A Distributed Correlative Power Control Scheme for Mobile Ad hoc Networks using Prediction Filters

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Abstract

Transmission power control (TPC) in a Mobile Ad hoc network (MANET) environment reduces the total energy consumed in packet delivery and/or enhances network throughput by increasing the channel’s spatial reuse. In this paper, a distributed correlative power control scheme using prediction filters (Kalman or extended Kalman) is proposed. The prediction filter is used to estimate the forthcoming interference. Both the transmitter and receiver in MANET environment make use of predicted interference to assign correlative power values to their associated ensued packets to guarantee the success of the IEEE 802.11 four-way handshaking communication (RTS/CTS/DATA/ACK). Simulation results for different topologies are used to demonstrate the significant throughput and energy gains that can be obtained by the proposed power control scheme.

1 Introduction

Significant research has been done to improve the performance of IEEE 802.11 medium access control (MAC) protocol[10]. One area of research consists of partially incorporating power control protocols [5],[7] into IEEE 802.11. Power control protocols can provide better spatial reuse and energy efficiency. Although the IEEE 802.11 MAC protocol [1] reduces the hidden terminal problem, it has drawbacks. One of the drawbacks is that all packets are transmitted at the same power, generally the maximal possible transmission power, which is unnecessary. In the case where the network is dense, a low transmission power is sufficient to maintain network connectivity whereas high transmission power brings about more interference to other transmissions, resulting in more retransmissions and higher energy consumption. The throughput of the network is also poor in such a case because high transmission power reduces the spatial reuse of the network bandwidth. By reducing the transmit power of wireless nodes, it is possible to reduce their power consumption. Since a wireless node often operates on a battery, it is important to preserve energy and potentially extend the lifespan of an ad hoc network. Moreover, lower transmit power leads to shorter range of interference. As a result, multiple flows of transmission may occur in the vicinity of each other. This increase in spatial reuse could lead to increased capacity of the network.

In this paper, we propose a distributed correlative power control algorithm using prediction filters (Kalman and extended Kalman filter)[3]. A mobile node measures the interference around its transmission zone. Based on this measured interference, this node makes use of any of the prediction filters to predict the future interference. This predicted interference is encapsulated within the RTS (request-to-send) message initiated towards the destination. Upon receiving the RTS message, the destination makes use of the included predicted interference to assign a power value to the ensued CTS (clear-to-send) message. Before sending the CTS message, the destination node repeats the same procedure in measuring the surrounding interference and then predicting the interference in the future. This information is sent within the CTS message towards the source node and used for assigning a power value to the DATA packet. The same criteria is carried again by the source node and used by the destination node for assigning power value to the Acknowledgement (ACK) message. This class of power control is referred to as correlative power control.

The organization of the rest of the paper is as follows. In section II, we discuss the related work and the motivation for the proposed research. The TPC using prediction filters is derived in section III. We carry various simulations for different topologies in section IV to demonstrate the significant throughput and energy gains that can be obtained under the proposed protocol. Finally, we present our conclusions and future work in section V.
Kalman filter has been recently proposed in the literature [4],[6] in different mobile cellular systems applications related to power control such as in interference estimation and channel gain prediction. A Kalman filter method for power control is proposed for broadband, packet-switched TDMA (Time division multiple access) wireless networks in [6]. In this work, a terminal sends data packets via an TDMA uplink channel to the base station and upon receiving the first data packet in slot n, the base station measures the channel interference around its area and predicts the future interference using Kalman filter. Based on the predicted interference, the base station calculates the required optimum power for receiving the next data packet in slot n+1. This information is relayed to the terminal via a downlink channel. Performance results revealed that the Kalman-filter method for power control enhances the network performance.

One of the first modifications of incorporating power control into the IEEE 802.11 distributed coordination function (DCF) for MANET was presented in [2]. In [2], the authors proposed to perform the RTS/CTS handshake at the highest initial power level to avoid packet collisions from the interfering nodes. The proposed protocol allows the sender and the receiver to negotiate a lower transmit power (the minimum required) level for sending the data frames. In this paper, we refer to this scheme as the BASIC scheme. BASIC consumes less energy than 802.11, yet it suffers from the interfering nodes problem [5].

