Topology Control in Wireless Ad-Hoc Networks-Shared Links

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Abstract
Mutual Communication (MC) allows save power and extend transmission coverage. However, prior research work on topology control considers MC only in the aspect of energy saving, not that of coverage extension. We identify the challenges in the development of a centralized topology control scheme, named Mutual Bridges, which reduces transmission power of nodes as well as increases network connectivity. Multiple nodes to simultaneously transmit the same packet to the receiver so that the combined signal at the receiver can be correctly decoded. Since MC can reduce the transmission power and extend the transmission coverage, it has been considered in topology control protocols. However, prior research on topology control with MC only focuses on maintaining the network Connectivity, minimizing the transmission power of each node, whereas ignores the energy-efficiency of paths in constructed topologies. This may cause inefficient routes and hurt the overall network performance. In this paper, to address this problem, we introduce a new topology control problem: energy-efficient topology control problem with mutual communication, and propose two topology control algorithms to build mutual energy spanners in which the energy efficiency of individual paths are guaranteed. Simulation results confirm the nice performance of the proposed algorithms.

Keywords
Mutual Communication; Topology, Control, Connectivity

I. Interdiction

Wireless nodes need to save their power as well assustain links with other nodes, since they are battery powered. Topology control deals with determining the transmissionpower of each node so as to maintain network connectivity andconsume the minimum transmission power. Using topologycontrol, each node is able to maintain its connection withmultiple nodes by one hop or multi-hop, even though it doesnot use its maximum transmission power. Consequently, topology control helps power saving and decreases interferencesbetween wireless links by reducing the number of links. Asan example of topology control, the authors of proposed a Minimum Spanning Tree (MST) based topology controlalgorithm in order to maintain the network connectivity andminimize the number of links.Recently, a new paradigm named the Mutual Communication (MC) technique has emerged and single antennadevices can share the antennas of others that have spatialdiversity such as the MST system. MC allows a source node and helper nodes to simultaneously transmit independent copies of analogous data to a destination node so thatthe destination node can combine partial signals of nodesand decode them [5-8]. One-hop neighbour nodes within thetransmission range of a source node can be helper nodes.In other words, individual antennas on multiple nodes canwork together to form an antenna array. There are extensivephysical layer research efforts on the MC technique and the importance of higher layer research is also beingincreasingly recognized. Since using MC results in robust connection, coverage extension, and power saving, MC can be applied to various areas such as topology control [12],broad casting and routing.

A topology control scheme [12], has been proposed forreduced power consumption using MC technology; however, it can be applied only when a strongly connected networktopology is given at the initial step. A strongly connectednetwork indicates a network where every node has a routeto reach any other node. A wireless ad hoc network can bedisconnected due to node mobility, low node density, andpower constraint. The authors of have shown that MC technology enhances connectivity among disconnectednetworks, but there has been no definitive answer given totopology control research considering coverage expansion with MC.

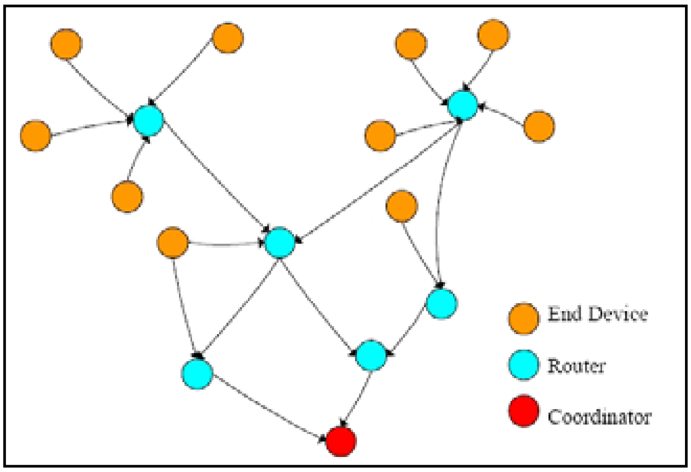

Fig. 1. Inefficiency of Current Topology Control Methods with MC

Therefore, we propose a centralized topology controlscheme, which aims to increase network connectivity as wellas reduce transmission power by minimizing the number of mutual communication links (MC links) among disconnected networks. As a part of the proposed topology controlscheme, we also suggest two helper decision algorithms tominimize transmission power for each MC link; an optimal method and a polynomial time heuristic algorithm. In addition, we also discuss how the proposed topology control scheme isperformed in a distributed manner.

