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Research Article

Multiple-Antenna Interference Cancellation for WLAN with MAC Interference Avoidance in Open Access Networks

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The potential of multiantenna interference cancellation receiver algorithms for increasing the uplink throughput in WLAN systems such as 802.11 is investigated. The medium access control (MAC) in such systems is based on carrier sensing multiple-access with collision avoidance (CSMA/CA), which itself is a powerful tool for the mitigation of intrasystem interference. However, due to the spatial dependence of received signal strengths, it is possible for the collision avoidance mechanism to fail, resulting in packet collisions at the receiver and a reduction in system throughput. The CSMA/CA MAC protocol can be complemented in such scenarios by interference cancellation (IC) algorithms at the physical (PHY) layer. The corresponding gains in throughput are a result of the complex interplay between the PHY and MAC layers. It is shown that semiblind interference cancellation techniques are essential for mitigating the impact of interference bursts, in particular since these are typically asynchronous with respect to the desired signal burst. Semiblind IC algorithms based on second- and higher-order statistics are compared to the conventional no-IC and training-based IC techniques in an open access network (OAN) scenario involving home and visiting users. It is found that the semiblind IC algorithms significantly outperform the other techniques due to the bursty and asynchronous nature of the interference caused by the MAC interference avoidance scheme.

1. INTRODUCTION

Interference at the radio receiver is a key source of degradation in quality of service (QoS) as experienced in wireless communication systems. It is for this reason that a great proportion of mobile radio engineering is exclusively concerned with the development of transmitter and receiver technologies, at various levels of the protocol stack, for mitigation of interference.

Multiple-antenna interference cancellation (IC) at the receiver has been the subject of a great deal of research in different application areas including wireless communications [1–3] and others. Despite the considerable interest in this area, IC techniques are typically studied at the physical (PHY) layer and in isolation from the higher layers of the protocol stack, such as the medium access control (MAC). However, it is clear that any gains at the system level are highly dependent on the nature of cross-layer interactions, particularly if multiple layers are designed to contribute to the interference mitigation process. This is indeed the case for the IEEE 802.11 family of wireless local area network (WLAN) systems [4], where the carrier sensing multiple-access with collision avoidance (CSMA/CA) MAC protocol is itself designed to eliminate the possibility of interference at the receiver from other users of the same system.

Although the MAC layer CSMA/CA protocol may be very effective for avoidance of intrasystem interference in typical conditions, certain applications which experience significant hidden terminal problems and/or interference from coexisting “impolite” systems may also benefit from PHY layer IC. PHY/MAC cross-layer design is clearly required in such situations.

One important example of the above is an open access network (OAN) where visiting users (VUs) are allowed to share the radio resource with home users (HUs) [5]. In many scenarios, VUs typically experience greater distances from an access point (AP) compared to HUs. This means that VUs may interfere with each other with higher probability compared to HUs, leading to throughput reduction for VUs or gaps in coverage. A multiple-antenna AP with IC may be a solution to this problem.

A cross-layer design in such a system is required because the CSMA/CA protocol leads to an asynchronous

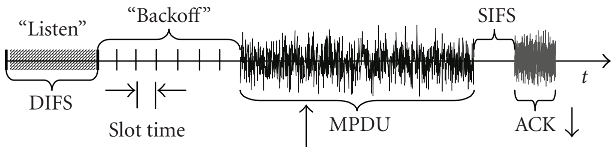

Figure 1: Transmission of MPDU and ACK bursts.

interference structure, where interference bursts appear with random delays during the desired signal data burst. One way to account for higher-layer effects is to develop interference models that reflect key features of cross-layer interaction and design PHY-layer algorithms that address these. This is the methodology adopted in [6–11], where semiblind space-time/frequency adaptive second- and higher-order statistic IC algorithms have been developed in conjunction with an asynchronous (intermittent) interference model. The second-order algorithm is based on the conventional least-squares (LS) criterion formulated over the training interval, regularized by means of the covariance matrix estimated over the data interval. This simple analytical solution demonstrates performance that is close to the nonasymptotic maximum likelihood (ML) benchmark [6, 7]. Further analysis is given in [8], which introduces nonstationary interval-based processing and benchmark in the asynchronous interference scenario. The regularized semiblind algorithms can be applied independently or as an initialization for higher-order algorithms that exploit the finite alphabet (FA) or constant modulus (CM) properties of communication signals. The efficiency of these algorithms has been compared to the conventional LS solution [1] by means of PHY simulations. These involve evaluation of metrics such as mean square error (MSE), bit-error rate (BER), or packet-error rate (PER), as a function of signal-to-interference ratio (SIR) for given signal-to-noise ratio (SNR), and a number of independent asynchronous interferers.

Our goal in this paper is to evaluate cross-layer interference avoidance/cancellation effects for different algorithms and estimate the overall system performance in terms of throughput and coverage. The combined performance of different IC algorithms at the PHY layer and the CSMA/CA protocol at the MAC layer is evaluated in the context of an IEEE 802.11a/g-based OAN. This is performed via simulations where the links between all radios are modelled at symbol level based on orthogonal frequency multiplexing (OFDM) as defined in specification [4], subject to path loss, shadowing and multipath fading according to the IEEE 802.11 channel models [12, 13]. Conventional and semiblind multiple-antenna algorithms are assumed at the PHY layer in order to identify possible improvements in system throughput and coverage for different OAN scenarios with VU and HU terminals. Cross-layer effects of continuous and intermittent intersystem interference from a coexisting impolite transmitter are also addressed.

The asynchronous interference model is derived in Section 2 in the context of typical OAN scenarios. The 802.11 CSMA/CA protocol is also briefly reviewed in Section 2. Problem formulation is given in Section 3. This is followed in Section 4 by a description of the conventional and semiblind IC receiver algorithms, along with a demonstration of their performance at the PHY layer. Section 5 provides a description of the simulation framework and the cross-layer simulation results in typical OAN scenarios with intra- and intersystem interference. Conclusions are presented in Section 6.

