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An Efficient Bandwidth Allocation Scheme for Real-Time Control Systems Built upon the Dual Wireless LANs

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이중 무선 LAN에 설치된 실시간 제어 시스템을 위한 효율적인 대역폭 할당 스킴

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ABSTRACT

This paper proposes and analyzes the structure of dual wireless LAN architecture for the real-time communication along with its bandwidth allocation scheme. The bandwidth allocation scheme searches the feasible network parameters, including the repetition period and capacity vector, which satisfy all of utilization, deadline, and protocol constraints. The constraints are calculated from the careful analysis of traffic characteristics of the given message stream set. On the dual network, by making the repetition interval of one network precede that of the other by half, we can reduce the worst case medium access time by half. Simulation results executed via SMPL show that reduced overhead enables the wireless LAN to schedule more stream sets than the network whose bandwidth is just doubled.

Key Words : wireless LAN, real-time communication, bandwidth allocation scheme

I. INTRODUCTION

The instance of real-time control system includes nuclear power plant system, air traffic system, space mission system, and industrial process control system. As shown in Figure 1, these systems can be abstractly modeled as a feedback loop consisting of four components, namely, a controlled process, a controller, sensors, and actuators[1].

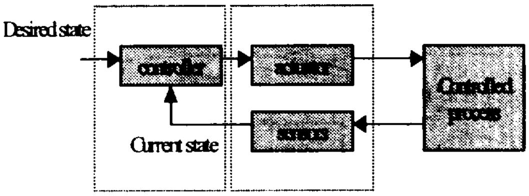

Fig. 1. Real-time system architecture

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The sensors provide the controller with information about the current state of the controlled process. The controller is an information processing system that makes use of the information provided by the sensors to compute the actions required to reduce the disparity between the current state and the specified desired state of the system. The actuators realize the actions computed by the controller. As the size of this control system grows and the required control function becomes involved, real-time control systems will be distributed, complex and exhibit highly dynamic, adaptive, and intelligent behavior. Consequently, the distributed real-time system has been designed and developed in the various area for the various purpose. In this system, the role of network component is magnified[2].

As an example of the distributed real-time system, ET (Electronic Tomography) data processing network shown in Figure 2 consists of a collection node along with one or more computing nodes[3]. The collection node gathers the data from the bubble phantom, reports them to the computing node periodically, and controls the collection logic after the basic data analysis. Other computing nodes, having and executing respective algorithms such as Newton-Raphson, genetic and so on, receive the state information from the collection node and exchange messages with one another for further detailed analysis. In this example, real-time network protocol is indispensable as the messages have time constraint.

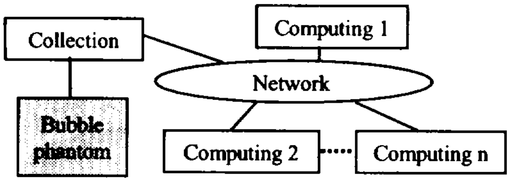


Fig. 2. ET processing network

In order for the system to operate correctly, the network should deliver messages within their deadlines. The wireless LAN is a promising candidate for the system as it is a rapidly emerging technology providing users with network connectivity without being tethered off of a wired network[4]. Additionally, its medium access control protocol, namely, CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance), contains the channel for the real-time traffic. Moreover, as the wireless LAN supports multiple frequency bands, a group of components belonging to the same control loop can be linked with more than two wireless LANs. The dual network architecture is not uncommon in the wired network, either.

The dual link system can meet more message deadlines by reducing the worst case overhead for each node to wait until it gets the right to transmit its message. As the performance of real-time system is greatly dependent on the worst case behavior, the reduced network access time enables the system to guarantee the delivery of more real-time messages. This paper is organized as follows: Section 2 discusses the related works on dual network architecture, message model, and bandwidth allocation scheme on wireless LAN. Section 3 describes in detail the proposed dual wireless LAN model and accompanying bandwidth allocation scheme. Then Section 4 shows the simulation result exhibiting the performance improvement made by the proposed scheme and discusses the result. Finally, we summarize and conclude the paper in Section 5.

II. RELATED WORKS

2.1 Dual Networks

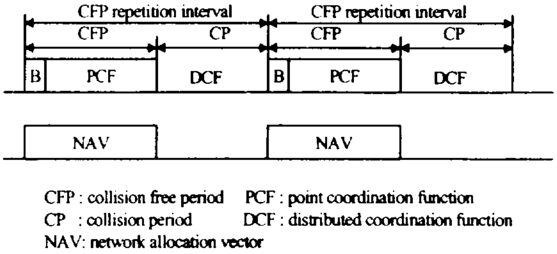
The duplicated network architecture has been researched on the various areas for the various purposes. The first example on real-time communication is dual ring LAN whose main idea is to use one LAN for packet transmission and the other for scheduling[5]. In the work, a medium access protocol for integrated service, video and data traffic, operating on a dual-ring LAN is discussed. B. Gao and H. Garcia-Monila suggested a scheme which sends duplicate packets over redundant paths to enhance communication timeliness[6]. The authors also proposed another scheme that schedules soft real-time messages over dual non-real-time network according to the slackness of the message[7]. However, there is no scheme aiming at reducing bandwidth waste in hard real-time communication via duplicated network.

