PLFC: The Packet Length Fuzzy Controller to Improve the Performance of WLAN under the Interference of Microwave Oven

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Abstract - **In this paper, we design a novel fuzzy controller to dynamically adjust the packet length to against the interference from microwave oven over the IEEE 802.11 FHSS (Frequency Hopping Spread Spectrum) wireless LAN card. The idea of adjusting the packet length under the noise environment is referring from the measurement results about the effects of microwave ovens over the wireless LAN card in [1]. Simulation results show that the designed fuzzy controller can effectively improve the transmission performance in terms of network throughput.**

I. Introduction

Recently, the technology of wireless communication has progressed rapidly and the wireless data communication products such as wireless LAN and wireless ATM have been investigated in laboratories. In June 1997, the IEEE 802.11 draft 6 [2] has been announced by the IEEE computer society. Many manufacturers manufacture the wireless LAN cards and some products have been brought into markets now. Because the operation frequencies of the wireless LAN card are within the ISM (Industrial, Scientific and Medical) band, there exist some extraneous sources within the same frequency band to interfere each other. Since the most significant interference in this band is caused by the microwave oven, many researches have investigated the effects by it. In paper [3], the authors have experimentally measured the interference radiated from the microwave oven and discussed the statistical characteristics of interference from the time domain. The performance improvement with Bose-Chaudhuri-Hocquenghem (BCH) code has been shown in [4]. The statistical model of microwave oven in the time domain has been shown in [5]. The interference from two kinds of microwave ovens over the wireless LAN cards has been investigated in [6]. However, few papers actually measure the interference using the wireless LAN card in terms of MAC frame error rate (FER) and UDP packet error rate (PER). Therefore, in [1], we use the IEEE 802.11 FHSS wireless LAN cards to measure the MAC FER in individual channels to obtain the interference distribution from the microwave oven. In order to demonstrate the measurement results of FER, we have measured the signal spectrum radiated by microwave oven and compared to the differences of FER. However, the FHSS system transmits data through a set of hopping sequences, in this paper we measure the PER by transmitting the UDP frames for the sake of realistic application. According to the measurement results, we obtain that decreasing the packet length can apparently resist effects from microwave oven. Although some authors have investigated the adaptive frame length control to improve the throughput in wireless transmission [7]-[9], they only study the relationship between frame length and throughput without proposing an exact method to dynamically control the frame length. Because the channel states would exchange with time, it is hard to control just have the relationship between the frame length and throughput under a certain degree of noise. Therefore, we design a fuzzy controller to dynamically adjust the packet length according to the interfering degree.

This paper is organized as follows. In section II, we describe the measurement environment and results of the PER. The proposed fuzzy controller is described in section III and simulation model and results are shown in section IV. Finally, some conclusions of this paper are given in section V.

II. The Measurement Environment and Results of the PER

In this paper, we used the same measurement environment as the paper [1]. We used one pair notebooks connected by IEEE 802.11 FHSS wireless LAN cards to measure the effects from the operating microwave oven in Ad Hoc network. We transmitted the UDP packets at the transmitter and recorded the PER at the receiver. In order to study the effect of PER at each direction of the microwave oven, we first measured the PER at each directions with different distance (1m, 2m, 3m, 4m, and 5m) to the microwave oven when the packet length is 400 bytes. Furthermore, we also adjusted the packet length from 100 to 400 bytes to study the effect of packet length to the PER in the front direction.

Figure 1 shows the measurement results about PER versus distance in four directions as the packet length is 400 bytes. From this figure we can find that the interference in the front end is the most serious. However when the distance is larger than 4m, the receiver would not be interfered in the front end. Similarly, the safe distance in the back end is 2m.

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From these measurement results we can easily derive the safe distance in all directions when the packet length is 400 bytes.

Figure 2 shows the measurement results in the front end of microwave oven when we adjust the packet length from 100 to 400 bytes. From this figure we can see that the PER would be reduced with the decreasing of packet length. When the packet length is 100 bytes, the transmission would not be interfered no matter what the distance is. Although effects from the microwave oven can be resolved by reducing the packet length, the throughput would be degraded by the additional header overhead occupies the transmission bandwidth. Therefore, if the packet length can be adaptively adjusted, the maximal throughput would be achieved under the effects of microwave oven. Therefore, in the next section, we will design a fuzzy controller to dynamically adjust the packet length to maximize the network throughput.