2. INTERFERENCE SCENARIOS

The MAC mechanism specified in the IEEE 802.11 family of WLAN standards describes the process by which MAC protocol data units (MPDUs) are transmitted and subsequently acknowledged. Specifically, once a receiver detects and successfully decodes a transmitted MPDU, it responds after a short interframe space (SIFS) period, with the transmission of an acknowledgement (ACK) packet. Should an ACK not be successfully received and decoded after some interval, the transmitter will attempt to retransmit the MPDU.

Each IEEE 802.11 transmitter contends for access to the radio channel based on the CSMA/CA protocol. This is essentially a "listen before talk" mechanism, whereby a radio always listens to the medium before commencing a transmission. If the medium is determined to be already carrying a transmission (i.e., the measured background signal level is above a specified threshold), the radio will not commence transmission. Instead, the radio enters a deferral or back-off mode, where it waits until the medium is determined to be quiet over a certain interval before attempting to transmit. This is illustrated in Figure 1.

A "listen before talk" mechanism may fail in the so-called "hidden" terminal scenario. In this case, a transmitter senses the medium to be idle, despite the fact that a hidden transmitter is causing interference at the receiver, that is, the hidden terminal is beyond the reception range of the transmitter, but within the reception range of the receiver.

A single-cell uplink scenario is illustrated in Figure 2. An AP equipped with N antennas is surrounded by K terminals, uniformly distributed up to a maximum distance D. Terminals located within distance D_v of the AP are referred to as HUs. Terminals located at a distance greater than D_v are referred to as VUs[1] .

One can expect that the extent of possible collisions in this scenario depends on the distance from the AP. HUs located near the AP do not interfere with each other because of the CSMA/CA protocol. Even if signals from certain VUs collide with the signals from the HUs, the VU signal power levels received at the AP are most probably small, and will not result in erroneous decoding of the HUs' data. On the contrary, weaker VU signals are likely to be affected by collisions with stronger "hidden" VU and/or HU signals. This means that without IC, the VU throughput may suffer, leading to reduction or gaps in coverage even if the cell radius is sufficient for reliable reception from individual users.

[1] This distinction is made for illustrative purposes only. In practice, location bounds of HU and VU may be more complicated than the concentric rings shown in Figure 2.

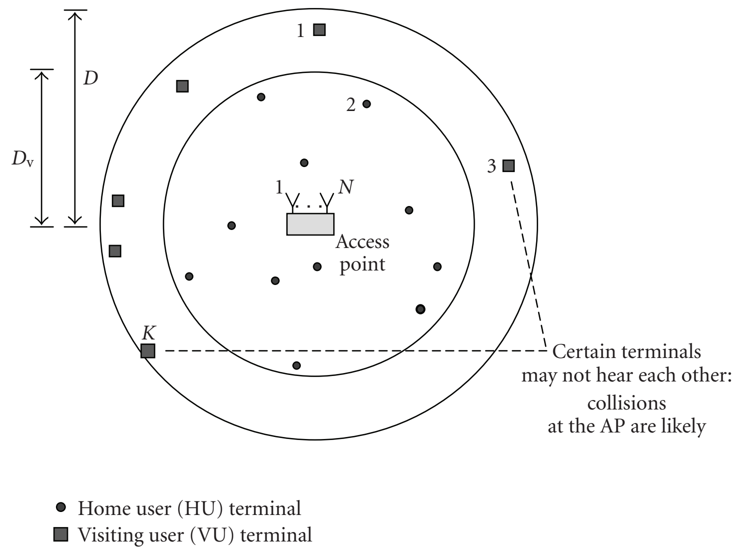

Figure 2: A single-cell OAN scenario with HUs and VUs.

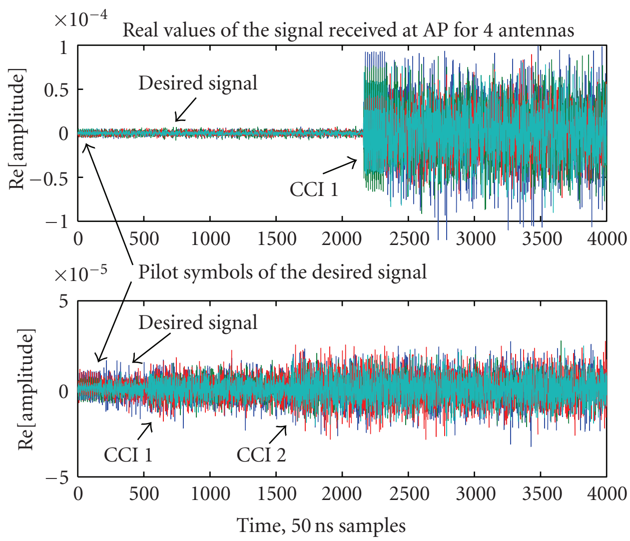

Figure 3: Typical collision patterns for $N = 4$.

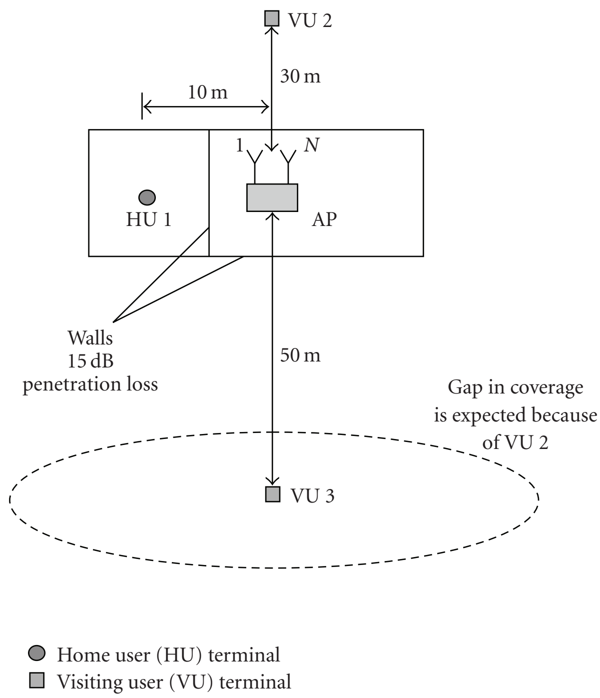

Figure 4: Residential OAN scenario with home and visiting users.