Signal-to-interference-ratio (SIR) based power control schemes for MANET either uses the current interference measurement [2],[7] or estimates future interference using predefined models [13]. The accuracy of those models is not exact to a great extent. The authors in [13] proposed a class of correlative power control algorithms for single channel MANET. A model has been derived to estimate the interference power. The Interference model as shown in Figure 1 was estimated on an assumption that all potential interfering nodes are using an average transmission power \( P_{\text{avg}} \) and average radius of transmission zone \( R_{\text{avg}} \). Active interfering nodes located outside the transmission range of node A (the circle with radius \( R_{\text{RTS}} \)) are separated from each other by a distance of at least \( R_{\text{avg}} \). Moreover, the density of the simultaneous interferes is upper bounded by a factor of \( 1/R_{\text{avg}}^2 \); here, the total interference was derived as \( \int_{R_{\text{RTS,A}}}^{\infty} \frac{2\pi x \times x \times P_{\text{avg}} \times \text{dx}}{R_{\text{avg}}^2 \times x^2} \). Three scenarios for finding \( P_{\text{avg}} \) were presented. In the worst case scenario, all active nodes generate interference at the maximal power, \( P_{\text{avg}} = P_{\max} \). In the adaptive scenario, \( P_{\text{avg}} \) is estimated from the node performance. That is \( P_{\text{avg}} \) increases when one frame is lost and decreases when N consecutive frames are received successfully. Another adaptive scenario, \( P_{\text{avg}} \) is estimated as a moving average from the network performance, i.e. \( P_{\text{avg}} = 0.9 \times P_{\text{avg}} + 0.1 \times P_t \), where \( P_t \) is the transmission power of any captured packet. The authors reported better network performance and energy gain can be achieved using the proposed algorithms.

The advantages of the Kalman filter are its simplicity due to its recursive structure, robustness over a wide range of parameters and conditions, and the fact that it possibly provides an optimal estimate with minimum square error. These features and the successful reported application stories in various research fields (such as target tracking and detection, digital signal processing, digital image processing, etc) for Kalman filter have motivated us to apply it for power control in MANET. To the best of our knowledge, no power control scheme based on Kalman filter has been proposed to enhance the capabilities of the IEEE 802.11 protocol. We report here that a Kalman filter is also useful in controlling transmission power in MANET. This is what we are going to present in the following section.

### 3 Power control Scheme using prediction filters

Our proposed protocol scheme is based on the following properties:

- A transmitter cannot initiate any communication if it receives a power level larger than a given carrier-sensing threshold denoted by \( \eta \).
- The channel loss gain between a pair of nodes can be determined and is stationary for the duration of the control and ensuing data and control packets. The channel loss gain can be measured as follows:

\[
\text{Gain} = \frac{P_r}{P_t}.
\]

\( P_r \) and \( P_t \) are the received and transmitted power respectively.
Figure 2. The ongoing Kalman filter cycle. The time update projects the current state estimate ahead in time. The measurement update adjusts the projected estimate by an actual measurement at that time

where $P_r$ is the received power from the transmitted power $P_t$.

- A receiver is able to receive and decode correctly a packet if and only if the defined signal to interference noise ratio (SINR) at the receiver side is larger than a predetermined threshold denoted by $\zeta$; thus we have the following constraint:

$$P_r \geq \zeta \times P_n$$

where $P_n$ is sum of the interference power plus thermal noise power. Substituting (1) into (2), we get

$$P_t \geq \frac{\zeta \times P_n}{\text{Gain}}$$

- The received power is equal or greater than a minimum power level denoted by $\kappa$. Thus, the minimum transmission power is:

$$P_{min} = \frac{\kappa}{\text{Gain}}.$$  

- The received power of a frame from a transmitter node in its transmission zone is higher than or equal to $\kappa$ and the received power level of a frame a from transmitter node in its carrier sensing zone is higher than or equal to $\eta$. When the received power at the receiver side is higher than $\eta$, we say that receiver can sense the transmission from the transmitter.

- Interference power at each time instant can be measured quickly, but probably with errors at each node. The interference power is equal to the difference between the total received power and the power of the desired signal.

The IEEE 802.11 MAC is adopted i.e., nodes lying in the transmission vicinity of the sender or the receiver are not allowed to initiate any transmission for the the duration of the ongoing communication between the sender and the receiver nodes. Only nodes lying outside the sender or receiver transmission zone are potential interfering nodes.

