

Space–Time Block-Coded OFDM Systems With RF Beamformers for High-Speed Indoor Wireless Communications

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Abstract—A beamforming network is considered for a space–time block-coded orthogonal frequency-division multiplexing system in a high-speed indoor wireless network. We find that choosing the most powerful beams for transmission provide the best performance in the absence of interference. In the presence of interference, an iterative two-metric beam-selection method is proposed.

Index Terms—Interference suppression, orthogonal frequency-division multiplexing (OFDM), radio frequency (RF) beamformers, space–time block coding (STBC), transmit diversity.

I. INTRODUCTION

SPACE–TIME block coding (STBC) has been recently proposed as a way for a transmitter to provide diversity gain to a receiver that has a very simple maximum-likelihood decoding algorithm [1]. The diversity antennas for STBC are typically assumed to be broadbeamed and nonsteerable. In this letter, we propose to replace these antennas with two narrow, steerable beams selected from a multibeam radio frequency (RF) beamformer [2], [3]. The beamformer provides antenna gain and, on receive, interference suppression resulting from the use of many antenna elements. We assume an indoor environment at 5.8 GHz, and assume that the beamformer is on the base station (BS). To address frequency selectivity, we propose to use orthogonal frequency-division multiplexing (OFDM) [4]. For a high bandwidth system operating in a typical indoor environment, OFDM will have lower complexity than an appropriately designed decision-feedback equalizer (DFE) [5].

This letter focuses on the issue of beam selection. For an environment without interference, such as a single cell with time-division multiple access/time-division duplexing (TDMA/TDD), we assume the channel has slow enough time variation that reciprocity holds. In this case, the two beams selected on the uplink are used for two-channel transmit diversity using STBC on the downlink. The two most powerful beams are often adjacent and have partially correlated fading. We compare the most-powerful beams strategy to one that reduces the likelihood of adjacent beams.

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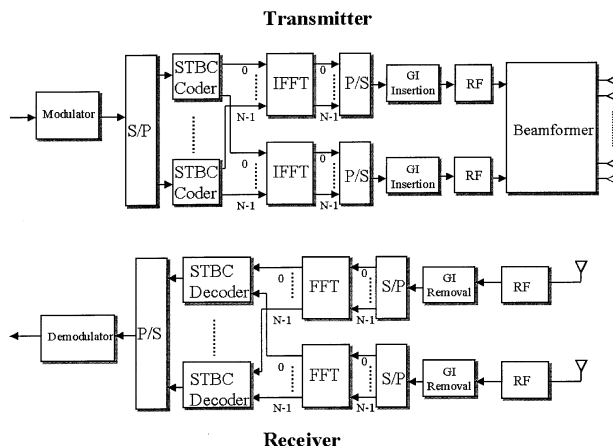


Fig. 1. Transmitter and receiver of the space–time block-coded OFDM.

In addition to providing additional gain for transmit diversity, the beamformer can also suppress interference when receiving. Beams selected on the basis of received power might contain too much interference; this is the beam-falsing problem [6]. As a remedy, the beams with the highest signal-to-interference-plus-noise-ratio (SINR) may be selected. This generally requires that the number of full receiver subsystems (RF-to-baseband conversion chains) must be equal to the total number of beams formed [6], which would be excessive for the architectures we are considering. To take advantage of the many antennas while keeping the number of full receiver subsystems limited to two, we propose an iterative two-metric beam-selection algorithm. The first, “analog” metric, is received signal strength (RSS), which does not require a digital signal processor (DSP) and is measured for all beams simultaneously. The second, or “digital,” metric is computed in the DSP, is based on SINR, and is computed only for two beams at a time because of the hardware constraint.

Downlink operation of our system is shown in Fig. 1. Each pair of like-subcarrier frequencies for the two beams carry STBC quaternary phase-shift keying (QPSK) symbols [7]. A proposed system for cellular networks [8] is similar, however, details about the beams and their selection were not addressed.

The beamformer comprises four linear arrays, placed end to end such that each array serves a 90° sector [9]. Each array feeds its own RF beamformer, which forms M untapered beams to cover its sector. Thus, there are a total of $4M$ beams covering 360° . For this paper, we consider $M = 2$ and $M = 6$, which use two and eight elements ($1/2$ wavelength spacing) per linear array, respectively. Scanning loss is included in the model [2]. The insertion loss, which varies among beamformer implementations [2], is not included. The two omnidirectional receive antennas at the mobile station (MS) are spaced by ten wavelengths.