It is important to emphasize that collisions are typically asynchronous with random overlap between the colliding bursts. Typical collision examples are illustrated in Figure 3, which shows the real values of the received signals for $N = 4$ AP antennas, involving the desired signal and one or two cochannel interference (CCI) components. In both cases, the desired signals correspond to VUs and the interference comes from one HU in the first plot, and from two VUs in the second plot. In both cases, the interference bursts are randomly delayed with respect to the desired signal because of the random back-off intervals of the CSMA/CA protocol. The main consequence of this asynchronous interference structure for IC is that there is no overlap between the pilot symbols of the desired signal (located in the preamble) and the interference bursts.

The single-cell OAN scenario of Figure 2 can be specified for particular home/visitor situations. Figure 4 illustrates a residential scenario with walls that can be taken into account by means of a penetration loss. Home user HU 1 would always get a good connection in this scenario. Visiting users 2 and 3, however, may not hear each other and their transmissions may collide in some propagation conditions. Signals received from VU 2 would typically be much stronger than those from VU 3 due to the shorter distance, resulting in low throughput for VU 3. Another residential scenario with

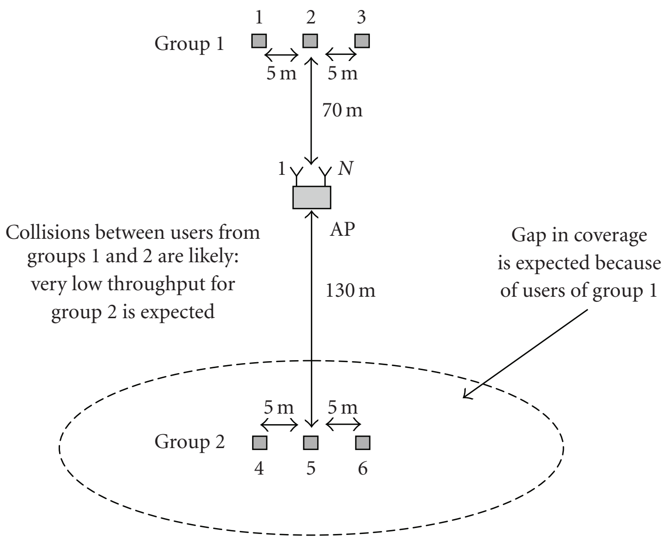

Figure 5: Residential scenario with two groups of visiting users.

two groups of three visiting users each is shown in Figure 5. This scenario illustrates the situation, where gaps in coverage can be expected for VUs 4–6 without effective IC at the PHY layer because of another group of strong VUs 1–3. The asynchronous structure of the interference in these scenarios is similar to the one illustrated in Figure 3.

3. PROBLEM FORMULATION

Based on the scenarios in Figures 2, 4, and 5, and other similar OAN scenarios, one may conclude that the MAC layer impact on the interference structure can be taken into account by means of an asynchronous interference model. An example of such model for three interference components is illustrated in Figure 6, where random delays and varying burst durations are assumed. This model can be exploited for developing and comparing different IC algorithms at the PHY layer. After this cross-layer design, the developed PHY IC algorithms can be tested via cross-layer simulations.

The problem formulation, including the main objective, constraints, and system assumptions, as well as the main effects taken into account, is as follows.

Objective

- Increase uplink throughput for VUs in an OAN system based on OFDM WLAN with CSMA/CA.

Constraints and system assumptions

- Single-antenna user terminals.
- Multiple-antenna AP.
- CSMA/CA transmission protocol at the AP and terminals.
- PHY layer interference cancellation at the AP taking into account the asynchronous interference model induced by the MAC layer.

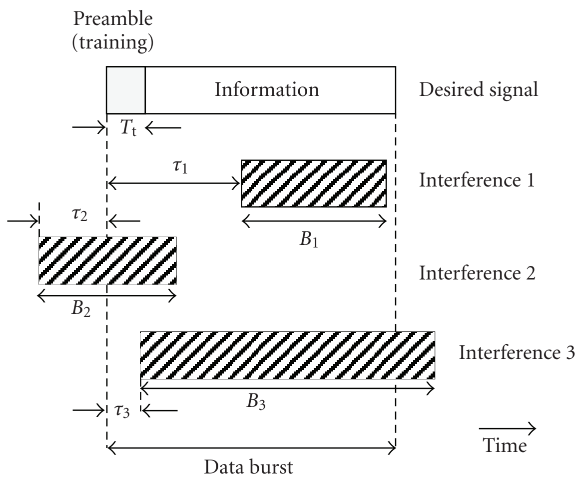

Figure 6: Asynchronous interference model.

- OAN scenarios with HUs and VUs as well as external interference from a coexisting system.

Effects taken into account

- MPDU and ACK structures, interleaving, coding, and modulation according to the IEEE 802.11a/g PHY.
- Propagation channels: multipath delay spread; path loss and shadowing; line-of-sight (LoS) and non-LoS (NLoS) conditions; spatial correlation between antenna elements at the AP.

4. INTERFERENCE CANCELLATION

Since training symbols are most reliable for estimation of the desired signal by means of the conventional LS criterion, the main idea here is to apply regularization of the LS criterion by a penalty function associated with the covariance matrix estimated over the data interval. In the narrow-band scenario, that is, for each individual OFDM subcarrier, the modified (regularized) LS criterion can be expressed as follows [6, 7]:

$$\widehat{\mathbf{w}} = \arg\min_{\mathbf{w}} \sum_{t\in\tau_t} \left| s(t) - \mathbf{w}^*\mathbf{x}(t) \right|^2 + \rho F(\mathbf{w}), \quad (1)$$

where t is the time index, $s(t)$ is the training sequence for the desired signal, $\mathbf{x}(t)$ is the output $N \times 1$ vector from the receiving antenna array, N is the number of antenna elements, $\mathbf{w}$ is the $N \times 1$ weight vector, τ_t is the interval of T_t known training symbols assuming perfect synchronization for the desired signal, $\rho > 0$ is a regularization parameter, $F(\mathbf{w})$ is a regularization function that exploits *a priori* information for specific problem formulations, and $(\cdot)^*$ is the complex conjugate transpose.

