Kalman Filter Estimation of the Number of Competing Terminals in an IEEE 802.11 Network Utilizing Error Pron-Channel

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Abstract

Numerous applications of the wireless local area networks (WLANs) are sensitive to the state of the employed channel. Packet delay and throughput which are the crucial characteristic for almost all recent applications of the WLANs are sensitive to: number of associate stations in the network, amount of error in the employed channel, and type of the adopted transmission mechanism. The number of competing stations is essential to be known in terms of optimizing the system performance. Although several of considered studies have investigated these aspects most of them are anchored in some assumptions which turn into far from the reality, such as using ideal channel (errorless) or assuming unlimited number of retransmissions with the adopted accessing mechanism. In this paper, number of competing stations based on using Kalman filter technique with taking state of the channel into consideration is estimated. The achieved results show that amount of the error and number of retransmissions with the utilized mechanism play a key role on the estimation number of stations in the WLANs compare with the other studies.

Keywords: *IEEE 802.11; WLAN; Kalman filter; Error-prone channel.*

1. Introduction

IEEE 802.11 wireless local area networks (WLANs) have widespread deployment in enterprises, public areas and homes. The standard, 802.11, defined the DCF (Distributed Coordination Function) as a default mechanism to access the medium. This mechanism is based on the carrier sense multiple access with collision avoidance (CSMA/CA) [1, 2]. The CSMA/CA access scheme is typically adopted in the wireless environment due to its reliability, flexibility, and robustness. Its strategy has been investigated in details in the literature; see for example [3-6]. CSMA/CA is used to make the access control adaptive to the channel conditions through the backoff algorithm. The CSMA/CA strategy stated in the standard is particularly useful when the load is relatively light, low noise and number of instantaneous associated stations. A considerable research activity has concentrated on improving performance of the IEEE 802.11 DCF [7]. Authors in [8-10] show that the performance of IEEE 802.11 protocol strongly depends on the number of active stations. Bianchi and Tinnirllo in [11] have estimated number of stations based on extended Kalman filter approach which is coupled with a change detection mechanism to capture variation in the number of competing terminals in the network. However, the estimation has based on assumption that the utilizing transmission channel is ideal (errorless and noiseless) and the number of retransmission times is unlimited. Recently, Der-Jiunn Deng et. al, [10] stated that improving performance of the CSMA/CA and hence 802.11 protocol is strongly relays on knowledge number of stations.

In this paper, estimation number of competing stations is analytically formulated, then Kalman filter approach is extended for the estimation with using non-ideal (error-prone) channel with considering a limited number of retransmissions. The achieved results show that number of retransmissions plays a substantial role in the estimation and tracking accuracy for the competing stations in the WLAN. The rest of the paper is outlined as follows: section 2 presents explanations for estimating number of stations in WLAN with employing ideal (errorless) and error-prone channels. Estimation by using auto regressive moving average

(ARMA) filter is illustrated in section 3. And, Section 4 is conducted to explain using Kalman filter with using error-prone channel. Finally, section 5 summarizes the main conclusions.

2. Estimation number of active stations

In IEEE 802.11 wireless networks the packet delay greatly increases when there are serious collisions due to the heavy traffic, generated from many users are simultaneously sharing the same access point. The packets may be dropped either by the buffer overflow or by the MAC layer contentions. Such packets losses may affect high layer networking schemes. Assuming that there are N stations in the wireless LAN are considering and p(n) is the probability of a collision seen by a packet being transmitted on the medium at time n. This time dependency should be considered since the process is dynamic, i. e., number of stations associated with a WLAN is changing from time to time. So, p(n) is the probability that there is at least one packet transmission in the medium among other (N-1) stations in the range of stations under consideration. It is called conditional collision probability and given as in [12], with considering the moment of estimation (n):

$$p(n) = 1 - [1 - (1 - p_o(n))\tau(n)]^{n-1}$$

(1)

Where Po(n) is the probability that there is no packet ready to be transmitted at time n in the MAC layer of the wireless station under consideration. $\tau(n)$ is the packet transmission probability that the station transmits in a randomly chosen slot time given that the station has packets to transmit at the MAC layer. It is given as:

$$\tau(n) = \frac{1 - p^{m+1}(n)}{(1 - p(n))} \cdot \Phi_{0,0}$$

(2)

where :

$$\Phi_{0,0} = \begin{cases} \dfrac{2(1-2p(n)).(1-p(n))}{W(1-(2p(n))^{m+1}.(1-p(n))+(1-2p(n)).(1-p(n)^{m+1}))} & m \le m' \\[4mm] \dfrac{2(1-2p(n)).(1-p(n))}{W(1-(2p(n))^{m'+1}).(1-p(n))+(1-2p(n)).(1-p(n)^{m+1})+W.2^{m'}p(n)^{m'+1}.(1-2p(n)).(1-p(n)^{m-m'})} & m > m' \end{cases}$$

