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Distributed Algorithms for Delay Bounded Minimum Energy Wireless Broadcasting

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ABSTRACT

In this article, we investigate two different distributed algorithms for constructing a minimum power broadcast tree with a maximum depth Δ which corresponds to the maximum tolerable end-to-end delay in the network. Distributed Tree Expansion (DTE) is based on an implementation of a distributed minimum spanning tree algorithm in which the tree grows at each iteration by adding a node that can cover the maximum number of currently uncovered nodes in the network with minimum incremental transmission power and without violating the delay constraint. In Distributed Link Substitution (DLS), given a feasible broadcast tree, the solution is improved by replacing expensive transmissions by transmissions at lower power levels while reserving the feasibility of the tree with respect to the delay bound. Although DTE increases the message complexity to $O(n^3)$ from $O(n^2\Delta)$ in a network of size n, it provides up to 50% improvement in total expended power compared to DLS. [Article copies are available for purchase from InfoSci-on-Demand.com]

Keywords: *Delay Bound; Distributed Systems; Energy Efficient Broadcasting; Networks; Quality-of-Service; Wireless Technologies*

INTRODUCTION

In broadcast communication, messages are concurrently sent to all nodes in the network. Mechanisms to support such a form of communication are an important component of the design and implementation of high-speed networks. For reasons related to the efficient use of the network resources, typical approaches to multicast/broadcast routing require the transmission of packets along the branches of a tree spanning the source and destination nodes. Among the most crucial issues related to ad hoc and sensor networks is that of operation in limited energy environments because devices are usually equipped with batteries of limited lifetime. Unlike in wired networks, wireless multicast/broadcast sessions may reach several nodes with a single transmission, when nodes are equipped with omnidirectional transmitters. For omnidirectional wireless broadcast to a node, all nodes within the transmission range receive the message. This property is fundamental to the design of energy-efficient multicast/broadcast trees in wireless networks. We focus on a specific type of ad hoc network where all nodes are stationary and the transmission range of the transmitter can be adjusted from 0 up to a maximum range R_{max}. Naturally, when the node transmits a message to a longer range, it consumes more energy. Note that because each node can only transmit up to distance R_{max}, it is possible that the source node *s* cannot reach all nodes in the network directly. Therefore, some nodes have the responsibility of forwarding messages on behalf of *s*. In addition, networks that support real-time traffic are also required to provide certain quality of service (QoS) guarantees. The QoS guarantee considered in this work is the delay bound of the broadcast tree, and we employ the number of hops from the source to a given node as a surrogate measure of delay to that node. Recent research in broadcast scheduling (Gandhi, R., Mishra, A., & Parthasarathy, S., In Press) establishes that latency is influenced primarily by the depth of the tree. Furthermore, research on random networks characterizing the fundamental trade-offs in wireless networks indicates that the delay in the network increases as the amount of hopping increases (Gamal, A. E., & Mammen, J., 2006). Thus, while we recognize that there are other types of delay, e.g., queueing and contention, there is strong evidence that both delay and energy-efficiency are clearly affected by the amount of hopping in the network, and as a proxy for the maximum delay guarantee we require that the number of hops from the source to each node in the network is no greater than a pre-specified value.

In this article, we focus on constructing a minimum power (energy) broadcast tree with a maximum depth Δ which corresponds to the maximum tolerable end-to-end delay in the network. We refer to this problem as DMEB. In (Bulbul, K., Ercetin, O., & Unluyurt, T., In Press), we discussed a centralized algorithm for the solution of this *NP*-hard problem, where the source node has the global network topology information and performs the broadcast tree calculations centrally. In the present work, we investigate the construction of the delay bounded minimum power wireless broadcasting tree in a distributed fashion when each node in the network has only limited topology information and contributes to the construction of the tree.

We note that the algorithm in (Bulbul, K., et al.) requires one node to collect the position information of every node in the graph, compute the tree, and distribute the solution to all other nodes in the network. This can result in considerable time, message complexity, and power consumption. Additionally, this requires that the node performing the computation also has significant resources (power, processor, and memory). These reasons motivate a need for localized distributed algorithms that can compute broadcast trees efficiently. A localized algorithm is one in which nodes base their decisions on network conditions within some limited distance. In this article, we describe two different localized distributed algorithms, Distributed Tree Expansion (DTE) and Distributed Link Substitution (DLS) that compute broadcast trees.

DTE is constructive in nature, where a modified version of the distributed Minimum Spanning Tree (MST) algorithm is implemented. The algorithm begins initially with only the source node in the tree. The algorithm extends the tree by adding a new node to the tree which can cover the maximum number of currently uncovered nodes in the network with minimum incremental transmission power while also taking delay into account. The proposed algorithm only keeps 1-hop neighborhood information[1] and is similar in nature to the one given in (Kompella, V. P., Pasquale, J. C., & Polyzos, G. C., 1993).

DLS is an improvement algorithm, which begins with an initial feasible broadcast tree

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