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Broadcast capacity of a WSN under communication and information coordination

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ABSTRACT

The broadcast capacity of a wireless sensor network (WSN) is defined as the maximum rate at which the network may generate messages intended for distribution to the entire network when subject to certain conditions on coverage and delay. Broadcast capacity is limited by factors such as communication collisions and congestion. Collisions may be reduced through the use of communication coordination (CC), and congestion may be reduced through information coordination (IC), ensuring that only useful messages are transmitted and stored. We study the broadcast capacity of a WSN when subject to various real world phenomena that affect wireless communication, namely channel variations, interference and random node failures. We study the benefits and costs associated with using the IC and CC mechanisms on different topologies through the use of various metrics.

1. Introduction

This paper focuses on the performance benefits of coordination for broadcasting messages across a wireless sensor network (WSN). Most of the existing proposed broadcast algorithms for wireless sensor networks are variants of the gossip protocol.[1] Such protocols are appealing in that they offer a simple and distributed method to disseminate information to most of the nodes in a network using significantly fewer redundant transmissions than flooding. A transmission is redundant if each of the receivers of the transmission has already received the message at an earlier time. Using randomized broadcast to reduce redundant transmissions at the expense of some nodes not receiving a message is an acceptable tradeoff in sensor networks, where energy constraints often trump the desire for message delivery to all nodes. Simple flooding is inefficient in terms of redundant transmissions, and hence, wastes energy.

1.1. Gossip and its variants

An often cited gossip protocol is the `GOSSIP1`(p,k) protocol from [1] where *each node, upon first receiving the message, transmits the message in the following time slot with probability p, unless the message was received in time slot* $i \leqslant k$ *in which case the message is transmitted with probability 1.* Transmitting with probability 1 for the first k time slots helps ensure that the message does not die out prematurely. The `GOSSIP1` protocol with $k \to \infty$ or $p = 1$ reduces to flooding. As shown in [1], this protocol offers significant reduction in redundant transmissions relative to flooding by incurring the cost that not all nodes will necessarily receive the message. There is an obvious tradeoff between reducing redundancies and achieving a near-complete message distribution: increasing p will increase the number of nodes that receive the message but also will increase the number of redundant transmissions. Fig. 1 highlights this tradeoff. When p is low efficiency (defined as the number of unique receptions per transmission) is high, but coverage is low. Increasing p increases coverage but lowers the efficiency. Choosing $p = 0.7$ results in a coverage of nearly 90% while maintaining an efficiency of 1.4.

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[1] Gossip protocols, in current parlance, denote randomized broadcast and routing protocols; our use of the term will be restricted to randomized broadcast.

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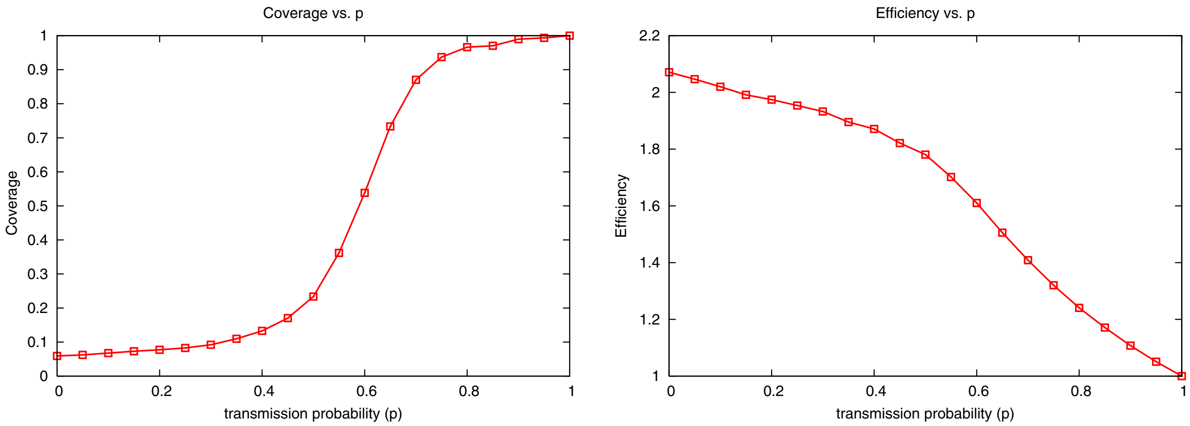

Fig. 1. Coverage and efficiency for the gossip protocol [1] vs. the transmission probability p. Lower p improves efficiency, but penalty is lower coverage.

Under gossip each node operates independently, there is no coordination at all. Many researchers have proposed protocols that improve on gossip by making use of various types of local information. Instead of simply gossiping with some gossip probability p, the transmission decision can be made based on local information gathered either passively (through listening) or actively (through issuing query messages to neighbors). In [2] we studied these gossip variants via simulations. We then proceeded to combine and optimize them into a superior protocol, which we called `SmartGossip`. This protocol makes use of several improvements: (1) a state vector for recording all available information, (2) "directed" transmissions to reduce latency, (3) a sigmoid based transmission probability function that parametrizes the impact of randomization, (4) confirmation messages which facilitate listening by a node's neighbors, and (5) query-request messages which permit nodes to pull messages from neighbors.

1.2. WSN performance metrics

There are several performance metrics relevant to evaluating the performance of any proposed broadcast protocol. We shall formally define these metrics in Section 3. First, the *coverage* is the average fraction of nodes in the network that receive a typical message. Second, the *efficiency* is the average ratio of the number of nodes receiving the message over the number of transmissions of that message. Third, the *delay* is the average time a message spends in the system. Fourth, the *collision quotient* is the average number of communication collisions per transmission attempt. Fifth, the *broadcast capacity* is the maximum rate at which the network may generate new broadcast messages subject to a constraint on the minimum coverage and maximum delay. Sixth, the *energy consumption* is the energy consumed by the nodes in the network.

1.3. Topology of network

A uniform distribution is often used to model the spatial locations of nodes in large size WSNs. This arrangement, although simple and analytically tractable, discounts the fact that the node distribution is not likely to be completely spatially random, i.e., the nodes are generally going to exhibit some degree of clustering. As an example, consider the case where nodes are dropped in a terrain that has small hills and valleys: it is quite possible that sensors will fall more densely in the valleys than on the hills. To characterize the impact of clustering on performance, we will look at two different topologies: a uniform distribution and a cluster process.

1.4. Channel model

We use a standard channel model for communication where a message is received provided its instantaneous signal to interference and noise ratio (SINR) exceeds a particular threshold over the duration of the transmission. Transmissions are subject to distance dependent path loss attenuation and distance independent channel variations (in our case, Rayleigh fading).

1.5. Coordinations

We focus on two coordination mechanisms: information coordination (IC) and communication coordination (CC). When using IC, whether or not a node transmits depends on the fraction of neighboring nodes not having the message. By deciding to transmit a message only when some minimum number of the node's neighbors do not already possess the message, the number of redundant transmissions can be reduced. When employing CC, nodes only transmit when a certain number of its neighbors are not already receiving from another transmitter. This reduces the number of collisions that may occur. IC improves efficiency, whereas CC reduces collisions. We study the performance of a WSN using IC and/or CC under variations in topology and when nodes die due to energy constraints (battery depletion). We study four broadcast protocols to gauge the individual and joint benefits of IC and CC. These protocols are the combinations of either using or not using IC and CC.

1.6. Summary of findings

We show how the use of IC and CC in the presence of interference achieves a higher broadcast capacity. We