Cooperative Bridge Topology Control with Adaptation for Improved in Wireless Ad Hoc Networks

VADAPALLY VENKATESWARA RAO, M.Naveen Kumar M.Tech, RAVI MATHEY M.Tech, Ph.D
ASSISTANT PROFESSOR, H.O.D CSE DEPARTMENT
VIDYAJYOTHI INSTITUTE OF TECHNOLOGY

Abstract - Cooperative Communication (CC) is a technology that allows multiple nodes to simultaneously transmit the same data. It can save power and extend transmission coverage. However, prior research work on topology control considers CC 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 Cooperative Bridges, which reduces transmission power of nodes as well as increases network connectivity. Topology control algorithms allow each node in a wireless multi-hop network to adjust the power at which it makes its transmissions and choose the set of neighbors with which it communicates directly, while preserving global goals such as connectivity or coverage. This allows each node to conserve energy and contribute to increasing the lifetime of the network. Previous work on topology control has largely used an approach based on considering only the energy costs across links without considering the amount of energy available on a node. Further, previous work has largely used a static approach where the topology is determined at the beginning of the network’s life and does not incorporate the varying rates of energy consumption at different nodes. We propose two algorithms that select the most energy efficient neighbor nodes, which assist a source to communicate with a destination node; an optimal method and a greedy heuristic. In addition, we consider a distributed version of the proposed topology control scheme. Our findings are substantiated by an extensive simulation study, through which we show that the Cooperative Bridges scheme substantially increases the connectivity while consuming a similar amount of transmission power compared to other existing topology control schemes.

I. Introduction

Wireless ad hoc networks, especially sensor networks, the battery life of each node plays a critical role in determining the functional lifetime of the entire network. Each node is typically equipped with limited battery resources and when a node exhausts its energy supply, it may lead to a disconnected network that disables essential communications or it may fail to continue the environmental monitoring activities essential to the functional operation of the system. Adding redundant nodes in the network may extend the functional lifetime but it is ultimately not a cost-effective approach. In this paper, we consider the problem of extending the lifetime of a network using a new adaptive game-theoretic approach. Wireless ad hoc networks are multi-hop structures, which consist of communications among wireless nodes without infrastructure. Therefore, they usually have unplanned network topologies. Wireless nodes need to save their power as well as sustain links with other nodes, since they are battery powered. Topology control deals with determining the transmission power of each node so as to maintain network connectivity and consume the minimum transmission power. Using topology control, each node is able to maintain its connection with multiple nodes by one hop or multi-hop, even though it does not use its maximum transmission power. Consequently, topology control helps power saving and decreases interferences between wireless links by reducing the number of links. As an example of topology control, the authors of [1-3] proposed a Minimum Spanning Tree (MST) based topology control algorithm in order to maintain the network connectivity and minimize the number of links. Recently, a new paradigm named the Cooperative Communication (CC) [4] technique has emerged and single antenna devices can share the antennas of others that have spatial diversity such as the MIMO system. CC allows a source node and helper nodes to simultaneously transmit independent copies of analogous data to a destination node so that the destination node can combine partial signals of nodes and decode them [5-8]. One-hop neighbor nodes within the transmission range of a source node can be helper nodes. In other words, individual antennas on multiple nodes can work together to form an antenna array. There are extensive physical layer research efforts on the CC technique [9-11] and the importance of higher layer research is also being increasingly recognized. Since using CC results in robust connection, coverage extension, and power saving, CC can be applied to various areas such as topology control [12], broadcasting [5-7], and
A topology control scheme [12] has been proposed for reduced power consumption using CC technology; however, it can be applied only when a strongly connected network topology is given at the initial step. A strongly connected network indicates a network where every node has a route to reach any other node. A wireless ad hoc network can be disconnected due to node mobility, low node density, and power constraint. The authors of [8][14][15] have shown that CC technology enhances connectivity among disconnected networks, but there has been no definitive answer given to topology control research considering coverage expansion with CC. To the best of our knowledge, we are the first to try topology control considering extended links with CC. While the existing topology control schemes preserve the given connectivity, we propose a new framework of topology control that increases connectivity. Moreover, the connectivity-power-ratio of cooperative bridges is similar to or higher than the existing algorithm. Our basic idea is based on a 2-layer MST structure. The MST-based methodology is not original but our problem formulation has novel elements. Several studies have been undertaken on helper selection algorithms considering the channel state in order to increase throughput [16]. However, the helper selection algorithm considering energy efficiency has not been identified by prior research. This paper describes the trade off between the power for a CC link and that for helper links that should be considered so that we can construct an energy efficient CC link.

