Average Throughput Link Adaptation using HARQ Information and MIMO Systems

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ABSTRACT

In this article, we discuss about link adaptation (LA) for multiple-input multiple-output (MIMO) wireless systems. We present a cross-layer approach that takes into account a hybrid automatic repeat request (HARQ) information which is a medium access control layer (MAC) layer information. The expected throughput is then used in order to evaluate the influence of retransmissions in the average throughput. Therefore, we propose a modulation, coding and antenna scheme (MCAS) selection using HARQ information aiming to maximize the average throughput considering two different MIMO schemes: Alamouti and Bell labs layered space-time (BLAST).

1. INTRODUCTION

Wireless communications systems are very attractive due to their advantages like mobility and flexible network deployment. However, in these systems, channel impairments are the main difficulties to be dealt. Slow and fast fading degrade signal characteristics and increase the error probability in the symbol transmission. With the popularization of wireless communications and cheaper adopted prices, the demand of new services is ever increasing and, consequently it has been growing the requirements for data rates, packet delay, link capacity, etc. Statistical network planning is not sufficient anymore and online updates of resource allocations are demanding. Hence, online solutions must be required to exploit channel variations. Even though substancial knowledge is acquired from information theory, when some services come online the required bandwidth is much more larger than the supported network bandwidth. Therefore, it is essential find new solutions to avoid the waste on the use of network resources such as frequency, time and space. Along these later decades, the growth of wireless networks has motivated the development of new solutions to combat these inherent effects, such as adaptive modulation and coding (AMC), utilization of multiple-input multiple-output (MIMO) antennas and hybrid automatic repeat request (HARQ).

AMC is a well-known technique where the modulation and coding schemes adapted according to channel variations enables robust and spectrally-efficient transmission over time-varying channels [1] becoming a must-have feature in the new cellular systems since enhanced data GSM evolution (EDGE). In general, link adaptation (LA) is denoted as a set of techniques with the objective of tracking channel variations in order to optimize some criterion such as minimization of bit error rate (BER), minimization of frame error rate (FER), maximization of the achieved capacity, etc.

The utilization of multiple antennas in both transmit and receiver has become very attractive in recent wireless networks. MIMO channels are used to provide diversity and/or spatial multiplexing gains using the links multiplicity through the multiple antennas in both end links. Alamouti scheme [2] is a typical transmission scheme which provides a diversity gain with two antennas on the transmitter side. The main goal of Alamouti scheme is to decrease the error probability in the symbol transmission.

On the other hand, spatial multiplexing gain is another way to take advantage of MIMO channel and Bell labs layered space-time (BLAST) [3] scheme is the best known example of that. The BLAST principle is to transmit different streams through the different transmit antennas at the same time slot. The main goal of BLAST scheme is to increase the system throughput. Therefore, Alamouti and BLAST have different purposes and establishing a way to select a scheme that best fits system constraints is a subject of a vast field in the literature [4]–[9].

HARQ is a technique that combines forward error correction (FEC) and error treating with automatic repeat request (ARQ) retransmission mechanism. FEC consists of a mechanism to insert extra bits that will be necessary to detect transmission errors. Various types of error-correcting codes and applications for them can be found in [10]–[12].

Traditional ARQ uses FEC mechanism to identify and requests a new transmission. The most common HARQ approaches are Chase combining (CC) and incremental redundancy (IR). In CC, bit transmission is the same, but received frames are combined at the receiver side and, because of that, error detection probability is decreased. At the first time of IR mechanism, the transmitter sends the information bits added to a few redundant bits. In the following transmissions, the number of redundant bits increases while the number of information bits decreases. At the receiver side, receive frames are combined to compose the original message (information bits) with redundant bits. Thus, HARQ is a useful mechanism to decrease error probability as well.