In the considered asynchronous interference scenario, the working interval may be affected by interference components that are not present during the training interval. Thus, selection of the regularization function such that it contains information from the data interval increases the ability to cancel asynchronous interference. For the second-order statistics class of algorithms, this can be achieved by means of the following quadratic function [6, 7]:

$$F(\mathbf{w}) = \mathbf{w}^*\widehat{\mathbf{R}}_t\mathbf{w} - \widehat{\mathbf{r}}_t^*\mathbf{w} - \mathbf{w}^*\widehat{\mathbf{r}}_t, \quad (2)$$

leading to the semiblind (SB) solution

$$\widehat{\mathbf{w}}_{\text{SB}} = \left[(1-\delta)\widehat{\mathbf{R}}_t + \delta\widehat{\mathbf{R}}_b\right]^{-1}\widehat{\mathbf{r}}_t, \quad (3)$$

where $\widehat{\mathbf{R}}_t = T_t^{-1}\sum_{t\in\tau_t}\mathbf{x}(t)\mathbf{x}^*(t)$ and $\widehat{\mathbf{r}}_t = T_t^{-1}\sum_{t\in\tau_t}\mathbf{x}(t)s^*(t)$ are the covariance matrix and cross-correlation vector estimated over the training interval, $\widehat{\mathbf{R}}_b = T^{-1}\sum_{t=1}^{T}\mathbf{x}(t)\mathbf{x}^*(t)$ is the covariance matrix estimated over the whole data burst of T symbols, and $0 \le \delta = \rho/(1+\rho) \le 1$ is the regularization coefficient. Selection of the regularization parameter δ has been studied in [6, 11] and will be discussed below.

One can see that the SB estimator (3) contains the conventional LS solution

$$\widehat{\mathbf{w}}_{\text{LS}} = \widehat{\mathbf{R}}_t^{-1}\widehat{\mathbf{r}}_t, \quad (4)$$

as a special case for $\delta = 0$.

An iterative higher-order statistics estimation algorithm with projections onto the FA with SB initialization (SBFA) can be described as follows:

$$\begin{aligned} \widehat{\mathbf{w}}_{\text{SBFA}} &= \widehat{\mathbf{w}}^{[J]}, \\ \widehat{\mathbf{w}}^{[j]} &= \left(\mathbf{X}\mathbf{X}^*\right)^{-1}\mathbf{X}\Theta\left[\mathbf{X}^*\widehat{\mathbf{w}}^{[j-1]}\right], \quad j = 1,\ldots,J, \quad (5) \\ \widehat{\mathbf{w}}^{[0]} &= \widehat{\mathbf{w}}_{\text{SB}}, \\ \widehat{\mathbf{w}}^{[J]} &= \widehat{\mathbf{w}}^{[J-1]}, \quad (6) \end{aligned}$$

where $\mathbf{X} = [\mathbf{x}(1),\ldots,\mathbf{x}(T)]$ is the $N \times T$ matrix of input signals, $\widehat{\mathbf{w}}^{[j]}$ is the weight vector at the jth iteration, $\Theta[\cdot]$ is the projection onto the FA, and J is the total number of iterations with stopping rule (6).

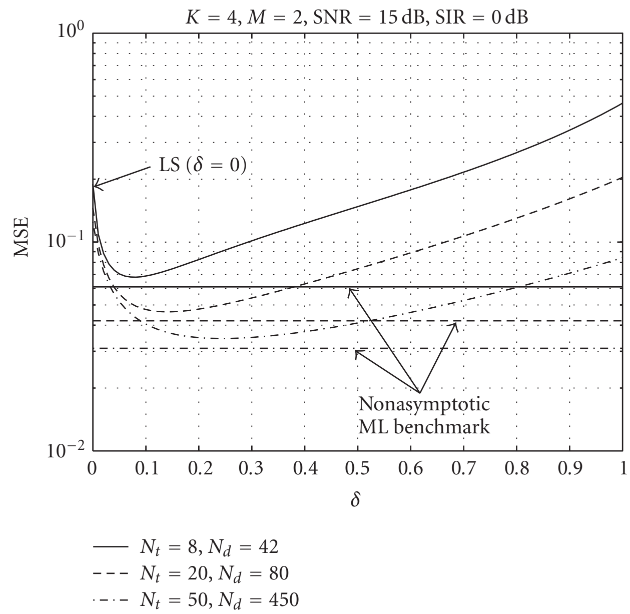

Figure 7: Typical MSE performance for the SB algorithm for variable regularization parameter.

Efficiency of the SB algorithm (3) is studied in [6, 7] by means of comparison to the especially developed nonasymptotic ML benchmark. Typical estimated MSE performance for different burst structures and variable regularization parameter δ is illustrated in Figure 7 for $N = 4$, $K = 2$, SNR = 15 dB, SIR = 0 dB, QPSK signals, and independent complex Gaussian vectors as propagation channels. The corresponding ML benchmark results from [6] are also shown in Figure 7 for comparison. One can see that the SB performance is very close to the ML benchmark for properly selected regularization parameter. Furthermore, the MSE functions are not very sharp, which means that some fixed parameter δ can be used for a wide range of scenarios. Indeed, the results in Figure 7 suggest that $\delta \approx 0.1$ can be effectively applied for very different slot structures.

The narrowband versions of the LS, SB, and SBFA algorithms can be expanded to the OFDM case. The problem with this expansion is that the available amount of training and data symbols at each subcarrier may not be large enough to achieve desirable performance. Different approaches can be applied to overcome this difficulty, such as grouping (clustering) or other interpolation techniques [14, 15]. According to the grouping technique, subcarriers of an OFDM system are divided into groups, and a single set of parameters is estimated for all subcarriers within a group, using all pilot and information symbols from that group.

Next, we compare the LS, SB, and SBFA algorithms at the PHY layer of an OFDM radio link subject to asynchronous interference. We consider the "D-"channel [13] environment and apply a group-based technique [14] with $Q = 12$ groups of subcarriers. We simulate a single-input multiple-output (SIMO) system ($N = 5$) for IEEE 802.11g time-frequency bursts of 14 OFDM QPSK modulated symbols and 64 subcarriers (only 52 are used for data and pilot transmission).

