IJCSC International Journal of Computer Science and Communication Vol. 3, No. 1, January-June 2012, pp. 181-185

COLLABORATIVE BEAMFORMING FOR WIRELESS AD-HOC NETWORKS

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ABSTRACT

In this paper, we present collaborative/cooperative beam forming for wireless ad-hoc networks. Via collaborative beamforming, nodes in wireless network are able to transmit a common message over a long distance in an energy efficient manner. To improve the performance, we have developed a cooperative beamforming algorithm. The idea of cooperative beamforming is to take the help of neighboring nodes to form a beam of electromagnetic energy i.e. the idea of antenna array is used. Since, in this type of network the nodes cannot have antenna array to implement beamforming, we take the help of nearby node to participate in beamforming process. Source node in the network is allowed to transmit. Collaborating nodes receives the transmitted packets. Subsequently each collaborating node transmits its received signal. One or multiple beams are formed each focusing on one destination node and reinforcing the signal intended for a particular destination as compared to the other signals. The proposed work achieves higher throughput and improved SNR in the ad-hoc network.

Keywords: Beamforming, Collaborative, Throughput, Ad-hoc Networks.

1. INTRODUCTION

In last few years, there has been tremendous updation in wireless networks and a big interest has been developed in ad-hoc wireless networks. An Ad-hoc wireless network is a network, comprised of mobile computing devices that use wireless transmission for communication, having no fixed infrastructure. The mobile devices also serve as routers due to the limited range of wireless transmission of these devices that is several devices may need to route or relay a packet before it reaches its final destination. Ad-hoc wireless networks can be deployed quickly anywhere and anytime as they eliminate the complexity of infrastructure setup. These networks find application in several areas; some of them are military, collaborative and distributed computing wireless sensor networks and hybrid wireless networks. The special features of mobile ad-hoc networks bring the technology great opportunities together with different challenges. A challenge in the area of wireless ad-hoc network is transmission of signal over a long distance requires significant amount of energy in order to overcome attenuation. Energy is usually a scarce commodity in wireless ad-hoc networks, as nodes typically operate on batteries, which in many cases are difficult to replace or recharge. Thus, energy-efficient schemes for long-distance transmission in wireless networks have recently been of much interest. In some such situations, multihop may be a preferred solution. However, there are several challenges in transmitting real-time services over multiple hops. Also, multihop networks require a high node density which makes routing difficult and affects the reliability of link [1].

Recently, a collaborative beamforming technique was proposed in [3], in which randomly distributed nodes in a network cluster form an antenna array and beamform data to a faraway destination without each node exceeding its power constraint. The destination receives data with high signal power. A challenge with implementing beamforming in ad-hoc networks is that the geometry of the network may change dynamically.

In this paper we propose a scheme that is based on the idea of collaborative beamforming, and reduces the time required for information sharing. A preliminary version of the proposed scheme appeared in [4]. The work in this paper contains error analysis that provides insight into the performance of the proposed approach. The main idea is as follows. Source node in the network is allowed to transmit. Collaborating nodes receive the transmitted packets. Subsequently, each collaborating node transmits its received signal. One or multiple beams are formed, each focusing on one destination node, and reinforcing the signal intended for a particular destination as compared to the other signals.

The rest paper section II describes Beamforming Background. Section III describes the Proposed scheme. Section IV presents Simulation. Finally section V Conclusions.

2. BEAMFORMING BACKGROUND

For simplicity, let us assume that source and destination are coplanar. We index source nodes using a subscript t, with t_i denoting the i-th node. At slot n, one source node tm needs to transmit the signal $s_m(n)$ to a faraway destination node q_m. Suppose that set of N nodes, designated as collaborating nodes $c_1, \ldots, c_N$, have access to $s_m(n)$. The locations of these collaborating nodes follow a uniform distribution over a disk of radius R. We denote the location of c_i in polar coordinates with respect to the origin of the disk by (r_i, Ψ_i). Let $d_{im}(\varphi_m)$, or simply d_{im}, represent the distance between c_i and the destination q_m, where φ_m is the azimuthal angle of q_m with respect to the origin of the disk. $d_{0m}(\varphi_m)$ or d_{0m} *denotes* the distance between the origin of the disk and q_m, so the polar coordinates of q_m are (d_{0m}, φ_m). Moreover, let $d_i(\varphi)$ denote the distance between c_i and some receiving point with polar coordinate (d_{0m}, φ). The initial phases at the collaborating nodes are set to

$$\Psi_i(\phi_m) = -\frac{2\pi}{\lambda} d_{in}(\phi_m), \ i = 1, \ldots, N \tag{1}$$

