# Distributed Interference Avoidance

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***Abstract*—In unplanned wireless deployments such as femtocells, interference is a major barrier to achieving high data rate. While there exist numerous methods for dealing with planned deployments (macrocells), there are very few effective methods for managing interference in unplanned scenarios. Additionally, most techniques of dealing with interference in unplanned deployments involve exchanging large amount of channel state information, which is infeasible to implement. In this paper, we introduce a distributed way of dealing with interference involving very little information exchange between nodes. We show that this method is very effective in reducing interference to a particular node through simulations.**

## I. Introduction

As a consequence of higher demand for data traffic in cellular systems, there is an increasing trend towards a denser deployment of base stations or access points to increase the data rate of users. As a result, new deployment models, such as femtocells [1] have been considered by many mobile operators as critical factors in the growth of the cellular market.

However, dense deployment of base stations or access points comes with their own set of problems, of which, the most significant is inter-cell interference. There is a consensus among operators and vendors alike that the interference that comes with dense home deployments have to be solved before such deployment scenarios can be seriously considered.

For femtocellular deployments, there are two main interference scenarios which operators are especially concerned with. The first, is the downlink interference a femtocell access point (FAP) can cause to user equipments (UEs) attached to another macrocell basestation (MBS) (from now on denoted as macrocell UE or MUE) due to the utilization of the same frequency spectrum. The second, is the uplink interference caused by MUEs to FAPs.

In interference scenarios, there exist one or more interference source(s) or aggressor(s), and also one or more sufferers of the interference, or victim(s). There are, in general, two ways of mitigating interference. One is to operate on the interference source or aggressor and modify its transmission characteristics such that the interference felt at the victim is reduced. The other alternative is to change the reception behaviour of the victim such that it is less susceptible to interference from the aggressor. In this paper, we aim to achieve interference mitigation through the former, with the victim broadcasting very limited information to the aggressors.

Over the years, numerous proposals on how to contain and manage interference in femtocells have been made. A survey of some of the proposed methods can be found in [2]. One of the most common interference avoidance method is orthogonal channel assignment, which assigns orthogonal sets of channels to neighbouring femtocells and macrocells. However, such interference avoidance methods are extremely bandwidth inefficient and femtocells can only realise a small fraction of the total possible capacity. Additionally, as femtocell deployments are usually customer deployed, operators may have little visibility of the location of neighbouring femtocellls. On the other hand, co-channel assignments will allow a higher transmission capacity and less frequency planning, but at the same time, are much more susceptible to interference from neighbouring cells.

For co-channel assignments, either a centralised or distributed approach to interference management or avoidance can be taken. Centralised approaches usually optimise the resource allocation across all nodes while minimising the interference. However, information required for the task is usually impossibly large to handle. The more promising alternative is the distributed approach, which usually require less information exchange. Some examples of such interference management schemes include distributed resource allocation [3], [4], and distributed power control [5], [6], [7], [8]. Unfortunately, most of these algorithms still require large amounts of information when the number of interferers increases.

It is clear that unless the amount of feedback can be contained, proposed solutions will not be feasible when the number of interferers is large. Consequently, we need a solution where the information exchange required do not scale with the number of interferers. On the other hand, there are reported successes in using only very limited feedback (single bit) to perform traditionally difficult tasks such as distributed beamforming [9], [10], [11], [12] and distributed spatial multiplexing [13]. The algorithms used to perform the distributed tasks are closely related to stochastic optimization [14]. In this paper, we propose the use of the single bit feedback mechanism to perform interference avoidance. Using the single bit feedback, the interferers adapt to minimise interference to a selected node by iteratively changing their transmission behaviours. This can be viewed as the inverse of distributed beamforming algorithms, where different nodes align their beams towards a certain node. Here, the interferers steer the nulls towards the victim node.

