Percentile-based Contention Window Design for Random Access MIMO Interference Networks

Zhenzhe Sun†, Chengnian Long
Dept. of Automation Shanghai Jiao Tong University,
Key Lab. of System Control and Information
Processing, Ministry of Education
Corresponding Author Email: longcn@sjtu.edu.cn

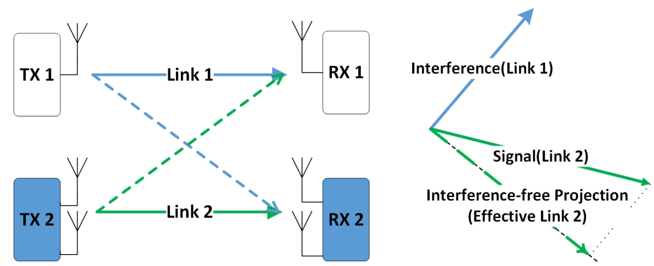
Mary Ann Weitnauer
School of Electronic and Computer Engineering
Georgia Institute of Technology,
Atlanta, Georgia 30332-0250
Email: mary.ann.weitnauer@ece.gatech.edu

***Abstract*—This paper describes a new method for how interfering MIMO links might transmit more effectively in a random access network. We assume perfect transmitter-side channel state information, zero-forcing pre-coding to guarantee no interference on links that have already won access, and zero-forcing receiver processing at the still-contending links to suppress interference from the links that have already won. We define an effectiveness metric, the Instantaneous Equivalent SNR Percentile (IESP), in which the Equivalent SNR is the SNR of a single-input-single-output (SISO) link that would have the same capacity of a MIMO link after its interference constraints have been met and the IESP is the percentile of the Equivalent SNR, assuming independent Rayleigh fading. We propose that fairness among heterogeneous contending links be realized by giving the shorter contention window to the link with the higher IESP based on its own distribution, enabling links with few antennas to compete with links that have many antennas. Through simulation of the sum capacity of the winning set of links, the proposed contention window design is shown to provide a higher sum capacity than contention based on equal-sized windows.**

I. Introduction

Multiple-input multiple-output (MIMO) links are well known to improve spectral and time efficiency by using multiple spatial channels in the same system bandwidth at the same time [1]. The number of degrees of freedom (DoFs), which is the number of antennas, offers some important theoretical boundaries for multiple user MIMO transmissions [2]. Practical techniques such as *zero-forcing* and *interference alignment* [3], *Min-Leakage* and *Max-SINR* [4] and *Minimum Mean Square Error* [5] have been used to manage and suppress interference at both transmitters and receivers in MIMO networks. Assuming the zero-forcing method, we propose a percentile-based metric that could be used to resolve contention between interfering MIMO links in just a few iterations or rounds, in a way that doesn't penalize a link if it has fewer DoFs than the other contending links.

After applying a method of interference cancellation, different links will have different data rates, because some links may have fewer DoFs than others, some links will use a fraction of their DoFs for interference cancellation, and some links have channel outcomes that are better than others. Also, if interference exists in a subspace that is not perpendicular to the best desired signal subspace, then desired signal power will be diminished when the interference is cancelled or suppressed. For example, in Fig. 1, suppose the single-input-single-output (SISO) Link 1 has already been granted access and the 2×2 Link 2 desires access. Link 2 is eligible for access because it can accommodate Link 1, in the sense that it can transmit one data stream, while the second DoF in its transmitter (TX) can be used to avoid making interference on the receiver (RX) of Link 1 and the second DoF in its RX can cancel the interference transmitted by Link 1. All such eligible links could contend with Link 2. However, as shown in Fig. 1b, Link 2's best signal dimension (limited by the interference constraint at Link 2's TX) is not aligned with the interference-free dimension in Link 2's RX, so Link 2's signal power will be diminished. In this paper, we use a percentile approach, which is similar to proportionally fair approach based on the rate that a link can achieve, given the links that have already been granted access.