This requires knowledge of distances (relative to wavelength λ) between nodes and destination, and applies to the closed loop case [3]. Alternatively, the initial phase of node i can be

$$\Psi_i(\phi_m) = \frac{2\pi}{\lambda} r_i \cos(\phi_m - \Psi_i) \tag{2}$$

which requires knowledge of the node's position relative to some common reference point, and corresponds to the open loop case [3].

The path losses between collaborating nodes and destination are assumed to be identical for all nodes. The corresponding array factor given the collaborating nodes at radial coordinates $r = [r_1, \ldots, r_N]$ and azimuthal coordinates $\Psi = [\Psi_1, \ldots, \Psi_N]$ at location with polar coordinate (d_{0m}, φ) is

Finally, the average beampattern can be expressed as [3]

$$P_{av}(\phi) = E_z\{|F(\phi\,|\,z)|^2\} = \frac{1}{N} + \left(1 - \frac{1}{N}\right)\left|2\frac{J_1(\alpha(\phi;\phi_m))}{\alpha(\phi;\phi_m)}\right|^2 \tag{3}$$

When plotted as a function of φ, $P_{av}(\varphi)$ exhibits a main lobe around φm, and side lobes away from φm. It equals one in the target direction, and the side lobe level approaches $1/N$ as the angle moves away from the target direction. The statistical properties of the beampattern were analyzed in [3], where it was shown that under ideal channel and system assumptions, directivity of order N can be achieved asymptotically with N sparsely distributed nodes. As we have noted, all of the collaborating nodes must have the same information to implement beamforming. Thus, the source nodes need to share their information symbols with all collaborating nodes in advance.

3. THE PROPOSED SCHEME

Here we refine the model of [3], focusing more directly on the physical model for the signal, fading channel and noise. In addition to the above assumptions, we will further assume the following:

1. The network is divided into clusters, so that nodes in a cluster can hear each other.
2. A slotted packet system is considered, in which each packet requires one slot for its transmission. Perfect synchronization is assumed between nodes in the same cluster.
3. Nodes transmit packets consisting of phase-shift keying (PSK) symbols each having the same power. Also, nodes operate under half-duplex mode, *i.e.*, they cannot receive while they are transmitting.
4. Communication takes place over flat fading channels. The channel gain during slot n between source t_i and collaborating node c_j is denoted by $a_{ij}(n)$. It does not change within one slot, but can change between slots.
5. The distances between collaborating nodes and destinations are much greater than the maximum distance between source and collaborating nodes.

Suppose that cluster C contains J nodes. During slot n, source nodes $t_1 \ldots t_K$ need to communicate with nodes $q_1, \ldots, q_K$ that belong to clusters $C_1, \ldots, C_K$, respectively. The azimuthal angle of destination q_i is denoted by φ_i. The packet transmitted by node t_i consists of L symbols $s_j(n)$. Due to the broadcast nature of the wireless channel, non-source nodes in cluster C hear a collision, i.e., a linear combination of the transmitted symbols. More specifically, node c_i hears the signal

$$x_i(n) = \sum a_{ji}(n)\, s_j(n) + w_i(n) \tag{4}$$

where $w_i(n)$ represents noise at the receiving node c_i. Let q_m denote the destination of $s_m(n)$. In slot $n + m$, $m = 1 \ldots K$, each collaborating node c_i transmits the signal

$$x_i(n+m) = x_i(n)\, \mu_m a^*_{mi}(n)\, e_i^{\Psi}(\varphi_m) \tag{5}$$

where μ_m is a scalar used to adjust the transmit power and is the same for all collaborating nodes. μ_m is of the order of $1/N$.