$\tau(n)$ does not depend on the type of the mechanism adopted by a station, two-way (basic) or four-way (request to send (RTS)/clear to send (CTS)) handshaking. Instead, it depends on the designed maximum number of the backoff stages, m, and condition of the transmitting channel via the probability of collision [7, 8]. When a station transmits and the remaining $N - 1$ stations defer their transmissions, the packet would be arriving successfully with probability $p_s(n)$ at time n. Thus, under assumption of absent error in the channel (ideal case) the number of estimated stations can be formulated as in [11] but with considering the moment of estimation to be as:

$$N(p(n), m') = \begin{cases} 1 + \dfrac{\log(1 - p(n))}{\log\left[1 - \dfrac{1-p^{m+1}(n)}{1-p(n)} \cdot \dfrac{2(1-2p(n))(1-p(n))}{W(1-(2p(n)))^{m+1} \cdot (1-p(n))+(1-2p(n))(1-p^{m+1}(n))}\right]} & m \le m' \\[6mm] 1 + \dfrac{\log(1 - p(n))}{\log\left[1 - \dfrac{1-p^{m+1}(n)}{1-p(n)} \cdot \dfrac{2(1-2p(n))(1-p(n))}{W(1-(2p(n)))^{m+1} \cdot (1-p(n))+(1-2p(n))(1-p^{m+1}(n))+\chi}\right]} & m > m' \end{cases}$$

(3)

where,

$$\chi = w.2^{m'}.p^{m'+1}(n).(1 - 2p(n))(1 - p^{m-m'}(n))$$

and m' is the retry limit.

Influence of error in the transmitting channel may be included through considering the parameter $p_c(n)$ as introduced in Ref. [13]:   In the case of adopting two-way access mechanism[1]1:

$$p_c(n) = 1 - (1 - BER)^L \tag{4-a}$$

where, $L = PHY_h + MAC_h + p(n) + ACK$. And, in the case of using four-way handshaking:

$$P_c(n) = 1 - (1 - BER)^{RTS} * (1 - BER)^{CTS} * (1 - BER)^P * (1 - BER)^{ACK} \tag{4-b}$$

thus, rewriting the above relations with some simple manipulation steps the number of users can be obtained as:

$$N(p(n), m') = \begin{cases} 1 + \dfrac{\log\left[\dfrac{(1-p(n))}{(1-p_c(n))}\right]}{\log\left[1 - \dfrac{1-p^{m+1}(n)}{1-p(n)} \cdot \dfrac{2(1-2p(n))(1-p(n))}{W(1-(2p(n))^{m+1} \cdot (1-p(n)) + (1-2p(n))(1-p^{m+1}(n))}\right]} & m \le m' \\[4ex] 1 + \dfrac{\log\left[\dfrac{(1-p(n))}{(1-p_c(n))}\right]}{\log\left[1 - \dfrac{1-p^{m+1}(n)}{1-p(n)} \cdot \dfrac{2(1-2p(n))(1-p(n))}{W(1-(2p(n)))^{m'+1} \cdot (1-p(n)) + (1-2p(n))(1-p^{m+1}(n)) + \chi}\right]} & m > m' \end{cases} \tag{5}$$

in this case, the probability that each packet collides after launched into the channel, the conditional collision probability, is:

$$p(n) = 1 - (1 - \tau)^{n-1}(1 - p_c(n)) \tag{6}$$

which is proportional to amount of error in the channel via the parameter $p_c(n)$.

3. ARMA Filter Estimation

One of the available estimation for the time-varying of the competing station is achieved through monitoring the channel. This might be gotten with using auto regressive (AR) mechanism or auto regressive moving average (ARMA) filters.