The main contribution of this paper includes the follow in gaspects.

- To the best of our knowledge, we are the first to trytopology control considering extended links with MC. While the existing topology control schemes preservethe given connectivity, we propose a new framework oftopology control that increases connectivity.
- The connectivity-power-ratio of mutual bridges is similar to or higher than the existing algorithm. Our basicidea is based on a 2-layer MST structure. The MST-basedmethodology is not original but our problem formulationhas novel elements.
- Several studies have been undertaken on helper selection
- Algorithms considering the channel state in order toincrease throughput [16]. However, the helper selectionalgorithm considering energy efficiency has not beenidentified by prior research.
- This paper describes thetrade-off between the power for a MC

link and that forhelper links that should be considered so that we canconstruct an energy efficient MC link. Furthermore, wepropose two helper selection algorithms to minimize thepower of nodes in order to participate in maintaining a MC link.

The rest of this paper is organized as follows. Reviews the related work. Section II, describes the networkmodel and formulates our problems. Section IV, proposes ourtopology control algorithm including helper decision algorithms distributed version.

II. Related Works

Mutual communication is different in that it originates fromphysical layer techniques; when a source node transmits amessage, helper nodes around the source can overhear andretransmit it. Under amplify-and-forward, a helper node receives a noisysignal and amplifies it before retransmission. Under decode-and-forward, on the other hand, a helper node must firstlydecode the signal and then retransmit the detected data. Adestination node combines several copies of the signal froma source node and helper nodes, and obtains the advantage ofspatial diversity. The concept of combining partial signals hasbeen traditionally known as maximal ratio combining. In order to adapt to various channel states among nodes andto increase throughput, a source node can decide whether ituses only one helper node or two helper nodes simultaneously. It can even select no helper nodes for the same reason.MAC layer-based algorithms for such helper selection havebeen studied many times. For example, in CoopMAC,a source node records the channel state at each helper andselects the one that has the best state. Proposethe optimal algorithm that selects each helper for every source-destination pair in the whole network.

In general, topology control minimizes the total or maxenergy consumption per node. Sometimes it also hasother objectives such as to increase the throughput or to meetQoS requirements. Finding a strongly connected topology thathas the minimum total energy consumption is known as an NP-complete problem in proved that the optimaltopology control problem using MC is also NP-complete, wepropose a heuristic algorithm for topology control.

A. Relaying Strategies

- Amplify-and-forward
- Decode-and-forward

In amplify-and-forward, the relay nodes simply boost the energy of thesignal received from the sender and retransmit it to the receiver. In decode-and-forward, the relay nodes will perform physical-layer decoding and then forwardthe decoding result to the destinations. If multiple nodes are available forcooperation, their antennas can employ a space-time code in transmitting therelay signals. It is shown that cooperation at the physical layer can achieve fulllevels of diversity similar to a system, and hence can reduce theinterference and increase the connectivity of wireless networks.

B. Mutual Communications

Mutual transmissions via a mutual diversity MC two consecutive slots. The destination combines the two signals from the source and the relay to decodethe information. Mutual communications are due to the increased understanding ofthe benefits of multiple antenna systems. Although multiple-input multiple-output (MST) systems have been widely acknowledged, it is difficult for some wireless mobiledevices to support multiple antennas due to the size and cost constraints. Recent studies show that mutual communications allow single antenna devices to work together toexploit the spatial diversity and reap the benefits of MST systems such as resistanceto fading, high throughput, low transmitted power, and resilient networks.

C. Multi-Hop Transmission

Multi-hop transmission can be illustrated using two-hop transmission. Whentwo-hop transmission is used, two time slots are consumed. In the first slot, messagesare transmitted from the source to the relay, and the messages will be forwarded to thedestination in the second slot. The outage capacity of this two-hop transmission can bederived considering the outage of each hop transmission.