II. Related work

We are extending the life of a wireless sensor network can be tackled through multiple complementary ways involving routing protocols, medium access strategies or any of several other protocols that facilitate network operations. In this section, we will discuss only the approaches most related to the proposed algorithm, that is, approaches based on changing the topology of the network by individual nodes changing the power level at which they make their transmissions while preserving network connectivity. Traditional topology control algorithms such as SMECN [6], DRNG [1], DLSS [1] and STC [2] usually start the topology control process with each node transmitting at its maximum transmission power to discover all of its neighbors. Local neighborhood and power-level information is next exchanged between neighbors. The minimum transmission power of each node such that the graph is still connected is later computed at each node without further communication between nodes. The Weighted Dynamic Topology Control (WDTC) [7] algorithm improves upon the work of MST [8], and considers the remaining energy of each node in addition to the energy cost of communication across each pair of nodes. The algorithm, however, forces bidirectional communication between each pair of nodes and, in addition, requires periodic communication by each node at its maximum possible power level. Other related algorithms seek to offer a robust topology where the graph can stand multiple channel failures; for example, a k-connected graph is sought in [9], [10] and a two-tiered network in [11]. Other topology control algorithms may require communication between nodes throughout the topology control process. One typical example is the work described in [12], which is based on a selfish game on network connectivity to help reduce the transmission power on each node. By offering a utility function which indicates a high (low) profit if the node’s transmission power is small (large), each node selfishly reduces its transmission power to maximize its profit. On the other hand, if the node has reduced its transmission power to such an extent that the graph becomes disconnected, the profit of each node becomes 0. This algorithm was later improved in [3], where the requirement of global information (to establish connectivity) is eliminated and a distributed topology control algorithm is proposed. Another class of topology control algorithms is represented by the work reported in [13], where the authors provide a decentralized static complete-information game for power scheduling, considering both frame success rate and connectivity. Other approaches to increasing the lifetime of a wireless sensor network include grouping nodes into clusters to create a communication hierarchy in which nodes in a cluster communicate only with their cluster head and only cluster heads are allowed to communicate with other cluster heads or the sink node [14]–[16]. By carefully selecting the cluster head or alternating the role of being the cluster head, the lifetime of the sensor network can be extended. In cases where the cluster heads are designated, algorithms for placing relay nodes into the higher hierarchy network such that the
energy depletion on the cluster heads can be reduced [17]. A survey of topology control algorithms can be found in [18], [19] and a survey of the applications of game theory in wireless sensor networks can be found in [20]. In traditional multi-hop networks, intermediate nodes cooperate with a source node by forwarding the message to a destination node, which is performed on the network layer. Accordingly, the destination can receive only one copy of the message from the source or relay node. However, cooperative communication is different in that it originates from physical layer techniques; when a source node transmits a message, helper nodes around the source can overhear and retransmit it. There are two categories for this type of retransmission: amplify-and-forward and decode-and-forward [10]. Under amplify-and-forward, a helper node receives a noisy signal and amplifies it before retransmission. Under decode and forward, on the other hand, a helper node must firstly decode the signal and then retransmit the detected data. A destination node combines several copies of the signal from a source node and helper nodes, and obtains the advantage of spatial diversity. The concept of combining partial signals has been traditionally known as maximal ratio combining [17]. In order to adapt to various channel states among nodes and to increase throughput, a source node can decide whether it uses only one helper node or two helper nodes simultaneously [11]. It can even select no helper nodes for the same reason. MAC layer-based algorithms for such helper selection have been studied many times. For example, in CoopMAC [16], a source node records the channel state at each helper and selects the one that has the best state. Shi et al. [18] propose the optimal algorithm that selects each helper for every source destination pair in the whole network. In this paper, we assume that a source node can choose one or several helpers considering node location, connectivity, and power consumption, which is similar to the assumption of [5-8]. Network layer research usually considers simple physical characteristics for CC instead of variations of channel state. In [5][6][12], a hitch-hiking model based on decode-and-forward and maximal ratio combining is employed, and [15] shows a simpler CC model. Our research is also based on a similar model. In [12] and [5], a topology control and broadcasting algorithm is proposed, respectively, which reduce average power consumption by utilizing the CC technique after a strongly connected network is given at the initial step. In [6], the proposed algorithm selects a smaller number of forwarding nodes for broadcasting by CC. Observing that the CC technique extends the transmission range and it can link disconnected networks, [15] analyzes the improvement of network connectivity via percolation theory when CC is applied. None of the existing topology control research acknowledges that coverage extension with CC results in linking disconnected networks. We propose a novel topology control algorithm that minimizes average transmission power as well as maximizes the connectivity of divided networks. In general, topology control minimizes the total or maximum energy consumption per node. Sometimes it also has other objectives such as to increase the throughput or to meet QoS requirements. Finding a strongly connected topology that has the minimum total energy consumption is known as an NP-complete problem in [19]. Since [12] proved that the optimal topology control problem using CC is also NP-complete, we propose a heuristic algorithm for topology control. Minimum spanning tree (MST) preserves connectivity, and builds a sparse graph, therefore, it is a good approximation of the optimal solution to the topology control problem [20]. Ramanathan et al. [2] introduce the MST-based centralized algorithm and Gallager et al. [3] propose the distributed MST algorithm (DMST). The LMST algorithm [1] enables us to make a pseudo-MST by letting each node construct a localized MST. We also adapt the MST structure for the proposed topology control considering.