In recent wireless networks the utilization of MIMO is becoming mandatory to achieve the promised increase in data rate throughput in the physical layer. HARQ mechanisms are also mandatory and generally they are considered separately from the physical layer decisions. Since both features are channel dependent, as long as AMC, the integration AMC and HARQ in a broader concept of link adaptation and it involves a cross-layer particular interest.

In this work, we propose a solution to choose modulation, coding and antenna scheme (MCAS) with the criterion of maximizing the expected average throughput considering HARQ information. The paper is organized as follows. In Section 2 we explain the main related works in AMC subject considering an expected throughput criterion whose we have inspired our contribution. In Section 3, we analyze and propose our MCAS selection using the expected throughput and HARQ information. In Section 4, we explain the system model considered in the rest of the paper. In Section 5, we show comparative curves whose are important to analyze the proposal's performance. Finally, we present our conclusions in Section 6.

2. Related Work

The expected average throughput has already been investigated in the literature for AMC selection as in [13]–[15]. In [15], the authors proposed a Single Input Single Output (SISO) optimal modulation and coding scheme (MCS) selection criterion for maximizing the user throughput in cellular networks. In this paper, the throughput of the retransmissions, using CC-based HARQ, is decreased, since in each retransmission the same information is sent, therefore, for a data rate of R_i for the MCS i, in the k^{th} retransmission the data rate is R_i/k. This behavior is illustrated in Figure 1.

Herein, we use the concept of expected probability of success (EP) where only one transmission has a success decoding along N_{max} transmissions, which is defined in function of the conditional probability of the success event in a specific transmission and the error event in other past transmissions, as defined

$$EP = \Pr(S_1) + \sum_{k=2}^{N_{max}} \Pr(S_k|E_1, \cdots, E_{k-1}), \qquad (1)$$

where S_k represents the event of success decoding at the kth (re)transmission and E_k represents the event of decoding with errors at the kth (re)transmission. $\Pr(a|b,c)$ is the conditional probability of variable a given the conditioning of variables b and c.

Therefore, the expected throughput for a given MCS i with an associated data rate of R_i can be written in function of the expected probability of success (EP) where its terms are multiplied by the term $\frac{R_i}{k}$ which is the actual data rate using the ith at the kth transmission. Putting R_i as a common factor, we can define as follows

$$T_{exp}(i) = R_i \left(\Pr(S_1) + \sum_{k=2}^{N_{max}} \frac{\Pr(S_k|E_1, \cdots, E_{k-1})}{k} \right). \qquad (2)$$

It is considered that channel characteristics stay constant during retransmissions due that it is considered that CC-based HARQ mechanism causes a linear increase on the perceived signal-to-noise ratio (SNR) resulting of the cummulation of the successive retransmissions. Then, we can rewrite the expected throughput as

$$T_{exp}(\gamma, i) = R_i \left(F_1(\gamma) + \sum_{k=2}^{N_{max}} \frac{(1 - F_i(k\gamma)) \prod_{m=1}^{k-1} F_i(m\gamma)}{k} \right), \qquad (3)$$

where k and m are a index representing the current transmission and a index representing the past transmission, respectively. The variables γ and $F_i(\gamma)$ are the SNR value and the error function for the ith MCS and γth SNR value, respectively.

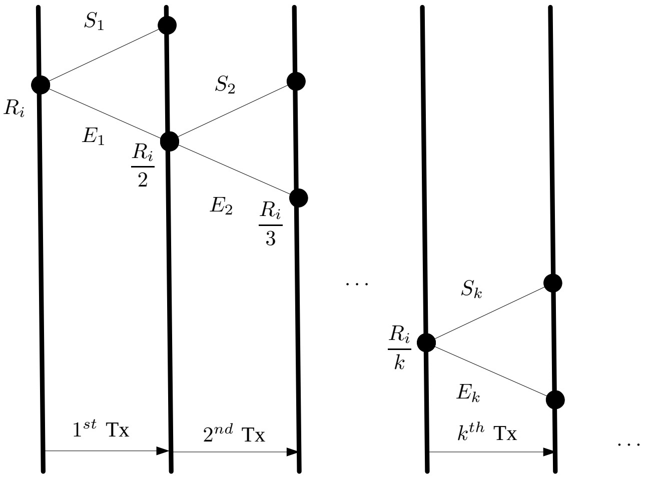

Figure 1: Illustration of the expected throughput with CC-based HARQ.

