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RESEARCH ARTICLE

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ENERGY AWARE LINK ADAPTATION FOR 'MIMO-OFDM' SYSTEMS

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ABSTRACT

In this paper,we develop an energy aware link adaptation protocol for MIMO-OFDM systems. Energy efficient communications in wireless communications is very important as mobile devices are battery constrained. We present a link adaptation strategy for multiple input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) based wireless communications. We sounding the channel periodically and observing the channel characteristics. Our objective is to choose the optimal mode that will maximize energy efficiency or data throughput subject to a given quality of service (QoS) constraint. link level simulations confirm that the proposed solution achieves significant improvement over existing link adaptation algorithms when the aim is to maximize the throughput, and provides orders of magnitude

gain in energy efficiency compared to poorly chosen fixed modes when used for energy efficiency maximization purposes. In this paper we, present an energy aware link adaptation as well as transmit search path algorithm for complexity algorithm.

Keywords–OFDM, MIMO, PER, SNR, link adaptation, energy efficiency

1. INTRODUCTION

Orthogonal frequency-division multiplexing (OFDM) can effectively combat multipath fading and has been used in or proposed for many wireless communication systems, such as 3GPP LTE-Advanced and WiMAX. In recent years, energy efficiency (EE) has received much more attention due to steadily rising energy consumption and environmental concerns. It has been reported in that information and communication technology already contributes to around 2% of the global carbon dioxide emissions. Recently, the dramatic growth in high-rate multimedia data traffic driven by usage of smart Android and iPhone devices, tablets, eBook readers, and other wireless devices has been straining the capacity of today’s networks and has caused a large amount of energy consumption. It has been anticipated in that mobile traffic will grow further by over 100 times in the next ten years.

In **OFDM** that the sub-carriers are orthogonal to each other, meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. The orthogonality also allows high spectral efficiency. In OFDM the signal itself is first split into independent channels, modulated by data and then remultiplexed to create the OFDM carrier.A subcarrier is a separate analog or digital signal carried on a main **radio transmission**, which carries extra information such as voice or data.

The orthogonally allows simultaneous transmission on lot of subcarriers in a tight frequency space without interference from each other. In essence is similar to CDMA, where codes are used to make data sequences independent which allows many independent users to transmit in same space successfully. If the path from the transmitter to the receiver either has reflections or obstructions, we can get the fading effects. In this case signal reaches the destination from many different routes, each a copy of the original. Each of these rays has different delay and slightly different gain. It causes the signal degradation. PAPR is known as peak-to-average power ratio. The transmission signal in an OFDM system can have peak values in the time domain since many subcarrier components are added together via an IFFT operation. So OFDM have a high peak-to-average power ratio when compared to single carrier system. It degrades the efficiency of power amplifier in the transmitter.

MIMO based communication systems provide significantimprovements in capacity by increasing the robustness of a link or by improving the spectral efficiency (spatial multiplexing - SM). Hence,MIMO techniques have found their way into many high-speed wireless communication standards such as IEEE802.11n and IEEE802.16e, to name a few. A secondary impact of integrating MIMO into a radio is that it has a multiplicative impact on the number of modes available to close the link,i.e. satisfying the throughput and delay requirements of the application. For instance, a MIMO radio can change system

parameters, such as the number of spatial streams, number of transmitter/receiver antennas, modulation, code rate, and transmit power. A MIMO enabled mode-rich radio can thus sense its surroundings and choose the best mode that optimizes an objective function. This problem is generally referred to as the link adaptation problem. Our aim in this work is to develop a practical, energy-aware, link adaptation protocol. Our definition of practicality implies that the protocol should (1) track and respond to the fast fading changes in the channel, (2) be implementation friendly in terms of the hardware complexity, and (3) be applicable to

a large variety of coded MIMO-OFDM systems.

Past work dealing with link adaptation has mostly focused on maximizing throughput When the aim is to maximize the throughput of a link, one approach is to perform link adaptation at the MAC layer according to observed packet error rate (PER) statistics. In this paper, we present a practical energy-aware link adaptation protocol which minimizes the total energy consumption of the link required to successfully transmit information bits while maintaining an application's QoS requirements. Additionally, we present a smart transmit power search algorithm to further reduce the complexity, and propose solutions to other practical problems such as determination of the sounding period. The result is a highly practical fast link adaptation algorithm which delivers orders of magnitude energy savings compared to poorly chosen static modes.