(a) System Model

(b) Signal and interference power at receiver 2

Fig. 1. Two User Example: contending link 2 transmit concurrently with winning link 1

Other authors have proposed related works for allocating streams and computing transmit and receive beam-forming vectors for MIMO interference channels in ad hoc networks. Using round-robin iterations among links, the scheme of [6] changes the number of streams in a given link if the change increases the overall sum of link capacities of the network; in each iteration, with a given stream allocation and given beam-forming vectors at the other links, each link whitens

†Z. Sun (Email: stephen0520@sjtu.edu.cn) is also a master's student in School of ECE, Georgia Institute of Technology, and this paper is made during his visiting period in Smart Antenna Research Lab in Georgia Institute of Technology.

the noise and interference at its receiver and computes its highest capacity beam-forming weights, therefore the beam-forming approach is greedy and there is no fairness mechanism nor consideration for the best utilization of the network. [7] presents a centralized scheme for a joint optimization of stream allocation and beam-forming weights that implicitly maximizes the sum rate of the network, by minimizing the sum of weighted mean squared errors (MSEs) of the soft received symbols in each MIMO receiver. Their method requires iteration between beam-forming vectors and weighting functions until convergence and assumes global knowledge of the CSI and the MSE at each receiver. In contrast to [6] and [7], the present paper requires neither iteration for optimization nor global knowledge of CSI or MSE, the system can be heterogeneous, and we add a fairness mechanism. The method of [8] includes a persistence-type fairness mechanism. Within a given contention region (i.e., a set of white?MIMO links), nodes obtain explicit information about each others available resources, by piggy backing information onto RTS/CTS packets and by each contending node transmitting in an additional separate time slot training sequences on its maximum number of streams, so other nodes can compute their fair share. The present paper attempts to reduce the overhead in [8] by having the transmitter and the receiver of the winning link in each round of contention transmit their contention control packets respectively *through their beam-forming weights*, computed just prior to that round of contention, thereby necessitating no explicit sharing and no overhead for sharing of their CSI information.

In a MIMO network, either streams or links could contend. If links contend, a winning link will be allocated as many streams as it can support with its available DoFs. If streams contend, the link corresponding to the winning stream is allocated only one stream, even if the activated link could support more streams. There are pros and cons for both methods. We consider link contention, because the contention method of the IEEE 802.11n standard [9] takes a link as one unit and link contention is less complicated.

Contention windows are used for collision avoidance in the IEEE 802.11 standards. Allowing different contention window sizes for different users is also a well known way to give preference to one user in the contention [10]. In this paper, we give the smaller (higher priority) contention window size to the MIMO link that can best use its available resources, as measured by its Instantaneous Equivalent SNR Percentile (IESP, to be defined later). The contention proceeds in stages or rounds, with losing links contending in the next round. Our method is not greedy because we select window size at random rather than always taking the best. Each contending link can calculate its own IESP based on overheard transmissions by the winners in previous rounds, without needing to know information about the other contenders, which makes the proposed algorithm distributed and scalable.

While other metrics, such as capacity, might be used, we prefer IESP because it gives fairness to the links with different numbers of antennas, whereas capacity will give privilege to the links with more antennas.