Based on the expected throughput of (3) for the CC-based HARQ, the optimal MCS selection considering retransmissions using CC is given by

$$MCS^{CC}_{T_{exp}} = \arg\max_{i \in I} R_i \sum_{k=1}^{N_{max}} \frac{(1 - F_i(k\gamma))}{k} \prod_{m=1}^{k-1} F_i(m\gamma), \qquad (4)$$

where I is a set containing all available MCS and the terms $F_i(\cdot)$ are the associated error function of MCS i and the term $1 - F_i(\cdot)$ is associated with the successful (re)transmission.

Differently of [15], in the next section we propose to extend the work of [15] considering two different MIMO schemes, Alamouti and Vertical Bell labs layered space-time (V-BLAST), in combination of HARQ.

3. Average Throughput Link Adaptation using HARQ Information and MIMO Systems

In our proposal, we consider a MIMO system with 2 antennas at the both transmitter and receiver sides. We consider an Alamouti scheme to take advantage of diversity gains and, in the other hand, we also use a V-BLAST scheme in order to achieve spatial multiplexing gains.

As multiple antennas are presented in our scenario, we have to modify the expected throughput presented in (3) and consequently the MCS selection criterion presented in (4). In an Alamouti scheme, a number of M_t transmit time intervals are used to transmit M_t streams. Therefore, the expected throughput considering a MIMO system with Alamouti scheme with two transmit and receive antennas is represented as

$$T^{Ala}_{exp}(M_t, i) = \frac{M_t}{t_{Ala}} T_{exp,Ala}(i) \tag{5}$$

where M_t and t_{Ala} are the number of transmit antennas and the transmission time required to transmit M_t frames which is equal to $t_{Ala} = 2$ for $M_t = 2$. $T_{exp,Ala}(i)$ is the expected throughput shown in (2) for the ith MCS using Alamouti scheme.

Then, we can rewrite the expected throughput in function of error function as

$$T^{Ala}_{exp}(M_t, \gamma, i) = \frac{M_t}{t_{Ala}} T_{exp,Ala}(\gamma, i), \tag{6}$$

where γ and $T_{exp,Ala}(\gamma, i)$ is the expected throughput shown in (3) for the ith MCS and the γ SNR value using Alamouti scheme, respectively. The MCS selection considering retransmissions using CC and an Alamouti scheme is based in the expected throughput (6) as in

$$MCS^{CC,Ala}_{T_{exp},M_t} = \frac{M_t}{t_{Ala}} \times MCS^{CC,Ala}_{T_{exp}}, \tag{7}$$

where $MCS^{CC,Ala}_{T_{exp}}$ is the MCS selection criterion shown in (4) for the Alamouti scheme.

In a BLAST scheme, a number of M_t streams is transmitted in one transmit time interval, thus, $t_{Blast} = 1$. Therefore, the expected throughput and the MCS selection criterion for a system with BLAST scheme $M_r \times M_t$ can be derived from (6) and (7), respectively. Changing t_{Ala} by t_{Blast} and using the error function associated to the BLAST scheme.

Finally, our MCAS selection considering a maximum number of retransmissions N_{max} using CC is written in function of the MCS for each scheme as shown in

$$MCAS^{CC}_{T_{exp},M_t} = \arg \max_{scheme=\{Ala,Blast\}} MCS^{CC,scheme}_{T_{exp}}. \tag{8}$$

4. SYSTEM MODEL

In our simulation, we suppose that physical resources have already been assigned for a specific user. Therefore, we do not consider the scheduling process, in order to avoid its impacts in the time domain. Our system consists on a base station with M_t transmit antennas and one mobile user with M_r receive antennas, where $M_t = 2$ and $M_r = 2$. We consider a link adaptation scheme that takes into account the presence of multiple antennas in both link ends. The idea is to dynamically adapt the signal transmission parameters (modulation level, code rate, antenna structure) to the current conditions of the wireless channel. We refer to the different sets of parameters as MCAS.