The main contributions of this paper are threefold:

- We address the problems of the existing MAC based throughput maximization algorithms which are slow in their response to changing environmental conditions. We propose a fast-responsive link adaptation protocol for coded MIMO systems. It is more realistic than other published works on energy-aware link adaptation which assume uncoded systems or employ channel capacity based derivations.
- Practical problems of the proposed algorithm, such as computational complexity, are addressed by novel formulations and an iterative search strategy.
- Feasibility was proven via experimental validation of the algorithms on a real-time MIMO-OFDM testbed and we report the experimental results on mode selection trends.

2. SYSTEM MODEL

Transmitter and receiver blocks of MIMO-OFDM system is shown.

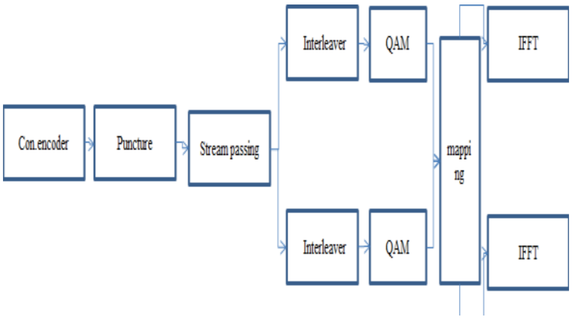

Fig.1.MIMO-OFDM transmitter block

ENCODER: Information bits are first encoded with a convolution encoder and punctured to achieve the desired code rate.

PUNCTURE: Code rate of convolutional code can be modified via symbol puncturing. This technique allows encoding and decoding of higher data rate codes using standard ½ encoder& decoder.

STREAM PARSING: Parses the bit stream into multiple spatial data streams.The encoded bits are then parsed and interleaved over multiplespatial streams and subcarriers. The bits in each spatial streamare mapped to symbols by a quadrature-amplitude-modulator (QAM) which is followed by the spatial mapper.

INTERLEAVER: Errors in data communication can be corrected through interleaving.

SPATIAL MAPPING: The spatial mapping (or antenna mapping) is a linear operation that transforms *Nss*(number of spatial streams) dimensional symbol vector into *Nt*dimensional signal, which is then transmitted after IFFT and cyclic prefix (CP) addition operations.

IFFT: OFDM modulation performed by FFT.IFFT process converts the frequency domain phase & amplitude data for each sub channel into block of time domain samples which are converted into analog modulation signal for an RF modulator.

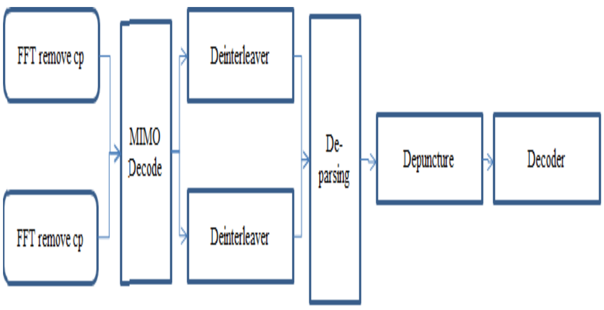

Fig.2.MIMO-OFDM Receiver block

At the receiver, *Nr* dimensional time domain samples ofthe received signal are transformed back into the frequency domain by an FFT operation after removal of the CP. MIMO decoder is then used for separating individual spatial streams from the total received signal. Soft bits are then fed to the Viterbi decoder after the deinterleaving, deparsing and depuncturing operations. The system model is meant to be generic and applicable to most, if not all, MIMO-OFDM systems with minor modifications.

A. FAST LINK ADAPTATION:

Fast link adaptation for MIMO-OFDM systems have been implemented to improve throughput. We investigate link-quality metrics (LQMs) basedon raw bit-error-rate, effective signal-to-interference-plus-noise ratio, and mutual information (MI) for the purpose of fast link adaptation (LA) in communication systems employing orthogonal frequency-division multiplexing and multiple-input–multiple output (MIMO) antenna technology. From these LQMs, the packet error rate (PER) can be estimated and exploited to select the modulation and coding scheme (MCS) among a class of candidate MCSs that achieves the maximum throughput for the current channel state under a specified target PER objective.