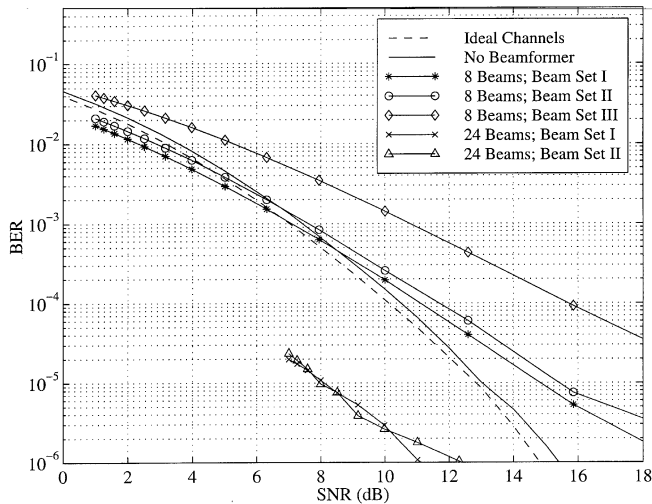


Fig. 2. Performance of the space-time block-coded OFDM system with perfect coherent detection when the clustered channel model (HPCM) is used.

II. BEAM SELECTION WITHOUT INTERFERENCE

Our goal is to select two beams that provide high gain and sufficiently decorrelated fading for the purpose of transmit diversity. To investigate the tradeoff between power and correlation, we consider three beam selection strategies. Beam Set I has the two largest power beams, Beam Set II has the first and third largest power beams, and Beam Set III has the first and eighth most powerful beams. As the power difference between the two beams grows, the correlation between the two beams decreases. The power used for beam selection is total power over the entire OFDM band.

We assume that there are no signal distortions at transmitters and perfect synchronization at receivers. For the no-interference case, 256 OFDM carriers, covering a total bandwidth of 100 MHz, are transmitted from each beam. A range of 30 m and a mobile speed of 2 m/s (38 Hz max) are used. More than 10 000 trials of channel impulse responses from the homogeneous Poisson clustered model (HPCM) [3], [10] were simulated. Angles of arrival (AOAs) of rays within a cluster are Laplacian distributed with a standard deviation of 25.5° . The optimum guard-interval length [4] is 300 ns, implying a data rate of 175 Mb/s using the “20 dB below the main peak lobe” rule [11]. Total transmitted power is conserved in the simulations.

The average bit error rate (BER) performances of the proposed system with perfect coherent detection are shown in Fig. 2. The signal-to-noise ratio (SNR) is defined as the SNR per bit per receive antenna when one transmit omnidirectional antenna element is used at the transmitter. We compare to the “ideal” case, which has independent identically distributed (i.i.d.) complex Gaussian random gains for every carrier and spatial channel, and the “no-beamforming” case, which uses the HPCM model and two omnidirectional antennas, spaced 10λ apart, at each end of the link. We observe that the proposed system with 24 beams using either Beam Sets I or II yields a SNR improvement relative to the no-beamforming case of about 5 dB at the BER of 10^{-5} . The performance differs little between Beam Sets I and II because the SNR penalty from the correlation in Beam Set I is apparently about the same as

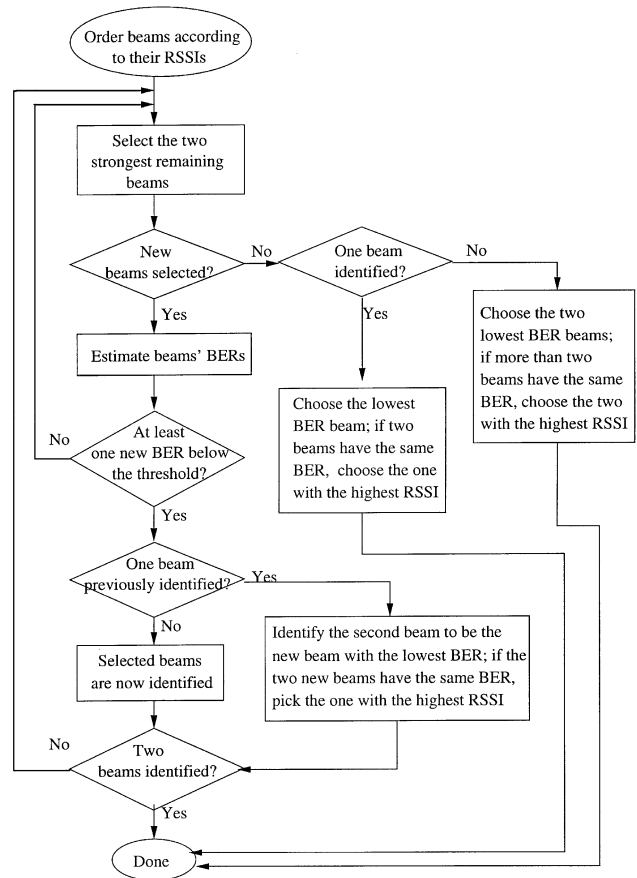


Fig. 3. Flow diagram of the proposed iterative two-metric beam-selection method.

the loss from the lower power of the second beam in Beam Set II. With Beam Set III, however, we shall lose the diversity gain because the two selected beams have such a large power difference. In summary, we conclude that the lesser-powered beams in Beam Set I and II provide diversity gain, and that there is no advantage to avoiding adjacent beams because too much power is sacrificed. Similar trends hold for differential detection [3].