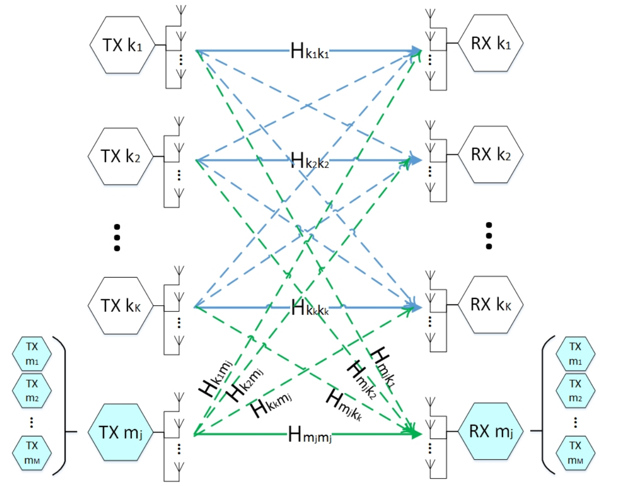


Fig. 2. M links contend to transmit concurrently with K winning links

The rest of this paper is organized as follows. Section II reviews the system model of MIMO interference channels and zero-forcing. Section III presents the algorithm to determine the contention window size. In Section IV, numerical results about the distribution and the improvement of the new approach are offered. Section V concludes the paper.

II. System Model

We assume a multi-user MIMO interference channel, wherein several links contend for the available DoFs. In each round of contention, one of the links that has enough DoFs will win. A general round of contention can be illustrated in Fig. 2, where K links, namely $k_i (i = 1 \dots K)$, have won and the remaining M links, namely $m_j (j = 1 \dots M)$, are still contending to transmit along with the the winning links.

Consider link m_j out of those M links. Let d_{m_j} be the number of multiplexed streams, Nt_{m_j} and Nr_{m_j} represent the number of antenna elements at the transmitter and the receiver, $F_{m_j} \in \mathbb{C}^{Nt_{m_j} \times d_{m_j}}$ be the beam-forming matrix at the transmitter, $C_{m_j} \in \mathbb{C}^{Nr_{m_j} \times d_{m_j}}$ be the combining matrix at receiver, $x_{m_j} \in \mathbb{C}^{d_{m_j}}$ be the transmit signal vector, satisfying $\mathbb{E}[x_{m_j} x_{m_j}^\dagger] = I$, and $n_{m_j} \in \mathbb{C}^{Nr_{m_j}}$ be a vector of Gaussian noise. Let $H_{m_j k_i} \in \mathbb{C}^{Nr_{m_j} \times Nt_{k_i}}$ be the matrix of complex channel gains between the antennas of transmitter k_i and those of receiver m_j and vice versa. In addition, $(.)^\dagger$ is the Hermitian (i.e, complex-conjugate transpose) operation.

Considering the winning links, the decoded signal at the receiver of m_j is given by

$$\begin{aligned} \hat{x}_{m_j} &= C_{m_j}^\dagger y_{m_j} \\ &= C_{m_j}^\dagger H_{m_j m_j} F_{m_j} x_{m_j} + C_{m_j}^\dagger \sum_{i=1}^{K} H_{m_j k_i} F_{k_i} x_{k_i} + C_{m_j}^\dagger n_{m_j}, \end{aligned}$$

where y_{m_j} is the received vector at the receiver. The interference m_j makes on the winning receivers is

$$IF_{sum} = \sum_{i=1}^{K} C_{k_i}^\dagger H_{k_i m_j} F_{m_j} x_{m_j}.$$

In this paper, we assume independent Rayleigh fading channels and perfect transmitter-side channel state information. The approach used to deal with the interference is *Zero-forcing* as in [3]. So for link m_j, the pre-coding weights should satisfy

$$\begin{aligned} & tr\left(\sum_{i=1}^{K} C_{k_i}^{\dagger} H_{k_i m_j} F_{m_j} F_{m_j}^{\dagger} H_{k_i m_j}^{\dagger} C_{k_i}\right) \\ & = tr\left(F_{m_j}^{\dagger}\left(\sum_{i=1}^{K} H_{k_i m_j}^{\dagger} C_{k_i} C_{k_i}^{\dagger} H_{k_i m_j}\right) F_{m_j}\right) = 0, \end{aligned} \tag{1}$$

and the combining weights should be

$$C_{m_j}\left(\sum_{i=1}^{K} H_{m_j k_i} F_{k_i} F_{k_i}^{\dagger} H_{m_j k_i}^{\dagger}\right) C_{m_j}^{\dagger} = 0. \tag{2}$$

With equations (1) and (2), the instantaneous SNR matrix at the receiver of contending link m_j is given by

$$SNRr_{m_j} = \frac{\gamma_{m_j}}{d_{m_j}} C_{m_j}^{\dagger} H_{m_j m_j} F_{m_j} F_{m_j}^{\dagger} H_{m_j m_j}^{\dagger} C_{m_j}, \tag{3}$$

where γ_{m_j} is the transmitting power normalized by noise power (input SNR) in link m_j. The SNR at the receiving side for each individual stream of the link is one of the eigenvalues of this SNR matrix.