The objective of FLA is to exploit the varying channel state to increase the throughput of the system while maintaining some target PER (*PER*target).

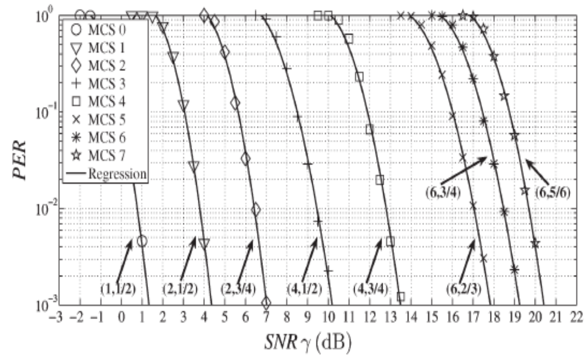

Fig.3.PER versus SNR in the AWGN channel of the MCSs

The FLA algorithm employed in the receiver feeds the index of the selected MCS back to the transmitter. This MCS feedback (MFB) response may occur based on a request from the transmitter.

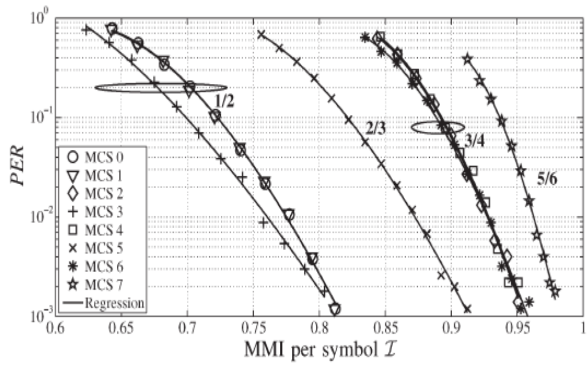

Fig.4.PER versus MMI per symbol in the AWGN channel of the MCS

B.PROPOSED LINK ADAPTATION PROTOCOL

Past work dealing with the link adaptation problem has mostly focused on maximizing the link throughput subject to QoS constraints. The throughput maximization problem can

be formally written as maximize

(1-PER)L/T

PER<=PER(max)

where *PERmax* is the maximum allowed instantaneous (orshort term) packet error rate which is usually determined by the application, *L* is the packet length in number ofinformation bits, and *T* denotes the total time needed to transmit the packet including the packet overheads and the time spent on the MAC layer related tasks. When our objective is to communicate *L* bits across achannel, maximization of throughput will reduce the total transmission time, but it will not necessarily maximize the energy efficiency of the system. The objective of energy-awarelink adaptation on the other hand, is to minimize the total energy consumed in the link per successfully received bit, which is equivalent to maximizing the number of successfully received bits normalized by the total energy consumption of the link. The energy efficiency maximization problem can thus be formulated as

maximize*EE* =(1 − *PER*)*L/Et*(bits/Joule)

subject to *PER ≤ PERmax*

TH ≥ THtargets

where*TH* indicates the instantaneous throughput and*THtarget* is the target throughput. The energy efficiency(*EE* = (1 − *PER*)*L=Et*) here is defined as the number of

successfully transmitted bits per unit energy consumption. *Et*is the total energy consumption of the link which includesthe energy consumed by the baseband portions and the RFtransceiver sections both at the transmitter and the receiver.

C.ENERGY CONSUMPTION MODEL:

We employ a comprehensive energy consumption model, which comprises the energy consumed in the RF and baseband portions of both the transmitter and the receiver. For the RF and baseband energy consumption calculation. Link adaptation works or based on actual implementation data for specific blocks. The total energy consumption of the link is a function of *Nss;Nt;Nr; PT* , modulation and code rate;therefore the link adaptation algorithm tries to optimize these parameters simultaneously for maximizing energy efficiency.

Et= ERF + EBASE + EMIMO

where*EBASE* is the energy consumption of the basebandblocks of the transmitter (tx) and receiver (rx) excluding the MIMO detector energy consumption, and *EMIMO* is the MIMO detector energy consumption.

