Data Link Control for Multiple Input Multiple Output Wireless Systems

Wessam Ajib; David Haccoun and Jean-François Frigon
C.P. 6079, succ. Centre-ville Montréal, Québec, Canada, H3C 3A7
Department of Electrical Engineering,
École Polytechnique de Montréal,
wessam.ajib@polymtl.ca david.haccoun@polymtl.ca j-f.frignon@polymtl.ca

Abstract

This paper investigates the adaptation of data link error control protocols to be more efficient over MIMO wireless links. Data link mechanisms control, among other things, the transmission errors at the link layer, whereas MIMO is a physical layer technology that handles the wireless link with a notably high efficiency and flexibility. A new cross layer protocol is proposed in this paper in order to improve the performance of error control mechanism by making use of the multi-channel transmission characteristics. The main idea is to divide each link layer data unit (block) into sub-blocks and transmit the sub-blocks from different transmit antennas and therefore take advantage of the spatial "diversity". Besides, the division helps the receiver to recognize some error-free parts of a block; consequently new algorithms that exploit this feature are proposed and analyzed. In addition, different methods for providing higher link reliability to retransmitted data are explored.

1. Introduction

Using multiple antennas at the transmitter and/or at the receiver becomes an important means to improve the performance of wireless networks. MIMO (Multiple Input Multiple Output) systems can be flexibly exploited by a spatial multiplexing technique in order to increase the transmission rate and/or by space-time diversity coding that combats the channel fading and hence produces diversity gain and enhances the link reliability. Since the pioneering work by Telatar [1] and Foschini [2] had predicted remarkable spectral efficiency for multiple antenna systems, theoretical and practical capacity of MIMO wireless systems as well as MIMO applications became highly attractive topics in wireless networks. MIMO capacity and gains are overviewed in [3] and [4]. A simple spatial multiplexing technique namely Vertical Bell Labs Layered space Time (V-BLAST) has been proposed in [5] in order to allow transmitting independent data from different antennas.

Instead of separately exploiting the MIMO technology at the physical layer and the error control mechanism at the data link layer, we define in this paper a new cross layer design in the light of combining judiciously these two layers in order to decrease the error rate. For simplicity we assume the use of type-I Hybrid Automatic Repeat reQuest (HARQ) [6]. Even so, our proposal can be adapted for different error control mechanisms. It is to be underlined that our proposal is a link layer design issue that exploits the availability of MIMO physical layer for link layer performance improvements. Anyhow, it does not attempt to improve the physical layer performance. Different ARQ procedures adapted for particular MIMO systems have been proposed and studied in the literature [7] – [8].

The technique proposed in this paper is based on the following observation. If the HARQ codeword is transmitted from multiple antennas (using V-BLAST architecture), HARQ mechanism may make use of the spatial "diversity" which leads to a minimization of the Block Error Rate (BLER). The proposed transmission technique does not combine the symbol level coding done at the physical layer with the block level HARQ protocols done at the link layer. Instead, our proposal is independent of the space-time symbol level coding that could be added at the physical layer improving the reliability of the physical layer communication. The performance improvement due to the proposed transmission technique is investigated using both analytical and simulation methods.

The division of a single block into sub-blocks may allow recognizing some error-free parts of an erroneous block at the receiver side. In this case, the receiver can request only the retransmission of those erroneous sub-blocks and consequently uses the
resources more efficiently. Giving higher priority in
term of link reliability to retransmitted data at the
transmit side decreases the Failure Block
Transmission Rate (FBR) for truncated ARQ system. In
this paper, we investigate different techniques for
implementing this prioritization. Both complexity and
efficiency of those techniques are considered.

The paper is organized as follows. The system
model is given in section 2. In section 3, we present
the proposed novel cross layer design that combines
the multiple antenna transmission with HARQ
procedure. Some analytical results are also provided.
Section 4 investigates the possibility of sub-blocks
error detection. Section 5 presents different methods
for retransmitting the negatively acknowledged blocks.
Section 6 includes the simulation results illustrating
the performance of the proposed techniques as well as
some discussions. The last section contains the
conclusions.

