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An error control scheme based on adaptation of polling schedule for real-time communication on IEEE 802.11 Wireless LANs

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Abstract

This paper proposes an error control scheme that dynamically adjusts the polling schedule so that more corrupted messages can be manipulated within their deadlines for real-time communication on IEEE 802.11 Wireless LAN. Monitoring the current traffic on CP interval as well as inspecting whether a node is executing an error control procedure, AP terminates CP, if possible, to extend the duration of the next CFP. With the enlarged time, AP gives more polls to the node in need to increase the number of timely recovered messages. Simulation result performed via SMPL shows that this adaptation scheme can reduce the message discard due to transmission error by 5.5 %, compared with the existing error controls method for real-time communication on WLAN.

Keywords
Electrical tomography, real-time communication, error-control, polling sequence, deadline meet ratio

1. INTRODUCTION

Wireless local area networks(WLANs) are emerging as an attractive alternative, or complementary, to wired LANs, because they enable us to set up and reconfigure LANs without incurring the cost of wiring[4]. It makes a sense that various real-time systems also adopt WLAN as their communication network. We mean by real-time that an information package has to be received by the recipient before a certain deadline, so the network should be able to meet the requirement of the time-constrained traffic[11].

As an example, in ET(Electrical Tomography) system, the measured data should be transmitted within a reasonable time bound via the underlying network to timely visualize the internal structure of the given object[6].

The traffic requires bounded delays, but is usually tolerant of some message loss. Hence, the requirement of these messages includes a guarantee from the system that they should be delivered within their deadlines as long as there is no network error[1]. That is, hard real-time messages must be properly scheduled for transmission, and scheduling messages in a multiple-access network is the function of the MAC (Medium Access Control) protocol [11]. In the transmission control based real-time network, each node sends its message according to the round robin policy at run time while the central off-line scheduler determines how long a node can continue to access the network. This procedure, named as bandwidth allocation, is based on the traffic characteristics of the given message stream set. Though WLAN can schedule the message transmission according to this strategy, wireless transmissions are subject to interference from outside sources, absorption, scattering, and fading [5]. While the error correction code such as FEC (Forward Error Correction) is able to recover many damaged messages so reduce the probability of message discard, it can not deal with all of the transmission errors. Indeed this error correction mechanism seems to be promising, but information overhead and processing complexity are not negligible. More errors can be overcome by the additional error control procedure.

The networking community has explored a broad spectrum of solutions to deal with both wired and wireless error environments[7]. For a real-time system, however, the traditional error recovery schemes, originally proposed for non-real-time data transmission, may introduce an unacceptably long delay. To the worse, the retransmitted message may interfere or prolong the delivery of other normal messages, resulting in the cascaded deadline miss. Hence, the error control scheme on real-time system should directly consider the time constraint of messages to eliminate a meaningless control step, or error control after deadline expiration.

The authors of this paper have propose d an error control scheme for real-time messages on the wireless LAN[9]. Being built on top of a transmission control-based message scheduling policy, their scheme can satisfy the requirements pointed at the previous paragraph. It makes the receiver node report errors in a best-effort manner as a non-real-time message during CP(Collision Period), originally reserved for the non-real-time traffic. As contrast, the sender is forced to retransmit the damaged message via the overallocated bandwidth within

CFP(Collision Free Period). So it is possible to completely obviate the interference of error control messages to the delivery of other real-time message. However, more errors can be recovered if the retransmission is performed on the idle time of CP. To this end, the coordinator node should monitor the current traffic on the network as well as adjust the polling schedule for real-time sources.

This paper is organized as follows: After issuing the problem in Section 1, we will introduce target ET system architecture as well as related works on error control for real-time messages on WLAN in Section 2. Section 3 and 4 describe real-time communication and corresponding error control procedures in detail, respectively. Section 5 shows the performance measurement results and finally Section 6 summarizes and concludes this paper.

