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Transmit antenna selection for multiple antenna systems with stall avoidance[☆]

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ABSTRACT

This paper presents an analysis of the performance of transmit antenna selection in multiple-input multiple-output (MIMO) systems with N Stop and Wait (N-SAW) at the data link layer. The impact of packet size, number of SAW processes and the stalling of packets inside the receiver reordering buffer, due to N-SAW, on transmit antenna selection is investigated. Antenna selection is implemented as a signal processing technique that enhances the performance of the MIMO system; two schemes, throughput and capacity based transmit antenna selection are considered. Results show that under similar conditions, throughput maximization outperforms capacity maximization in terms of throughput, transmission latency and dropped packets when stall avoidance is implemented. The results further show that throughput and dropped packets increase with increase in SAW processes and decrease with increase in packet size. Transmission latency increases with increase in packet size and remains unchanged with increase in number of SAW processes.

1. Introduction

The provision of fast reliable data communications in wireless systems faces several challenges, including limited radio spectrum availability and fading. MIMO is an innovative technology that overcomes these challenges by providing improved spectral efficiency and link reliability. MIMO systems can be configured to provide spatial diversity, e.g. using orthogonal space time block coding (OSTBC) [1,2]; diversity techniques stabilize the wireless link leading to improved reliability. Enhanced data rates are achieved by configuring the MIMO system for spatial multiplexing (SM), e.g. the Bell Laboratories Layered Space-Time (BLAST) configuration [3,4].

Automatic repeat request (ARQ) and forward error control (FEC) schemes are widely used to control errors in data communication systems, resulting in improved system reliability [5,6]. ARQ combines an error detecting code and a retransmission protocol, for encoding blocks of data into code words (packets) before transmission and determining how erroneously received packets are retransmitted. On the other hand, FEC uses an error correcting code, which enables the receiver attempt to correct errors detected in the received packets [5,6]. Achieving high system reliability with ARQ is simpler and less costly compared to FEC, making ARQ the preferred scheme for maintaining data integrity in a wide range of communication systems [5].

Depending on the retransmission protocol, ARQ schemes can be divided into three; stop and wait (SAW), go back to *N* (GBN) and selective repeat (SR). The simplest ARQ scheme to implement is SAW; when a packet is transmitted, the

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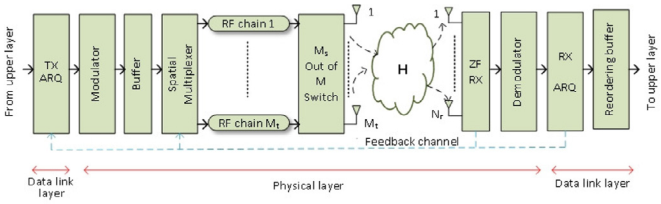

Fig. 1. System model.

next packet is only transmitted after the preceding packet has been received correctly. Therefore, packets always arrive in sequence at the receiver, resulting in SAW having minimal signaling and buffer requirements. The idle time spent waiting for an acknowledgement (ACK) or a negative acknowledgement (NACK) for each transmitted packet, severely affects the throughput efficiency of SAW [5]. To compensate for the idle time, the $N-$SAW retransmission protocol runs multiple SAW processes in parallel, resulting in improved throughput efficiency [7]. The parallel SAW processes experience unique channel conditions leading to SAW dependent packet error rates. Consequently, the packets transmitted in different SAW processes may require different number of retransmissions resulting in out of sequence packet arrival at the receiver. A reordering buffer is now required at the receiver; the received packets are temporarily stored in the buffer, reordered before being delivered in sequence to the higher layer. Stalling occurs in the reordering buffer when packet(s) cannot be forwarded to the higher layer because some preceding packet is missing. Stalling results in increased buffer storage requirements and introduces latency in delivering the packets to the higher layer. Stall avoidance mechanisms can be used to decrease stalling in the reordering buffer [8].

The gains of MIMO are accompanied by increased hardware complexity and cost, due to the multiple radio frequency (RF) chains; one for each antenna. Antenna selection offers a low cost and efficient technique that alleviates this problem. The MIMO system is equipped with less RF chains than antennas, and the antenna subset that optimizes a specific criterion is selected. The system complexity and cost is thus reduced while maintaining the performance of the MIMO system [9]. Antenna selection can also be used as a signal processing technique for improving system performance. The MIMO system is equipped with the same number of antennas as RF chains, and the antenna subset, of adaptive size, that optimizes the system performance is selected.

Capacity is the most commonly used antenna selection criterion in MIMO systems [10,11]. Capacity based antenna selection utilizes information from the physical layer, therefore capacity maximization does not necessarily result in overall improved system performance. The use of throughput as a selection criterion in transmit antenna selection is studied in [12–15], with Hybrid-ARQ (H-ARQ), SR-ARQ (or SR plus GBN-ARQ), truncated selective repeat ARQ (TSR-ARQ) and $N-$SAW implemented at the data link layer respectively. Throughput based antenna selection utilizes information from the data link and physical layers, resulting in a cross layer approach to antenna selection. Therefore, throughput maximization improves the overall system performance remarkably compared to capacity maximization as shown in [12,15]. The evaluation of the performance of throughput and capacity maximization in previous works, including in [12,13,15], is done at fixed packet size and number of ARQ processes. Stalling of packets in the reordering buffer is only considered in [15].

In this work, the performance of transmit antenna selection for MIMO systems with $N-$SAW implemented at the data link layer, is investigated. The performance of throughput based transmit antenna selection is analyzed and compared to that of capacity based transmit antenna selection at various packet sizes and number of SAW processes. Further, the performance of the antenna selection schemes is evaluated when a timer based stall avoidance mechanism is implemented at the receiver.

The rest of the paper is organized as follows. The system and signal model is presented in Section 2 and stall avoidance is discussed in Section 3. The transmit antenna selection schemes are described in Section 4. The simulation setup is given in Section 5 and the results discussed in Section 6. Finally, the conclusions are given in Section 7.

Notations: Boldface uppercase is used for matrices while boldface lowercase is used for vectors. $[.]_{k,\,k}$ represents the element in the kth row and kth column of a matrix. $\mathbb{C}^{x \times y}$ denotes the space of $x \times y$ matrices with complex entries, $(.)^H$ and $det(.)$ represent the conjugate transpose and determinant of a matrix respectively while $Q(.)$ represents the Gaussian Q-function.

2. System and signal model

The system model, which consists of a MIMO system with M_t transmit and N_r receive antennas (where $M_t \leq N_r$), is shown in Fig. 1. MIMO systems configured for SM require that $M_t \leq N_r$, to ensure proper recovery of the transmitted signals at the receiver [9]. The MIMO channel matrix is represented by $\boldsymbol{H} \in \mathbb{C}^{N_r \times M_t}$. The following assumptions are made regarding the system model:

1. $\boldsymbol{H}$ has zero mean circularly symmetric complex Gaussian (ZMCSCG) elements with unit variance.
2. The channel experiences frequency flat Rayleigh fading.
3. The receiver has perfect knowledge of the channel.
4. The feedback channel has a low bandwidth, is error free with zero delay.