INTERFERENCE AWARE ROUTING FOR CDMA WIRELESS AD HOC NETWORKS

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ABSTRACT

The CDMA technology represents an appealing choice for ad hoc networks deployments in military communications, due to its intrinsic resistance to jamming and interference, and its low probability of intercept property. On the other hand, ad hoc CDMA network performance is severely limited by strong interferers, and for peer-to-peer communications the near-far effect problem cannot be mitigated through power control as in cellular systems. In this paper, we propose to alleviate the near-far problem at the network level, by designing an interference aware routing scheme. The proposed routing algorithm seeks to minimize the total energy expenditure for an end-to-end path, subject to constraints on the interference caused by the nodes participating in a route to other nodes in their neighborhood. Our simulation results using this routing technique show improvements in throughput of up to 60%, compared with the classic minimum energy routing approach. These improvements are achieved at the expense of only a slight increase in the average energy per bit transmission for an end-to-end path.

Index terms - *routing metric, routing protocols, CDMA*

INTRODUCTION

In wireless ad hoc networks there is no fixed infrastructure and no centralized management. The network topology is dynamically changing based on the location of the nodes and the transmission conditions. Nodes can communicate with other nodes either directly or via intermediate nodes. The choice of a route in a multi-hop network can influence the overall network performance by effectively changing the spatial interference distribution in the network.

An important performance measure in ad hoc network is the network lifetime, there has been a keen interest in the literature for designing energy efficient routing protocols for ad hoc networks. For example, a performance comparison for different protocols such as DSR [1], DSDV [2], AODV [3], and TORA [4], based on energy consumption, is presented in [5].

Designing an energy efficient routing protocol usually implies a cross-layer component [10] [11], since the energy expended for transmission on a particular link depends on the type of physical layer access technology used, whether or not the network is power controlled, the type of the receiver, and the choice of channel codes.

While many studies in the literature have focused on simple collision models for the physical layer (due to easier deployment schemes), CDMA technology provides some very attractive features for these kinds of networks, especially for military applications: soft QoS degradation, resistance to jamming and interference and low probability of intercept. On the other hand, CDMA ad hoc network performance is severely limited by strong interferers, i.e., by the near-far effect.

A classical solution to mitigate the near-far effect problem is to enforce equal received powers through power control, i.e., the desired signal and all the interference signals are received with the same power at the receiving node. While power control can still improve the performance in ad hoc networks, due to their peer-to-peer communication nature, interference will be perceived at the receiving nodes at various levels, thus resulting in near-far effect. The near-far problem can also be mitigated by using multi-user receivers [13], with a penalty in the increased computational complexity and overhead [15].

Our proposed solution is to alleviate the near-far problem using a network level approach. The routing criteria we use is the energy per bit consumption minimization, subject to constraints on avoiding near-far effect hot spot nodes. We consider as near-far effect hot spot nodes, the nodes that create high interference to their neighbors. Our solution departs from the classic minimum energy routing approach by imposing a level of cooperation in determining the routes. Minimum energy routing considers only the cost associated with the current route, while our proposed algorithm also accounts for the interference impact of the route on the neighboring nodes.

Our simulation results using this routing technique show improvements in throughput of up to 60%, compared with the classic minimum energy routing approach. These improvements are achieved at the expense of only a slight increase in the average energy per bit transmission for an end-to-end path.

The remaining of this paper is organized as follows. We first present the system model and present how the nodes are organized in the network. Then we present the performance metric. This follows by interference aware routing algorithm and finally we present the simulation results and conclusion.

SYSTEM MODEL

The ad hoc network consists of *N* nodes, randomly positioned in a given deployment area. The nodes can transmit, receive or relay traffic. In our simulation results we have considered the nodes as being uniformly distributed in a square area, with half of the nodes being transmitting nodes and the remaining half receiving nodes.

The network is operating at maximum load when all the transmitting nodes are sending information to their corresponding destinations.

All nodes (transmitting or receiving) can participate in a route as relaying nodes. A relaying node transmits the traffic using one or multiple codes (multi-code CDMA).