2. BACKGROUND AND RELATED WORKS

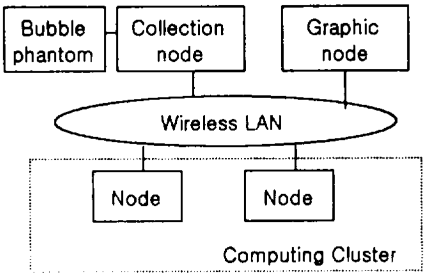


Figure 1. ET network architecture

According to our design, the target ET system consists of a collection node, a graphic node, and several nodes forming a computing cluster as shown in Figure 1. The collection node periodically generates a raw data after measuring the voltaic current through electrodes surrounding the target object(bubble phantom in this figure). The nodes in computing cluster, after receiving the data via network, analyze the internal structure by executing the well-known algorithms such as Newton-Rapson, Kalman filter, genetic, and so on[6]. In this step, the node may exchange messages with one another to perform a cooperative computing. Then the analyzed results are sent to the graphic node where they are visualized on the display device.

During the system operation, each node generates a message stream whose period and size are known in advance. It is natural that the period of message stream is closely related to sampling rate at the collection node. Each message is then segmented into several MAC frames as large as allocation vector element, as will be described later. All frames belonging to a message should be transmitted within its period. Any bit error brings th e loss of the entire frame, resulting in degrading the correctness of data analysis procedure at the computing node. That is, on a frame error, a computing node executes its job with imperfect data. The more the processing node receives the correct message s, the better the quality of the reconstructed images.

As for the real-time communication on WLAN, a unified wireless architecture has been proposed[3]. The authors addressed how to support real-time and non-real-time communication services in a wireless LAN with D-TDD(Dynamic Time Division Duplex) transmission. For real-time traffic, a non-preemptive EDF(Earliest Deadline First) policy is adopted. The polling order is determined based on the contracted traffic characteristics so that every node is polled at the regular intervals. However, the size of its polling sequence table may increase, let alone the admission control mechanism becomes too complex.

As for the error control scheme for real-time traffic on wireless LANs, H. Bengtsson has proposed a protocol based on retransmission fulfilled on demand within a given time window[2]. Each retransmission is coded with a varying number of redundant symbols. The protocol is supported by the Reed-Solomon codes that can transform the message into a data stream with the desired probability of success. There remains some margin to improve the recoverability if some supplementary error control mechanism is integrated at LLC(Logical Link Level) layer.

In addition, a two-step adaptive error recovery scheme is proposed which uses both Reed-Solomon code and Stop-and-Wait ARQ(Automatic Retransmission reQuest)[13]. The protocol is based on both the wireless channel condition and the deadline constraint, adaptively selects the best error correcting code by looking up an optimal code table which is predetermined before the start of message stream. As every transmitted packet needs one or more ARQ message according to Stop-and-Wait scheme, the error control induces unnegligible overhead, so reduces the guarantee ratio.

The error control schemes described up to here do not directly consider IEEE 802.11 WLAN but are built upon the specific MAC protocols of their own. J. Lee and his colleagues have proposed an error control scheme on WLAN which is aiming at improving the timely transmission of messages by a selective retransmission mechanism via the wasted bandwidth incurred by the hard real-time guarantee [9].

3. REAL-TIME COMMUNICATION ON WLAN

According to the general real-time message model, we assume that there are *n* real-time message streams, *S1*, *S2*, ... , *Sn* . Each stream can be characterized as follows: A message arrives at the beginning of its period and must be transmitted by the end of the period[7]. The period of stream *Si* is denoted while *Pi* and the maximum length of *Si* is *Ci* . The first message of each stream arrives at time 0, namely, the start of the first repetition cycle. In our ET system, this assumption is not true temporarily at the system initialization, as only the collection node has a message to send. However, after the first image appears on the graphic node, all participant nodes generate their messages with their own periods.