III. Architecture

We propose a Capacity-Optimized Mutual (COCO) topology control scheme to improve the network capacity in MANETs by jointly considering both upper layer network capacity and physical layer mutual communications. Through simulations, we show that physical layer mutual communications have significant impacts on the network capacity y, andthe proposed topology control scheme can substantially improve the network capacity in MANETs with mutual communications.

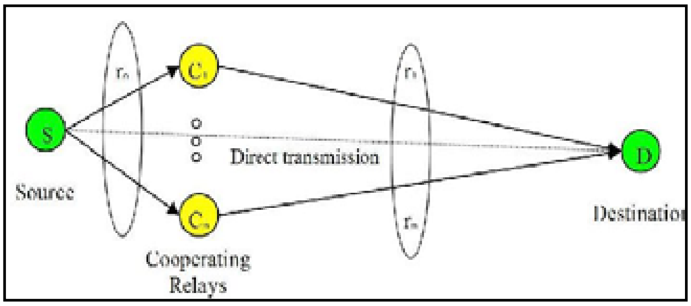

Fig. 2:

A Capacity-Optimized Mutual (COCO) topology control scheme toimprove the network capacity in MANETs by jointly optimizing transmissionmode selection, relay node selection, and interference control in MANETs with mutual communications. Through simulations, we show that physical layer mutual communications have significant impacts on the network capacity,and the proposed topology control scheme can substantially improve thenetwork capacity in MANETs with mutual communications.

IV. Existing System

Existing works are focused on link-level physical layer issues, such asoutage probability and outage capacity. Consequently, the impacts of mutual communications on network-level upper layer issues, such as topology control, routingand network capacity, are largely ignored. Indeed, most of current works on wirelessnetworks attempt to create, adapt, and manage a network on a maze of point-to-point non-mutual wireless links. Such architectures can be seen as complex networks ofsimple links.

A. Disadvantages

- Low Network Capacity.
- Communications are focused on physical layer issues, such as decreasing outage probability. and increasing outage capacity, which are only link-wide metrics.

V. Proposed System

We propose a Capacity-Optimized Mutual (COCO) topology control scheme to improve the network capacity in MANETs by jointly considering both upperlayer network capacity and physical layer mutual communications. Throughsimulations, we show that physical layer mutual communications have significant impacts on the network capacity, and the proposed topology control scheme cansubstantially improve the network capacity in MANETs with mutual communications.

A. Energy-Efficient Topology Control With MC

In this section, we propose two topology control algorithm switch build energy-efficient mutual energy spanners. Tokeep the proposed algorithms simple and efficient, we onlyconsider its one-hop neighbours as possible helper nodes for each node when MC is used. Thus, the original mutual communication graph Gcontains all direct links and MC-links with one hop helpers, instead of all possible direct links and MC-links. In addition, for each pair of nodes vi and vj, we only maintain one link with least weight if there aremultiple links connecting them. Both proposed algorithms aregreedy algorithms. The major difference between them is theprocessing order of links. The first algorithm deletes links fromthe original graph G greedily, while the second algorithm addslinks into G″greedily. Here G″is a basic connected sub graph of G. Both algorithms can guarantee the mutual energy spanner property of the constructed graph G′

A. Greedy Algorithm 1 - Deleting Links

We first propose a simple greedy algorithm for energy-efficient topology control, which is inspired by the classical greedy algorithm for low-weight spanner. Thegeneral idea is to start with the original mutual communication graph G as described above. Then, gradually deletethe least energy-efficient link (the link with highest weight)from G if doing so does not break the energy stretch factorrequirement. Finally, the transmission power of each node isdecided from the constructed topology G′

The details of thesethree steps are as follows.

Step 1: Construction of G. Initially,is an empty graph.

First, add every direct links vivj into G, if node vi can reach node vj when it operates with PMAX. Then, for every pair of nodes vi and vj, we select a set of helper nodes Hij for node vi from its one-hop neighbours(vivj), such that the link weigh w(˜ vivj) of the constructed MC-link is minimized. This helpernodes decision problem is challenging even under our assumption that the transmission powers of vi and its helper node setto maintain MC-link are the same. If we try all combinationsof the helper sets, the computational complexity is exponentialto the size of(vi). It is impractical to do so in case of a largenumber of neighbours.

