Once gaining the medium access right, a QSTA may transmit a series of frames instead of one frame as conventional station does. For the EDCA channel access method, the TXOP is called EDCA TXOP, which is announced in beacon frame by QAP. The QSTAs contend for EDCA TXOP. For HCCA channel access method, the TXOP is called HCCA TXOP, which is contained QoS poll frame transmitted to QSTA by QAP when it polls the QSTA to start frame transmission.

According to IEEE 802.11e standard, when a QSTA has a TS such as AV stream to transmit it shall send an add TS (ADDTS) request to QAP to ask for transmission permission for the TS before starting transmission. The ADDTS request contains several fields in it. One of them is called traffic specification (TSPEC) element, which specifies the characteristics and QoS expectations of the TS, such as TS ID, data rate, data unit size, desired PHY rate, medium access method (EDCA or HCCA), etc. Upon receipt of an ADDTS request, the QAP shall determine to accept or deny the request based on the information contained in TSPEC element, available bandwidth, channel condition, network loading, etc. If the bandwidth is available the QAP shall accept the request. Otherwise, the QAP shall deny the request. The QAP shall transmit its decision with an ADDTS response to the requesting QSTA. If the request is accepted the QSTA shall start transmitting the TS. Otherwise, the QSTA shall not transmit the TS.

A key issue is how to determine if the bandwidth is available or not. The proposed QoS algorithm resolves this issue by developing a new medium time algorithm. IEEE 802.11e MAC divides time into beacon interval with each beacon interval started by beacon frame. Each beacon interval is composed of a contention period and a contention free period. The starting time and the length for contention period and contention free period are announced in the beacon frame by QAP. For each TS, the QoS algorithm has to figure out how much time, within each beacon period, is needed for this TS to occupy the wireless medium in order to transmit amount of the data required by TS. This time is called medium time. The bitrate of the TS indicates amount of the data to be transmitted per second. Based on the amount of the data to be transmitted per second, the QoS algorithm calculates the amount of the data to be transmitted per beacon interval. Using this data amount, information contained in TSPEC element, PHY type, current PHY rate, etc., the QoS algorithm calculates medium time for the TS within each beacon interval. The QoS algorithm then calculates the total medium time for all TSs transmitted using EDCA method and the total medium time for all TSs transmitted using HCCA method respectively. If the total medium time for TSs transmitted with EDCA method exceeds the length of the contention period the required bandwidth by those TSs is greater than available bandwidth. Similarly, if the total medium time for all TSs transmitted with HCCA method is greater than the length of contention free period the required bandwidth by those TSs is greater than available bandwidth. If this happens, the QoS algorithm shall take action by reducing transmission time of the selected TSs as described in following paragraphs. The QoS algorithm also takes other data transfer into account when it decides if the bandwidth is in shortage.

It is very important to point out that the proposed QoS algorithm uses current PHY rate instead of the desired PHY rate specified in TSPEC element in calculating the medium time. This will reflect the instant wireless channel condition and variability of the wireless links.

To achieve our goal, in this paper we have defined a new type of the priority for each TS. This new priority is different from the user priority described in IEEE 802.11e standard. This new priority is determined by QoS algorithm based on TS information received in TSPEC element. This new priority is locally defined and stored in QAP. The QoS algorithm uses this new priority to adjust medium time allocation for TSs.

The proposed QoS algorithm handles the bandwidth shortage issue based on medium access method used.

The first case is the EDCA, which is a prioritized best-effort channel access mechanism, that is, a contention based channel access method. Based on user priority, EDCA mechanism divides network traffic into four access categories (ACs): AC_VO, AC_VI, AC_BE, and AC_BK. Each AC has its own transmit queue and its own set of AC parameters. The differentiation in user priority between ACs is realized by setting different values for the AC parameter set. The definition of those AC parameter set can be found in IEEE 802.11e standard. The most important ones are the minimum time interval between the wireless medium becoming idle and the start of transmission of a frame, a random backoff time, and EDCA TXOP.

Among four ACs, AC_VO has the highest priority, AC_VI has the second highest priority, AC_BE has the third highest priority, and AC_BK has the fourth highest priority that is actually the lowest priority. According to the division rules defined in IEEE 802.11e standard, all AV streams belong to same access category, that is, AC_VI. That means that a HD stream has same priority as a standard video stream in terms of channel access. Since the HD stream requires much more bandwidth than other lower bitrate video streams do, the quality of HD stream will first be affected when bandwidth is in shortage. The proposed QoS algorithm dynamically performs bandwidth check. If the total medium time required by all TSs transmitted using EDCA method is less than the length of the contention period the QoS algorithm takes no action. Otherwise, based on the new priority defined in this paper, the QoS algorithm selects a lowest priority video stream as victim. It re-calculates a new AC parameter set for this victim and informs victim stream transmitter to use the new AC parameter set for the victim immediately until further notification. The QoS algorithm may also let the transmitter use the lower priority AC parameter set for the victim stream transmission. Further more, the QoS algorithm may let the transmitter stop transmitting victim stream. Upon receipt of such a notification from Qos algorithm, the transmitter shall use new AC parameter set immediately for victim transmission. To avoid retransmission attempts and to let all packets be successfully decoded by receiving side video codec, the transmitter may chose to reduce the bitrate of the victim stream until further notification received from the QoS algorithm. QoS algorithm may select more than one victim if the bandwidth is in severe shortage. When bandwidth becomes available later the QoS algorithm shall notify the transmitter of the victim stream to use normal AC parameter set.