2.2 Characteristics of Message Stream

In the real-time systems, the node produces the message periodically and the period and message size is usually known in priori of system operation. According to the general real-time message model, we assume that there are *n* streams of real-time messages, *S1, S2, ..., Sn*. Each stream can be modeled as follows: A message arrives at the beginning of its period and must be transmitted by the end of the period[8]. The period of stream, *Si*, is denoted as *Pi*, as well as the maximum length of a message is *Ci*. The first message of each stream arrives at time 0, the start of the first repetition cycle.

Wireless LAN operates on CP(collision period) interval and CFP(collision free period) interval alternatively as shown in Figure 3. In CFP interval, only the node polled by coordinator node, or AP(access point) can transmit its messages up to the predefined amount of time. The real-time messages should be sent during this interval to meet its time constraint excluding message collision[9].

2.3 Bandwidth Allocation



CFP : collision free period PCF : point coordination function
CP : collision period DCF : distributed coordination function
NAV: network allocation vector

Fig. 3. Time axis of wireless LAN

The amount of time permitted for a node to send its message is determined with careful consideration of the given stream set before system begins operation. This off-line procedure is called as bandwidth allocation and it calculates the repetition interval *F* as well as capacity vector *Hi*. A node possessing the stream *Si* can send its message as large as *Hi* when polled. Hence, the following relation holds for allocation scheme *B*:

$$B : (\{Pi, Ci\}) \rightarrow (F, \{Hi\}) \qquad (1)$$

With *Hi* and *F* the time axis of collision free period can be described as shown in Figure 4.

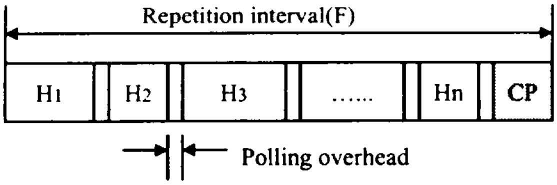


Fig. 4. Bandwidth allocation

As for the bandwidth allocation scheme, there are many researches and works for the various type of networks including FDDI(Fiber Distributed Data Interface), TDMA(Time Division Multiple Access), and so on[8]. The allocation scheme for TDMA can be applied to wireless LAN as the repetition interval can be set to constant and AP is forced to poll each node only at the predefined time. The allocation step finds a feasible solution that satisfies the following constraints for a given stream set. For detailed description, refer to[10].

[Range of repetition interval] For a stream set, the frame time, or the repetition interval should be in the range as shown in the following inequality for the feasible allocation to exist.

$$\frac{\gamma}{1-U} \le F \le \frac{P_{\min}}{2} \qquad (2)$$

, where *Pmin* is the minimum value of period.

[Protocol constraint] The sum of slot time assigned to each node should be less than the available part of the frame time.

$$\sum_{i=1}^{n} H_i \le F - \gamma \qquad (3)$$

[Utilization constraint] The sum of utilization of each message stream, overhead resulting from determination of frame time, *Of*, and overhead due to polling procedure, γ, should be less than 1.0.

$$O_f + U + \frac{\lambda}{F} \le 1.0 \qquad (4)$$

O_f is the overhead produced because the remnant part of *Pi* over *F* can't be used for message transmission. The normalized waste ratio is calculated as follows:

$$O_f = \sum_{i-1}^{n} \frac{P_i - \left\lfloor \frac{P_i}{F} \right\rfloor F}{P_i}$$

[Deadline constraint] Slot time should be assigned to real-time messages to be transmitted within their deadlines. So the minimum available transmission time for each message stream, *Xi*, should be larger than message transmission time.

$$X_i \ge C_i \qquad (5)$$

, where $X_i = \left(\left\lfloor \frac{P_i}{F} \right\rfloor - 1 \right) H_i$

[Slot time] If *Hi* is allocated as follows, message stream *Si* can meet its deadline constraint.

$$H_i \ge \frac{C_i}{\left\lfloor \frac{P_i}{F} \right\rfloor - 1} \qquad (6)$$

The performance of bandwidth allocation is measured by schedulability which implies the possibility of finding feasible solution for the given stream sets. This factor is affected by the amount of overhead produced by the network parameter. The overhead originates mainly from the fact that the period of messages stream and the repetition interval are not harmonic. However, it is possible to reduce the overhead by using the dual network link architecture, especially on the wireless LAN network.