D. PER PREDICTION MODEL

PER is known as Packet Error Ratio. The **packet error rate** (PER) is the number of incorrectly received data packets divided by the total number of received packets. A packet is declared incorrect if at least one bit is erroneous. The expectation value of the PER is denoted **packet error probability**p_p, which for a data packet length of *N* bits can be expressed as

Pp=1-(1-Pe)N

assuming that the bit errors are independent of each other. For small bit error probabilities, this is approximately

Pp=PeN

Prediction of the instantaneous PER of the link is the mostcritical task in the link adaptation process since the optimum mode is chosen based on the predicted PER. Unlike the other

Works,which are based on simulations and curve fitting methods, we employ a PPSNR based model for the PER prediction.

E. PROPOSED PPSNR BASED FAST LINK ADAPTATION PROTOCOL

The wireless channel changes rapidly due to the mobility of the transmitter, the receiver and the surrounding objects. As a result, the channel exhibits small-scale fading (fast-fading) in addition to the path loss and shadowing effects (large-scale effects or slow-fading. The link adaptation work is aimed at finding the optimal mode based on the average error rate performance and as such, disregards the fast-fading in the channel. However, significant performance improvements can be achieved if the link adaptation algorithmsare designed to take into account the instantaneous (or short term) channel conditions, rather than making a decision based on the long term average behavior of the channel. The latter approach is called fast link adaptation, which aims toprovide improved performance by tracking and responding tothe rapid variations in the channel.Our PPSNR based fast link adaptation protocol is based on sounding the full MIMO channel periodically and determining the optimal mode to transmit. A mode *m* is a 6-tuple (*PT* , *Nss*,*Nt*, *Nr*, *Modulation*, *Code Rate*) containing the parameters to be optimized, and the optimal mode is defined as the one which has the maximum energy efficiency or throughput depending on the desired objective.

Steps:

(i) Send a channel sounding packet to estimate the full channel matrix, **H**, for each subcarrier. The sounding packet is sent using all transmit antennas with the highest possible transmit power, and all the antennas are enabled for

reception at the receiver side. This enables us to estimate all possible channels between each tx-rx antenna pair. It should be noted that we only need the preamble portion of this packet to get the channel estimates. Depending on the

design, the sounding packet can also be a specially designed packet filled with channel estimation symbols to get a less noisy channel estimate.

(ii) Based on the estimated channel matrices, the PERsand the resulting throughputs for all available modes can be calculated.

(iii) The modes that can not satisfy the QoS constraints,*THtarget*or *PERmax*, are removed from the search space.

(iv) Energy efficiencies for the remaining modes are calculated based on the predicted PER values. We enumerate all possible 6-tuples such that the mode index *m* distinctly

maps to a realization of 6-tuple. Among the modes that satisfy the QoS constraints, we choose the mode with index *m*∗that has the maximum predicted energy efficiency.

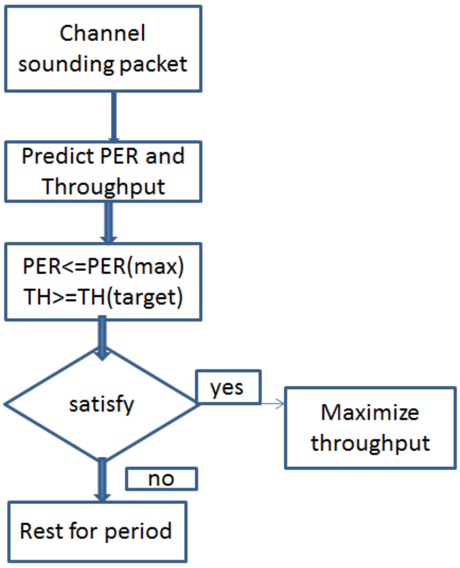

Fig.5.Link adaptation

(v) If none of the available modes satisfy the QoS constraints,the algorithm chooses the mode that has the highest predicted throughput. A second implementation choice in such a case could be to let the application decide whether to relax the QoS constraints or stop the transmission. If all the predicted PERs are very high (≈ 1), which means that the channel is too bad, the algorithm forces both the transmitter and the receiver to enter sleep mode to save energy.

(vi) The receiver feeds back only the number *m*∗to thetransmitter to reduce the amount of information to be fed back. The transmitter then uses the mode chosen by the link adaptation algorithm for the remainder of the session. The sounding period is defined as the duration between two sounding packets.