The second case is the HCCA, which supports for parameterized QoS mechanism. It provides polled access to the wireless medium. The central concept of HCCA is controlled access phase, which is a bounded time interval and formed by concatenating a series of HCCA TXOPs. HCCA TXOPs are generated by QAP based on information received in TSPEC elements. Scheduling of HCCA TXOP is performed by the QAP. The QAP gains access to the wireless medium based on a shorter timing to poll QSTAs for transmission. If the channel condition does not fade the scheduled HCCA TXOPs shall guarantee the data transmission as requested in TSPEC element for each admitted TS. However, when channel condition worsens the scheduled HCCA TXOPs may be too short to guarantee the transmission of the corresponding TS frames. The longer HCCA TXOPs may be needed. As a result, the quality of admitted TSs may be degraded.

The proposed QoS algorithm also performs bandwidth check dynamically for TSs transmitted using HCCA channel access method. If the total medium time required by all TSs transmitted with HCCA method is greater than length of the contention free period the QoS algorithm shall first select a lowest priority TS transmitted using EDCA method as victim if there is such a stream, and then increases the length of HCCA TXOPs. This will actually increase the length of the contention free period. If there is no stream transmitted using EDCA method the QoS algorithm shall select a lowest priority stream transmitted using HCCA method as victim. It shall reduce HCCA TXOPs allocated for the victim stream and increase HCCA TXOPs for the higher priority TSs. The QoS algorithm may also stop polling victim stream for transmission. The QoS algorithm informs the transmitter about its decision. When a transmitter receives such notification it may reduce bitrate of the victim stream to increase transmission efficiency and packet usability. When channel condition improves later the QoS algorithm shall use the original HCCA TXOPs to poll all TSs.

3. The QoS implementation and tests

The principle of the QoS algorithm is to dynamically provide enhanced QoS control mechanisms on top of IEEE 802.11e MAC and to protect the quality of the higher priority traffic streams whenever bandwidth is in shortage, which can be resulted by either network overloading or fading channel condition. The proposed QoS algorithm has been implemented, and extensively tested in an 802.11 wireless AV network as illustrated in figure 1. The QoS algorithm runs on a wireless transmitter (WT), which is composed of the proposed QoS algorithm and an 802.11a+e component. The WT uses CE-Linux as its operating system. There total six WTs used for in the tests. Three WTs are for transmission with one connected to a DVHS player via 1394 interface, one connected to DVD player and another connected to a VCR via s-video interface. There are three receiving WTs with one connected a DTV via 1394 interface and two connected to analog TVs via s-video interface. There are also two PCs within network to perform best effort data transfer and to consume some bandwidth. The WT connected to DTV is configured as QAP. All other WTs are configured as QSTAs. Two PCs are configured as non-QoS stations that do not support IEEE 802.11e mechanisms.

The DVHS player plays a 19.4 Mbps HD video. The analog inputs from DVD player and VCR are first converted into digital streams by a MPEG2 codec, and then transmitted over wireless medium. The bitrates for DVD stream and VCR stream are dynamically changeable through a control interface. As shown in Fig.1, the QoS algorithm sits above IEEE 802.11a/e component. WTs transmit or receive AV streams over wireless medium using 802.11a PHY. In a perfect environment, 802.11a PHY provides 54 Mbps raw data rate. The throughput is about 30 Mbps. In the reality, the throughput could be even lower.

The proposed QoS algorithm has been extensively tested in various situations. In all cases, it provides enhanced QoS functions as expected and resolves QoS issues for which IEEE 802.11e standard do not provide any solution.

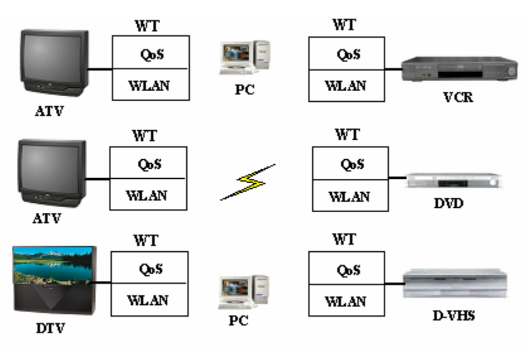

Figure 1. Wireless AV Network Architecture

In the tests, a HD stream, a DVD stream and a VCR stream are transmitted simultaneously with HD stream bitrate greater than DVD stream bitrate, DVD stream bitrate greater than VCR stream. By new priority defined in the QoS algorithm, the HD stream has highest priority and VCR stream has the lowest priority, and DVD stream possesses the middle priority. The followings are two test scenarios and test results.

