Stochastic Approximation Algorithm for Optimal Throughput Performance of Wireless LANs

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ABSTRACT
In this paper, we consider the problem of throughput maximization in an infrastructure based WLAN. We demonstrate that most of the proposed protocols though perform optimally for connected network (no hidden terminals), their performance is worse than even that of standard IEEE 802.11 in presence of hidden terminals. Here we present a stochastic approximation based algorithm that not only provide optimum throughput in a fully connected network but also when hidden nodes are present.

Categories and Subject Descriptors
G.1.6 [Numerical Analysis]: Optimization—Constrained Optimization

General Terms
Algorithms, Performance

Keywords
IEEE 802.11, Hidden Nodes, Weighted fairness, Stochastic Approximation

1. INTRODUCTION
Infrastructure based IEEE 802.11 has emerged as one of the most popular access mechanisms for wireless local area networks (WLANs). Since its inception, significant effort has been made for improving its throughput. Most of the proposals aimed at maximizing the throughput of IEEE 802.11 DCF, propose algorithms to tune the access probability of p-persistent CSMA adaptively using parameter estimation. Through simulations we see that the performance of such algorithms though optimal in a connected network (no hidden terminals), their throughput is lesser than even that of standard 802.11 in the presence of hidden terminals Fig. 1(c). Node i is hidden from node j if i is outside the sensing range of j, and as a result i can not perform carrier sensing on j’s transmissions. We note that hidden nodes cannot always be eliminated without incurring significant throughput penalty on account of RTS/CTS exchange.

The reason behind the failure of the existing algorithms when hidden terminals exist is due to the fact that the algorithms are designed using the mathematical model proposed in [1]. This model, however, is valid only in a fully connected network. Quantifying the throughput of Wireless LANs when hidden terminals exist has been an open problem for over a decade. In the absence of a mathematical model, obtaining provably throughput optimal algorithms remained illusive.

In this paper we present an algorithm that not only performs optimally in a fully connected network, but also achieve near optimal throughput when hidden terminals are present. In our approach, we use stochastic approximation algorithms to tune the attempt probability based on the estimates of throughput at the Access Point. The algorithm is designed to maximize the estimated throughput and hence is not dependent on the mathematical model that defines the throughput equation. Our key contributions are as follows:

• We propose the Weighted Fair Throughput optimal p-Persistent CSMA (wTOP-CSMA) that is an on-line mechanism for tuning access probability of p-persistent CSMA to achieve a weighted fair throughput allocation while maximizing the system throughput in a fully connected network.

• We also show that if the throughput is a quasi-concave function of the access probability in network with hidden nodes, then wTOP-CSMA maximizes the system throughput among all p-persistent CSMA schemes even when hidden nodes are present (assuming that all users have the same weight).

2. SYSTEM MODEL
We consider a system with N nodes. We consider the saturated case; i.e., all nodes always have a packet for transmission to a central Access Point (AP). We assume that transmissions by AP can be received by all nodes. A node cannot receive and transmit simultaneously. Every node t is associated with a weight w_t. For the channel access mechanism, we assume the following. A node t transmits a packet in a slot with probability p_t. A slot can be either an idle slot of a pre-determined duration or a busy slot with some node transmitting. An idle slot for transmitter t is a slot in which no transmission is sensed by t. A busy slot for t is the duration for which it senses the channel to be busy followed by an idle duration of DIFS (Distributed Inter-Frame Space). It is assumed that all users transmits the packet using the same fixed rate R. A transmission by t to AP is successful if for the entire duration of transmission there is no other transmission.

We consider a channel access scheme to be weighted fair throughput optimal if it maximizes the system throughput while ensuring that the throughput obtained by each node is proportional to its weight.
the attempt probability even in general networks. We for-
implies that the throughput is a quasi-concave function of
of throughput can be seen as follows. For either "small" or
a quasi-concave function of the variable. Quasi-concavity
algorithm only requires that the objective function must be
Kiefer Wolfowitz algorithm \[2\] which uses stochastic approx-
is weighted fair.

3. OUR APPROACH

The \textit{wTOP-CSMA} algorithm is give in Algorithm 1. The
algorithm was also implemented in \textit{ns-3} and the results for
Algorithm 1 \textit{wTOP-CSMA} Algorithm
Algorithm at Access Point
1: \( k \leftarrow 2, \ a_k = 1/k, \ b_k = 1/k^{1/3}, \ p_{\text{eval}} \leftarrow 0.1, \)
2: \textbf{while} Nodes in Network \textbf{do}
3: \hspace{1em} Set \( p \leftarrow p_{\text{eval}} + b_k \) and measure the throughput \((S_{\text{plus}})\)
4: \hspace{1em} Set \( p \leftarrow p_{\text{eval}} - b_k \) and measure the throughput \((S_{\text{minus}})\) for a fixed duration \( \Delta \)
5: \hspace{1em} Set \( p_{\text{eval}} \leftarrow p_{\text{eval}} + \frac{a_k S_{\text{plus}} - S_{\text{minus}}}{b_k} \)
6: Increment \( k \) and set \( a_k = 1/k, \ b_k = 1/k^{1/3} \)
7: For every successfully received packet transmit \( p \) in the
ACK packet
Algorithm at Node \( t \) (with weight \( w_t \))
1: \textbf{while} Node in Network \textbf{do}
2: \hspace{1em} Transmit packet in a slot with probability \( p_t \)
3: \hspace{1em} If ACK received obtain \( p \) from ACK and set \( p_t =
weight fair throughput optimal.

Unfortunately, in the absence of a mathematical model
for networks with hidden terminals quasi-concavity cannot
be proven. Nonetheless we verify the quasi-concavity using
extensive simulations in \textit{ns-3} as shown in Fig. 1(a). Of
course, validation through simulations does not prove that
our proposed scheme is optimal when hidden terminals are
present, but it at least states that in the numerous random
topologies that we investigated, our scheme is throughput
optimal as stated here.

\textbf{Theorem 3.} \textit{If the throughput function of a} \( p \)-persistent
\textit{CSMA channel access scheme is a quasi-concave function of
the attempt probability then the \textit{wTOP-CSMA} algorithm
maximizes system throughput.}

The proof of the above theorems are presented in the
technical report. The simulations results from \textit{ns-3} are shown
in Fig. 1(b) and Fig. 1(c). The \textit{wTOP-CSMA} algorithm
has been compared with the IdleSense algorithm given in [3]
which is an optimal algorithm in a fully connected network.
It can be seen that while both the algorithms perform opti-
\textit{wTOP-CSMA} algorithm
performs worse than even Standard 802.11 when hidden ter-
\textit{wTOP-CSMA} algorithm
outperforms both the IdleSense and the Standard 802.11 al-
\textit{wTOP-CSMA} algorithm
when hidden terminals exists. The detailed proofs and simulations
results for weighted fairness are included in the technical report [4].

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\begin{figure}[h]
\centering
\begin{subfigure}{0.33\textwidth}
\centering
\includegraphics[width=\textwidth]{figure1a.png}
\caption{Throughput plot of \( p \)-persistence CSMA}
\end{subfigure}\hspace{0.05\textwidth}
\begin{subfigure}{0.33\textwidth}
\centering
\includegraphics[width=\textwidth]{figure1b.png}
\caption{Throughput comparison (in fully connected network)}
\end{subfigure}\hspace{0.05\textwidth}
\begin{subfigure}{0.33\textwidth}
\centering
\includegraphics[width=\textwidth]{figure1c.png}
\caption{Throughput comparison (in presence of hidden nodes)}
\end{subfigure}
\caption{Results from \textit{ns-3} simulations}
\end{figure}