III. SCHEDULING ON DUAL NETWORKS

For a message stream *Si*, its period is consist of several components as shown in Figure 5. A node should wait for the first poll when a message is produced. This network access time is denoted as *w*. *v* is the sequence of valid repetition intervals in which the node receives a poll and can transmit its message. *r* is the remaining part of *Pi* over *F*, which is unavailable for transmission, so another overhead.

The waiting time is bounded with *F*. The worst case happens when a message arrives just after the node is polled. On the dual wireless LAN architecture, if we make the repetition interval proceed as Figure 6, *w* decreases and schedulability improvement is expected.

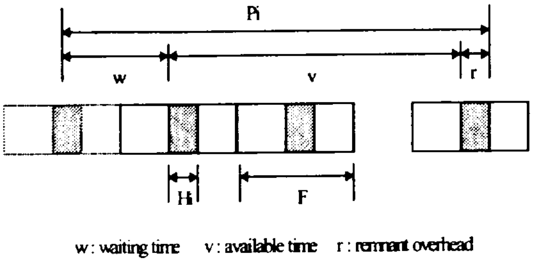


Fig. 5. Overhead analysis of stream *Si*

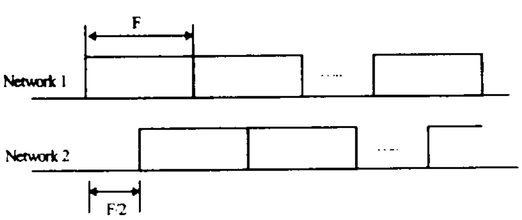


Fig. 6. Repetition periods on dual wireless LAN

In Figure 6, the repetition period of one network precedes the other by *F/2*. Then, as waiting time decreases by half, a node meets more poll message than the case expected when two periods proceeds simultaneously or randomly. If two periods go at the same time, it is identical to the case when network bandwidth is just doubled, so the transmission time decreases by half. Hence, the constraint (6) is modified as (6').

$$H_i \geq \frac{Ci \;/\, 2}{\left[\frac{P_i}{F} \right] - 1} \qquad (6')$$

On the contrary, when the period goes as in Figure 5, the constraint (6) is modified into (6"), which is the weaker constraint than (6').

$$H_i \geq \frac{Ci}{\left[\frac{P_i}{F} \right] . 2 - 1} \qquad (6'')$$

IV. PERFORMANCE MEASUREMENT

In order to assess the performance of the proposed bandwidth allocation scheme for dual wireless LAN, we have generated 680 stream sets and analyzed their schedulability via SMPL[11]. The task sets have the characteristics as follows: Utilization of the first 20 stream sets ranges from 1.00 to 1.05, that of next 20 ranges from 1.05 to 110, and so on. Each set contains random number of streams from 3 to 10. The period of a stream randomly distributes between 1 and 200 ms while transmission time between 0.02 and 30 ms. The experiment are performed for the set with polling overhead fixed to 10 μs. As shown in Figure 7, the schedulability of the proposed dual wireless network is better than that of the network in which bandwidth is just doubled. The gap is at maximum at the utilization 1.45 up to 32 %. Above utilization 1.60, any scheme cannot find feasible schedule as the overhead stemming from the factors mentioned above, encroaches the available network bandwidth.

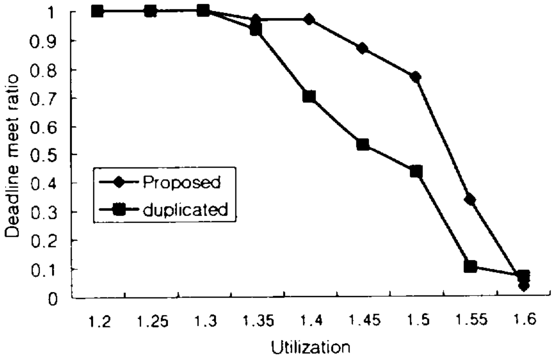


Fig. 7 utilization vs. deadline meet ratio

V. CONCLUSION

This paper has proposed and evaluated bandwidth allocation scheme that improves the schedulability of hard real-time communication on dual wireless LANs. The enhancement results from the reduction of worst case network access time by differentiating the polling schedule of the two networks. We have also showed that the network parameters determined by the allocation scheme can meet the time constraints of real-time message streams. As a future work, we consider a message scheduling scheme combined with an error control mechanism as the wireless environment is prone to transmission errors.

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