In the first case, time multiplexing (TM) is used to relay packets for different flows. Since the transmission power is considered equal for all transmitting nodes, this scenario results in equal interference created by all nodes in the network. The interference level is not affected by the routing protocol. As a disadvantage, since the relayed flows are time multiplexed, the throughput per flow goes down proportional to the number of multiplexed flows. In order to limit the throughput degradation a maximum number of relayed flows at a given node must be imposed: α_{max}.

If the relayed traffic is simultaneously transmitted using multi-codes (one code per flow) the interference created by a particular node varies with the number of relayed flows, and it is thus influenced by the routing protocol. The interference level can again be bounded by imposing a limit on the maximum number of relayed flows (α_{max}). This limit imposed on the number of packets that a node can relay also yields more uniform battery utilization across all nodes in the network.

PERFORMANCE METRICS

We consider as performance metrics for the routing protocol the average energy per bit expended on an end-to-end path, and the average throughput obtained on an end-to-end path. Both metrics are tightly related to the current link quality characterized by the bit error rate (BER).

A certain target bit error rate (BER) constraint is defined as a physical layer requirement (e.g. 10^{-2} for voice, 10^{-4} for data). The BER constraint can be mapped into an equivalent target signal to interference ratio (SIR) requirement. For the case of data communication, the packets received in error must be retransmitted until they are correctly received. The energy consumed for the transmission of a data packet can be defined as in [14] to be

$$E_b = \frac{MP_i}{mRP_C(\gamma)}, \qquad (1)$$

where *M* is the length of the packet, *m* is the number of information bits, *R* is the transmission rate for this node, and $P_C(\gamma)$ is the probability of correct reception. As we can see from (1), the energy per bit consumption is reduced when the achieved SIR is higher and/or the transmission rate is higher.

In order to estimate the achieved SIR for a particular link, for our simulations we consider a simplified path loss model with propagation exponent $n=2$. Consequently, the received signal power P_r from the i^{th} node, depends on the link gain h_i, and is given by [7]

$$P_r = P_t \frac{\lambda^2}{d^2} = P_t h_i, \qquad (2)$$

where the link gain for user i, h_i is defined as

$$h_i = \frac{\lambda^2}{d^2}. \qquad (3)$$

In the above formula, λ is the wavelength, d is the distance of the i^{th} node from the receiver and P_t is the power transmitted by the i^{th} node. The signal to interference ratio for a link between nodes (i,j) is then calculated as

$$SIR_{(i,j)} = \frac{h_{(i,j)}P_i}{\frac{1}{L_i}\sum_{k=1,k\neq i,j}^{N} h_{(i,j)} m_k P_k + \sigma^2}, \qquad (4)$$

where $h_{(i,j)}$ is the link gain for link (i,j) and σ^2 is the thermal noise power. P_i represents the transmitted power of the i^{th} node, m_k represents the number of codes used for transmission by user k (m_k = 1 for time multiplexing), and L_i is the spreading factor for the code of user i.

For equal power transmission (P_t) and for a given measured SIR of a link (i,j), the maximum spreading gain that can be used by user i using code s_i (i.e., maximum transmission rate) can be determined as:

$$L_i = \frac{SIR_{(i,j)} \sum_{k=1,k\neq i,j}^{N} h_{(i,j)} m_k}{h_{(i,j)} - SIR_{(i,j)} \sigma^2 / P_t} . \quad (5)$$

Equation (5) determines the throughput of link (i,j) for the current measured SIR. The throughput for an end-to-end route is the minimum of the throughput of all the links in a route. The link with the least throughput is the bottleneck for that particular route.
Alternatively, a constant rate may be used for transmission and the transmitted powers may be adjusted accordingly using a power control algorithm. This is subject of future work.

INTERFERENCE AWARE ROUTING

Routing protocols are generally classified into two types: table driven protocols and on demand routing protocols. In table driven protocols a table of next hop to the destination is maintained [16] and updated according to changes in the network configuration. On demand routing protocols do not maintain any information about the routes. These protocols initiate route discovery requests only when needed. The algorithm presented here is suitable for table driven implementation, due to the fact that the route selection is optimized based on the cost information for the overall network.