The rest of the paper is organised as follows. The next

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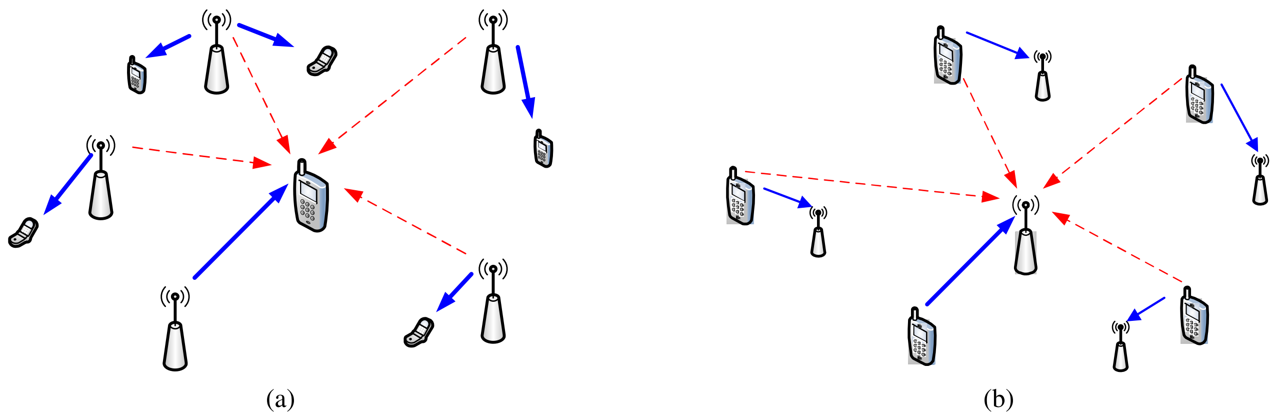

Fig. 1. Multiple interferers scenarios with (a) multiple FAPs, (b) multiple MUEs. The blue arrows denotes desired links, while the red arrows denote interference.

section will describe the system model on which we design the proposed interference avoidance algorithm. This is immediately followed by Section III which describes the proposed algorithm. Section IV presents the simulation results, and the paper is concluded in Section V.

## II. System Model

In this paper, we assume a high density deployment scenario with one victim node and $K$ aggressor nodes. The victim node is equipped with one antenna, while the aggressor nodes are each equipped with $M$ antennas. The victim and aggressor nodes share the same frequency resources. We also assume that channel state information between the nodes are unknown at both the victim and aggressor nodes. Examples of such scenario includes, multiple femto access points interfering with a user equipment of a neighbouring femtocell (downlink interference) as shown in Figure 1(a) or multiple UEs interfering with a FAP (uplink interference) as shown in Figure 1(b). FAPs interfering each other in time domain duplexing (TDD) mode is one other example.

We use $\mathbf{h}_k$, $\mathbf{x}_k(n)$, and $y(n)$ to denote the channel vector from node $k$ to the victim node, the transmit vector from node $k$, and the receive signal at the victim node at time interval $n$ respectively, where node $k = 0$ is the desired transmit node and $k = 1, \ldots, K$ are the aggressor nodes. The received signal at the victim node at time interval $n$ can hence be written as

$$y(n) = \mathbf{h}_0^T \mathbf{x}_0(n) + \sum_{k=1}^{K} \mathbf{h}_k^T \mathbf{x}_k(n) + w(n), \tag{1}$$

where $w(n)$ is the additive white Gaussian noise with variance of $\sigma_w^2$.

In this instance, we assume the presence of $M$ antennas each at the transmit nodes and a single antenna at the receive node. $\mathbf{f}_k(n)$ denotes the transmit beamforming vector at transmit node $k$ at time interval $n$. Consequently, part of (1) can be decomposed as

$$\mathbf{h}_k^T \mathbf{x}_k(n) = \mathbf{h}_k^T \mathbf{f}_k(n) s_k(n), \tag{2}$$

where $\mathbf{f}_k(n) \in \mathbb{F}$ and $\mathbb{F}$ is a set of beamforming vectors or codebook. This codebook is a pre-agreed set of vectors which all the nodes involved in the scheme shared. This can be a set of vectors chosen from the identity matrix to represent antenna selection or beamforming vectors, such as those from a Hadamard matrix. $s_k(n)$ is the transmitted symbol from node $k$ at time interval $n$. We assume that each node will transmit symbols which are independent of each other.

## III. Proposed Algorithm

In this section, we present the proposed iterative distributed interference avoidance algorithm. Here, we assume that mitigation of interference to other parties are prioritised over increasing data rate. Hence, antennas of aggressor nodes are used to reduce interference to victim nodes rather than increasing their own data rates. In essence, all the aggressor nodes attempts to reduce interference through changing their beamforming vectors, and this is done in a distributed manner based on feedback broadcasted by the victim node.

On observation of (1), we can see that in order to remove the interference term, the following cost function needs to be adopted,

$$\min_{\mathbf{f}_k} \mathbf{h}_k^T \mathbf{f}_k(n) \quad \forall k = 1 \ldots K. \tag{3}$$

The physical interpretation of the cost function (3) is that each of the interfering node will try to form a null in the direction of the interfered node, causing each of the interference terms to approach zero. Unfortunately, to achieve the optimal minimization of (3), joint optimization will have to be performed, requiring extensive bandwidth for reporting of channel state information and sending of beamforming vectors. As a result, such algorithms are impractical as large scale reporting of accurate information wirelessly or otherwise to a central entity is infeasible in most communication systems. This problem is not exclusive to beamforming alignment, but also extends to synchronization for distributed or cooperative beamforming [9], [11].