The capacity of link m_j in bits/sec/Hz is given by

$$Cap_{m_j} = \log_2\left|I + SNRr_{m_j}\right|. \tag{4}$$

III. Contention Window Design

The main idea of our design approach is to give a smaller window size to the more effective link. First, we define a parameter called "Equivalent SNR" (ESNR) given as

$$SNR_{eq}^{(m_j)} = \left(\left|I + SNRr_{m_j}\right|\right) - 1, \tag{5}$$

where SNR_{m_j} is in (3). It represents the SNR of a SISO link that would have the same capacity of link m_j. The reason we define this is its distribution is easy to get and capacity, as in (4), can be computed directly from it, as

$$C_{m_j} = log_2(1 + SNR_{eq}^{(m_j)}).$$

The effectiveness is evaluated by Instantaneous ESNR Percentile (IESP), defined as the probability that a random ESNR from this distribution is less than or equal to the instantaneous ESNR outcome for this link. High IESP means high effectiveness. The method for obtaining IESP will be described the following sections.

A. A sketch of a protocol for identifying IESP

To compute its IESP, a link needs to know the interference constraints imposed on it from the links that have won in previous rounds of contention. We assume that the contention resolution happens within the coherence time of the MIMO channel gains. We also assume that no two transmitters have the same desired receiver and that each transmitter has identified the MIMO channel between it and its desired receiver. In the first round, each TX transmits an orthogonal training sequence through each pre-coding weight vector (i.e beam) that is optimal for its desired RX, in the absence of interference, at a random time within its computed contention window (CW). Suppose the k_nth TX transmits first and therefore wins the first round; in the meantime, the RX of the m_jth losing link can learn the dimensions of that interfering signal from the training sequences in the packet that was just sent by the kth TX, by estimating $F_{k_n} H_{k_n m_j}$. Next the RX of the winning link transmits through its combining weights, letting all the losing TXs learn $C_{k_n}^{\dagger} H_{k_n m_j}$. Now each losing link that has at least the minimum DoFs to contend in the second round re-computes its pre-coding and combining weights according to (1) and (2). Then the TX of each 2nd-round contending link transmits through its pre-coding weights at a random time within its re-computed CW. The winning RX in the 2nd-round transmits through its combining weights, allowing all third-round contenders to learn the new interference constraints. This procedure continues as long as there are eligible links.

B. Instantaneous ESNR Computation

In the first contention, there is no interference constraint, so for link m_j, C_{m_j} and F_{m_j} are all identity matrices.

In general, if some links have won, Eqn.(1) is solved in terms of a Single Value Decomposition (SVD) as

$$Ut_{m_j} St_{m_j} Vt_{m_j}^{\dagger} = \sum_{i=1}^{K} H_{k_i m_j}^{\dagger} C_{k_i} C_{k_i}^{\dagger} H_{k_i m_j},$$

where $St_{m_j} \in \mathbb{R}^{Nt_{m_j} \times Nt_{m_j}}$ is a diagonal matrix containing the singular values of $\sum_{i=1}^{K} H_{k_i m_j}^{\dagger} C_{k_i} C_{k_i}^{\dagger} H_{k_i m_j}$ ordered in decreasing order from top left to bottom right, Ut_{m_j} and $Vt_{m_j} \in \mathbb{C}^{Nt_{m_j} \times Nt_{m_j}}$ have orthonormal column vectors that respond to the left and right eigenvectors.