Collaborating nodes need to know which are source nodes and then estimate the channel between all source nodes and themselves. Also, collaborating nodes require the knowledge of their initial phases. To obtain initial phases, collaborating nodes also require knowledge of the azimuths of the destinations so that the beams can be steered toward desired directions. Given the collaborating nodes at radial coordinates r and azimuthal coordinates Ψ, the received signal at an arbitrary location with polar coordinates (d_{0m}, φ), is

$$y(\varphi; m \mid r, \Psi) = \sum b_m x_i(n+m)\, e^{j2\pi/\lambda\, d_i(\varphi)} + v(n+m) \quad (6)$$

where v (n + m) represents noise at the receiver during slot n + m.

4. SIMULATIONS AND RESULTS

In this section we study the BER performs of the proposed method via simulation. We assume a playground area of network as 8 × 8. This area is two dimensional. Then 400 nodes with uniform distribution populate this area. Then this area is divided into four clusters. The simulation is performed using 8, 16 and 32 nodes along with 2 and 4 nodes as a collaborating node. Figure 1 and figure 2 shows the BER versus SINR. It shows that BER for 32 nodes is better than other two i.e. 16 and 8 nodes. Figure 3 and figure 4 shows for different numbers of collaborating nodes. Also BER is better for 16 nodes as compared to 8 nodes. Hence we can say that BER depends on the number of collaborating nodes.