2. System Model

2.1. Channel Model

In this paper, we consider a wireless link model
with \( M_T \) transmit antennas and \( M_R \) receive antennas.
The \( M_R \times M_T \) channel matrix \( \mathbf{H} = [h_{ij}] \) describes
the channel. The fading coefficient \( h_{ij} \) is the complex path
gain from transmit antenna \( j \) to receive antenna \( i \). We
assume that the \( h_{ij} \)'s are independent identically
distributed (i.i.d.) random variables, zero mean
circularly symmetric Gaussian with unit variance. We
assume a flat fading channel with rich scattering
environment, i.e., \( \mathbf{H} = \mathbf{H}_M \) (spatially white channel) [4].

We consider that the channel state varies slowly,
so that \( \mathbf{H} \) can be assumed to be constant during one
block transmission period but varies from one block
transmission period to another. In other words, the
block length is smaller than the channel coherence
time. The receiver is assumed to have a perfect
knowledge of the channel state. On the other hand, the
transmitter does not know the channel state. Though,
limited feedback information may be available.

In the discrete time model and under these
assumptions, the received \( M_R \times 1 \) vector, \( \mathbf{r} \), can be
written as

\[
\mathbf{r} = \mathbf{H} \mathbf{s} + \mathbf{w}
\]

where \( \mathbf{s} \) is the \( M_T \times 1 \) transmitted vector and \( \mathbf{w} \) is the
\( M_R \times 1 \) additive white circularly symmetric complex
gaussian noise vector associated with the transmission
of \( \mathbf{s} \). The covariance matrix of the noise is \( \mathbf{N}_0 \mathbf{I}_{M_R} \). We
assume that independent noise vector \( \mathbf{w} \) is observed
for each signal vector transmission.

2.2. HARQ model

The protocols based on the ARQ, Automatic
Repeat request, technique are used at the link layer of
data transmission networks for controlling the
transmission errors by retransmitting the blocks
detected in errors. In this paper, ARQ denotes the
Selected Repeat ARQ where blocks are transmitted
continuously and the transmitter repeats only the
negatively acknowledged ones. Another technique for
controlling the transmission errors is Forward Error
Coding (FEC), which uses an error correcting code to
correct some error patterns. A proper combination of
FEC and ARQ (called type-I hybrid ARQ or HARQ)
is often preferable compared to an ARQ or an FEC
system alone. In such a system, if the errors are within
the code error correcting capability, the FEC decoder
corrects them and the block is delivered to the ARQ
process as an error-free block. If an uncorrectable
error pattern is detected, then that block is rejected and
the ARQ system requests a retransmission [5].

The FEC encoder encodes blocks of \( K \) bits into
codewords of \( N \) code symbols \( (N > K) \). For linear
codes, the minimum distance between two codewords
is upper bounded by \( d_{\min} \leq N-K+1 \). In our analysis, we
do not consider a particular error correcting code. Any
binary error correcting code, such as Golay codes,
Hamming code or convolutional codes, can be used.

The error correcting code guarantees to correct up
to \( t \) erroneous bits where \( t = \lfloor (d_{\min}-1)/2 \rfloor \) is the
code error correcting capability. If there are less than \( t \)
bits in error, the FEC decoder decodes the codeword
correctly and hence the block is handled as an error-
free one by the ARQ process. We notice that if there is
1, 2 ..., or \( t \) erroneous bits per block, HARQ runs into
the same performance. When the receiver detects an
uncorrectable erroneous block, it sends back a
negative acknowledgment and requests the retrans-
mission of that block. It is generally assumed that the
probability of non-detectable errors is negligible.