A possible way of solving such a problem is through distributed optimization of beamforming vectors such that aggressors place a null in the direction of the victim(s). However, even so, such optimization requires a minimum of the channel state information (CSI) between the aggressors and victim, which can put a considerably large strain on available resources.

The minimising of the cost function (3) can be achieved by minimising each part separately, *i.e.* $\mathbf{h}_k^T\mathbf{f}_k(n)$. In this paper, this is achieved by an iterative algorithm which attempts to do this at each step. In the initial stage (time interval 0), each of the aggressor nodes will transmit with a beamforming vector of their choice, $\mathbf{f}_k(0)$, and the victim node will record the initial amount of interference power received, $I_0$. The algorithm can run for a prescribed number of iterations, $L$, or when the received interference power at the victim node has dropped below a certain threshold, $I_{Threshold}$.

Before each transmission interval, the aggressor nodes will choose a new beamforming vector randomly from the codebook $\mathbb{F}$, which is pre-agreed among all the participants. The victim node will note the amount of interference power received for that interval, $I(n)$. At the end of each transmission interval, the victim node broadcasts a single bit of data to all the aggressor nodes, signalling either an increase (1) or a decrease (0) in the interference power received. If there is an increase in the interference power received, the aggressor nodes with revert to their previous beamforming vector, *i.e.* $\mathbf{f}_k(n) = \mathbf{f}_k(n-1)$. Otherwise, they will keep this new beamforming vector. Additionally, to ascertain that the interference avoidance is not detrimental to their own communications link, each aggressor node will check that the signal-to-noise ratio (SNR) (through feedback) is above a certain acceptable level. If this is not the case, they will revert to their previously chosen beamforming vector.

The algorithm will iterate until either the interference power level has dropped below $I_{Threshold}$, or the number of iterations have reached $L$. A flow diagram describing the proposed algorithm is shown in Figure 2.

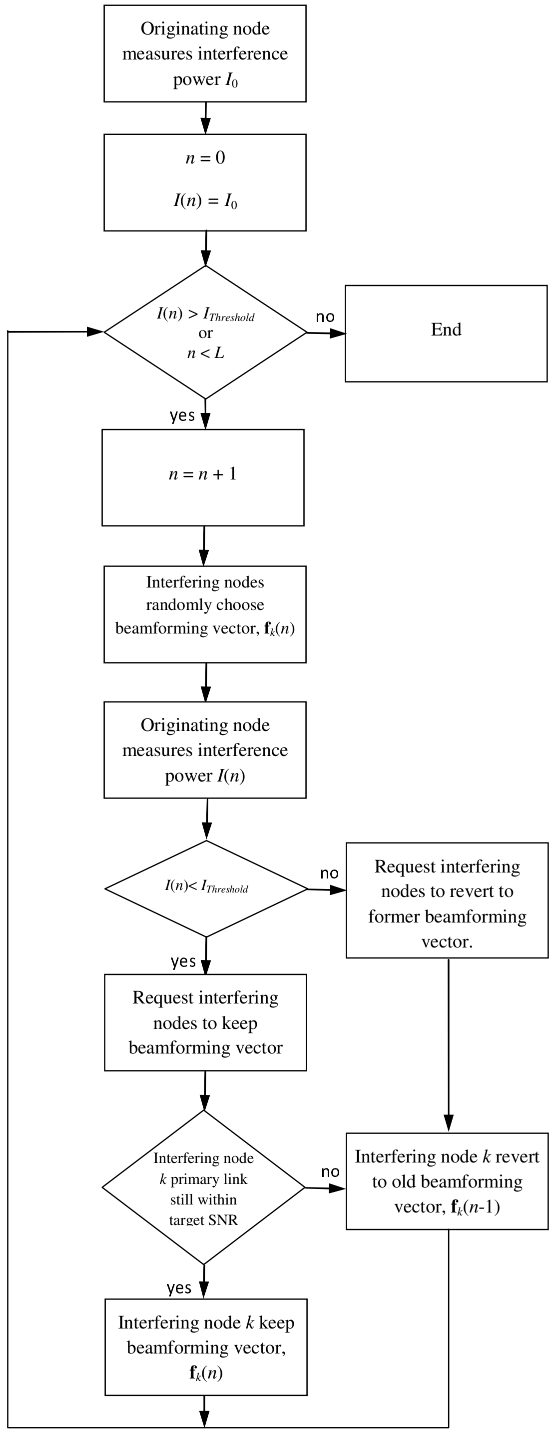


Fig. 2. Flow chart describing the operation of the proposed algorithm.