The first scenario is to test the network overloading situation. In this case, all transmitters and receivers are within 10 meter range. At the beginning, a 19.5 Mbps HD stream, a 4 Mbps DVD stream and a 3 Mbps VCR stream are transmitted simultaneously using EDCA method. This means all three streams are transmitted during contention period and they need to contend for EDCA TXOP with each other and also with other best effort data transmission. The quality of all three streams is good since there is enough bandwidth for all three streams. Next, the bitrates for DVD stream and VCR stream are dynamically increased to 6 Mbps and 4 Mbps respectively. Now, the total bitrate of the three streams is about 30 Mbps, which is higher than the total available bandwidth. Without running the proposed QoS algorithm, the quality of the HD stream is not acceptable. However, both DVD and VCR streams have good quality because they require much lower bandwidth than HD stream does. Once QoS algorithm starts running, the quality of HD stream becomes good and the image of the VCR stream is almost frozen since the VCR stream has been selected as the victim stream by the QoS algorithm. At this point, the bitrates for DVD stream and VCR stream are dynamically changed back to 4 Mbps and 3 Mbps. The quality of all three streams becomes good again. However, when two PCs start data transfer to ftp a big file from one PC to another PC the quality of the HD stream is degraded again if the QoS algorithm is not running. Once the QoS algorithm starts running, the HD stream improves to good quality and the quality of the VCR stream is degraded. This is due to the fact that the QoS algorithm is running on QAP and it is aware of the start of the data transfer, and selects VCR stream as the victim again. The quality of the DVD stream is still good because it has not been selected as victim.

For a 4 Mbps DVD stream and 3 Mbps VCR stream, if a 19.5 Mbps HD stream is transmitted using HCCA method, DVD stream and VCR stream are transmitted using EDCA method the quality of HD stream is good with or without PC doing data transfer. However, without running the QoS algorithm, the quality of both DVD stream and VCR stream is degraded by PC's data transfer. With the QoS algorithm running, the quality of the DVD stream becomes good and the quality of the VCR stream gets worse.

If a 19.5 Mbps HD stream, a 6 Mbps DVD stream and a 4 Mbps VCR stream are transmitted using HCCA method the VCR stream is rejected for transmission by QAP because the actual throughput of the network is lower than 30 Mbps.

The second scenario is to test the channel fading situation. In this case, a 19.5 Mbps HD stream, a 4 Mbps DVD stream and a 3 Mbps VCR stream are transmitted simultaneously using HCCA method. When all devices are within 10 meter range the quality of the all three AV streams are good. However, when TVs are moved further away from the transmitters, without running the proposed QoS algorithm the quality of all three streams is degraded because of the fading wireless channel. Each AV stream actually needs more transmission time than actually allocated transmission time. Once QoS algorithm starts running, the quality of both HD stream and DVD stream improves to good, and the quality of the VCR stream becomes worse because it has been selected as the victim, and, therefore, its transmission time has been reduced in order to increase transmission time for HD stream and DVD stream. In this scenario, PCs do not affect quality of the AV streams because PCs do not support any IEEE 802.11e mechanism, and they use conventional best effort channel access method to transmit data during the contention period. All three AV streams are transmitted using HCCA method during contention free period.

4. Conclusion

The QoS control mechanism is very important especially for wireless AV networks. The required bandwidth may exceed available bandwidth. Even though the network may has enough bandwidth for transmitting AV streams the other applications may cause bandwidth overflow. Also, the throughput will drop when channel condition worsens, which may also result in the bandwidth shortage. In such an overloaded situation, 802.11 wireless networks can't provide adequate QoS functionality even with IEEE 802.11e mechanisms. Therefore, a complete QoS solution is crucial for 802.11 wireless AV networks.

The QoS algorithm proposed in this paper sits at LLC layer above the MAC layer. This QoS algorithm runs on top of IEEE 802.11e standard to provide a better QoS solution for 802.11 wireless networks. Specifically, the QoS algorithm provides an efficient QoS mechanism to handle bandwidth overflow problem caused by either unexpected network overloading or fading wireless channel condition, where IEEE 802.11e standard provides little solution. With the proposed QoS algorithm, the required bandwidth for the higher priority AV streams is guaranteed. The test results show that the proposed QoS algorithm is an enhancement and a complement to IEEE 802.11e QoS mechanisms. Working together with IEEE 802.11e QoS mechanisms, the proposed QoS algorithm has achieved a better QoS solution for 802.11 AV networks. Clearly, QoS technologies beyond the MAC layer can be deployed to provide a complete QoS solution.

The proposed QoS algorithm utilizes existing information required by IEEE 802.11e mechanisms as input data to provide new QoS capabilities. There is no new input information needed from the upper layers or users. There is also no frame types needed. It does not change any existing system information.

It is necessary to point out that the proposed QoS algorithm can be implemented without IEEE 802.11e standard as the base. It can be implemented in any infrastructure networks, especially for streaming-centered networks. It can also been implemented for coordinated ad-hoc networks such as IEEE 802.15.3 networks.

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