The block diagram of transmission is shown in Figure 2. As we can note, the first step consists of the MCAS selection according the proposed criteria that were shown in the Section 3 by the equation 8. The main goal of this criterion is the average throughput maximization over the $N_{max} + 1$ possible transmissions. We consider the Chase combining (CC)-based HARQ mechanism, in which, the same frame transmitted previously is retransmitted and for decoding processing the energy of the symbol decisions is increased after each retransmission.

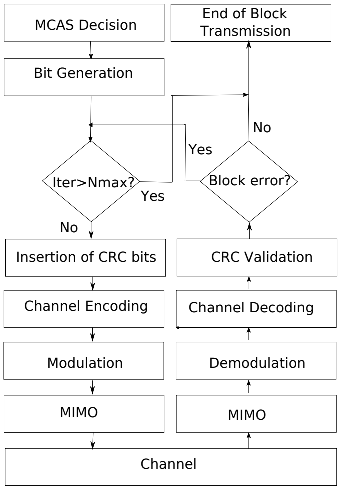

Figure 2: Block diagram of transmission.

After this step, in order to maintain constant the number of symbols in the frame, consider a frame length of $frameSize = 88$ symbols, we generate N random bits, considering M the number of points in the constellation ($M = 2^b$), thus, N is equal to $frameSize * \log_2(M)$. The number of current iteration is then verified to see if the maximum number of retransmissions is achieved and the next steps are the insertion of cyclic redundancy check (CRC) bits, for error detection; the channel encoding with turbo coding rate $1/3$ which is used to add redundancy extra bits, in order to lower the BER; the bit modulation which its available modulation schemes are quadrature phase-shift keying (QPSK), 16 quadrature amplitude modulation (16-QAM) and 64 quadrature amplitude modulation (64-QAM) and MIMO coding. The resulting symbols are multiplied by the channel coefficients (it is considered a Rayleigh fading model channel).

The reverse procedures are executed: the MIMO decoding, the bit demodulation, the channel decoding and the extraction of CRC bits, if an error is detected the program repeats the steps described above, if the transmission is successful, the program exits the block transmission.

We calculate the equivalent SNR value at the receiver for each MIMO scheme. For the BLAST scheme, it is considered a Zero-Forcing (ZF) detector and its equivalent SNR is defined as

$$\gamma_{Blast} = \min_{k} \frac{\overline{\gamma}}{M_t} \frac{1}{[(\mathbf{H}^H\mathbf{H})^{-1}]_{k,k}}. \tag{9}$$

where $\overline{\gamma}$, k and $\mathbf{H}$ are the average SNR value, the stream index and the complex channel matrix $M_r \times M_t$. The operator $[\mathbf{A}]_{k,k}$ refers to the diagonal element $\mathbf{A}_{j,j}$.

For the Alamouti scheme, it is considered an equivalent SNR is defined as

$$\gamma_{Ala} = \frac{\overline{\gamma}}{M_t} \sum_{i=1}^{M_r} \sum_{i=1}^{M_t} |h_{i,j}|^2. \tag{10}$$

Until now, we considered a general error function, $F_i(\gamma)$ in the throughput calculation. However, in the remaining of this work, we will use the FER measure, $FER_i(\gamma)$, as the error function. This estimate represents how often the frames are not correctly received in the receiver side. The CRC procedure, shown in 2, has an output a flag that indicates whether the frame is or not in error. The FER calculation is based on this CRC output flag. We consider that FER measure is function of the BER as follows

$$FER_i(\gamma) = 1 - (1 - BER_i(\gamma))^{\mathit{frameSize} * \log_2(M)}. \tag{11}$$

The BER function was obtained through exhaustible link layer simulations for each combination of one MIMO scheme and one modulation scheme. Alamouti and V-BLAST MIMO schemes were used with the following modulation schemes: QPSK, 16-QAM and 64-QAM. After a polynomial approximation stage, the BER function is shown in Figure 3.