In order to define practical limits for delay and
buffer size, truncated ARQ is adopted in most of
wireless networks. In those networks, whenever a
block is transmitted many times (up to a certain limit)
without success, the transmission of that block is
considered failed and no further retransmission is
initiated. The rate of failed transmissions, which
corresponds often to an important quality of service
criterion, is the Failure Block transmission Rate
(FBR). Retransmitted data may be given higher
priority than data transmitted for the first time in order
to improve the FBR in data networks. We assume that
the receiver keeps track of the transmission number \( U \) for each block and a block cannot be transmitted more than \( U_{\text{max}} \) times.

### 3. HARQ- MIMO transmission techniques

The main idea of our proposed transmission technique is to divide the code symbols (called bits) belonging to one HARQ codeword into \( M_T \) sub-blocks and transmit each single sub-block from a different transmit antenna. Without loss of generality, we assume that \( N \) is divisible by \( M_T \).

![Diagram of HARQ codewords over MT transmit antennas]

**Fig. 1 Dividing HARQ codewords over MT transmit antennas**

As shown in figure 1, after coding a block of \( K \) bits into a HARQ codeword of \( N \) “bits” (code symbols), the codeword is divided into \( M_T \) sub-blocks of \((N/M_T)\) bits. Each sub-block is transmitted from one transmit antenna. Figure 1 considers also a possible addition of CRC. It is to be noted that this CRC does not conflict with the principle of splitting a single block over multiple transmit antennas. The optional addition of CRC per sub-block is discussed in detail in the next section.

To illustrate the error rate improvement of our proposed technique, let us consider the following example. A 2x2 MIMO system uses an error correcting code with parameters \( N=24 \) and \( t=3 \) where the channel raw error rates are given by \( P_I = 0.15 \) and \( P_e=10^{-5} \) related to the data transmitted from antenna 1 and antenna 2, respectively. In the first transmission scenario, a codeword is completely transmitted from one antenna. If it is transmitted from antenna 1, it has on average \( 24 \times 0.15 = 3.6 \) erroneous bits, which exceed \( t \), the code error correcting capability. On the other hand, a codeword transmitted from antenna 2 has 0.24 erroneous bits on average, which are correctable.

In the second transmission scenario, if the codeword is transmitted from the two antennas i.e., \( N/2 \) bits per antenna, then on average the sub-block transmitted on antenna 1 has 1.8 erroneous bits and the one transmitted from antenna 2 has 0.12 erroneous bits. The decoder can correct 2.02 erroneous bits in a codeword. We conclude that, considering average values, in the first scenario, when two blocks are transmitted, one block needs to be retransmitted but in the second scenario, no retransmission is required.

#### 3.1. Bit error probability

Without loss of generality, we assume a simple, Binary Phase Shift Keying, BPSK encoder/modulator for data transmitted from each antenna. Let us assume that \( \mathbf{s} = [s_1, \ldots, s_{M_T}]^T \) is the vector of symbols transmitted during a particular symbol transmission period. We assume the utilization of Maximum Likelihood (ML) detection at the receiver [9]. The ML receiver performs vector decoding and it is the optimal receiver. It chooses the vector \( \hat{s} \) that realizes

\[
\hat{s} = \arg \min_{s} \| y - \frac{E_s}{M_T} \text{Hs} \|_F^2
\]

where \( E_s \) is the code symbol energy, \( \| \|_F \) is the Frobenius norm of a matrix. The optimization is performed through an exhaustive search over all the candidate vector symbols \( s \). The ML receiver implementation is complex. However, our proposal is straightforwardly applicable to simpler spatial multiplexing receivers such as Zero Forcing (ZF) or Minimum Mean Square Error (MMSE) receivers.