Real-time traffic requires guarantee on the delay bound for each packet and real-time connection usually lasts for a long time[1]. Among several scheduling schemes that perform admission test and guarantee meeting time constraints, transmission control based model is efficient when there exist a small number of real-time connections[11]. With this real-time scheduling model in IEEE 802.11 WLAN, AP(Access Point) polls each sender once for each CFP observing the round-robin discipline. The network parameters such as the length of repetition cycle, CFP ratio, and the allocation vector are determined by the bandwidth allocation procedure. Allocation vector determines how long a node can access the network when it receives a poll. Figure 3, shown at the next section, depicts the network parameters and corresponding run-time operation. A message, periodically generated at a node, is segmented into several frame s, in size of *Hi*, to be transmitted on each network access[12]. The message is transmitted successfully only when all frames belonging to it is delivered within its deadline.

As shown in Figure 3, *Si* is polled once a repetition cycle, *F*, whether it has messages to send or not, and is able to transmit for at most *Hi*. There exist a number of bandwidth allocation schemes which correspond to the transmission control based real-time communication [11]. Among these, we choose local allocation scheme for simplicity, as we are mainly concerned on the error control scheme. It is natural that another allocation scheme may be also applied. If we let *U* denote the utilization of message stream of given stream set, it can be calculated as (*Ci* / *Pi*). In addition, denotes the polling overhead in a repetition cycle. Then the local allocation scheme calculates the network parameters as in Eq. (1).

$$F = \frac{P_{\min}}{\left\lceil \frac{-3 + \sqrt{9 + 8P_{\min} / \gamma}}{2} \right\rceil}$$

$$H_i = \frac{C_i \cdot P_i}{U}(F - \gamma) \text{ , for all } i \quad (1)$$

, where *Pmin* is the smallest period in the stream set. If that allocation meets the constraints produced from the given stream set, it is called as a feasible solution. Then the duration of contention period, *CP* , is the remaining portion of *F*, as in Eq.(2).

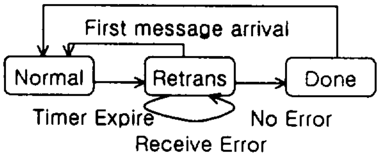
$$CP = F - Hi \qquad (2)$$

In CP, each node can transmit its non-real-time messages according to CSMA/CA(Carrier Sense Multiple Access/

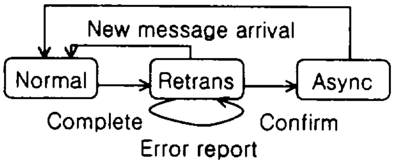
Collision Avoidance) medium access protocol. Repetition cycle starts at regular intervals because the interaccess time is more crucial to the real-time performance than the average amount of access time. For a message stream, the number of polls from AP is different period by period[8]. To guarantee that the message always meets its time constraint means the following condition: A message transmission even on the period which has the minimum access time will be completed within the requested bound. This also implies that the stream has additional network access time for other periods. Retransmission via this overallocated bandwidth does not result in missing deadline nor interferes the transmission of normal messages. The retransmission procedure should be performed within the deadline, namely, the period of the message.

When a connection is established, the receiver can know how many frames will be delivered in a period. As the receiver is also polled just once a repetition cycle, it can determine the number of cycles undergone by counting how many times it meets polls from any reference point. Consequently, the receiver is able to determine whether the transmission is completed on each period as long as it receives at least a frame containing its sequence number during that period. It is desirable to send this message during CP in order not to interfere the transmission of nor mal real-time messages.

To construct the error report message, the receiver initializes the error packet list on the arrival of the first packet. If the sequence number of this packet is not 1 but k , the receiver adds the numbers from 1 up to $(k-1)$ into th e list. From then, the receiver appends each number of erroneously received or omitted frame.



(a) Receiver Side



(b) Sender Side

Figure 2. Error control procedure

Figure 2 shows the behaviors of sender and receiver for a message delivery. As shown in Figure 2(a), the receiver experiences *Normal*, *Retrans*, and *Done* states. At *Normal* state, each frame arrives at the receiver , while the receiver being independently polled. The receiver increases its counter each time it is polled, and goes to *Retrans* state when the counter reaches the target value. In case the error list is not empty , the receiver sends the error report back to the sender and then waits for the retransmission of frames in the list.

