Adaptive Optimal Frame Length Predictor for IEEE 802.11 Wireless LAN

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Abstract

In this paper, we present an optimal frame length predictor in terms of maximizing the channel utilization. Kalman filter is adopted to predict the optimal frame size under noisy wireless channel. Simulations results show that the performance of proposed frame size predictor is much better than other prediction methods like moving average.

Keywords: Wireless LAN, IEEE 802.11, Adaptive, Prediction, Indoor Wireless Channel

1 Introduction

Wireless channel is dynamically time-varying and bursty caused by fading, noise and interference, shadowing, path loss and so forth. In order to combat the affect of wireless channel and provide Quality of Service (QoS), a lot of kinds of approaches are proposed. Link adaptation is one approach focusing on through building a reliable MAC and PHY layer to provide committed QoS. There are many research work focusing on this topic. In [3, 2], link adaptation are approached through parameter adaptation like frame size, fragmentation. In [7], link adaptation is discussed in terms of frame size and power control. In [5, 6, 9], adaptive modulation schemes are proposed for maximizing the channel efficiency and their performance are simulated and analyzed. In [8], an adaptive algorithm for optimizing the packet size used in wireless ARQ protocols is proposed. The optimal packet size is derived by using maximum efficiency approach. But this algorithm is not based on wireless LAN, which has some special issues like random exponential back off, so it is not appropriate to IEEE 802.11 wireless LAN. In [4], the optimal packet length is derived under a indoor wireless environment by using Kalman filter , but there is no consideration of random back off and transmission overhead in MAC and PHY layer.
In this work, we present a link adaptation approach by pursuing Kalman filter to predict the optimal frame size. First, we analyze the channel utilization of IEEE 802.11 wireless LAN and we get the equation of the optimal frame size to maximize the channel utilization. Due to changes of network environment like number of users, different channel qualities sensed at transmitter and receiver and so forth, this optimal frame size is a local optimal and it is diverged. Kalman filter is adopted to estimate and predict this optimal frame size for the next transmission with the maximum channel utilization. In order to analysis the proposed prediction algorithm, we conduct a channel measurement of indoor office environment and we use this channel quality data set to verify our algorithm. It shows, through simulations, the proposed algorithm can substantially lower the estimation error by the order of tens compared with moving average method and it is also easy to implement.
The rest of this paper is organized as follows. The predictor using Kalman filter is introduced in section 2. A simulation is described and the results are given and analyzed in section 3. Finally, the paper is concluded with a conclusion.

2 Optimal Frame Size Predictor

2.1 Brief of Kalman Filter

Considering a general prediction problem with noisy data.

$$\mathbf{x_{k+1}} = F[\mathbf{x_k}, \mathbf{u_{k+1}}, \mathbf{w_{k+1}}] \quad (1)$$

In this equation, x_k is the system state at time k, u_{k+1} is the system control input at time $k+1$, w_{k+1} is the processing noise at time $k+1$ which is assumed to be additive process noise , and $F(.)$ is the process model. For the observation system, we have the following equation

$$\mathbf{z_{k+1}} = H[\mathbf{x_{k+1}}, \mathbf{u_{k+1}}, \mathbf{v_{k+1}}] \quad (2)$$

Here, $H(.)$ is the observation model, v_{k+1} is assumed to be additive observation noise. V and W could be any kind of distribution but generally they are uncorrelated at all time k. In this paper, our concern is to estimate system states X by using noisy observations Z under known process model and observation model. When $F(.)$ and $H(.)$ are linear systems, Kalman Filter can be used to provide prediction with least-mean-squared error of true system states recursively.

In 1960, R.E. Kalman published the discrete-time linear filter theory. Today, Kalman filter is widely adopted for different scenarios like prediction, estimation and smooth. The advantage of Kalman filter is that it is a efficient computational recursive solution of least mean squared error [10, 11]. Kalman filter uses a predictor-corrector structure. Predictor predicts the system state at the next time slot through processing model. Corrector will update the Kalman gain, and then observe the new measurement from the observation model. A posteriori prediction of system state can be derived from Kalman gain, a priori state and the measurement of updated system state. Kalman filter can be represented by the following set of equations.

The processing model is

$$\mathbf{x_{k+1}} = \mathbf{A}\mathbf{x_k} + \mathbf{B}\mathbf{u_{k+1}} + \mathbf{w_{k+1}} \quad (3)$$

and the observation model is

$$\mathbf{z_{k+1}} = \mathbf{H}\mathbf{x_{k+1}} + \mathbf{v_{k+1}} \quad (4)$$

The Kalman gain is

$$\mathbf{K_{k+1}} = \mathbf{P_{k+1}}\mathbf{H^T_{k+1}}(\mathbf{H_{k+1}}\mathbf{P_{k+1}}\mathbf{H^T_{k+1}} + \mathbf{R_{k+1}})^{-1} \quad (5)$$

here $\mathbf{P_{k+1}}$ is a priori prediction error covariance which can be written as

$$\mathbf{P_{k+1}} = \mathbf{E}[(\mathbf{x_{k+1}} - \hat{\mathbf{x_{k+1}}})(\mathbf{x_{k+1}} - \hat{\mathbf{x_{k+1}}})^T] \quad (6)$$

and the a posteriori update of x_{k+1} is

$$\hat{\mathbf{x_{k+1}}} = \mathbf{x_{k+1}} + \mathbf{K_{k+1}}(\mathbf{z_{k+1}} - \mathbf{H_{k+1}}\mathbf{x_{k+1}}) \quad (7)$$