The probability of errors on \( s \) is given by [9]:

\[
P_{es} = \sum_{i=1}^{2^{M_T}} P_h \cdot P_{e|h_i}
\]

where \( P_h \) is the probability that the vector \( s_h \) is transmitted, \( 2^{M_T} \) is the total number of possible vectors and \( P_{e|h} \) is the probability that the receiver does not detect \( s_h \) correctly. The probability of decoding \( s_h \) incorrectly is equal to the probability that one of the other vectors \( s_k \) is detected where \( k \neq i \). For \( \forall \, i \in \{0, \ldots, 2^{M_T}\} \) and \( \forall \, k \in \{0, \ldots, 2^{M_T}\} \), \( P_h = P_{s_h} \) and \( P_{e|h} = P_{e|h_i} \), consequently \( P_{e|a} = P_{e|h_i} \), \( \forall \, i \).

For BPSK, the bit error rate is equivalent to the symbol error rate. Using the union bound on
probabilities, and considering V-BlasT transmission with BPSK coding, the probability $P_{e,i}$ can be upper bounded as follows:

$$P_{e,i} \leq \sum_{i=1}^{2^{M_i+1}} \left( \frac{\rho \|H_{D_k}\|_F^2}{2M_i} \right)^i, \quad \forall i.$$  \hspace{1cm} (4)

where $D_k$ is the Euclidean distance between $s_i$ and any other vector $s_k$ and $\rho$ may be interpreted as the average Signal to Noise Ratio (SNR) at the receive in a SISO link, $\rho = E_s/N_0$.

Let us assume that $s[j]$ is the symbol transmitted from a particular antenna $j$. The probability that $s[j]$ is received in error is the sum of probabilities to detect a vector $\hat{s}$ where $\hat{s}[j] \neq s[j]$.

Let $P_j$ denotes an upper bound on the bit error rate for data transmitted from antenna $j$. Without loss of generality, we assume that $s_i = [1, \ldots, 1]^T$ is the transmitted vector, then the probability $P_j$ is equal to the sum of probabilities that the estimated vector has $\hat{s}[j] \neq 1$. It is to be reminded that a symbol error rate is equivalent to a code symbol (bit) error rate in our analysis because we consider the utilization of BPSK modulation as a SISO encoder for data transmitted at each channel (from each antenna). Consequently, the bit error rate $P_j$ is given by:

$$P_j = \sum_{i=1}^{2^{M_i+1}} Q \left( \sqrt{\frac{\rho \|H_{D_k}\|_F^2}{2M_j}} \right)^i,$$  \hspace{1cm} (5)

where $D_k$ is the Euclidean distance between $s_i$ given above and any other vector $s_k$ where $s_k[j] \neq 1$ and $2^{M+1}$ is the total number of possible erroneous vectors. We assume the independence of errors on bits.

3.2. Comparison of transmission scenarios

Considering a first scenario where block 1 is transmitted over antenna 1 and block 2 is sent over antenna 2, let us consider a binary symmetric channel for the data transmitted from antenna $j$ where the transition probability is $P_j$. Then, the probability that the ARQ process receives correctly the codeword corresponding to the block of $N$ bits transmitted from antenna $j$ is given by:

$$\sum_{i=1}^{N} \left( \frac{N}{i} \right) \left( 1 - P_j \right)^{N-i} P_j^i$$  \hspace{1cm} (6)

where $\left( \frac{N}{i} \right)$ is the binomial coefficient. It corresponds to the number of ways of picking $i$ unordered outcomes from $N$ possibilities.

When a single block is transmitted using scenario 1, it is either transmitted from the antenna 1 with probability $\frac{1}{2}$ or from antenna 2 with probability $\frac{1}{2}$. Then, the probability that this particular block has $i$ errors is:

$$P_{e,i,1,2} = \left( \frac{1}{2} \right) \left( 1 - P_j \right) \left( \frac{N}{i} \right) \left( 1 - P_j \right)^{N-i} P_j^i + \left( \frac{1}{2} \right) \left( 1 - P_j \right) \left( \frac{N}{i} \right) P_j^i$$  \hspace{1cm} (7)