(vii) The whole process is repeated when the next soundingpacket is transmitted at the beginning of a new session.

F.SIMULATION RESULTS:

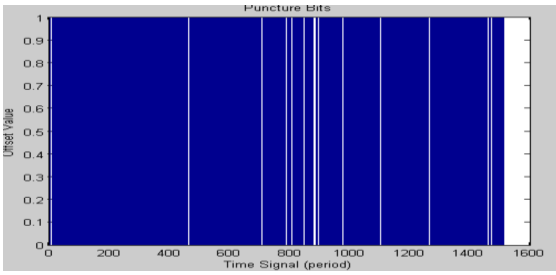

Fig.6.punctured bits

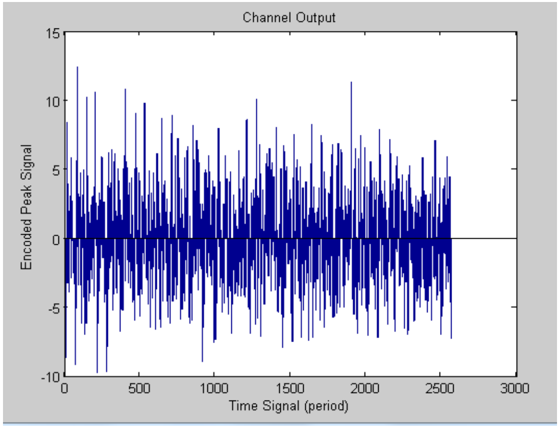

Fig.7.encoded signal

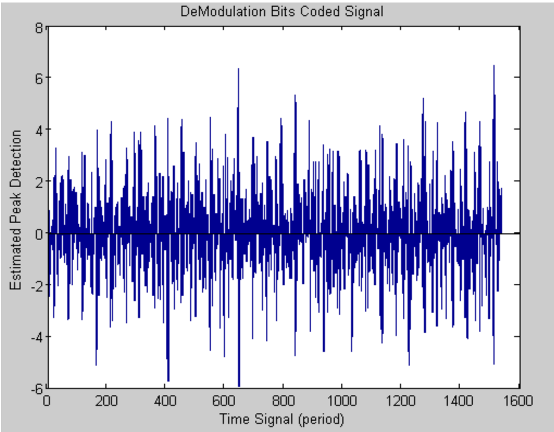

Fig.8.demodulated signal

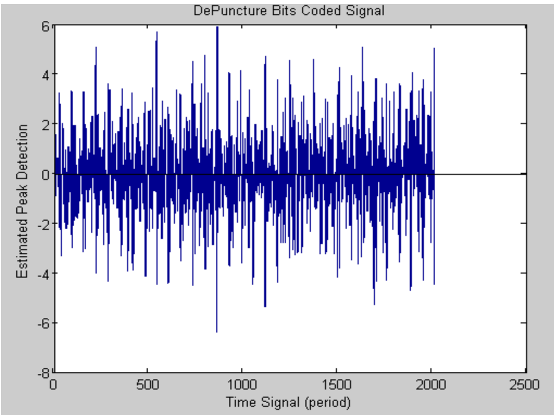

Fig.9.depunctured signal

3.TRANSMIT POWER SEARCH ALGORITHM

The complexity ofthe link adaptation algorithm can be further reduced by pruning the search space for transmit power levels. This can bedone by manipulating the ordering of transmit power levels for PER prediction calculations. For instance, if 10 dBm transmit power level does not satisfy the *PERmax* requirement for some of the modes, there is no need to perform PER prediction calculations for these modes for transmit power levels less than 10 dBm. Similarly, if the predicted PER ≈ 0 for some of the modes at a *PT* level, we no longer need to perform PER prediction calculations for these modes for higher *PT* levels. We can assume that they will achieve PER ≈ 0.

4.CONCLUSION

Wireless channel varies rapidly because of the environment conditions. In this work, link adaptation for MIMO-OFDM wireless systems was successfully formulated as a convex optimization problem. The proposed solution is based on sounding the channel periodically and choosing the optimal mode that will maximize the throughput or energy efficiency (EE) while satisfying the application’s quality of service (QoS) requirements. We address the complexity problem of the proposed algorithm by deriving a new closed form solution to PPSNR, which provides an 80% reduction in complexity.

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