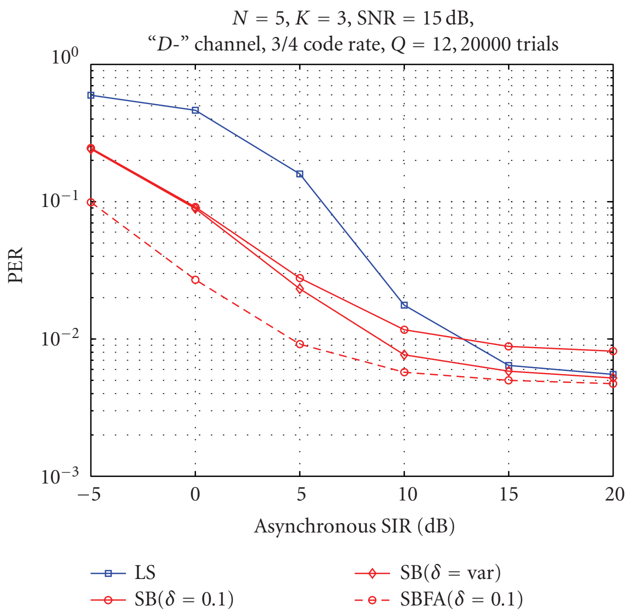

Figure 8: Typical PHY-layer OFDM performance for LS, SB, and SBFA.

The transmitted signal is encoded according to the IEEE 802.11g standard with a 3/4 code rate [4]. Each packet contains 54 information bytes. Each time-frequency burst includes two information packets and two preamble blocks of 52 binary pilot symbols. This simulation environment corresponds to an over-the-air data rate of 18 Mbit/s.

Figure 8 presents the packet-error rate (PER) curves for LS, SB, and SBFA with a fixed SNR of 15 dB. The SB algorithm is presented for fixed ($\delta = 0.1$) regularization as well as adaptive ($\delta = var$) regularization parameter selected on a burst-by-burst basis based on the CM criterion:[2]

$$\hat{\delta} = \arg\min_{\delta} \sum_{t=1}^{T} \left[\left| \hat{\mathbf{w}}_{\text{SB}}^{*}(\delta)\mathbf{x}(t) \right|^{2} - 1 \right]^{2}. \quad (7)$$

In Figure 8, the SIR is varied for two asynchronous interference components, and is fixed at 0 dB for a synchronous interference component (note that the latter is still asynchronous on a symbol basis, but always overlaps with the whole data burst of the desired signal including the preamble).

One can see that the regularized SB solution with the fixed regularization parameter significantly outperforms the conventional LS algorithm for low asynchronous SIR. Particularly, it outperforms LS by 4 dB at 3% PER, and by 7 dB at 10% PER. In the high SIR region, the scenario becomes similar to the synchronous case (asynchronous CCI actually disappears), where the LS estimator actually gives the best possible results [16]. Thus, $\delta \rightarrow 0$ is required for the best SB performance in this region. Online adaptive selection of the regularization parameter may be adopted in this case, as illustrated in Figure 8. However, one can see in Figure 7 that performance degradation for fixed $\delta = 0.1$ in the synchronous case is small and may well be acceptable. The SBFA algorithm brings additional performance improvement of up to 5 dB for low SIR at the cost of higher complexity.

OFDM versions of the LS, SB, and SBFA algorithms with a fixed regularization parameter, together with the conventional matched filter (no-IC), will be evaluated next via cross-layer simulations.

5. CROSS-LAYER SIMULATION RESULTS

5.1. Simulation assumptions

We simulate the IEEE 802.11g PHY (OFDM) and CSMA/CA subject to the following assumptions:

- 2.4 GHz center frequency,
- 4-QAM, 1/2 rate convolutional coding,
- MPDU burst of 2160 information bits, 50 OFDM symbols, 200 microseconds duration,
- ACK burst of 8 OFDM symbols, 32 microseconds slot duration,
- maximum ratio beamforming at the AP for ACK transmissions,
- trial duration of 10 milliseconds,
- "E"-channel propagation model [13] (100 nanaoseconds delay spread, LOS/NLOS conditions depending on distance),
- 1-wavelength separation between $N = 4$ AP antennas,
- 20 dBm transmit power for the AP and terminals,
- − 92 dBm noise power,
- − 82 dBm clear-channel assessment threshold.

A number of simplifying assumptions are made: ideal channel reciprocity (uplink channel estimates are used for downlink beamforming for ACK transmission); ideal (linear) front-end filters at the AP and terminals; zero frequency offset; perfect receiver synchronization at the AP and terminals; stationary propagation channels during a 10-millisecond trial. The last assumption is applicable in the considered scenario because all channel and weight estimates are derived on a slot-by-slot basis, and channel variations in WLAN environments are normally negligible over these time scales (200 microseconds).

5.2. Single-cell OAN

Typical histograms for collision statistics in the scenario of Figure 2 are shown in Figure 9 for $D = 150$ m. As expected, the average number of colliding MPDUs increases with the total number, K, of users contending for the channel.

The VU throughputs are presented in Figure 10 for variable visitor radius D_v and total number of users. The conventional matched filtering (no-IC), LS, SB, and SBFA ($\delta = 0.1$) algorithms are compared.

[2] A simplified switched CM-based selection of the regularization parameter is developed in [11].