### 3.1 Interference Power Prediction using Prediction Filters

The Kalman filter estimates a process by implementing feedback control form; the filter estimates the process at some time, then obtains feedback in the form of noisy measurement. Thus, Kalman filter prediction equations consist of two types: time update equations and measurement update equations. The time update equations estimate the process a priori value for the next time step by projecting forward in time the current state and error covariance estimates. Moreover, the measurement update equations integrate the new feedback measurement into the a priori estimate to obtain an improved posteriori estimate. Indeed the final prediction algorithm resembles that of a predictor-corrector algorithm [12] for solving numerical problems as shown in Figure 2 where the time update equations are the predictor equations, while the measurement equations are the corrector equations.

Let $I_n$ be the actual interference-plus-noise power in dBm received at time event $n$. $I_n$ is to be considered the process state to be predicted by the Kalman filter. The thermal noise power, which depends on the channel bandwidth, is given and fixed. The total interference is simply the thermal noise plus the measured interference. The system dynamics of the interference plus noise power can be modeled in state-space form as:

$$I_n = I_{n-1} + N_n$$

where $N_n$ is the variation of the interference-plus-noise power as new interfering nodes may start to initiate transmissions and/or adjust their transmission power in the time event $n$. According to the Kalman filter state-space model, $N_n$ is the process noise. Let $X_n$ be the measured interference plus noise power at time event $n$. Then,

$$X_n = I_n + E_n$$

where $E_n$ is the measurement noise. Equations (1) and (2) are commonly referred to as the state space generation model. The time equations of the Kalman filter in this case are

$$\tilde{I}_{n+1} = \hat{I}_n$$

$$\tilde{P}_{n+1} = \tilde{P}_n + Q_n$$
where $\tilde{I}_{n+1}$ is the a priori predicted interference at next time event. $I_n$ is the a posteriori estimate of $I_n$. $\hat{P}_{n+1}$ and $P_n$ are a priori and a posteriori estimate of the interference plus noise error variance at time event $n+1$ and $n$ respectively. $Q_n$ is the variance of the process noise $N_n$. The measurement update equations are:

$$K_n = \frac{\hat{P}_n}{\hat{P}_n + R_n} \tag{9}$$

$$\tilde{I}_n = \tilde{I}_n + K_n \times (X_n - \hat{I}_n) \tag{10}$$

$$\hat{P}_n = (1 - K_n) \times \hat{P}_n \tag{11}$$

where $\tilde{I}_n$ and $\hat{I}_n$ are a priori and a posteriori estimate of $I_n$. $\hat{P}_n$ is the a priori estimate of the error variance at time event $n$, $K_n$ is the Kalman gain, and $R_n$ is the variance for the measurement noise $E_n$.

In the actual tuning operation of the filter, the measurement noise covariance $R_n$ and $Q_n$ can be determined as follows:

$$Q_n = \frac{1}{M-1} \times \sum_{n=1}^{M} (X_M - \bar{X}_n)^2 \tag{12}$$

$$R_n = C \times Q_n \tag{13}$$

where $\bar{X}_n$ is the mean of the last $M$ measured values at time event $n$. The event $n$ is when a node successfully receives a control or data frame. $X_M$ is the last obtained measured value. $C$ is a constant between 0 and 1. $Q_n$ is an estimate of the variance of the sum of the process and measurement noise because measurements $\bar{X}_n$ include the fluctuation of both interference and measurement errors.

A necessary condition for Kalman filter to operate is that the process noise $N_n$ should have a normal distribution [12]. The radio channel model considered in this paper includes two ray path loss, antenna gain and shadowing [9]. Shadowing is a log-normal distributed random variable caused by terrain features. The received signal power at any node can be formulated as:

$$P_r = P_t \times r^{-4} \times G^2 \times h^2 \times 10^{3/10} \tag{14}$$

$r$ is the distance between the two nodes and $h$ is the height of the antenna. $G$ is the omnidirectional antenna gain of the nodes and is considered identical for all nodes. $P_r$ is the received power from the transmitting power $P_t$. Note that $\mathcal{O}$ is the shadowing component, which is characterized by a Gaussian random variable with zero mean and standard deviation of $\sigma$ dB. This makes $N_n$ in dBM normally distributed which verifies the use of Kalman filter in the prediction of interference in MANET environment.