The conditional collision probability is:

$$\hat{p}(n+1) = \alpha\, p(n) + \frac{(1-\alpha)}{q} \sum_{i=0}^{q-1} c_{t-i} \tag{7}$$

Where, α and q are the filter parameters, and the average number of competing stations given as:

$$\hat{N}(n+1) = f(\hat{p}(n+1)) \tag{8}$$

Because the non linearity of the relation $N = f(p)$, the estimation $\hat{N}$ is biased, as it is $f(E[\hat{p}]) \ne E[f(p)]$, Ref. [11]. Figure 1, shows the temporal behavior for different number of competing stations: 1, 5, 10, 25, and 15. Three state of the channel condition are considered: errorless (ideal), BER = 10^{-5}, and BER = 0.5×10^{-5}. The two different sets of backoff parameters corresponding to the two different physical layer specifications are considered: FHSS, which is characterized by W = 16 and m = 6 (Fig. 1-a), and DSSS is characterized by W = 32, m = 5 (Fig. 1-b). As number of retransmissions increases the estimation of conducting station offers more accuracy. This is due to increasing probability of reaching the destination successfully [14]. However, utilizing an error-prone channel play a distinguish role in the

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[1] Note that, in this study, all measured parameters are assumed for an instantaneous time which may be changed for another moment and the average values are considered.

estimation of the conducting station as number of retransmissions increases. This is due to increasing of probability of effecting by the state of the channel as number of using the channel increases. However, the fluctuation in estimation the number of conducting stations with using auto regressive moving average (ARMA) filters is obviously high and the average should be taken for each case.

4. KALMAN Filter Estimation

The Kalman filter is a state-space approach for parameter estimation in dynamic systems. The state-space model for a linear system lies in: first, the state updating law for the system under scope, second, a measurement model, i.e. the relationship between state and measures [10, 12]. The state-space is mathematically described as: the system variables, which may not be directly measurable given by a state vector as:

$$N(n) = N(n-1) + \upsilon(n) \tag{9}$$

where, $N(n)$, $N(n-1)$ and $\upsilon(n)$ are the number of stations at time n, number of stations at time n-1 and a random variable (state noise), respectively. While the measured noisy observations can be described in measurement model, which is represented by the conditional collision probability at time n, $p(n)$ as:

$$p(n) = H(N(n)) + u(n) \tag{10}$$

where, $H(n)$ can be found by solving equation 5 for $p(n)$, and $u(n)$ is the measurement noise vector. It can be found as: $H(N(n)).\{1 - H(N(n))\}/N_T$, N_T is number of slot-times.

Then, by utilizing the extended model presented in [11] with $p(n)$, $\hat{N}(n)$ can be expressed as:

$$\hat{\hat{N}}(n) = N(n-1) + G_K(n)(p(n) - H(N(n-1))) \tag{11}$$

where, $G_K(n)$ is the Kalman gain and depends on $p(n)$ and variance of the $\upsilon(n)$, $\sigma_v(n)$ as:

$$\frac{(p(n-1) + \sigma_\upsilon(n))H(n)N_T}{(p(n-1) + \sigma_\upsilon(n))H^2(n)N_T + H(\hat{\hat{N}}(n-1)).(1 - H(N(n-1)))} \tag{12}$$

with linearizing $H(n)$ around $\hat{N}(n-1)$.

The Kalman filter estimation is demonstrated in figure 2. The configuration parameters for the change detection filter, are adjusted as that in [11], for comparison purpose, as: $\upsilon(n) = 0.5$ and the state noise variance is 5, and then multiple discrete steps are taken for increasing number of stations associated in a WLAN (N(n) = 1, 5, 10, 25, and 15). Also, the simulation has been run for 100 seconds, as the period considered in [11]. Figure 2 –a and -b illustrate two different sets of backoff parameters corresponding to the two different physical layer specifications: FHSS, is characterized by W = 16, and m = 6 (Fig. 2-a), and DSSS is characterized by: W = 32, m = 5 (Fig. 2-b). Each case is considered for three state of the employing channel: errorless, BER = 10^{-5} and BER = 0.5×10^{-5}. The results show that the kalman filter offer better tracking and stability for the number of competing station with using wider competing window size, specifically, with using FHSS. On the other side, the accuracy for achieving the number of station is quite sensitive to the retransmissions and state of the channel. With adopting a certain number of retransmission the accuracy is affected by amount of error in the transmission channel. This is due to two factors. The first is due to the amount of delay which causes a number of packets discarded. And, the second is influence of number of packets arrived to the destination successfully.