The number of DoFs left at the transmitter can be represented by

$$Dt_{m_j} = Nt_{m_j} - rank(St_{m_j}).$$

If $Dt_{m_j} = 0$, it means no DoFs can be offered for signal transmission so the link is not eligible for contention. Else, the subspace available at transmitter m_j can be expressed as an Dt_{m_j}-dimensional space. The orthogonal unit vectors of this space, i.e, the vectors in F_{m_j}, are the eigenvectors corresponding to zero eigenvalues, which are the last Dt_{m_j} columns of Ut_{m_j}.

Similarly, solving (2), the solution SVD can be expressed as

$$Ur_{m_j} Sr_{m_j} Vr_{m_j}^{\dagger} = \sum_{i=1}^{K} H_{m_j k_i} F_{k_i} F_{k_i}^{\dagger} H_{m_j k_i}^{\dagger},$$

where $Sr_{m_j} \in \mathbb{R}^{Nr_{m_j} \times Nr_{m_j}}$ is a diagonal matrix containing the singular values of $\sum_{i=1}^{K} H_{m_j k_i} F_{k_i} F_{k_i}^{\dagger} H_{m_j k_i}^{\dagger}$ ordered in decreasing order from top left to bottom right, Ur_{m_j} and $Vr_{m_j} \in \mathbb{C}^{Nr_{m_j} \times Nr_{m_j}}$ have orthonormal column vectors that respond to the left and right eigenvectors.

The number of DoFs left at the receiver is

$$Dr_{m_j} = Nr_{m_j} - rank(Sr_{m_j}).$$

No transmission is allowed, if $Dr_{m_j} = 0$. Other than that the orthogonal unit vectors of Dr_{m_j}-dimensional interference-free space, i.e. the vectors in C_{m_j}, at the receiver are the eigenvectors corresponding to zero eigenvalues, which are the last Dr_{m_j} columns of Ur_{m_j}.

The numbers of streams in the link m_j is

$$d_{m_j} = min\{Dt_{m_j}, Dr_{m_j}\}. \quad (6)$$

So if $Dt_{m_j} = Dr_{m_j}$, then d_{m_j} streams are transmitted. The SNR matrix can be computed directly by applying (3).

Suppose Dt_{m_j} and Dr_{m_j} are not the same; we assume $Dr_{m_j} > Dt_{m_j}$ because it's almost the same otherwise. Then, we have more DoFs left in the receiver, so we need to find a d_{m_j}-dimensional subspace within the Dr_{m_j}-dimensional space at receiver to maximize the received SNR. To do that, we introduce $T \in \mathbb{C}^{Dr_{m_j} \times d_{m_j}}$ to help find the optimal d_{m_j}-dimensional subspace. Replacing C_{m_j} as $C_{m_j}T$ and (3) becomes

$$SNRr^*_{m_j} = \frac{\gamma_{m_j}}{d_{m_j}} T^\dagger C^\dagger_{m_j} H_{m_j m_j} F_{m_j} F^\dagger_{m_j} H^\dagger_{m_j m_j} C_{m_j} T.$$

To get the maximum received SNRs, we take the SVD of $SNRr^*_{m_j}$ and pick the eigenvectors corresponding to the d_{m_j} largest eigenvalues of the $SNRr_{m_j}$ as columns. After this, F_{m_j} and $C_{m_j}T$ will be the new orthogonal unit vector of signal space at transmitter and receiver respectively. We can compute SNR matrix as well as ESNR by applying (3) and (5).