## IV. Simulation Results

In this section, we present the simulation results to verify the algorithm proposed in Section III. In the simulations, we assume flat Rayleigh fading on all the channels, and that the transmit power of each node is fixed at 1W. Additionally, each aggressor node is equipped with 4 transmit antennas, and has a pre-agreed codebook. For our simulations, we use a Hadamard codebook, *i.e.*, each beamforming vector is chosen from the columns of the Hadamard matrix,

$$\mathbb{H} = \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{pmatrix}. \tag{4}$$

In the first experiment, we assumed 16 interfering nodes, each transmitting independent streams of data. The algorithm is then run for a fixed number of iterations, with $L = \{10, 50, 100, 200\}$. We show the cumulative distribution function (CDF) of received interference power with and without implementing the invented interference control algorithm in Figure 3. The black curve denotes the CDF of received interference power with no interference avoidance or mitigation. The other coloured curves showed the CDF of the received interference power for running the proposed algorithm with different number of iterations. It could be seen that the algorithm results in a reduction of received interference power, with the amount of reduction depending on the iterations of the algorithm performed. The most significant drop in received interference power can be seen with 10-

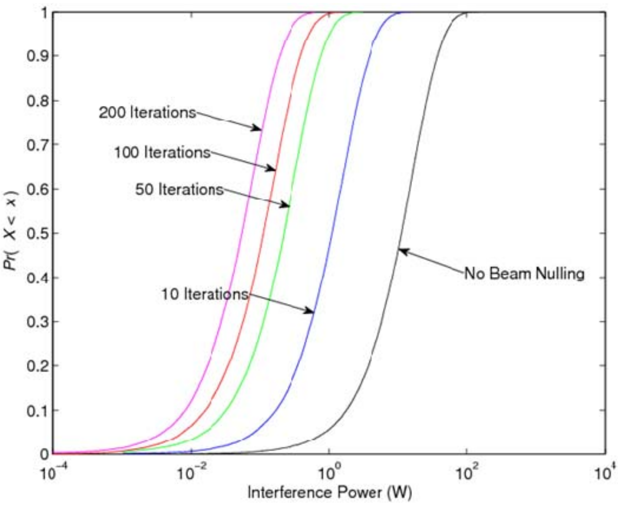


Fig. 3. Interference reduction with 16 nodes with 4 antennas each.

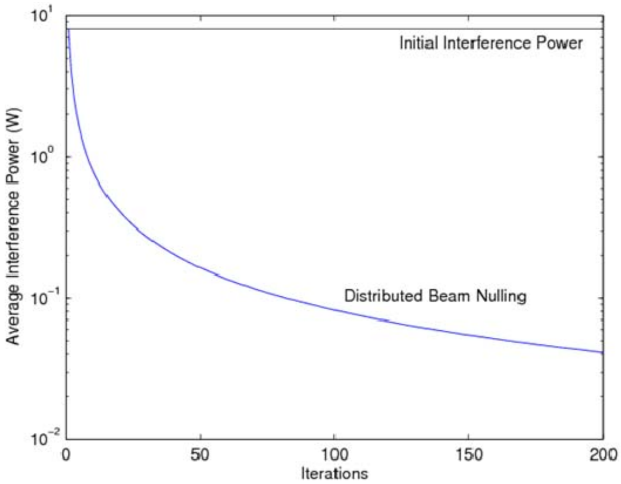


Fig. 4. Average interference power over different iterations of the algorithm..

50 iterations of the proposed algorithms. Additional iterations only brought about diminished returns.

In the second experiment, we assumed 8 interfering nodes. Here, we run the simulation with different number of iterations averaged over 5000 runs. In Figure 4, we show the average interference power experienced by the victim node over the different iterations the algorithm is run. Here, we can observe that 100 iterations resulted in an interference power reduction of up to 80 times, while the reduction is more than 200 times at 200 iterations. Just 10 iterations would be sufficient to effectively reduce the interference power by 10 times.

## V. Conclusion

In this paper, we have presented a distributed interference avoidance/mitigation technique where multiple antennas of neighbouring interferers are exploited to minimize interference to a victim node. The algorithm requires the interferers to participate in the scheme by using their antennas to reduce the interference caused rather than maximising their own throughput. The antennas at the interferers are exploited by aligning their spatial nulls towards the victim node, through either beamforming or antenna selection. The advantage of this technique is that the coordination of the algorithm can be achieved using only a minute amount of information (a single bit) from the victim node.

We have shown through simulations that the technique is able to reduce the interference dramatically even after a few iterations. Even with a small number of iterations, the algorithm is able to reduce the interference power by 10 times and up to 80 times if continued for 100 iterations.

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