Step 2: Construction of G′

Copy all links in G to G′, and sort them in the descending order of their weights. Startto process all links one by one and delete the link vivj from G′

If G′ −vivj is still a mutual energy t-spanner of G. In addition, when a MC-link ˜ vivj is kept in G′, all its helllinks must be kept in G′ too.

$$g_G^{G'}(v_i v_j) = \sum_{v_p, v_q \in V} \left(\rho_G^{G'}(v_p, v_q) - \rho_G^{G'+v_i v_j}(v_p, v_q)\right),$$

Step 3: Power Assignment from G′

For each node vi, transmission power is decided by

$$P_i = \max\{\max_{v_i v_j \in G'} P_i^d(j), \max_{\widetilde{v_i v_j} \in G'} P_i^{cc}(j)\}.$$

the following equation.

$$P_i^d(j) = \frac{\tau}{d_{ij}^{-\alpha}} \text{ and } P_i^{cc}(j) = \frac{\tau}{\sum_{v_k \in v_i \cup H_{ij}} (d_{kj})^{-\alpha}}$$

Here are theenergy consumption

We call this algorithm Greedy Algorithm 1(denoted by Greedy Del Link). The guarantee of the energy t-spanner property is straightforward, since links are deleted from G′ only when the deletion does not break the t-spanner requirement.

B. Greedy Algorithm 2 - Adding Links

The second topology control algorithm starts with a sparsetopology G" which is strongly connected under MC model. We can use the output of the algorithm in [2] as the initialtopology. Then, we gradually add the most energy-efficientlink into G". Here, the energy-efficiency of a link is definedas the gain on reducing energy stretch factors by adding thislink. Our algorithm will terminate until the constructed graph G′ satisfies the energy stretch factor requirement.

The detailsteps are summarized as follows.

Step 1: Construction of G and G″

He step of constructing G is the same as the one in GreedyDelLink. Then weconstruct G″, a connected sparse sub graph of G by callingthe algorithm in [2].

Step 2: Construction of G′

Initialize G′ = G″

For everylink vivj ∈ G−G′

Compute its stretch-factor-gain gG′(vivj)as follow:

Here,′ +vivj denotes the graph generated by adding edge vivj into G′

- In other words, the total gain of a link vivj is the Summation of the improvement of stretch factors of every pairof nodes in G after adding this link. In each step, we greedilyadd the link with the largest stretch-factor-gain into G′
- If thereis a tie, we use the link weight to break it by adding the linkwith the least weight. We repeat this procedure until G′ Meetsthe stretch factor requirement t.

Step 3: Power Assignment from G′

For every node vi…assign its power level Pi.

We call this algorithm Greedy Algorithm 2(denoted byGreedyAddLink).

The guarantee of the energy t-spanner property is also straightforward since the algorithm terminatesadding links until the t-spanner requirement is satisfied.

VI. Conclusion

We proved that this problemis proposed two new topology control algorithms using mutual communications. Both algorithms can build mutual energy spanner in which the energy efficiency of individual paths are guaranteed. Simulation resultsconfirm the nice performance of both proposed algorithms. Increase connectivity for separated networks, considering coverage expansion of mutual communication technology our present study is the first to investigate this approach.Our solution constructs an MST-based network connectivity graph with minimal MC links selected from possible candidates of MC links to reduce transmission power. Furthermore, twohelper-node selection schemes to maintain energy-efficient MC links were suggested; the optimal method and the greedyheuristic method. We also applied MST (or DTMC) to each cluster for direct links and it achieved further power reduction.Next, we discussed a distributed version of the proposedtopology control scheme. Via simulations, we concluded thatour algorithms lead to greater enhancements (up to 50%)in connectivity than other topology control schemes with tolerable increase of transmission power. The advantage of theproposed schemes is even bigger when the path loss exponenttends to be smaller and there are more disconnected networks.Our work can provide guidelines on how to construct energy-efficient MC links to extend network connectivity.

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