III. RECEIVER BEAM SELECTION IN INTERFERENCE

The proposed iterative two-metric beam-selection method, described in Fig. 3, aims to find two receive diversity beams that yield low BERs, but within the constraint that only two receiver chains are available. In the diagram, “selected” means that the beam is chosen based on uplink power, and “identified” means the beam’s uplink BER (that is, the BER if only that beam is used) is below a given threshold. Though estimation of BER is excessively time consuming in practice, we use it here to assess the promise of this sequential method.

To simulate algorithm performance, we assume that five temporally white interference sources are independently and spatially uniformly distributed within a circle centered at the BS with a radius of 30 m, which is also the distance between the BS and the MS. The HPCM model with the channel parameters described in Section II is used to generate independent channel impulse responses for the MS and interference sources.

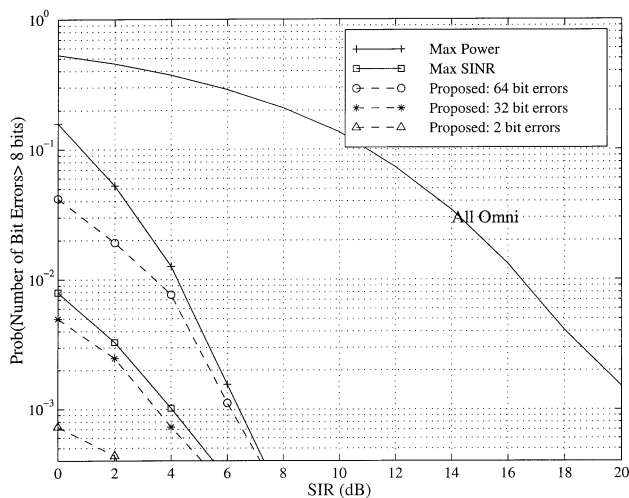


Fig. 4. Performances of the proposed beam-selection method with the thresholds 2, 32, and 64 bit errors, the maximum power method, the maximum SINR method, and space diversity. The 24-beam antennas without tapering are used.

We assume that STBC QPSK signals are transmitted from the MS using 64 carriers through a channel bandwidth of 20 MHz [13]. More than 10 000 trials are generated for simulation. We consider the 24-beam antenna described in Section I. To evaluate the performance, we compute the outage probability that the number of bit errors in a received OFDM block, after diversity combining, exceeds eight. The SNR and signal-to-interference ratio (SIR) are defined as the mean received SNR and SIR per bit, respectively, when one omnidirectional antenna is used at both ends. The “omnidirectional to omnidirectional” received SNR is 10 dB, and total transmit power is conserved when omnidirectional antennas are compared with RF beamformers.

The performances of the proposed beam-selection method with BER thresholds of 2, 32, and 64 bit errors per OFDM block are shown in Fig. 4. For comparison, we include the maximum power and maximum SINR methods, as well as space diversity with two omnidirectional antennas at both ends. From Fig. 4, we find that multibeam antennas outperform the space diversity case by a wide margin. At the 1% outage level, the SIR improvement for the proposed method with the 32-bit error threshold is greater than 16 dB relative to spatial diversity. Both the proposed and maximum SINR methods outperform the maximum power method. For the proposed method, as the threshold decreases, the performance improves. The proposed method with a threshold of 32 bit errors outperforms the maximum SINR method.

Though not shown here, we find that results for tapered beams are worse than in Fig. 4. We also find that lowering the threshold for the proposed method lowers the outage rate at the cost of a longer beam-selection processing time. We find that, at most, three iterations are required in 99% of the trials for the threshold of 32 bit errors [3].

IV. CONCLUSION

Our proposed STBC OFDM system, with a lossless RF beamformer and without error-correction coding, yielded an SNR improvement of about 5 dB without interference. Considering that the combined insertion loss of the beamformer and low-cost switches could be as high as 5 dB, switched-beam beamforming has little advantage in the noise-limited environment. However, when the beamformer is on the receiver in the presence of interference, we observed an SIR improvement of more than 16 dB. This suggests that if RF beamformers could be made inexpensively, they might be desirable for indoor wireless LANs in high interference when there is a restriction on the number of transceiver chains. It would be interesting to compare the performance of the proposed system with a nonbeamforming system that performs interference suppression in the DSP. Another topic for future research is the assessment of the system’s performance with the frequency diversity that is afforded by error-correction coding across the subcarriers (i.e., coded OFDM).

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