C. Theoretical ESNR distribution

If we apply zero-forcing in multi-user MIMO independent Rayleigh channels, according to the ideas in [11], the ESNR is distributed as exponential as if the DoFs left on both sides of the link are the same, i.e, $Dr_{m_j} = Dt_{m_j} = d_{m_j}$. For links with only one stream, the mean of the exponential distribution is the input SNR of this link. While for links with multiple streams, the mean of the exponential distribution is related nonlinearly with the number of streams in the link. There is still no closed-form expression, so in this paper, we compute the mean M_{m_j} of link m_j numerically and assume an exponential distribution with this mean.

$$SNR^{(m_j)}_{eq} \sim exp(M_{m_j}). \quad (7)$$

When DoFs of both sides are different, i.e, $Dr_{m_j} \neq Dt_{m_j}$, $|Dr_{m_j} - Dt_{m_j}|$ diversity gains will apply equally to d_{m_j} streams, so the equivalent SNR will follow the gamma distribution with the shape parameter $k = \frac{|Dr_{m_j} - Dt_{m_j}|}{d_{m_j}} + 1$ [12],. If there is only one stream in the link, the scalar parameter of this gamma distribution is the input SNR. For multiple streams, we have

$$SNRr^{(m_j)}_{eq} \sim \Gamma\left(\frac{|Dr_{m_j} - Dt_{m_j}| + 1}{d_{m_j}}, S_{m_j}\right), \quad (8)$$

where S_{m_j} is the scalar parameter under the condition of link m_j.

D. Percentile-based Contention Window Design

We use the distribution corresponding to that specific link to compute the IESP, so that fairness is given to links with different numbers of antennas. The fairness will be explained by an example in the second part of the next section. Other than fairness, another reason we use IESP is to make a distributed algorithm for the decision of contention windows size, without collecting other contenders' information.

To compute IESP for a specific link, like m_j, we compute the instantaneous ESNR and find its distribution for this link first. Then, the IESP of link m_j would be

$$IESP_{m_j} = \int_{-\infty}^{SNR^{(m_j)}_{eq}} f_{m_j}(x)dx, \quad (9)$$

where$f_{m_j}(x)$ is the probability density function of the ESNR distribution of link m_j, which is either a gamma or an exponential distribution.

If we normalize the contention window size by a proper value, namely L_{CW}, the contention window size for link m_j would be $(1 - IESP_{m_j}) \times L_{CW}$.

The Percentile-based CW Design Algorithm is summarized below in Algorithm 1.

Algorithm 1 Percentile-based CW Design Algorithm

compute d_{m_j} using (6)
if $d_{m_j} > 0$ **then**
  Compute SNR_{m_j} using (3)
  Compute $SNR^{(m_j)}_{eq}$ using (5)
  Get the distribution of $SNR^{(m_j)}_{eq}$ using (7) or (8)
  Compute $IESP_{m_j}$ using (9), and set window size
end if

During each round of contention, all the eligible links first compute their contention window size by applying the Percentile-based CW Design Algorithm.

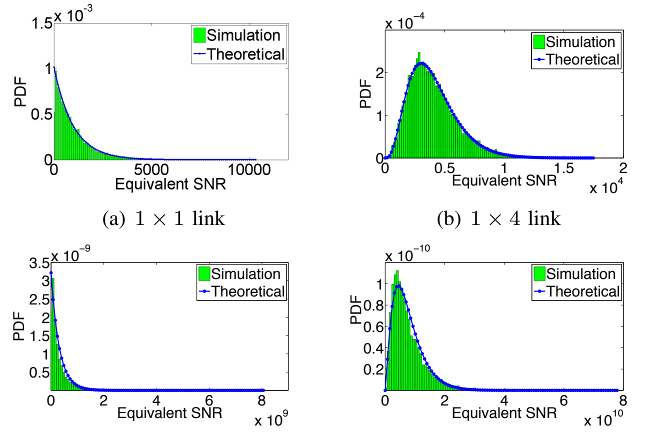
IV. Numerical Results

In this section, we first present a simulation of the theoretical distribution of ESNR. Then, an example about fairness analysis is provided. At last, some numerical results are given to compare the designed contention window to equal-sized contention window. Again, we assume the contention window to be continuous so that the probability of collision between two links is zero.