The convergence properties of the Kalman filter is dependent on the values of the variance denoted by ($P$) [12]. We will show by simulation that $P$ is within limits and has the convergence shape at the end of the performance evaluation section.

The Kalman filter algorithm functions as follows: for event $n$ , the interference measurements are input to (12) and (13) to estimate $Q_n$ and $R_n$. Using these values and the current measurement $X_n$ in (9) to (11), we get Kalman gain $K_n$, and the posteriori estimates for $I_n$ and $P_n$, respectively. The a priori estimates for the next time event are given by (8) and (6). Specifically, $I_{n+1}$ in (8) is used as the predicted interference plus noise power for power control as we are going to discuss in the coming section. Note that, $P_{n+1}$ is used as an initial value to get the next predicted value.

The extended Kalman filter (EKF) [12] attempts to correct the error induced between the process and measured values. Mainly the extended Kalman filter is used for non-linear systems. The process in evaluation has been modeled as linear system and thus a small enhancement can be added using the EKF scheme. This enhancement is incorporated with in time equations of the EKF. Thus EKF time update equation is given by:

$$\tilde{I}_{n+1} = \tilde{I}_n + (\tilde{I}_n - \hat{I}_{n-1}) \tag{15}$$

### 3.2 Power assignments for successful frame reception

Before initiating a transmission, node $A$ measures the interference at time instance $t$, the interference plus noise-power are used as input to the Kalman filter or extended Kalman filter to predict the estimated interference plus noise power $I$ at future time as discussed in previous section. Without loss of generality, $I$ notation will be used as the predicted interference plus noise power (in mw) in the coming formulas and for all nodes. The RTS message which is sent at maximum power carries the interference information $I$ to node $B$ as shown in Figure 3. Upon receiving the RTS message, node $B$ uses this value $I$ to calculate the required power of CTS as follows and according to the basic rule stated in (4). The transmission power of the CTS
Table 1. Simulation parameter settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_n$</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>4 dB</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>10 dB</td>
</tr>
<tr>
<td>$P_{max}$</td>
<td>15 dBm</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>-78 dBm</td>
</tr>
<tr>
<td>$\eta$</td>
<td>-83 dBm</td>
</tr>
<tr>
<td>Mobility factor</td>
<td>2 m/sec</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>300 sec</td>
</tr>
</tbody>
</table>

message is given by:

$$P_{CTS} = \max(P_{min}, \zeta \times \frac{I}{Gain})$$ (16)

Before sending the CTS message, node B measures interference around its transmission zone and then predicts the interference plus noise power $I+$ for the future in order for node A to be able to assign successfully a power value for its data packet. This predicted value is sent to A in the CTS message. When A receives the CTS message, it repeats the same procedure taken by node B to assign a suitable power value for DATA frame. The transmission power of the DATA message is given by:

$$P_{DATA} = \max(P_{min}, \zeta \times \frac{I+}{Gain})$$ (17)

Node B receiving the DATA frame will assign a power value to the ACK frame as follows:

$$P_{ACK} = \max(P_{min}, \zeta \times \frac{I++}{Gain})$$ (18)

where $I++$ is the predicted interference plus noise power at node A upon receiving the CTS message and is sent to node B in the DATA message.