The near-far effect is strongly affected by the nodes' position in the ad hoc network. We consider as near-far effect hot spot nodes, the nodes that create high interference to their neighbors. More specifically, a near-far effect hot spot node is defined to be a node that creates interference to its neighbors that it is higher than a threshold T, which is a parameter of the algorithm.

The network performance is affected by the level and distribution of the interference in the network, which can be controlled by (a) seeking minimum energy routes - optimizes the current route performance, (b) avoiding near-far effect hot spot nodes – accounts for the impact of the current route on the network performance.

Our routing approach departs from the classic minimum energy routing by imposing a level of cooperation in determining the routes. Minimum energy routing considers only the cost associated with the current route, while our proposed algorithm also accounts for the interference impact of the route on the neighboring nodes.

The proposed algorithm starts by determining a source to destination route using a minimum energy metric, based on the routing table available at the transmitting node. After a minimum energy route has been determined, the amount of interference caused by each node in a route to receiving neighboring nodes is estimated. If the interference caused to other transmissions is greater than a threshold T, we label the node as a probable near-far effect hot spot node, and we exclude the node from the current route.
Once a node is excluded from the current route, a new minimum energy route is determined for the remaining possible relaying nodes. The algorithm is repeated several times, every time generating a new possible path. The number of possible paths (D) is equal to the number of iterations. As the best path is selected among these candidates, more choices may give better performance, but at the expense of an increased computational complexity.

This process continues for the remaining pairs of communicating nodes until all the routes are completed. Due to the fact the all the routes are cross-coupled through interference, a new route selection may trigger re-routing for previously selected routes. To avoid this situation, we fix the routes once determined, and optimize the throughput/energy performance at the physical layer, by adjusting the transmission rate, via variable spreading gain. The routing algorithm is summarized below.

The Routing Algorithm

D: depth of algorithm
T: threshold of interference
n: number of available nodes for relaying

```
FOR all transmitters
    n = N-1;
    Find minimum energy route to the destination (using n
                                          available relaying nodes)
    Save route;
    FOR 1:(D-1)
        FOR each node in route
          Determine interference contributed by each node
          IF interference above threshold T
               Exclude node and find new minimum
                              energy route to the destination
```

(n = n-1 available relaying nodes).
END if
Save route;

END (for each node in route)
END D
Select best route out of D candidates
END For all transmitters

Figure 1: Algorithm for interference aware routing

The performance metrics considered are the end-to-end average throughput and the energy per bit. The throughput for a route is given by the throughput of the weakest link in the route, which will impose the performance bottleneck for an end-to-end transmission. In this scenario, although we significantly improve the throughput for most of the links in a route, the overall throughput is still given by the bottleneck link. It may be thus more efficient to reduce the transmission power rather than increase transmission rate, when the throughput is limited by a weak link. We expect further performance improvement if power control is used to reduce interference when increasing the rate is not beneficial. We are currently investigating this extension for the proposed algorithm.

SIMULATION RESULTS

The network consists of *N* nodes distributed in a square region of *100* x *100* m^2. The nodes are uniformly distributed in a region and are considered to be fixed for the simulation purposes. The number of nodes in the network is varied between a minimum number of 5 nodes, and a maximum number of 40 nodes. Target SIR (γ) is 5. Bandwidth of the system is 1 MHz and packet size is 1024 bytes. We consider half of the nodes as transmitters and half of the nodes as receivers.

We assume that a node configured as a transmitter has infinite data in it's transmit buffer. The path from source to destination may involve multiple hops (nodes). All nodes are capable of relaying packets. To avoid loops, a node cannot be repeated in a route from source to destination.

The transmitting and relaying nodes transmit in a time slot with a fixed power P_t. In case of time multiplexing, the transmitting power remains fixed irrespective of the number of nodes. In the case of simultaneous transmission, each code transmits with a power P_t, for a total of mP_t transmission power for m simultaneous transmissions.