Equation (7) considers a 2-antenna system. We can straightforwardly extend this result to a system with $M_T$ transmit antennas. In such system, the probability that a single block sent using scenario 1 has $i$ erroneous bits is:

$$P_{e,i,M_T} = \left( \frac{N}{i} \right) \frac{1}{M_T} \sum_{k=1}^{M_T} \left( 1 - P_j \right) \left( \frac{N}{i} \right) \left( 1 - P_j \right)^{N-i} P_j^i$$  \hspace{1cm} (8)

In the second scenario, each block is divided into two parts and every sub-block of length $N/2$ is transmitted from one or the other antenna. The probability that the ARQ procedure receives correctly a single block is given by $P_{e,i,2} = \sum_{i=1}^{i} P_{e,i,1,2}$ where $P_{e,i,1,2}$ is the probability that a single block has $i$ erroneous bits when it is transmitted from 2 antennas in the second scenario.

If we assume that the sub-block transmitted from the first antenna contains $l$ erroneous bits, then the sub-block transmitted from the second antenna contains $(i-l)$ erroneous bits. The probability of having $i$ erroneous bits in the block is the sum of all the possible values of $k$, i.e., $0 \leq l \leq i$. Accordingly, the probability that the block has $i$ erroneous bits can be given by the following expression:

$$P_{e,i,2} = \sum_{l=0}^{i} \left( \sum_{k=0}^{i} \left( \frac{N}{i} \right) \left( 1 - P_j \right)^{N-i} P_j^i \right) \left( 1 - P_j \right)^{N-i} P_j^i$$

After developments, we find that:

$$P_{e,i,2} = \left( 1 - P_j \right)^{N-i} P_j^i \left( 1 - P_j \right)^{N-i} P_j^i + \sum_{l=0}^{i} \left( \sum_{k=0}^{i} \left( \frac{N}{i} \right) \left( 1 - P_j \right)^{N-i} P_j^i \right) \left( 1 - P_j \right)^{N-i} P_j^i$$  \hspace{1cm} (9)

It is known that if $N$ is divisible by 2, then the binomial coefficients have the following property:
\[
\binom{N}{i} = \sum_{k=0}^{i} \binom{N}{k} \binom{k}{i-k}
\]

(10)

Using (10), we notice that, as expected, if \( P_1 = P_2 \)
then \( P_{\text{err},I,M} = P_{\text{err},I,M} \).

The average of \( l \) could be given by \( \mathbb{E}[l] = \frac{\lambda}{P_1} \)
because \( l \) corresponds to the number of erroneous bits
contained in the sub-block of \( \frac{N}{k} \) bits transmitted on
antenna 1.

The bit error probabilities \( P_1 \) and \( P_2 \) have the
same distribution with the same mean and variance.
Consequently for a large number of blocks, equivalent
to large number of \( H \) realizations, we can consider that
if \( P_1 \neq P_2 \) then on average:
\[
\frac{1 - P_1 P_2}{1 - P_1 P_2} \approx 1.
\]

Hence,

\[
P_{\text{err},I,M} \approx \binom{N}{i}(1 - P_1)^{\frac{N}{k} - i} P_1^i (1 - P_2)^{\frac{N}{k} - i} P_2^i
\]  

(11)

We can straightforwardly extend (11) to a system
with \( M_f \) transmit antennas.

\[
P_{\text{err},I,M_f} = \binom{N}{i} \prod_{k=0}^{M_f} \frac{1}{P_1^i (1 - P_1)^{\frac{N}{k} - i} P_2^i (1 - P_2)^{\frac{N}{k} - i}}
\]

(12)

According to the above analysis and comparing
(9) and (12), we conclude that for moderate and high
SNR \( P_{\text{err},I,M_f} \geq P_{\text{err},I,M} \) since for any positive real
numbers; the arithmetic mean is higher or equal to the
geometric mean.

Note that when SNR is low, equivalent to high
error rates, and the ratio \( P_1 / P_2 \ll 1 \), it may be better to
sacrifice all the blocks transmitted from antenna 1 than
loosing all the blocks by using scenario 2.