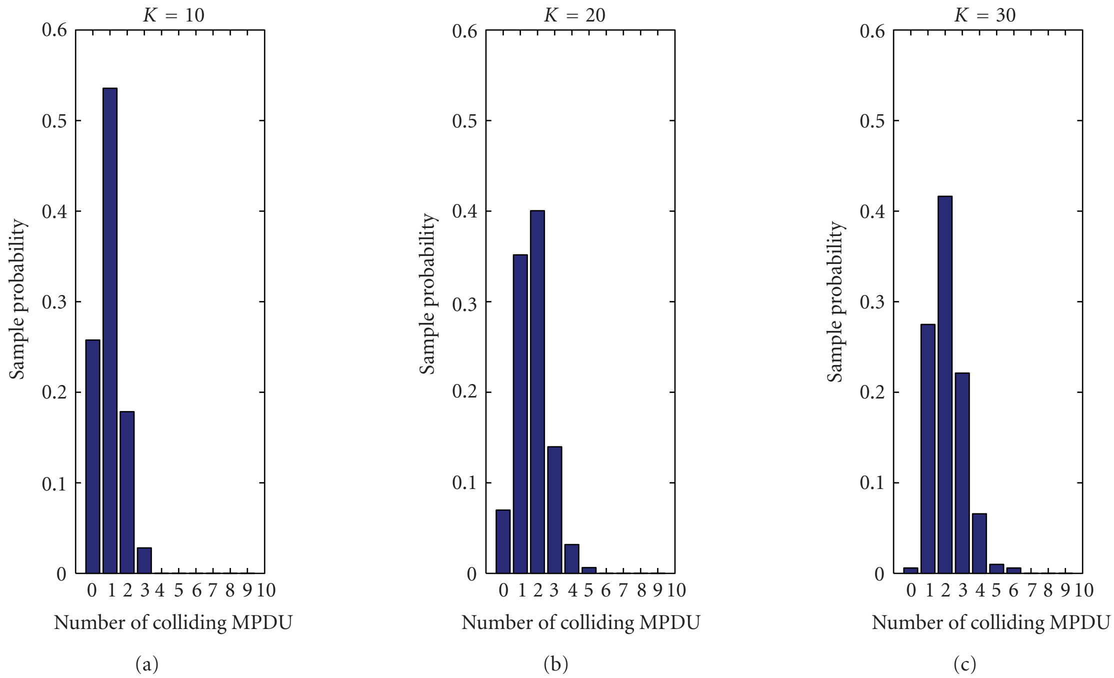

FIGURE 9: Collision statistics for $D = 150$ m with the single-cell scenario of Figure 2.

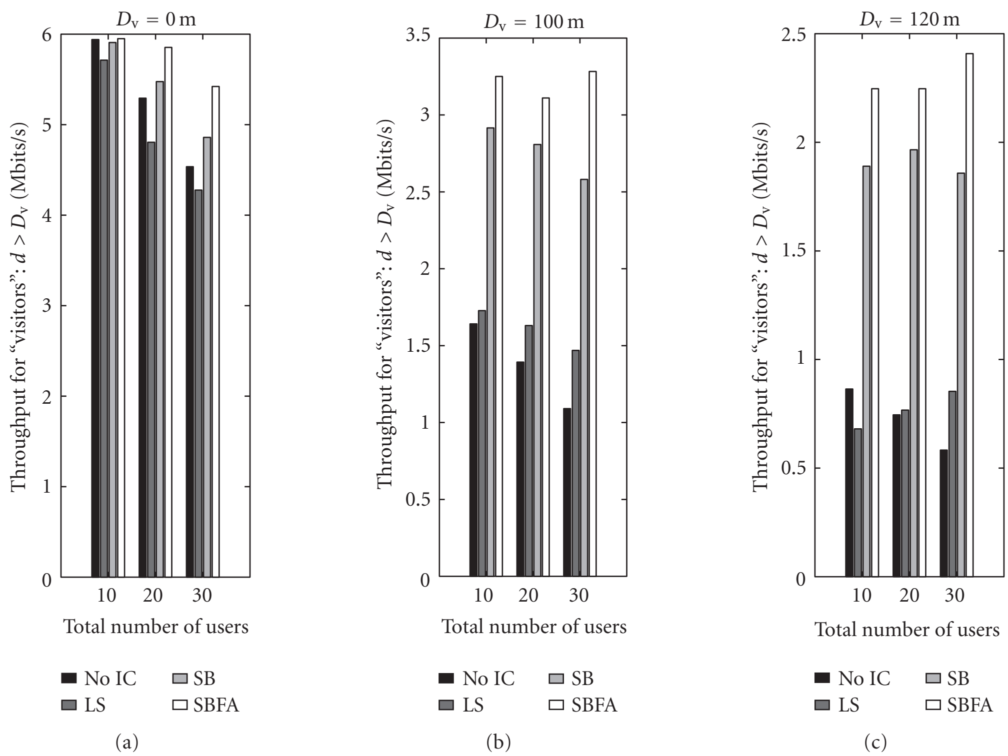

FIGURE 10: Visiting user throughput for $D = 150$ and $N = 4$ for no IC, LS, SB, and SBFA algorithms (left to right for each total number of users) with the single-cell scenario of Figure 2.

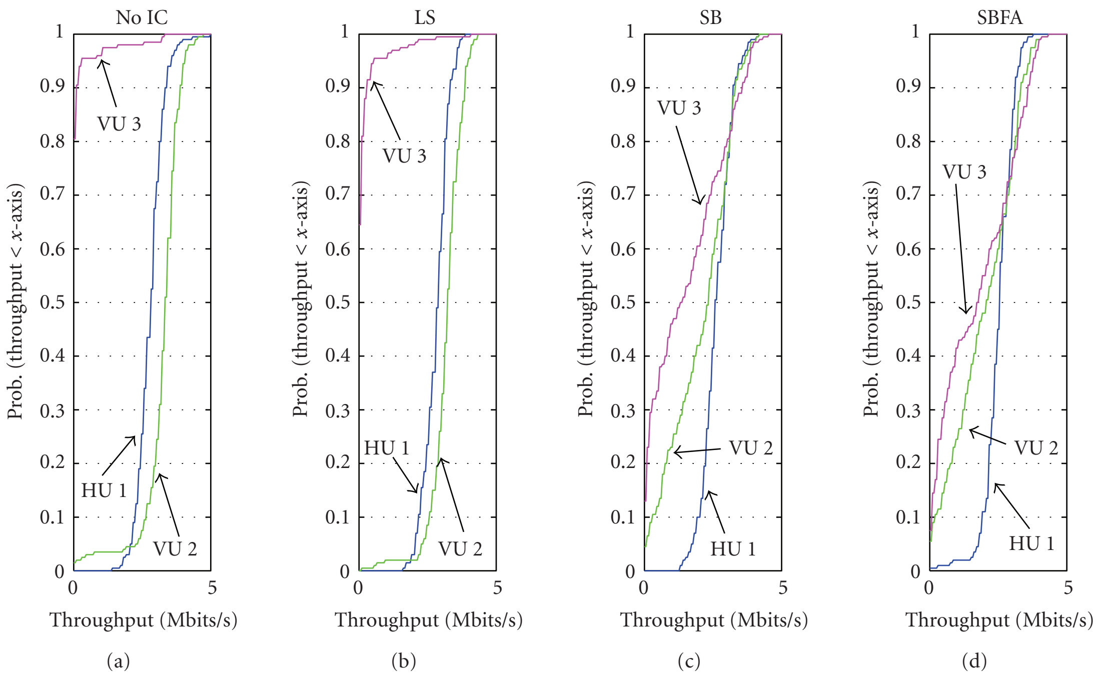

Figure 11: Throughput CDF for the residential scenario of Figure 4.