Otherwise, it returns *Confirm* and transits into *Done* state immediately. In states *Retrans* and *Done*, when the first frame of the next message arrives, the transition to *Normal* state occurs, whether the errors are recovered or not.

Figure 2 (b) shows the function of sender. In *Normal* state, the sender transmits the frames one by one each time it is polled. After completion, it goes to *Retrans* state and waits for the reply from the receiver. If *Confirm* returns, the sender goes to the *Async* state where it transmits non-real-time messages.

As contrast, if it receives the error report message, the requested frames are sent again until it gets the *Confirm* message or the deadline of message expires. The new message generation makes the transition to *Normal* state even in the case the sender does not complete the retransmissions.

4. ADAPTIVE ERROR CONTROL SCHEME

The message is successfully transmitted only when the number of additional polls exceeds that of damaged frames, so the number of recoverable errors for a period depends on how many times a sender meets additional polls. The number of additional polls depends on overbooking from the bandwidth allocation procedure. However, an efficient bandwidth allocation procedure induces less overbooking for the stream set, leaving more bandwidth to the other non-real-time traffic as well as enhancing the schedulability for real-time streams. Hence the number of additional polls may decrease, a bad news for the error control scheme mentioned above. Therefore, to improve the performance of error control scheme, it plays a role to give more polls to the node that is currently in *Retrans* state by saving even the idle time in CP period.

It is the AP that determines how long it operates the CFP during any given repetition cycle. Basically, the length of CFP may vary cycle by cycle while that of CP is usually fixed. Note that CP is not always occupied by non-real-time traffic, as the traffic has a dynamic nature. As a result, there may be an unused time in this time interval, and this wasted time can also provide a chance to enhance the performance of the error control scheme. However, only statistical possibility of occupancy can be estimated. Transmission error cannot be predicted in priori. Performance enhancement can be achieved only when both conditions are met, so it is impossible to provide a certain form of guarantee.

AP can monitor the current traffic load in CP and also gathers information on whether a node is performing the error control procedure. When there is no use of the medium in CP for a predefined time (denoted as *E* in Figure 3) before the scheduled termination of CP, AP adjusts the CFP start time to give more polls to the node that may need more network access for the error control. AP can adjust CFP start by trying to get access right to the shard medium, according to CSMA/CA protocol with network allocation time equal to E . If it succeeds, AP can start CFP early to give more poll. The adjusted gain, E should be sufficiently large enough to execute at least a packet recovery, while large E may increase the average delay of non-real-time messages. To minimize the delay, this paper considers the size of $E\cdot$ as the amount that can support just one more poll in the following repetition cycle. Hence, the size of E depends on the node currently executing the error control.

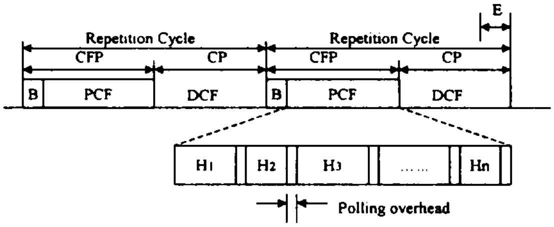


Figure 3. Time axis of repetition cycle

5. PERFORMANCE ANALYSIS

We have measured the performance of the proposed error control scheme via simulation using SMPL[10].

As a performance reference, we choose the dual link network model where all the duplicates are transmitted and a packet is regarded as error only when both of two duplicates miss the deadline[7]. At the other extreme, the performance in case of no error control will be presented. Deadline meet or miss ratio is the most important performance parameter in real-time systems. It can be obtained by dividing the number of successfully received messages by that of total generated messages. Among several performance measurement results, we show the deadline miss ratio according to the CP load. In this simulation, 50 stream sets are generated with the utilization ranging from 0.6 to 0.69, while bit error rate is set to 10 -6.