III. DISTRIBUTED ALGORITHM

In this section, we discuss how the proposed centralized algorithm works in a distributed fashion. First, each node establishes links with neighbor nodes that belong to the same cluster using direct communication with the maximum transmission power. Each node measures the current position using GPS or localization methods and exchanges the position information with other nodes in the cluster. Each node also broadcasts its node ID to other nodes in the same cluster and if the delivered ID is bigger than that of a receiver node, the receiver node saves the received ID as its cluster ID. After the construction of each cluster is over, with CC technology and PMAX, each node transmits the request message to other nodes in different clusters by using all neighbor nodes as Helper nodes. The result corresponds to The message
includes the position of a source node and the cluster ID of the source node. After receiving the request message, the node transmits the reply message except in the following cases: • The cluster ID in a request message is the same as that of a receiver node. • The cluster ID is different but successful CC transmission between a source node and a receiver node is impossible due to the lack of helper nodes. In the above second case, the receiver node and its helpers cannot send a message to the source node, while the source node and its helpers can do so. In this case an asymmetric link can be made but the source node does not maintain the asymmetric CC link because there is no reply message from the receiver. After generating CC links among clusters via the request and reply mechanism, each node determines its helper nodes and weight using the proposed algorithm in section 4(B). Then the node sends the following information 1) its ID, 2) the ID of the destination cluster and 3) the weight of the CC link to a representative node with the highest node ID in the same cluster. Within each cluster, the representative node with the highest node ID applies the Distributed MST algorithm (DMST) [3] to the CC links between its cluster and neighbor clusters, regarding each cluster as a node. DMST is an algorithm which generates a MST in distributed fashion. Accordingly, the node can determine which CC links should remain and then it broadcasts the information of the final CC links, which includes the source nodes' IDs and the destination clusters' IDs, to every node in the same cluster. Finally, we can construct an MST where each link is a CC link and each node is a cluster. After that, each node can also apply DMST to the direct links within each cluster.