A. Distribution of ESNR

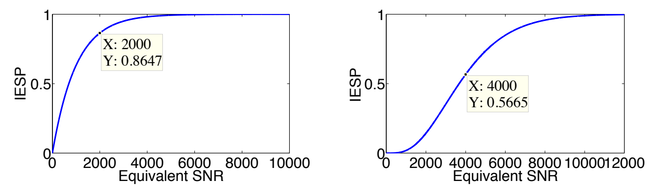
In this simulation, we test the distribution of the ESNR. The input SNR at the transmitter is set to $30dB$, since the distribution of ESNR is not accurate with an input SNR less than $10dB$. The entries of the channel gain matrix H are independent zero mean unit variance Gaussian complex random variables. Zero-forcing is applied to deal with interference for every link.

The simulation of the probability density function is shown in Fig.3. The ESNR of a link is computed 1000 times with



(a) 1×1 link
(b) 1×4 link
(c) 3×3 link
(d) 3×7 link

Fig. 3. Distribution of equivalent SNR simulation under different remaining DoFs



(a) 1×1 link
(b) 1×4 link

Fig. 4. IESP of two different links

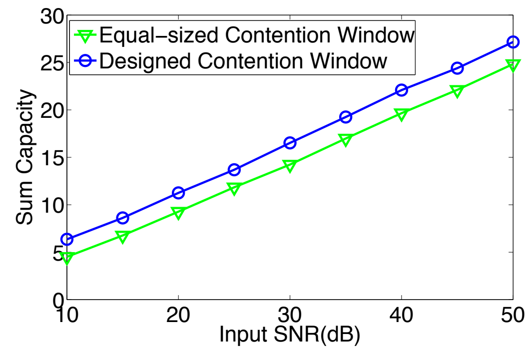


Fig. 5. The comparison of sum capacity between designed and equal-sized contention window when ten links with 1×1 or 2×2 are contending

random channel gains and the distribution is shown as the green bars of the plot. The theoretical exponential or gamma distribution corresponding to the DoFs condition on each link is given as the circled line in each plot.

Four typical situations are considered. Fig.3(a) demonstrates the situation of only one stream in the link, consuming 1×1 DoFs in the link, i.e, the ESNR is exactly the SNR of the stream, and diversity gain of this link is 1. In Fig.3(b), the link is with 1×4 DoFs, one stream in the link, but we have 4th order diversity. Three streams with the same (3×3) and different (3×7) DoFs at both ends of the link are shown in Fig.3(c) and Fig.3(d) respectively.

As we can see from the figure, the simulation results are almost the same as the theoretical ones. So these distributions can be used to compute IESP of the contending links.

B. An example of fairness

In this part, we show a simple example to explain the fairness approach. Assume that one link has already won the first round of contention. Two other links are contending for the remaining DoFs; one of them has 1×1 remaining DoFs after interference constraint, the other one has remaining 1×4 DoFs.

Assume the input SNR of the two links are both $30dB$. If both of the links have only one stream and if the contention were based only on the value of the ESNR, then the 1×4 link is more likely to win because its ESNR is 4000 while the ESNR for the 1×1 is only 2000.

The instantaneous capacity we get from 1×1 and 1×4 links are 11 and 12 respectively. Obviously, 1×4 link has a better capacity. But when we compute the IESP of these two links, as shown in Fig.4, in the 1×1 link, $IESP_{1\times1} = 0.8647$ while in the 1×4 link, $IESP_{1\times4} = 0.5665$. So compared with 1×4 link, 1×1 link uses the channel more effectively(with higher IESP), so we give it a smaller contention window, even if its capacity is smaller.

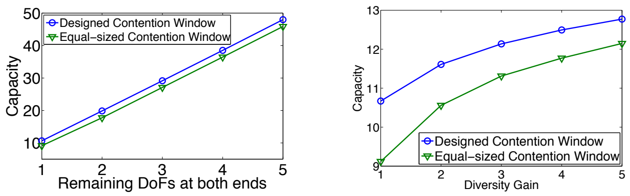
C. The comparison of equal-sized and percentile-based contention windows

With the IESP, we can apply the Percentile-based CW Design Algorithm to design the contention window size in each contending link. Next, we will give some comparisons between designed and equal-sized contention windows.