We conclude that when SNR is moderate or high,
the transmission of a codeword on many antennas
increases the probability of receiving a block correctly
by the ARQ process.

The SNR value, \( \rho_3 \), above which the second
scenario outperforms the first one depends on the
channels conditions (i.e., \( P_i \) with \( 1 \leq k \leq M_f \)) as well as
on the error correcting code parameters, \( t \) and \( N \).
Simulation results, presented in section 4, validate
these analytical results and show that \( \rho_3 \) value is
relatively low.

4. Sub-blocks error detection

At the reception side, estimated sub-blocks are
reassembled into a codeword delivered to the FEC
decoder, which then attempts to decode and correct the
errors. When decoding fails, the FEC decoder passes
that information to the ARQ process at the higher
layer. The block retransmissions are requested but
only for those erroneous sub-blocks. The expected
gain is mainly a better use of the bandwidth and thus a
throughput increase.

One way to implement a technique which is able
to recognize error-free sub-blocks is to add a simple
Cyclic Redundancy Check (CRC) to each sub-block.
The ensuing cost is essentially more overhead
(additional parity check bits) as well as more
processing and buffering. The CRC additional parity
check bits costs are considered in our simulations. The
advantage of this method is more pronounced as the
difference between channels quality increases.

Since the receiver is assumed to know the channel
state, it can decide whether or not the use of CRC is
beneficial. The transmitter does not need to know the
channel state to realize this. Instead, the feedback
information sent from the receiver to the transmitter
can indicate if the CRC can be used. We assume that
CRC is only used when the resulting cost is justified.

5. HARQ-MIMO retransmission

Since the number of retransmissions for a block is
limited in truncated ARQ systems, intuitively, we
expect that giving higher priority to retransmitted data
decreases the failure block transmission rate, BLER.
In this section, we propose and examine different
techniques for providing higher link reliability to the
retransmitted data. The five proposed retransmission
techniques are sorted according to their increasing
complexity. For simplicity, we consider \( M_f = 2 \).

5.1. Basic retransmission technique

The basic retransmission technique does not use a
CRC at the sub-block level and the whole erroneous
block is retransmitted anew. No prioritization is
provided to the retransmitted data. This technique will
be used as our base of comparison.

5.2. Alamouti Retransmission (AR) technique

The entire erroneous block is retransmitted
without considering any CRC at the sub-block level.
This scenario prioritizes the retransmission by using
the space-time symbol level diversity coding (i.e.,
Alamouti coding [10]) for each symbol of a
retransmitted block. This physical layer coding
increases the reliability at the cost of lowering the data
rate. It is to be noted that Alamouti coding is added
independently of the HARQ coding. The
retransmission of a single block lasts for two block transmission periods. The bit error probability with Alamouti coding, equivalent to a symbol error probability for BPSK modulation is given by:

$$P = Q\left(\sqrt{\frac{2\rho}{M_r}}\right)$$  \hspace{1cm} (13)

5.3. Transmit Antenna Selection
Retransmission (TASR) technique

The whole erroneous block needs to be retransmitted from the antenna with the “best” channel quality [11]. The retransmission of a single erroneous block requires two block transmission periods. This assumes a perfect knowledge of the channel by the receiver and it is the role of the receiver to indicate – using limited feedback information – the “best” antenna. The other antennas are not used.

5.4. Alamouti and CRC use (AR+CRC)
Retransmission technique

When only a sub-block has to be retransmitted, it is retransmitted using Alamouti space time coding during one block transmission period. The implementation adds some complexity to the buffering and processing. Moreover, if the whole block needs to be retransmitted, it will be retransmitted with Alamouti coding over two block transmission periods.

5.5. Transmit Antenna Selection and CRC use (TASR+CRC) Retransmission technique

When only a sub-block has to be retransmitted, it is retransmitted on the antenna having the “best” link quality. This assumes a perfect knowledge of the channel by the receiver and it is the role of the receiver to indicate the “best” antenna. The other antennas are not used. The implementation adds some complexity. If the whole block needs to be retransmitted, it will be also retransmitted from the “best” antenna but during two block transmission periods.