4 Performance Evaluation

4.1 Simulation Setup

We use Qualnet [11] to evaluate by simulation the performance of our proposed power control scheme using Kalman and extended Kalman filters. In those simulations, we consider the interference from all the interfering nodes. We compare the power control scheme using prediction filters with IEEE 802.11, BASIC, and Adaptive(case ii,B)[13]. We denote the power control scheme using Kalman filter as Adaptive-K and that of extended Kalman filter as Adaptive-EK. In Adaptive(case ii,B) the RTS frame is sent at a power level such that the RTS, CTS, DATA and ACK messages are all transmitted at the same transmission power. Moreover, the average transmitting power $P_{avg}$ of all interfering nodes is estimated from the node performance. That is, $P_{avg}$ increases when one frame is lost and decreases when $N$ consecutive frames are received successfully. The channel rate is 11 Mbps and CBR (Constant Bit Rate) and FTP (File Transfer Protocol) are used as traffic generators. Three network topologies are adopted in our simulations. One is a $10 \times 10$ grid network with ten end-to-end CBR (constant bit rate) or TCP (transport control protocol) flows. The flows start from the left most node to the right most node along the same row. The route to the destination node is determined via a routing algorithm and in our simulations we used Ad hoc on Demand Vector Routing (AODV)[8]. The distance between each node pair is 100 meters. The other scenario is a 50 nodes uniform random network with ten CBR or TCP flows and all nodes are inside a $1000 \times 1000$ square of meters. The third scenario is a clustered topology. For the clustered topology, we consider a $1000 \times 1000 m^2$ area with 50 nodes. These 50 nodes are divided into four clusters, and each cluster is placed in a $150 \times 150 m^2$ square. The nodes distribution inside each cluster is not uniformly distributed. The main purpose behind the clustered topology is to show the weakness of using model-based interference as interference prediction method. The packet sending rate is 400 packets per second for the CBR flows. Other simulation parameters are shown in Table 1.

We are considering the following seven scenarios:

1. Grid network with CBR flows;
2. Grid network with TCP flows;
3. Static random network with CBR flows;
4. Static random network with TCP flows;
5. Grid network with TCP flows;
6. Static random network with CBR flows;
7. Static random network with TCP flows;
5. Dynamic random network with CBR flows;
6. Dynamic random network with TCP flows;
7. Static clustered network with CBR flows;

In each scenario, one node may communicate with another node directly or by relaying, depending on the transmit power. We use three metrics to evaluate 802.11, BASIC, Adaptive(case ii,B) [13], Adaptive-K and Adaptive-EK: 1) Aggregate Throughput which is the sum of the data frames correctly received by the receivers per time unit; 2) Effective Data Delivered per Joule which is the received effective data frames divided by the entire energy consumption; 3) Data Frame Corruption Ratio which is the portion of MAC layer frames corrupted by interfering nodes.

4.2 Results and Analysis

Figure 4 shows the total network end-to-end throughput for different MAC protocols namely, IEEE 802.11, BASIC, Adaptive and Kalman and EKF. Without loss of generality, prediction filters points to both Kalman and EKF in this section. Clearly, the throughput of tuned prediction filters are higher than that of the others. As can be seen in scenarios 1 and 2, the IEEE 802.11 suffers from the channel access problems which make it inefficient in terms of throughput. This is because nodes within the transmission zone of the sender or the receiver are refrained from initiating any transmission for the duration of the ongoing communication between the sender and the receiver nodes. Thus as traffic increases, the duration to win the channel decreases; as a result, packets will be dropped because their transmission retry limit threshold has been reached. The traffic load of 400 packets/sec is considered high and thus the IEEE 802.11 starts to show its limitations in sharing the channel in the time domain. On the other hand, BASIC suffers from the hidden node problem which has a high effect on its final throughput.

The Adaptive method uses an interference model to estimate the interference in the future whereas tuned prediction filters predict this interference. Figure 5 shows an intuitive comparison for the first 40 sec between these two techniques for node 28 in scenario 3 and node 32 in scenario 7. Node 28 is taken randomly for performance evaluation whereas node 32 in scenario 7 is considered a gateway between two clustered groups. As can be viewed, tuned prediction filter can give better estimate for the interference with less error percentage. It is to be noted here that the error is defined by the measured value minus estimated or predicted value. Figure 6 shows all the average error considering all the scenarios for the interference estimation using Kalman, extended Kalman filters and the model-based. An interference estimation value that is higher than the measured actual interference with an error that is more than 10% may highly affect the overall performance of the network. This is because nodes with higher interference estimation value may increase their transmission power to overcome this high interference, thus the higher the transmission power is the more the interference effect on other nodes. As a result this may highly affect the overall network performance which is shown in Figure 4. Moreover, nodes with lower interference estimate value with an error greater than or equal to 10% will decrease their packet transmission power. In such a case, there is a probability that these packets may be corrupted along the path due to actual interference that nodes were not aware of when they assigned power values to their consecutive packets. To conclude this section, tuned prediction filters outperform the model
based by an average error enhancement of 11.4% and this was the reason behind the prediction filters achieving higher throughput gain.