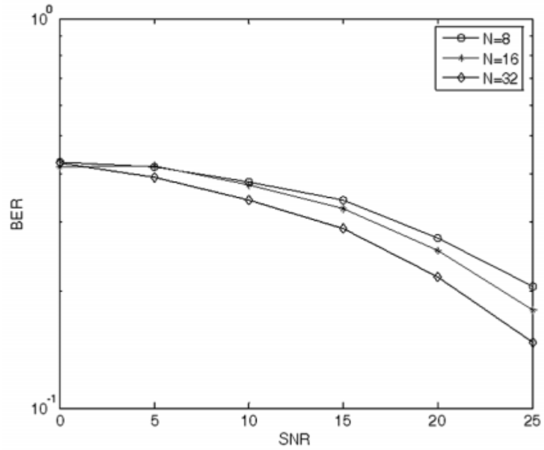

Figure 1: BER vs. SNR; *N* = 8, 16,32

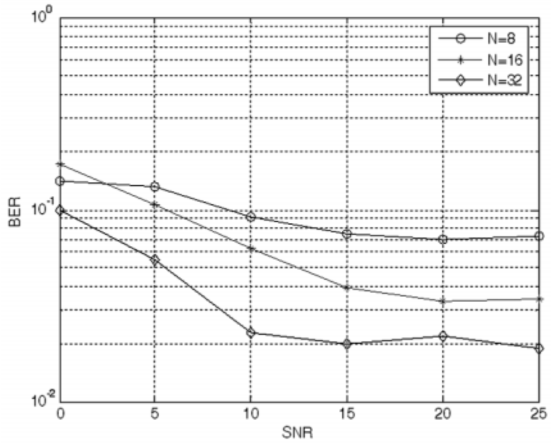

Figure 2: BER vs. SNR; N = 8, 16, 32; 2^8 Symbols

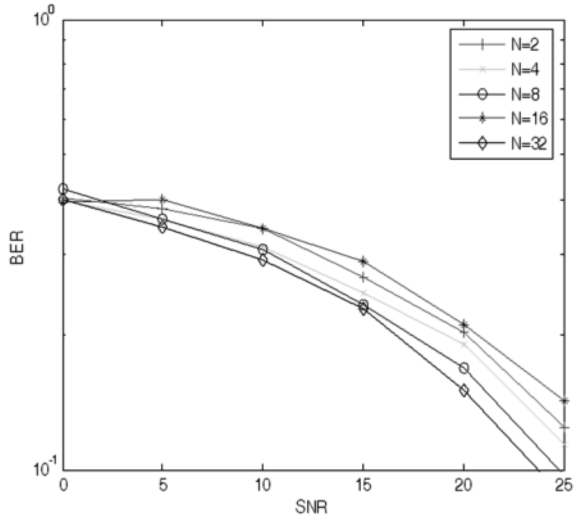

Figure 3: BER vs. SNR; *N*= 2,4,8, 16, 32

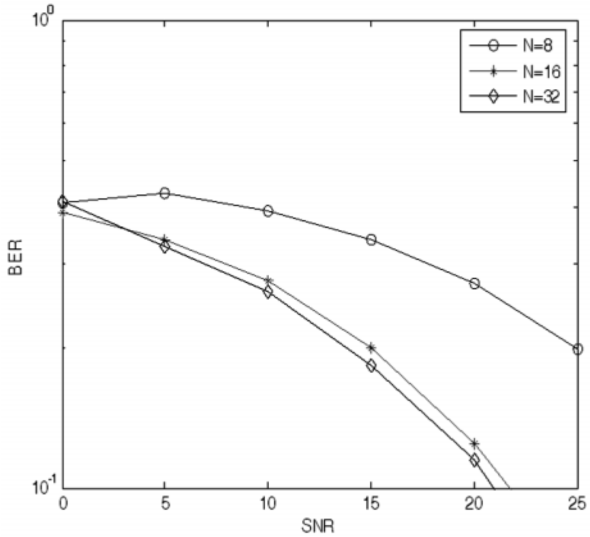

Figure 4: BER vs. SNR; *N*= 8, 16, 32

It was assumed that the network is randomly generated and during this case this generated network the position of network nodes is not changing and even the source and destination fixed. In this case the different collaborating nodes are considered and simulation was performed for above case. Figure 5(a) to 5(e) shows the result for above case. Figure 5(a) shows for 2 nodes as a collaborating nodes. Similarly figure from 5 (b) to 5 (e) shows for 6, 8, 16 and 32 as collaborating nodes. One can see that as collaborating nodes increase we get good beam pattern as in above case. If beam pattern obtained in the case of 2 nodes as collaborating with the case 6 nodes as collaborating it is observed that good beam are obtain in case of 6 nodes as collaborating nodes. Good beam pattern and more directivity in desired direction are observed if number of collaborating nodes increases. The main lobe is of interest which is in desired direction and other are the side lobe in any undesired direction. Side lobes are unwanted because they waste power.