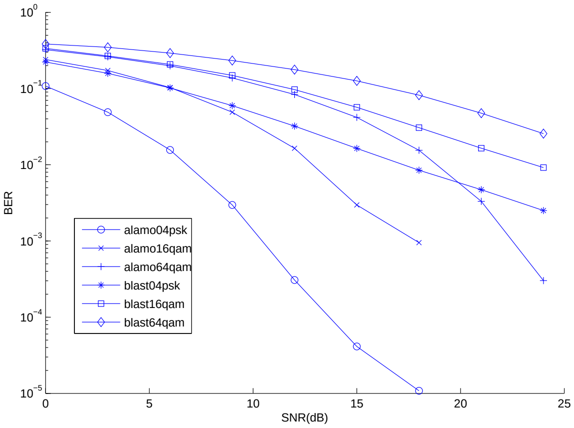

Figure 3: BER curve obtained by exhaustive link level simulations for different modulation and MIMO schemes

5. SIMULATION RESULTS

Most of the link adaptation algorithms found in the literature consider the adaptation of the link parameters (e.g. modulation, code data rate, and so on) based in a target error probability (e.g. minimal BER or minimal block error rate (BLER)). In order to compare our proposal with another solution presented in the literature [15], we have chosen a FER-based criterion that chooses the MCAS that provides the greater data rate with the constraint that its FER is smaller than a pre-established FER_{tar}, as described as follows

$$\text{MCAS}_{\text{FER}_{tar}} = \arg \max_{i \in I, j \in 1,2} \{G_j * R_i | F_{i,j}(m\gamma) < \text{FER}_{tar}\}, \tag{12}$$

where j is the corresponding index of the MIMO scheme, which assumes the value $j = 1$, for Alamouti and the value $j = 2$, for BLAST. G_j is MCS and the associated gain of the jth MIMO scheme which is $G_j = \frac{M_t}{t_j}$. R_i and $F_{i,j}(\cdot)$ are the available data rate of the ith MCS and the error function for the ith MCS and the jth MIMO scheme.

In the first transmission, the MCAS is selected by the expression in (12) and it is fixed in others transmissions. Meanwhile, CC is considered, the SNR value increase through retransmissions is not considered.

We configured our simulation for five average SNR values (in dB as [15 20 25 30 35]). For each SNR value, 2500 frames were generated and each frame containing 88 symbols. Our proposal were simulated besides the ones with FER criterion FER_{tar} of 1% and 10% with a maximum number of retransmissions equals to $N_{max} = 5$. The main simulation parameters are presented in the Table 5.

PARAMETER	VALUE	UNIT
Modulation Types	[QPSK, 16-QAM, 64-QAM]	
Turbo coding rate	[1/3]	
MIMO Schemes	[Alamouti, V-BLAST]	
Tx antennas	2	
Rx antennas	2	
Symbols in a Frame	88	symbols
Retransmissions	[5]	Chase combining
FER_{tar}	[1 10]	%
Average SNR	[15 20 25 30 35]	dB
Simulation time	2500	frames

In Figure 4, we show the throughput versus the average SNR when the maximum number of retransmissions N_{max} is equal to 5. Moreover, this figure compares the throughput performance of proposed solution besides MCAS selection by FER criterion shown in equation (12) with $FER = 1\%$ and $FER = 10\%$. As mentioned in Section 3, the proposed solution takes into account the retransmission information in the MCAS decision and has a better performance than the other compared solutions in all SNR values. As we can see in Figure 4, the FER criterion-based solutions with $FER = 1\%$ and $FER = 10\%$ are in outage for SNR values lower than 6 dB and 3 dB, respectively. This can be explained by the fact that before these SNR values the estimated FER of the first transmission can not achieve the considered FER threshold values. On the other hand, the proposed solution maintains a constant throughput of 176 bits per frame, which is achieved by the other solutions just with SNR values of 18 dB and 15 dB, for the $FER = 1\%$ and $FER = 10\%$ threshold values, respectively. The proposed solution and the other compared ones have similar performances in high SNR values after 40 dB because the estimated BER values of the first transmission are comparable to the estimated BER values considering N_{max} retransmissions.