III.The Design of Packet Length Fuzzy Controller (PLFC)

From previous section we know that the adjustment of packet length will improve the throughput. However, the packet length should be dynamically adjusted because the environment situation (e.g. distance and interference degree) may changes. Therefore, we design a fuzzy controller in this paper to adjust the packet length according to the environment interference.

The block diagram of the PLFC is shown in Figure 3. At first, two input linguist parameters are considered for the fuzzifier: the packet length ratio, which is denoted as *plr*, and the delta packet error rate, which is denoted as *dper*. The *plr* is the ratio of transmitted packet length to the maximal packet length. In this paper, we define the maximal packet length is equal to 400 bytes. The *dper* equal to $per_i - per_{i-1}$, where per_i indicates the packet error rate at time *i*. For input parameters, we define the corresponding fuzzy term sets: *T(plr)* = {Largest, Large, Small, Smallest} and *T(dper)* = {Negative Large (NL), Negative Small (NS), Equal (E), Positive Small (PS), Positive Large (PL)}. The selected membership functions for *T(per)* and *T(dplr)* are the shape of Gaussian-like function (see Figures 4(a) and 4(b)). For each membership function, the peak position and the scaling factor are specified according to our knowledge about the system model. The mathematics form of the Gaussian membership function is presented as follows:

$$\mu(x) = e^{-\left(\frac{x-m_i}{\sigma_i}\right)^2},$$

where m_i and the σ_i are the peak value and the scaling factor of the *i*-th membership function, respectively. In this paper, the scaling factor is equal to 0.212. According to the fuzzy set theory, the fuzzy rule base has $|T(plr)| \times |T(dper)|$ = 12 inference rules (see Table 1)

TABLE 1. THE FUZZY RULES FOR NEXT PACKET LENGTH RATIO.

Rule	plr	dper	nplr
1	Largest	PL	-0.1
2	Largest	PS	-0.15
3	Largest	E	0.075
4	Largest	NS	-0.15
5	Largest	NL	-0.2
6	Large	PL	-0.15
7	Large	PS	-0.2
8	Large	E	0.08
9	Large	NS	-0.25
10	Large	NL	-0.3
11	Small	PL	-0.2
12	Small	PS	-0.25
13	Small	E	0.12
14	Small	NS	-0.3
15	Small	NL	-0.35
16	Smallest	PL	-0.25
17	Smallest	PS	-0.3
18	Smallest	E	0.15
19	Smallest	NS	-0.35
20	Smallest	NL	-0.4

which is used to decide the optimal packet length in each distance and the output next packet length ratio *nplr* of each rule is displayed in Table 1. In this paper, the desired optimal packet length is calculated as follows:

$$Th(s,e) = \frac{s}{s+h} * (1-e),$$

where *s*, *e* and *h* are packet length, PER and additional header from UDP packet to the physical frame, respectively. Based on previous simulation results, we show that the PER and throughput under different distances and packet lengths in Table 2 and 3, respectively. Therefore, the optimal packet length in distances 1m, 2m, 3m, 4m and 5m are 100, 200, 200, 400, and 400 bytes, respectively.

TABLE 2. THE DERIVED PER UNDER DIFFERENT DISTANCES AND PACKET LENGTHS.

PER	1 m	2m	3m	4m	5m
100	0	0	0	0	0
200	0.5331	0	0	0	0
300	0.6491	0.6372	0.1478	0	0
400	0.8214	0.7945	0.7698	0	0

TABLE 3. THE CALCULATION OF OPTIMAL PACKET LENGTHS UNDER DIFFERENT DISTANCES.

Throughput	1 m	2m	3m	4m	5m
100	**0.5457**	0.5457	0.5457	0.5457	0.5457
200	0.3262	**0.6987**	**0.6987**	0.6987	0.6987
300	0.2703	0.2794	0.6564	0.7702	0.7702
400	0.1451	0.1669	0.1870	**0.8122**	**0.8122**
Optimal packet length	100	200	200	400	400

In the inference engine, the max-min inference method [10] is used. For the *i*-th rule, the corresponding membership values of these two input variables *plr* and *dper* are calculated by $\mu_i(plr)$ and $\mu_i(dper)$, respectively. The weight w_i used in defuzzifier is determined by the minimum value between $\mu_i(plr)$ and $\mu_i(dper)$. Considering the defuzzifer in PLFC, we employ the singleton method [11] as our defuzzification strategy to reduce the complexity of computation. For each fuzzy rule, the method will convert the output membership function into a crisp output control value. The singleton defuzzification method calculates the crisp output value y by the following equation:

$$y = \frac{\sum_{i=1}^{n} w_i \times p_i}{\sum_{i=1}^{n} w_i},$$

where $n = |T(plr)| \times |T(dper)|$, p_i is the peak value of the i-th output membership function of $T(nplr)$, and w_i is the weight of the i-th control rule. Hence, the next packet length is $y \times plr$.