2.2 Optimal Frame Size Prediction for IEEE 802.11 Wireless LAN

The channel efficiency (ρ) in IEEE 802.11 wireless LAN can be expressed by following equation

$$\rho = \frac{L}{(L + H + B + \mathrm{D})\,(1 - Pb)^{(L+H)} + A} \quad (8)$$

In this equation, L is the payload size of a frame and H is the overhead of transmitting a frame including headers of MAC and PHY and processing delays of hardware and software. P_b is the bit error rate under a certain channel quality. B is the average number of time slots for back off which is specified by IEEE 802.11 wireless LAN standard. In this paper, we only consider the basic part of IEEE 802.11 standard, distribution coordination function (DCF), which uses CSMA/CA as media access control algorithm. D and A are respectively DCF inter-frame space and acknowledgement, which are specified by the standard. Then we compute the optimal frame size by maximizing the channel efficiency.

$$\frac{\partial \rho(L, Pb, B)}{\partial L} = 0 \longrightarrow L_{opt}; \quad (9)$$

In general, most communication systems have restriction of frame size, L_{max} and L_{min}, thus following equations are developed as state transition model of the frame size predictor

$$L_{opt} = \begin{cases} L_{max} & L_{opt} > L_{max} \\ L_{opt} & L_{min} < L_{opt} < L_{max} \\ L_{min} & L_{opt} < L_{min} \end{cases}$$

The L_{opt} is a local optimal since the channel environment is changing in terms of bit error rate, back off time and so forth. Figure. 1 and Figure. 2 show relations among bit error rate, frame length and back off time.

Given a certain channel quality and network traffic condition, there is an local optimal frame size. But due to the characteristics of wireless

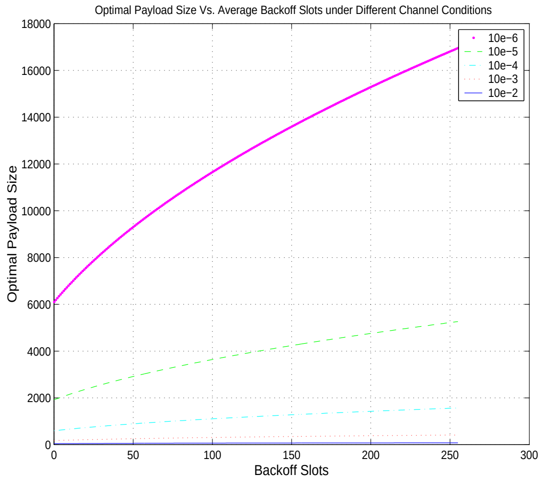

Figure 1. Optimal Payload Size Vs. Average Backoff Slots under Different Channel Conditions

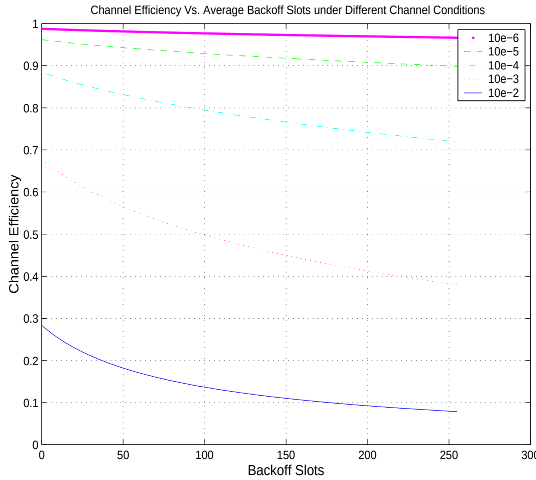

Figure 2. Channel Utilization Vs. Average Backoff Slots under Different Channel Conditions

LAN, the optimal frame size will be affected greatly by back off time slots and bit error rate. And this will cause distorted measurements. In order to get more accurate optimal channel prediction, we use Kalman filter to predict the optimal channel prediction for the next transmission. Thus following equations are developed as state transition model of the frame size predictor

$$L_{opt(k+1)} = \begin{cases} L_{opt(max)} \\ L_{opt(k)} + \theta \\ L_{opt(min)} \end{cases}$$

Here, θ s the difference between two optimal frame sizes due to changes of Pb and B. $L_{opt(max)}$ and $L_{opt(min)}$ are respectively maximum and minimum frame size specified by wireless LAN standard. For the observation model, we choose

$$Z_{k+1} = L_{opt(k+1)} \tag{10}$$

Z_{k+1} is the observation at time $k+1$ and it is distorted by changes in channel quality and different network traffic situation sensed from transmitter and receiver.