As we can notice in Figure 4, around the SNR value of 15 dB there is an approximation of the throughput curves of the proposed and the other solutions. Because of this fact, in Figure 5 we present the throughput cumulative distribution function (CDF) for $N_{max} = 5$ with a fixed SNR, $SNR = 15$ dB. We can see that the FER-based solution with SNR threshold of 10% has only a 4% of samples lower than 176 bits per frame while the proposed solution has 12% of samples. Nevertheless, around 5% of occurences for the both FER-based solutions are greater that 176 bits per frame, meanwhile, around 27.5% of occurences of the proposed solution are.

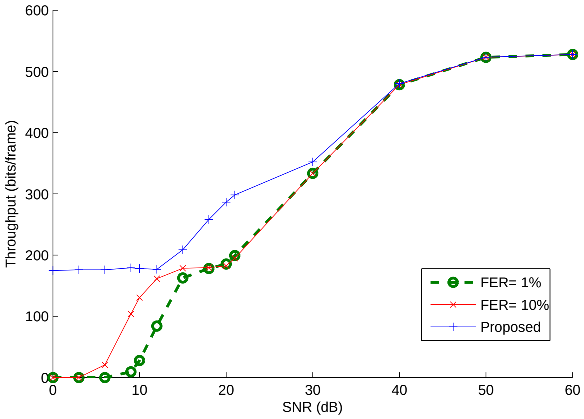

Figure 4: Throughput for selection by HARQ, FER$_{tar}$ = 1% and 10% considering $N_{max} = 5$.

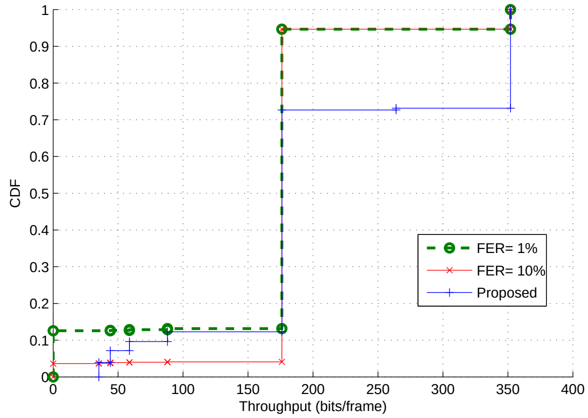

Figure 5: CDF of throughput for selection by HARQ, FER$_{tar}$ = 1% and 10% considering $N_{max} = 5$ with a fixed $SNR = 15$ dB.

6. CONCLUSIONS AND PERSPECTIVES

In this work, we discussed about a LA problem involving MIMO scheme and modulation selection, which are typical physical layer (PHY) parameters, on the other hand, we considered the number of retransmission of the HARQ, that involves a medium access control layer (MAC) parameter. We used an expected throughput measure of a CC-based HARQ mechanism. This measure was used in the MCAS criterion that was proposed in the paper for both V-BLAST and Alamouti MIMO schemes. We concluded that our MCAS criterion has superior throughput performance with all SNR values comparing with the FER criterion proposed in the literature for the chosen thresholds (1% and 10%). As we mentioned in the text, the error function curve was built with exhaustible link layer simulations. Because of this, as the perspective ideas, we plan to investigate other theorectical error functions and create a sub-optimal MCAS criterion that will avoid the comparison among all possible combinations (modulation, coding and MIMO schemes).

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