IV. The Simulation Model and Results

The simulation model is described as follows. We simulate the notebook initially located at 3 meter away from the microwave oven (D=3m) and moving around at the front end of the microwave oven. The moving range in this paper is between D=1 to D=R m. The total simulation time is T time units and at each time unit, the notebook would decide to move or not according to the moving probability mp ($0 \le mp \le 1$). Once it decides to move, the moving rate mr is used to derive the moving distance in this time. The moving direction (forward or backward) is decided according to the two states model shown in Figure 5. In this model, the state "Forward" means moving away from the microwave oven and in contrary, the "Backward" state means moving toward the microwave oven. The transition probabilities are moving backward probability (mbp) and moving forward probability (mfp). Therefore, according to the mbp and mfp we can simulate the moving direction of the notebook and simulation results will be shown in this section. Besides, the notebook would transmit UDP packets to the receiver and the generated packets are exponential distribution with a mean of L packets. If we use the fuzzy controller to adapt the frame length, the notebook would use the PLFC to adjust the packet length according to plr and $dper$ in order to get better transmission performance. Otherwise, the notebook would transmit the fixed length packet in any place. The delta packet error rate $dper$ is calculated after transmitting w packets and the parameter w is the transmission window size. In order to evaluate the performance of PLFC and normal fixed length methods, we use the following metrics:

Transmission Amount per times (TA) = the ratio of the total payload (without considering the header) which are successfully received to the simulation time T.

Transmission Efficiency (TE) = $\frac{d_S}{(d_S + h_S) + (d_F + h_F)}$, where d_S and h_S are the amount of payload and header which are received in success, respectively, and d_F and h_F are the amount of payload and header which are corrupted during transmission, respectively.

Successful Rate (SR) = the ratio of the number of packets which are received successfully to the number of packets being transmitted.

Following, we show the simulation results. In this simulation, the simulation time T is 1,000,000 time units and the parameters L and R are equal to 5 and 6, respectively.

Firstly, in our fuzzy controller, we have to decide the window size parameter (w) which is used to calculate the $dper$. Because the window size would effect the performance, we first investigate how the SR is effected by different window size when mr is 0.6. From the simulation results in Figure 6 we can find that the derived SR would be higher with the decreasing of window size. This is because the controller can adapt the packet length rapidly, the burst error phenomenon would not happen frequently. Therefore, we use window size w=5 in the following simulations.

After choosing the window size parameter, we simulate three different scenarios where (mbp,mfp) for scenario 1,2, and 3 are (0.6,0.4), (0.4,0.6), and (0.5,0.5), respectively. Therefore, in scenario 1 the notebook would have a higher chance moving near the microwave oven. In contrary, scenario 2 would move away from microwave oven and scenario 3 has the equal probability.

Figure 7 shows the number of transmitted packets under different packet lengths in the three simulation scenarios. From the results we can find that in scenario 1, the packet length is shorter because the notebook is moving near the microwave oven. Only decreasing the packet length can improve the transmission performance. This is because that the interference is obvious. In contrary, the packet length is almost 400 bytes in scenario 2 since the notebook is moving around the boundary (5m to 6m) and the optimal length over 5m is 400 bytes. Therefore, the number of transmitted packets of shorter packet length (shorter than 400 bytes) is less than that of scenario 3. In scenario 3, the packet number is almost the same when the packet length is longer than 100 bytes. Besides, we can find that the packet number between packet lengths 350 and 400 shakes very seriously. This can be explained from Figure 8. In Figure 8, we display the optimal length at each distance. From this figure we can find that the slope between 3.8m to 4m is very steep and the optimal packet length is between 300 and 400 bytes. Therefore, this is the reason why the curve shakes so serious in Figure 7. Furthermore, in Figure 8 we obtain that our fuzzy controller can adapt the packet length near the optimal length no matter what the simulation scenario is.