5. Conclusions

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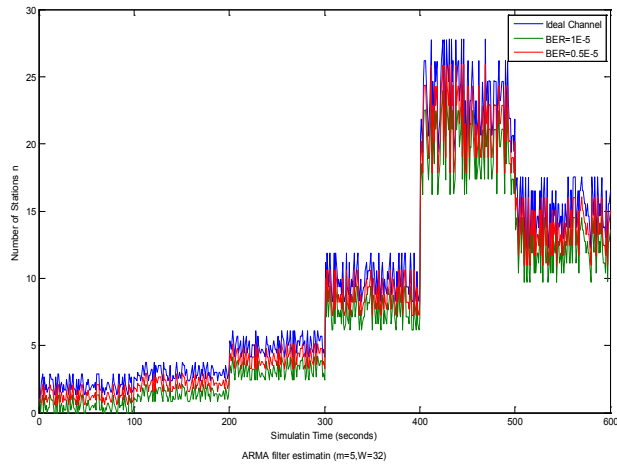Utilizing Error Pron-Channel
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This paper analyzed influence of error in the transmitting channel and number of retransmissions on the estimation number of competing stations in a WLAN by using auto regressive moving average (ARMA) and Kalman filter techniques. The analysis is based on numerical accurate closed form expressions which relate the number of competing stations with the probability of a collision seen by a packet being transmitted on the channel at a specific time. The simulation results show that to keep high accuracy in the estimation and tracking the dynamic changing in number of competing stations amount of error in the transmitting channel and number of retransmissions must be taken into consideration. Also, the achieved results show that at low level of error in the employing channel, influence of retransmission on the estimation process is more impact on the accuracy of estimation than amount of error. Considering amount of error and number of retransmissions with using Kalman filter technique offer more accuracy in the estimation and tracking than employing auto regressive moving average (ARMA) filters.

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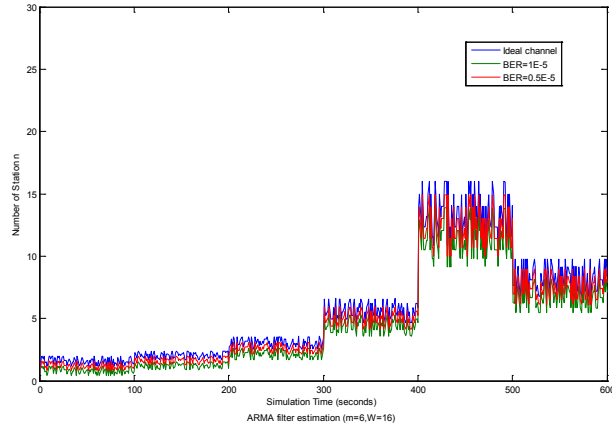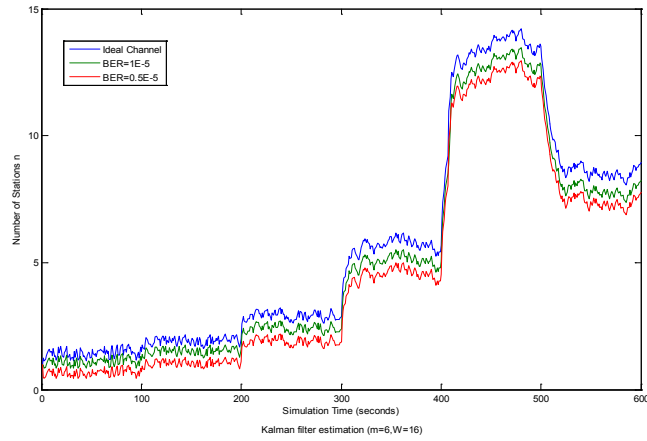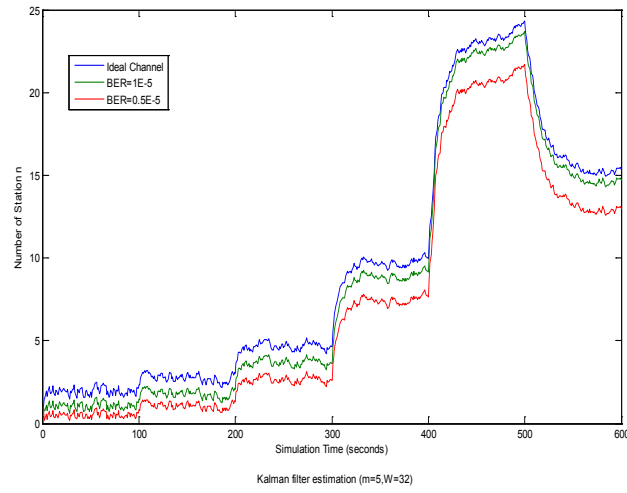
(a)

(b)

Figure 1. ARMA filter estimation for different number of competing stations.

(a)

Kalman filter estimation (m=5,W=32)

(b)

Figure 2. Kalman filter estimation for different number of competing stations.