Cooperative Distribution Algorithm

IV. Performance Evolution

Which ensure energy efficiency by assigning proper CC links, and which increase and maintain the network connectivity. In this section, we perform extensive simulations to compare the performance of the proposed energy-efficient topology controls using cooperative communication (Coop. Bridges, Coop. Bridges + DTCC) with other schemes. Coop. Bridges is the topology control applying the greedy heuristic in step 2 of section 4 and the MST algorithm within each cluster in step 4. Coop. Bridges + DTCC is based on Coop. Bridges, but the DTCC algorithm [12] is used within each cluster in step 4. The compared schemes are as follows: a scheme that maintains direct links to all neighbor nodes without using CC (Max- Power-w/o-CC) and a topology control scheme maintaining all possible direct links and CC links (Max-Power-w/-CC). In Max-Power-w/-CC, each source node selects all neighbor nodes as its helper nodes. In addition, DTCC [12] and a MST topology scheme without using CC (MST) are also compared. Since there is no existing topology control scheme using an extended transmission range with CC, we select MST and DTCC, which are common in topology control schemes without CC and with CC, respectively. The goal of topology control is to maintain the connectivity among as many nodes as possible while minimizing the power consumption of each node. Therefore, we use the average transmission power as the simulation metric for evaluation of energy efficiency. To evaluate the connectivity, we use the network connectivity which is defined in section 3. In addition, we also observe the connectivity-power-ratio (the ratio of network connectivity to average transmission power). In this simulation, 10-110 nodes are randomly arranged in a 500m x 500m area. The path loss factor $\alpha$ is set to 2 and 4. The value of $P_{MAX}$ is 4900 and 24010000 for each value of $\alpha$ so that the maximum transmission range for a direct link will always be 70 meters. For convenience, the SNR threshold $\tau$ is set to 1. In order to produce more reliable results, the data are generated by averaging the data from several random topologies. The number of types of random seed for node arrangement is 50. By fixing the network area to 500m x 500m and adjusting the number of nodes in the simulation environment, we can generate clusters. shows the number of
clusters generated according to the number of nodes. In figure 10, the greater the node density, the smaller the degree of network partitioning. The degree of network partitioning is defined as the ratio of the number of clusters to the number of nodes. The simulation results for the simulation metrics are described in the following three subsections.

V. Conclusion

In this paper, we proposed a cooperative approach using an ordinal potential game to determine the transmission power for each node so that it can periodically adapt to the current remaining energy on nodes within its neighborhood. We have proved the existence of a Nash equilibrium for the game and provided an algorithm which achieves such an equilibrium. Proposed scheme of topology control scheme to minimize the transmission power of nodes and increase connectivity for separated networks, considering coverage expansion of cooperative communication technology. Our present study is the first to investigate this approach. Our solution constructs an MST-based network connectivity graph with minimal CC links selected from possible candidates of CC links to reduce transmission power. Furthermore, two helper-node selection schemes to maintain energy-efficient CC links were suggested; the optimal method and the greedy heuristic method. We also applied MST (or DTCC) to each cluster for direct links and it achieved further power reduction. Next, we discussed a distributed version of the proposed topology control scheme. Via simulations, we concluded that our algorithms lead to greater enhancements (up to 50%) in connectivity than other topology control schemes with tolerable increase of transmission power. The advantage of the proposed schemes is even bigger when the path loss exponent tends to be smaller and there are more disconnected networks.

References


Ravi Mathey is a post-graduate specialized in Computer Science from BIT-Ranchi and he did Instrumentation technology in Andhra University. He has more than 20 years of experience in Research and Development; presently he is working as a Associate Professor and HOD of CSE Department at Vidya Jyothi Institute of Technology (VJIT). His area of research is wireless embedded application, cloud computing, image compression techniques by using fractals and wavelets.