The VU throughput U_v is calculated as follows:

$$U_v = \frac{1}{T_S I}\sum_{i=1}^{I}\sum_{D_v<d_{ik}\leq D} B_{ik}, \qquad (8)$$

where d_{ik} is the distance between the AP and the kth terminal at the ith trial, B_{ik} is the total number of bits from the kth terminal successfully received and acknowledged at the AP at the ith trial, and T_s and I are the duration and number of trials. The throughput results in Figure 10 are averaged over $I = 20$ trials of $T_s = 10$ milliseconds, each with independent user locations and propagation channel realizations[3].

The first plot for $D_v = 0$ actually shows the total cell throughput. One can see that all the algorithms show some performance degradation with growing total number of users in the cell. The SB and SBFA algorithms demonstrate a small improvement over both no-IC and LS for $K = [20, 30]$. The low IC gain is in fact expected in this case since the interference avoidance CSMA/CA protocol dominates for users located close to the AP, making any IC redundant.

The situation is quite different when we consider the throughput of the VUs only. One can see in Figure 10, for $D_v = [100, 120]$ m, that both semiblind solutions significantly outperform the other two techniques by up to a factor of 4. Furthermore, it appears that the main improvement comes from the second-order SB solution (3). Iterative projections to the FA in SBFA add up to 25% to the SB gain.

5.3. Residential OAN

Cumulative distribution functions (CDFs) of VU throughput over 200 trials are plotted in Figure 11. These corresponds to the residential scenario of Figure 4 with wall penetration loss of 15 dB. As expected, home user (HU) 1 is not affected by VU 2 and 3. On the contrary, visiting user (VU) 3 hardly achieves any throughput unless efficient semiblind IC is utilized. Both semiblind estimators demonstrate significant performance improvement and allow both visiting users (VU) 2 and 3 to share the radio resource almost equally.

The throughput results estimated over 100 trials in the scenario shown in Figure 5 are given in Figure 12. They illustrate the situation, where gaps in coverage because of strong VUs may be significantly reduced by means of the proposed semiblind cancellation at the PHY layer.

5.4. Intersystem interference in residential OAN

As mentioned in Section 2, PHY layer IC may also be effective in scenarios where interference from other systems is not subject to any interference avoidance schemes such as CSMA/CA (i.e., is "impolite"). We illustrate this situation in a residential scenario as presented in Figure 13, which consists of one HU, one VU, and a low-power (10 μW) "impolite" interferer located close to the AP. In this scenario,

[3] Cross-layer simulations are very computationally demanding. For each trial, we generated $(K+1)K/2$ independent propagation channels for random terminal positions (e.g., for $K = 30$ we generated 465 channels per trial). Typically, during 10 milliseconds we observed around ten collisions between different users (burst duration is 0.2 milliseconds) leading to approximately 200 collisions for 20 trials. This is why we accepted a low number of trials for the single-cell scenario. For particular residential scenarios with low number of terminals, we simulated around 100–200 trials to keep a similar level of averaging over different propagation conditions.

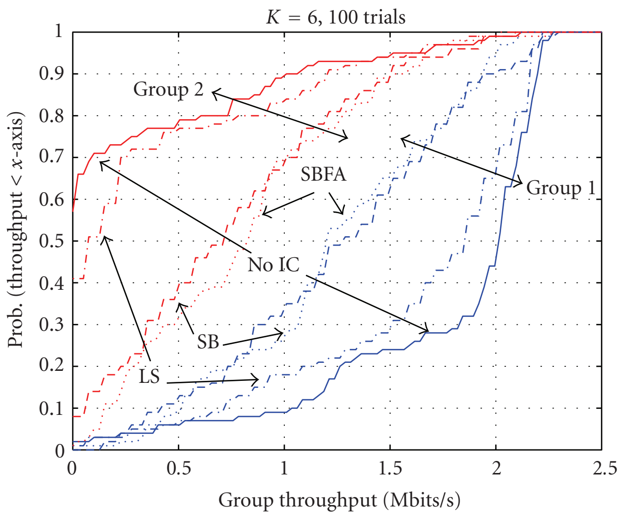

Figure 12: Throughput CDF for the residential scenario of Figure 5.

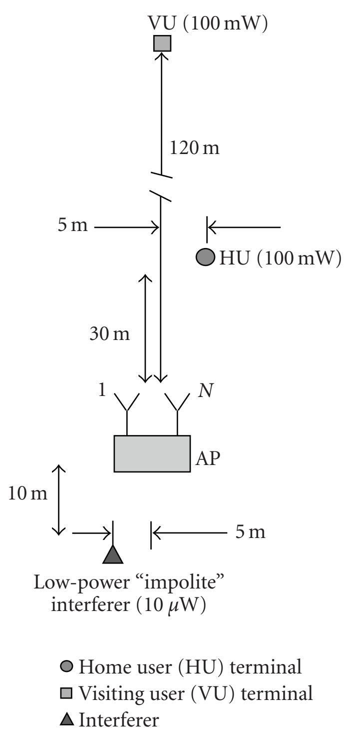

Figure 13: Residential scenario with intersystem interference.