In order to compare the performance with and without fuzzy controller, we first simulate the performance of TE in the case that network only uses the fixed length method (without fuzzy controller) at each distance. Figure 9 shows that when the distance is small than 1.5m, it is more efficiently to use 100 bytes packet length to transmit. Although using long packet length to transmit would obtain better transmission performance (considering the ratio of payload to the header + payload), the transmitted packet would be easily failed. As a result, the derived TE becomes smaller than the packet length equal to 100 bytes. From these simulation results we can find that this is a trade-off between transmission performance and transmission successful rate. Therefore whether the packet length is adapted in correct or wrong way would effect the transmission performance. After obtaining the results without fuzzy controller, we further simulate the performance with and without fuzzy controller using the scenario 3 where (*mbp,mfp*) is equal to (0.5,0.5). Figure 10 shows the obtained TAs by network with and without PLFC. We can find that the TA with fuzzy controller is higher than the TA without fuzzy controller no matter the packet length is fixed to 100, 200, 300, or 400 bytes. Besides, we also compare to the results obtained by network only uses the optimal length to transmit at each distance. We can find that our proposed fuzzy control method can obtain the performance is near the optimal results in every moving probability. The similar simulation results of TE are also shown in Figure 11. The obtained TE by proposed PLFC is near 75%. This is acceptable for wireless network environment with inevitable interference sources.

V. CONCLUSION

In this paper, from the measurement results of PER we found that the safe distance is 4m away from the microwave oven when the packet length is 400 bytes. The PER would also be further improved by decreasing the packet length, however the bandwidth would be wasted on the additional header. Therefore, we must care about the location of microwave oven when using the wireless LAN in office or residence. However, this will limit the flexibility of mobile users in indoor environment. In order to resist the interference from microwave oven, we designed a packet length fuzzy controller in this paper. The simulation results shown the performance of PLFC is better than the normal fixed length method. The PLFC may also be used in the other situations when the transmission environment is too noisy or in other applications.

REFERENCES

[1] Y.H. Lee, S.T. Sheu, M.H. Chen, Y.C. Yu, and Y.C. Huang, " The effects of microwave oven over the IEEE 802.11 FHSS wireless LAN card", APCC/OECC '99, pp. 817-820

[2] Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, the IEEE standards.

[3] Shinichi Miyamoto and Norihiko Morinaga, "Effect of microwave oven interference on the performance of digital radio communications systems", IEEE ICC '97, pp. 51-55, 1997

[4] Shinichi Miyamoto and Norihiko Morinaga, "Performance of digital radio communication system with BCH coding under microwave oven interference", Electronics Letters, pp.1465-1466, July 1998.

[5] Hideki Kanemoto, Shinichi Miyamoto, and Norihiko Morinaga, "Statistical model of microwave oven interference and optimum reception", Proceedings of the IEEE ICC'98, pp. 1660-1664, 1998.

[6] Ad Kamerman and Nedim Erkocevic, "Microwave oven interference on wireless LANs operating in the 2.4 GHz ISM band", Proceedings of the IEEE PIMRC '97, pp. 1221-1227, 1997.

[7] Chee K.S. and David J.G., "Packet Data Transmission Over Mobile Radio Channels," IEEE Trans. on Vehicular Technology, vol. 38, no. 2, pp. 95-101, May 1989.

[8] P. Lettieri and M.B.Srivastava, "Adaptive frame length control for improve wireless link range and energy efficiency," in Proceeding of the IEEE INFOCOM'98, pp. 564-571, 1998.

[9] Charles Chien, M.B.Srivastava, Rajeev Jain, Paul Lettieri, Vipin Aggarwal, and Robert Sternowski, "Adaptive Radio for Multimedia Wireless Links," IEEE Journal on Selected Area in Communications, vol. 17, no. 5, pp. 793-813, May 1999

[10] H. J. Zimmermann, "Fuzzy Set Theory and its Application", 2nd, revised edition, Kluwer Academic Publishers, pp. 11-17, 1991.

[11] R.R.Yager, L.A.Zadeh, "An Introduction to Fuzzy Logic Application in Intelligent System," Kluwer Academic Publishers, 1992.

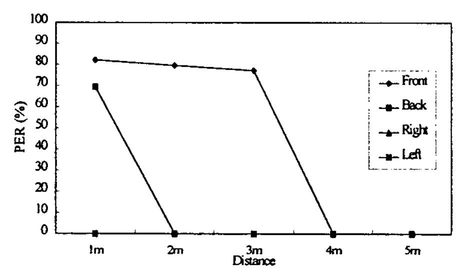


Figure 1. The measurement results of PER in four directions under different distance.

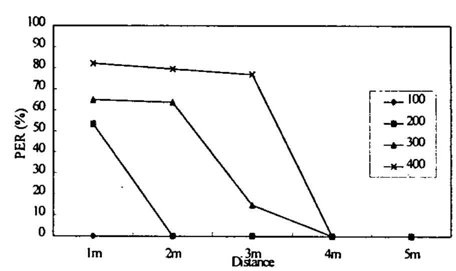


Figure 2. The measurement results of PER in different packet length under different distance.