6. Simulations and numerical results

In this section, simulation results are presented showing the performance improvement obtained by using our transmission techniques. In all the simulations, The extended Golay code \([N=24,K=12, r=3]\) code and \(U_{max} = 3\) have been used.

In figure 2 and figure 3, we compare block error rate, BLER for different \(M_R \times M_T\) MIMO systems with \(M_T = 2\), and \(M_R = 2, 3\) and 4. The BLER are calculated with (6) and (9) where the bit error probabilities are calculated with (5) for each realization of \(H\). This figure show the impact of \(M_R\), the number of receive antennas on BLER using the transmission of each block from one or multiple antennas. The first policy corresponds to the transmission of the bits belonging to a single block from one antenna, while the second policy corresponds to the transmission of the bits of a single block from \(M_T\) antennas.

We observe the BLER improvement when the second transmission policy is used since the BLER is always relatively low, (BLER < 20%). We notice that the improvement of BLER is more pronounced when SNR is higher. We observe also in figure 2 that as \(M_T\) increases, the BLER improvement becomes slightly more significant.

![Fig 2 BLER versus SNR for MIMO systems \(M_T = 2, M_R = 2, 3\) and 4](image1.png)

![Fig 3 BLER versus SNR for different MIMO with \(M_T = 4, M_R = 2, 3\) and 4](image2.png)
Figure 3 illustrates the impact $M_T$ on the gain obtained by the second transmission policy. We observe in Figure 3 that as $M_T$ increases, the BLER improvement becomes slightly more significant.

![Fig. 4 throughput versus SNR for 2x2 system with different retransmission techniques.](image)

Fig. 4 throughput versus SNR for 2x2 system with different retransmission techniques.

![Fig. 5 FBR versus SNR for 2x2 system with different retransmission techniques.](image)

Fig. 5 FBR versus SNR for 2x2 system with different retransmission techniques.

Figures 4 and 5 consider the second policy transmission i.e., transmission of each block from $M_T$ antennas, and compare the performance for 2x2 MIMO system with different techniques for the retransmission of uncorrectable erroneous blocks. The throughput in figure 4 denotes the ratio of blocks correctly received during a certain time. The curves correspond to the techniques detailed in section 5. As expected, using the basic technique gives the higher throughput. However, the basic retransmission technique suffers from the higher failure block transmission rate.

The utilization of Alamouti coding for retransmitted data is obviously more complex than the transmit antennas selection retransmission technique. Nevertheless, Alamouti retransmission technique provides better performances in terms of failure block transmission rate and throughput.

The impact of the CRC utilization is small and we believe that it does not justify the complexity introduced and the cost of the feedback required.

7. Conclusions

We have investigated new link layer data units (blocks) transmission techniques adapted to be efficiently used in MIMO systems. We have proposed to divide every HARQ codeword into sub-blocks transmitted from different antennas using V-BLAST. The use of an error detecting code at the sub-block level has also been proposed in order to retransmit the erroneous sub-blocks only. We have explored different methods to provide better link quality for the retransmitted data.

Analytical studies and simulations show that transmitting every link layer block from the $M_T$ antennas improves the error rate. Simulation results also show that in order to minimize the failure block transmission rate and increases the throughput the system can retransmit the erroneous data with higher priority, using Alamouti coding or transmit antenna selection. Alamouti coding is obviously more complex to be implemented but it outperforms the transmit antenna selection retransmission technique. The introduction of error detecting code at the sub-block level allows retransmitting only the erroneous sub-blocks. However, it adds complexity to the system and does not improve significantly the performances.

The study of our proposed transmission and retransmission techniques with sub-optimal receivers – instead of the ML receiver used in this paper – is presently under investigation.

8. References