We consider a CDMA air interface. Higher spreading gains reduce the number of information bits in a data packet. Throughput is determined based on the spreading required to achieve a certain target bit error rate (10^{-2}). The throughput is computed as the ratio of the number of data bits in a packet to the number of redundant bits [7].

Figure 2 shows the achieved throughput for minimum energy transmission schemes (simultaneous transmission -ST and time multiplexing –TM) [7] and the proposed interference aware routing schemes. The interference aware routing schemes result in a significant throughput advantage in the medium range density of nodes (10 to 30). For low number of nodes the near-far effect is not significant, while for high density of nodes the interference is too high and the near-far effect cannot be avoided.

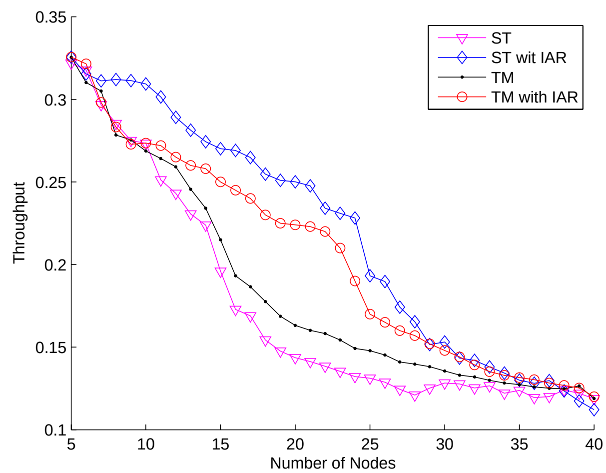

Figure 2: Throughput for Time multiplexed, Simultaneous transmission, and topology based routing.

We can see that a throughput improvement of up to 60% can be achieved compared to the conventional minimum energy routing scheme for the case of simultaneous transmissions when the number of nodes is in the range of 20 to 25.

Figure 3 shows the energy per bit plots for both minimum energy routing and interference aware routing for the two cases: time multiplexing and simultaneous transmission. It can be seen that the proposed scheme has a slightly higher energy cost for the density regions where the throughput performance is substantially improved.

All the performance results were obtained for an interference threshold T selected such that the interference increase due to a particular node transmission is no larger than 20%. The depth of the algorithm (D) was selected to be 7, in order to maintain a manageable computational complexity for the routing algorithm.

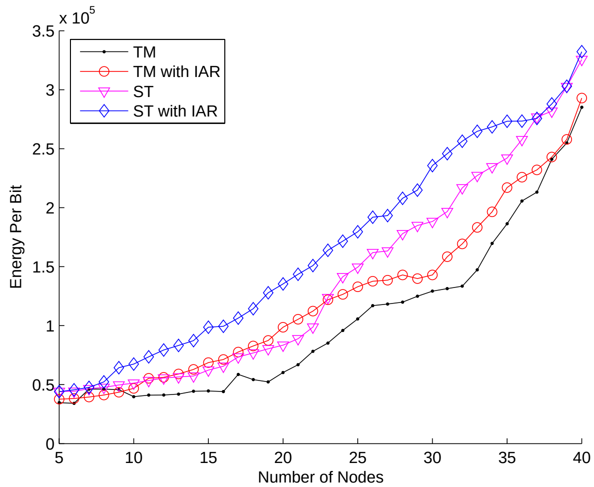

Figure 3: Energy per bit for Time multiplexed, Simultaneous transmissions, and Topology based routing.

CONCLUSION

In this paper, we have proposed an interference aware routing scheme for CDMA wireless ad hoc networks. The presented routing algorithm minimizes the total energy expenditure for an end to end path, subject to constraints on the interference caused by the nodes participating in a route to other nodes in their neighborhood. The considered optimization objective, energy minimization with interference constraints, is particularly useful for CDMA ad hoc network which are prone to performance degradation in the presence of strong interferers. Our simulation results have shown improvements in throughput as large as 60%, compared with the minimum energy routing approach for a multi-code CDMA ad hoc network. These improvements are achieved at the expense of only a slight increase in the average energy bit transmission for an end-to-end path.

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