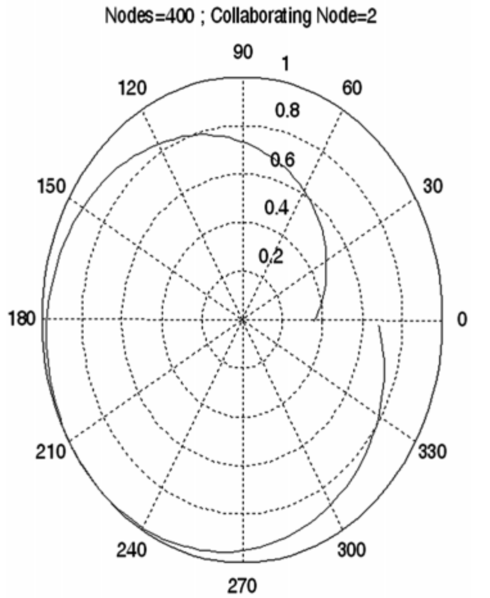

Figure 5(*a*): Nodes=400,Collaborating Nodes=2

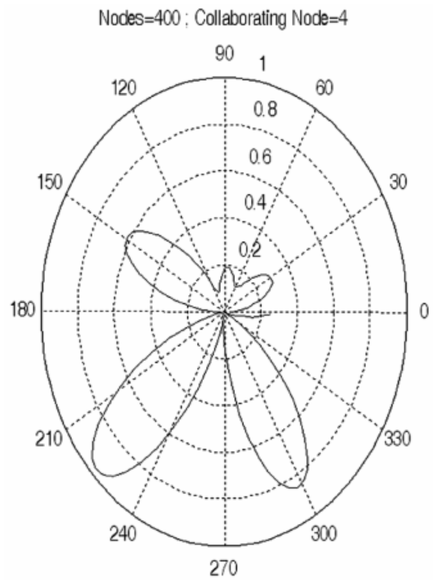

Figure 5(*b*): Nodes=400,Collaborating Nodes=4

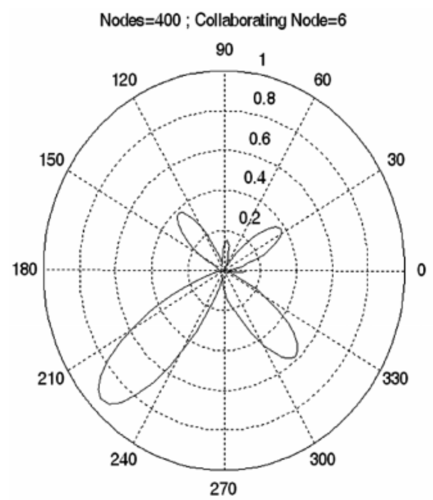

Figure 5(c): Nodes=400,Collaborating Nodes=6

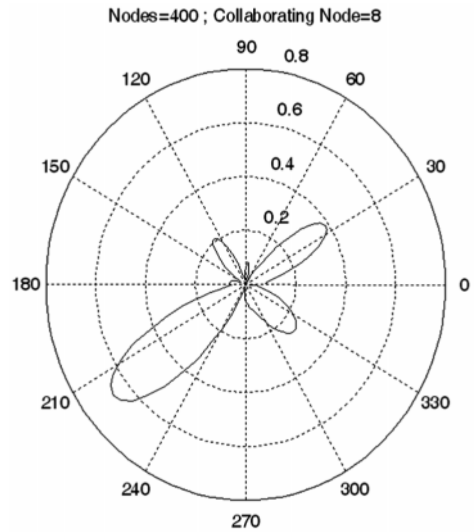

Figure 5(*d*): Nodes=400,Collaborating Nodes=8

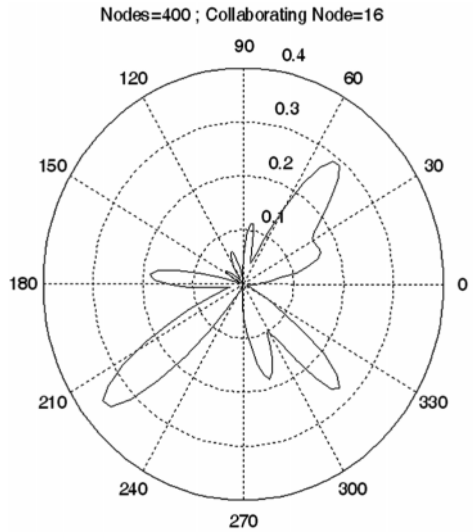

Figure 5(*e*): Nodes=400,Collaborating Nodes=16

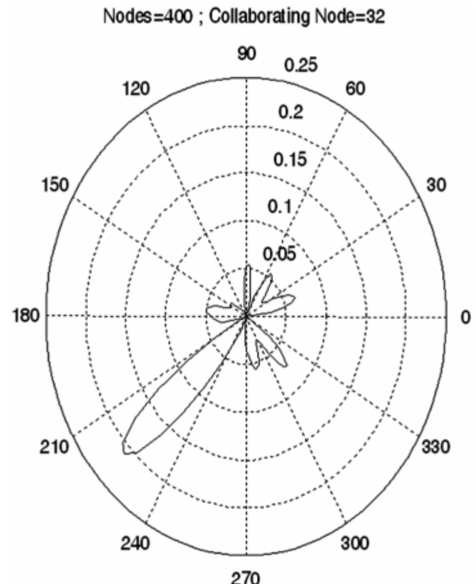

Figure 5(*f*): Nodes=400,Collaborating Nodes=32

5. CONCLUSION

We have proposed a scheme for wireless ad-hoc networks that uses idea of collaborative beamforming. We have provided analysis of SEP(Symbol error probability), which shows how performance depends on the number of collaborating nodes. Hence we conclude that the beamforming enhances the capacity and the power consumption reduction for retransmission.

On the other hand if a single source can already communicate with intend destination at the desired rate and range then beamforming can be employed to reduce the transmit power per source and to reduce the energy radiated in undesired directions, which can be exploited for energy efficient in many applications.

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