3 Simulation and Result Analysis

Simulations are designed in order to analyze the proposed prediction algorithm and the results are analyzed in this section. The simulation parameters are chosen according to IEEE 802.11b wireless LAN specification (1999). In 802.11b physical layer specification, four kinds of modulation schemes are supported, 1Mbps, 2Mbps, 5.5Mbps and 11Mbps. In this work, without losing generality, the system data rate is $11Mbps$ with non-FEC CCK modulation scheme. The channel quality is taken from the measurements at a typical office environment. L_{max} is 18400 bits; L_{min} is 1150 bits. The average back off time is difficult to compute due to the characteristics of CSMA/CA. According to [1], the back off time can be approximately represented by a geometric distribution which takes $p = \frac{1}{E[B]+1}$.

Figure. 4 shows the difference between state values and observation values. Another important issue left is to determine values of processing noise and observation noise. Sine here our goal is to verify and analyze the proposed predictor, we use the off-line method to determine these two values. The processing noise is mainly resulted in the equation approximation and the observation noise is mainly from quantization noise. Through off-line observation, the processing error covariance and measure error covariance used in this simulation are taken from the larger variance, which are 10000 bits and

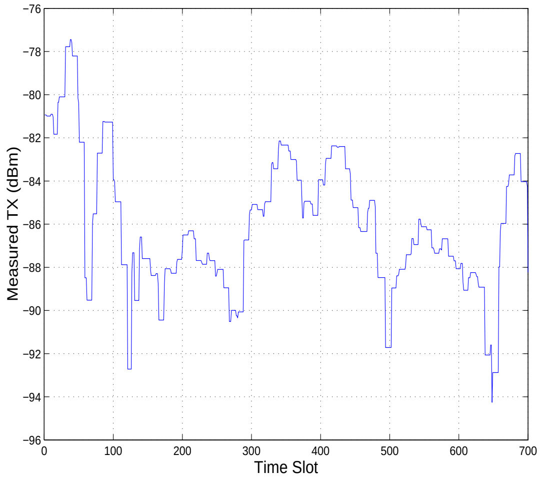

Figure 3. Channel Quality Measurements for a Typical Indoor Environment

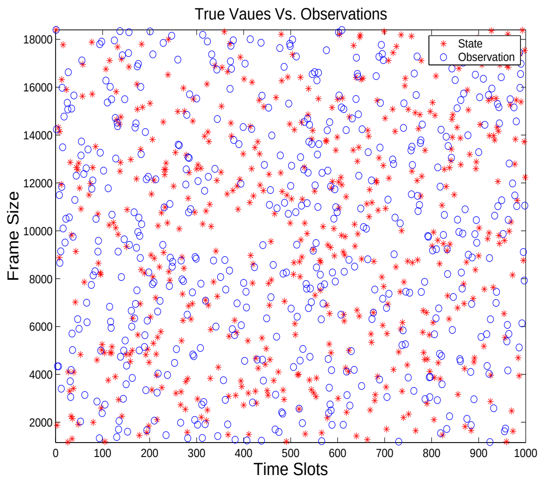

Figure 4. States Vs. Observations

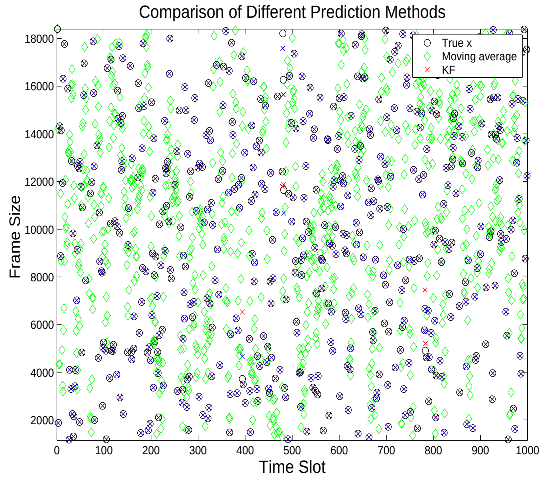

Figure 5. Proposed Predictor Vs. Moving Average (window=10)

10000 bits respectively in this paper. For future operational tuning, more observations and measurements could be pursued. The simulation time slots are 10^5 and the results are compared with results by using moving average method in Fig. 5. In this figure, we can see the comparison of different prediction methods. The RMS error of proposed predictor is 588.6 and the RMS error of moving average method whose window size is 10 is 12734.7. The root mean squared error of prediction samples is improved by the order of tens with the cost of more processing time. We think that, through implementing the proposed predictor in hardware or firmware, the execution time will be shortened greatly.

4 Conclusion

In this paper, we develop a optimal frame size predictor based on Kalman filter. The performance of proposed predictor is simulated and compared with the performance of moving average method. The simulation results show that the performance of the new predictor is much better than that of moving average algorithms. For example, the RMS prediction error is lower in the order of hundreds over moving average method. The prediction time will be lowered greatly when it is implemented in firmware or hardware.

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