To test the effectiveness of prediction filters for the prediction task, we consider scenario 5 and try to vary the interference fluctuation by adding additional flows between two simulation instances. Initially 10 CBR flows were running. We injected an additional 10 CBR flows between 5 sec and 200 sec to increase the interference. A snapshot for the same random node 28 is reported in Figure 7. As can be viewed from Figure 7, the measured interference increases between these two time instances. The prediction filters were able to follow the measured value with an excellent accurately estimate. The proposed prediction filters scheme can predict the interference in future, and based on this prediction, assign consecutive power values to frames which differentiate this method from others in terms of achieving better throughput gains as can be seen in Figure 4. In case of no interference, packets are transmitted with a sufficient minimal power $P_{\text{min}}$ for correct reception. This in turn decreases the interference and accordingly enhances the spatial reuse which results in better throughput gain. A slight improvement in terms of CBR end-to-end throughput for IEEE 802.11 is reported in Figure 4 for scenario 3. The randomness of nodes enhances the IEEE 802.11 performance due to the fact that there exists cases where fewer nodes may lie in the vicinity of the transmission range of the sender. On the other hand, BASIC transmits data packets at low transmission power; there is a big probability for data reception failure due to hidden node problem and accordingly this aspect decreases network throughput as can be seen in scenarios 3 to 6.

Figure 8 depicts the ratio of throughput to average energy consumption per node in Kbps/Joules. Energy consumption includes the energy of a successful transmission of packets and the lost energy in retransmitting a packet in case of collisions and the energy of the node while receiving a packet and when it is in idle state. The power saving is attributed to the correct assignment of power values for the power control schemes adopting the prediction filters techniques. Reduction in the mutual interference makes it feasible for nodes to deliver packets efficiently. Nodes with packets for delivery have always to access the channel in order to send their packets. To win the channel, a node has always to sense the channel to be idle before transmitting its packets. If a node was unable to send its packets for a certain duration, it follows a backoff procedure and after the backoff time ends, the node has again to check if the channel is idle or not in order to send its packets. This results in unnecessary carrier sensing. Our proposed scheme decreases to great extent this unnecessary carrier sensing. This decrease in the sensing activity has reduced the energy consumption as well. This can be pointed out in all the scenarios.

Figure 9 shows data frame corruption ratio with all scenarios. Power control using prediction filters causes less corruption than the others. BASIC causes less corruption than IEEE 802.11. The reason behind this aspect is that all packets with IEEE 802.11 are transmitted with maximum power, thus interference increases, and this results in more packet corruption. For BASIC, packets are transmitted with minimal power, nevertheless in case of interfering nodes, packets transmitted with minimal power may be corrupted before reaching their destination. The effectiveness of the power assignment in the power control scheme adopting prediction filters is intuitively shown to decrease the number of packets dropped. Figure 10 shows the convergence...
of the error of interference plus noise power estimates for a random node 28 in scenario 5. \( \hat{P} \) is within a value between 0 and 1 and has a convergence shape at the end of the simulation time. This proves that Kalman filter has operated successfully and fulfills the necessary condition for its convergence.

Finally, we considered a mobile environment and measured the network throughput; the figures are not shown due to the lack of space. Our results showed that adaptive schemes start to show throughput limitations after 16 \( m/sec \). For BASIC, average throughput drastically decreases after 14 \( m/sec \) whereas that of IEEE 802.11 after 12 \( m/sec \). Adaptive schemes, on the other hand, outperform the other two because they can better estimate the interference from interfering nodes and accordingly transmit frames using the optimal transmit power.

5 Conclusion

In this paper, we have proposed a distributed correlative transmission power control (TPC) scheme for mobile ad hoc networks using prediction filters. Prediction filters are used to predict the interference in future. Both the transmitter and receiver in MANET environment make use of the predicted interference to assign power values to their associated ensued packets to guarantee the success of the IEEE 802.11 (RTS/CTS/DATA/ACK) communication. We have compared our proposed power control scheme with the standard IEEE 802.11 MAC protocol, BASIC, and an Adaptive power control scheme proposed in [13]. Through simulations we proved that prediction filters are far better than interference-model-based in estimating the interference for SIR-based power control schemes. Moreover, significant throughput and energy gains are achieved under the proposed power control scheme.

References

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