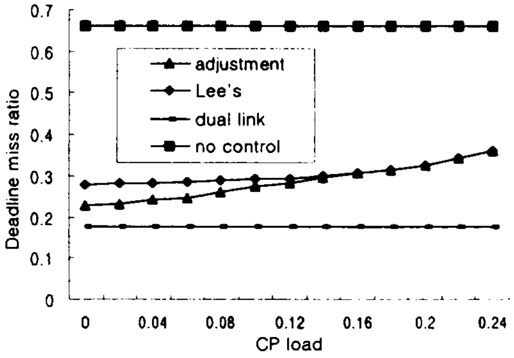


Figure 4. Deadline miss ratio vs. CP load

Figure 4 shows that the Lees scheme reduces the deadline miss ratio by more than 30%, exhibiting comparable performance with the expensive dual-link model. The deadline miss ratio on the case of no error control does never seem to be acceptable, however, this result happens on the pessimistic simulation environment where message size is too large, that is, frame error rate is extremely high. This parameter selection can signify the effect of error control scheme. The increase of CP load results in more deadline misses because less error report can be sent back to the sender within the period of the message stream. The improvement of CFP adjusting scheme is more remarkable when the CP load i s low. The adjustment method reduces deadline miss ratio by 5.5% at maximum, while t he increase of average delay for non-real-time messages is measured as less than 2.1%. We can expect more performance improvement when utilization of stream set is high, as the number of recovered errors via the overbooked polling time decreases. The performance improvement is maximized when there is little extra time in CFP.

6. CONCLUSION

This paper has proposed and analyzed the performance of an error control scheme for hard real-time communication for IEEE 802.11 WLAN, where CP and CFP proceed alternately under the direct control of coordinator node called AP. CFP is further divided into several intervals, and each interval is dedicated to a real-time message stream. On the contrary, all nodes share CP period for non-real-time message transmission. The previously proposed error control scheme makes the receiver node report errors in a best-effort manner as a non-real-time message. It also makes the sender retransmit the damaged message when the sender has additional bandwidth in a period. This scheme obviates the interference of error control messages to the other undeferred real-time messages.

To improve the number of timely recover for corrupted real-time messages, it is necessary to give more polls to the stream in need by saving even the idle time in CP period. To this end, AP can monitor the current traffic load in CP and also gathers information on whether a node is performing the error control procedure. The adjustment method reduces deadline miss ratio by 5.5 % at maximum, compared with Lee s scheme, while the increase of average delay for non-real-time messages is measured as less than 2.1%. As a future work, we are going to construct overall ET image reconstruction system first and then reinforce the error controls scheme which adjusts the size of E to give more than one polls to cope with the severe change in error rate of wireless communication environment.

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IEEE 802.11 무선 지역망상에서 실시간 통신 성능 향상을 위한 폴링 순서 적응에 의한 오류제어 기법

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요 약

본 논문은 IEEE 802.11 Wireless LAN에서의 실시간 통신에 대해 가능한 많은 손실된 메시지들을 종료시한 내에 처리할 수 있도록 폴링 스케줄을 동적으로 조절할 수 있는 에러 제어 기법을 제안한다. 조정자인 AP는 네트워크 내의 노드가 현재 오류 제어 절차를 수행하고 있는지 여부와 CP 구간마다 현재의 비동기 트래픽에 여유가 있는지 등을 감시하며 가능한 경우를 판단하여 CP를 조기에 종결시켜 다음 CFP의 기간을 연장시킨다. 연장된 CFP 시간은 AP에 의해 현재 오류제어를 수행중인 노드에 더 많은 폴을 부여함으로써 종료시한 이내에 회복된 메시지의 수를 증가시킬 수 있다. SMPL을 통해 수행된 모의실험 결과는 WLAN에서의 실시간 통신을 위한 기존의 에러 제어 기법에 비해 이 적응 기법이 전송 에러 때문에 버려지는 메시지를 5.5%까지 줄일 수 있다는 것을 보였다.