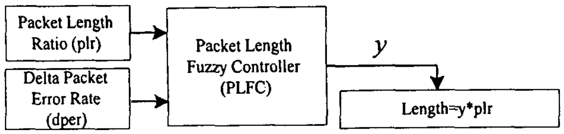
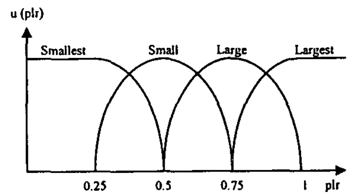
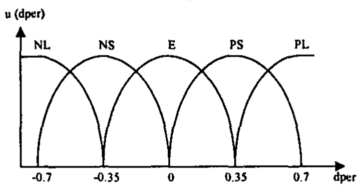


Figure 3. The block diagram of PLFC.



(a) T(plr)



(b) T(per)

Figure 4. The membership functions of the term sets.

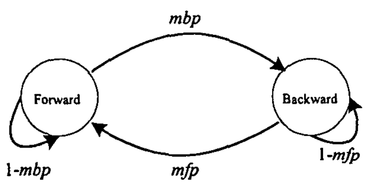


Figure 5. Moving direction model.

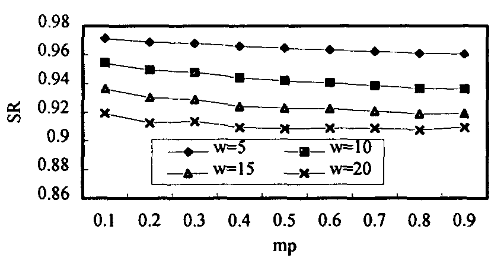


Figure 6. The SR under different window size.

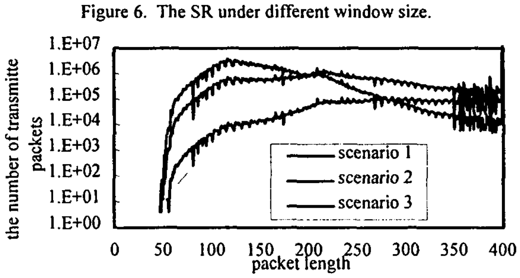


Figure 7. The number of transmitted packets obtained by PLFC under different simulation scenarios and packet length.

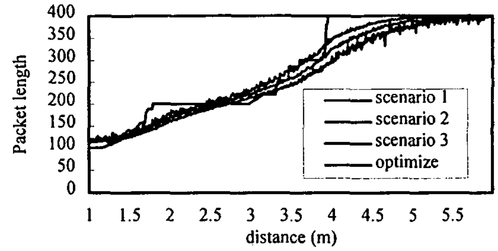


Figure 8. The adapted packet length obtained by PLFC at each distance under different simulation scenarios.

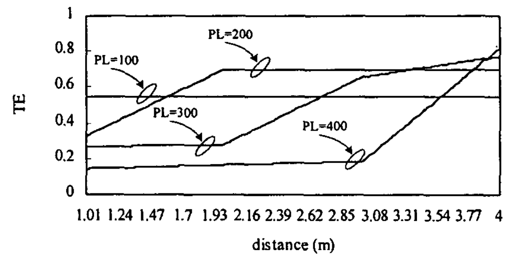


Figure 9. The obtained TE without fuzzy controller at each distance.

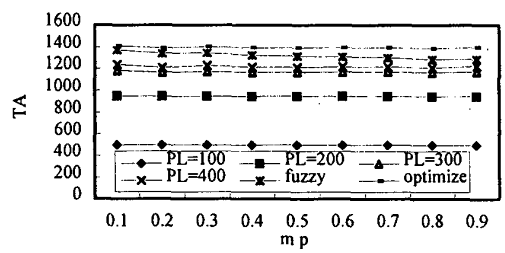


Figure 10. The comparison of TA with and without fuzzy controller under different moving probabilities.

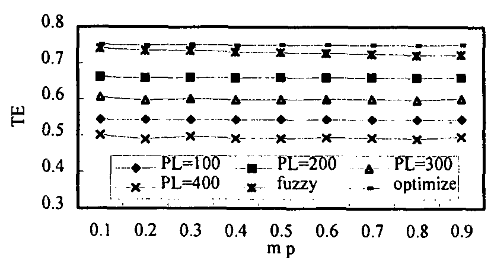


Figure 11. The comparison of TE with and without fuzzy controller under different moving probabilities.