CSMA/CA for HU and VU is not affected, because the interference power at the HU and VU locations is normally below the clear-channel assessment threshold. Furthermore, the HU signal received at the AP is much stronger than the interference. So, the HU is also unaffected at the PHY layer. On the contrary, the VU signal received at the AP may be comparable to the interference level, and so, may be significantly affected. Again, IC efficiency depends on the temporal interference structure, as discussed in Section 3.

Figure 14 shows the results for a continuous, white Gaussian, 10-μW "impolite" interferer. One can see that the VU

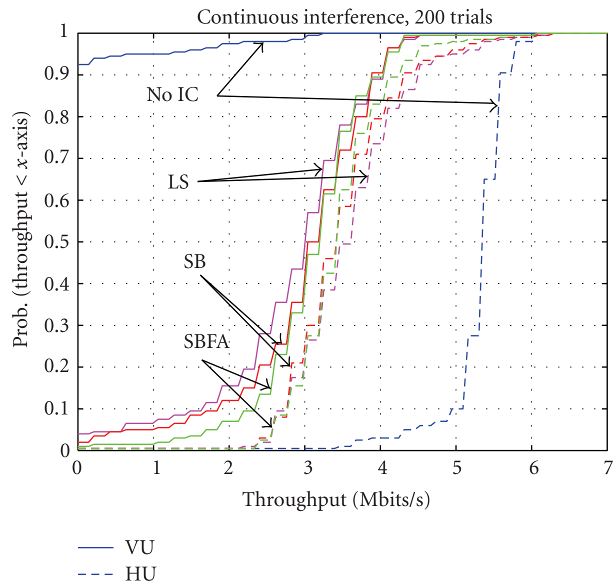

Figure 14: Throughput CDF for residential scenario of Figure 12 and a continuous intersystem interferer.

throughput can be significantly improved by means of all the considered training-based LS and semiblind SB and SBFA IC algorithms. This is because the interference always overlaps with the MPDU pilot symbols, resulting in what we classify in [16] as a synchronous interference.

Again, the situation becomes quite different for intermittent intersystem interference. We simulate this as a stream of 200 microseconds bursts with duty-cycle of 50%. Typical collision patterns between data and interference bursts are plotted in Figure 15. Here, the random MPDU back-offs result in random overlaps between the interference bursts and the training symbols. Figure 16 presents the throughput results for intermittent interference. It is not surprising that both SB and SBFA significantly outperform the conventional no-IC and pilot-based LS IC in this scenario. However, one can see in Figure 16 that LS demonstrates more significant performance improvement over the no-IC solution compared to the intrasystem interference scenario presented above. This is because in the considered intermittent interference scenario, collisions that overlap with the training symbols occur with practically the same probability as those involving no overlap with the training symbols. Both types of collisions are illustrated in Figure 15 in the upper and lower plots, respectively. In the intrasystem interference case, collisions that do not overlap with the training symbols dominate because of the CSMA/CA protocol, as discussed in Section 2, leading to significant semiblind gain over the conventional training-based IC algorithms such as LS.

6. CONCLUSION

The potential gains provided by multiantenna interference cancellation receiver algorithms, in the context of WLAN systems employing CSMA/CA protocols, were evaluated in this paper. Cross-layer interactions were captured via joint

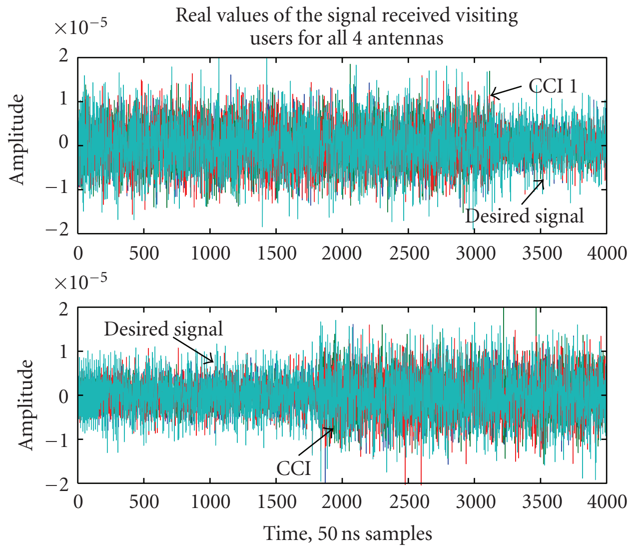

FIGURE 15: Typical received signal patterns in the intersystem intermittent interference scenario.

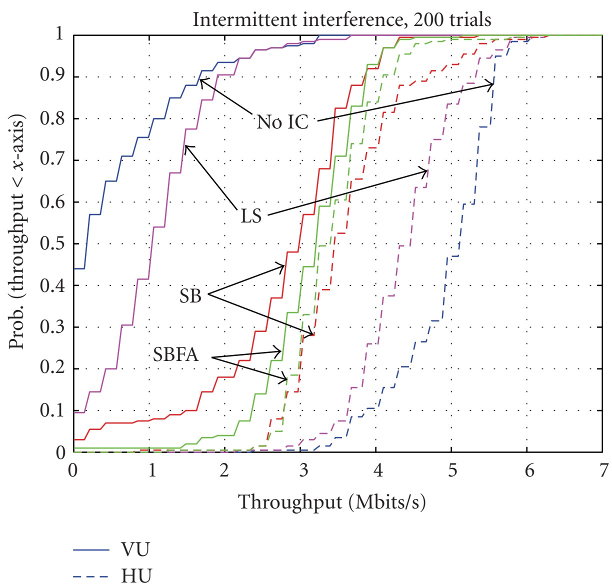

FIGURE 16: Throughput CDF for residential scenario of Figure 12 with an intermittent intersystem interferer (50% duty-cycle).

PHY/MAC simulations involving multiple terminals contending for the opportunity to transmit data to the access point. The impact of impolite cochannel interference from a coexisting system was also accounted for. It was shown that the developed semiblind interference cancellation techniques are essential for addressing the asynchronous interference experienced in WLAN. Significant performance gain has been demonstrated by means of cross-layer simulations in the OAN scenarios. It has been found that the main effect comes from the regularization in the SB algorithm with complexity similar to the conventional LS solution. The more complicated SBFA iterations lead to an additional marginal performance improvement.

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