First, we give a scenario where ten links are contending, starting with the first round. The input SNR is set to be $30dB$. Five out of ten links are 1×1 and other five ones are 2×2. When contention starts, the contention window size is computed independently in each link. The link is chosen by the random number generated in each window. If a 2×2 wins the first round of the contention, there are no more rounds. Else, all the 2×2 links will start up a second contention. Based on 1000 Monte Carlo trials, we plot the average sum capacity versus input SNR in Fig. 5. We see that designed contention windows (line with circles) improves the average sum capacity in this scenario by about 2 (bits/sec/Hz) and the improvement does not change much with input SNR.

Next we would like to know how our algorithm is influenced by the numbers of antennas on both ends of the contending links. So we simulate one round of the contention such that all the contenders have the same number of antennas at their transmitters as well as receivers.

First, the influence of available DoFs in the link is considered. Ten links with the remaining DoFs of $n \times n (n = 1, 2, 3, 4, 5)$ are contending. With an input SNR of $30dB$, the comparison of average capacities of the winning links in this round is shown in Fig.6(a), based on 1000 times Monte Carlo trials. The difference in numbers of DoFs changes only the width of the ESNR distribution, but all 10 distributions are the



(a) Influence from number of link DoFs (b) Influence from diversity gain

Fig. 6. Improvement affect by the numbers of antennas on both ends of the link

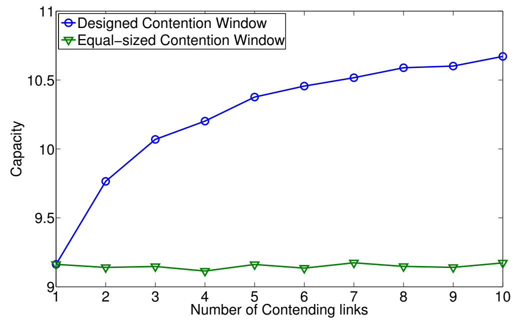


Fig. 7. The comparison of designed contention windows with equal-sized ones when different numbers of links are contending

same. So we expect the improvement from contention window design to not be affected much by the numbers of available DoFs, as proved in Fig.6(a).

The second consideration is the influence of diversity gain in the link. So in this example, ten links with 1 remaining DoF at the transmitter and $n (n = 1, 2, 3, 4, 5)$ remaining DoFs at the receiver are contending. With input SNR of $30dB$ and 1000 trials, the comparison of average capacity is shown in Fig.6(b). The figure shows the well known property that SNR improvements tend to diminish with increasing diversity order.

We also test the effect of numbers of contending links as well. We set the input SNR to be $30dB$, all links are with the available DoF of 1×1, and change the number of contending links. As we can see from Fig.7, the improvement of average capacity tends to be larger when more links are contending. This can be viewed as a form of selection diversity, which improves with the number of choices.

V. Conclusion

In this paper, we propose an approach to optimize the concurrent transmission among MIMO links by setting contention window size. We define the Instantaneous Equivalent SNR Percentile (IESP) as an effectiveness evaluation metric, in which equivalent SNR is defined to be be the SNR of a SISO link that would have the same capacity of a MIMO link after its interference constraints have been met. In each link, we compute the instantaneous equivalent SNR (ESNR) first. Next, the link evaluates the quality of its own ESNR by determining its percentile in the distribution of all possible ESNRs for that link. The link can compute its own IESP without needing to know details about the whole network and without many iterations. The contention window size is determined by this IESP and we summarize this idea to be Percentile-based CW Design Algorithm. By this algorithm, we remove the unfairness caused by the difference in the number of antennas elements in each link. Numerical results show that this algorithm can improve the capacity of the MIMO random access networks.

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