Brief Announcement: Randomized Blind Radio Networks

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Abstract

Radio networks are a long-studied model for distributed system of devices which communicate wirelessly. When these devices are mobile or have limited capabilities, the system is best modeled by the ad-hoc variant, in which the devices do not know the structure of the network. Much work has been devoted to designing algorithms for the ad-hoc model, particularly for fundamental communications tasks such as broadcasting. Most of these algorithms, however, assume that devices have some network knowledge (usually bounds on the number of nodes in the network n, and the diameter D), which may not be realistic in systems with weak devices or gradual deployment. Little is known about what can be done without this information.

This is the issue we address in this work, by presenting the first *randomized* broadcasting algorithms for *blind* networks in which nodes have no prior knowledge whatsoever. We demonstrate that lack of parameter knowledge can be overcome at only a small increase in running time. Specifically, we show that in networks without collision detection, broadcast can be achieved in $O(D \log \frac{n}{D} \log^2 \log \frac{n}{D} + \log^2 n)$ time, almost reaching the $\Omega(D \log \frac{n}{D} + \log^2 n)$ lower bound. We also give an even faster algorithm for directed networks with collision detection.

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1 Model and problem

In the *ad-hoc multi-hop radio network* model, a communications network is represented as a graph, with nodes corresponding to devices with wireless capability. A directed edge (u, v) in the graph means that device u can reach device v via direct transmission. Efficiency of algorithms is measured in terms of number of nodes n in the network, and eccentricity D (maximum distance between any pair of nodes). The defining feature of radio networks is the rule for how nodes can communicate: time is divided into discrete synchronous steps, in which each node can choose whether to transmit a message or listen for messages. A listening node in a given time-step then hears a message iff exactly one of its in-neighbors transmits. In the model *with collision detection*, a listening node can distinguish between the cases of having 0 in-neighbors transmit and having more than one, but in the model *without collision detection* these scenarios are indistinguishable.

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While, in the ad-hoc model, the underlying graph is unknown to the nodes, it is usual to assume that nodes do know the values of n and D. We do not make this assumption, and thus are dealing with a more restrictive model, which we call *blind* radio networks, in which nodes have no prior network knowledge whatsoever.

We design *randomized algorithms* for the task of *broadcasting*, in which a single designated *source* node starts with a message, and must inform all nodes in the network via transmissions. We assume that all nodes except the source begin in an *inactive* state, and become *active* when they receive a transmission. Our algorithms are Monte-Carlo algorithms succeeding with *high probability* (i.e., their failure probability is at most n^{-c} for some $c > 0$).

1.1 Related work

Broadcasting is possibly the most studied problem in radio networks, and has a wealth of literature in various settings. In networks without collision detection, optimal broadcasting was achieved by Czumaj and Rytter [3], and Kowalski and Pelc [5], who gave randomized algorithms that complete the task in $O(D \log \frac{n}{D} + \log^2 n)$ time with high probability. This matched a known $\Omega(D \log \frac{n}{D} + \log^2 n)$ lower bound for the task [1, 6]. However, their algorithms *intrinsically require parameter knowledge*, and algorithms that do not require such knowledge have been little studied. The closest analogue in the literature is the work of Jurdzinski and Stachowiak [4], who give algorithms for wake-up in single-hop radio networks under a wide range of node knowledge assumptions. Their Use-Factorial-Representation algorithm is the most relevant; the running time is given as $O((\log n \log\log n)^3)$ for single-hop networks, but a similar analysis as we present would demonstrate that the algorithm also performs broadcasting in multi-hop networks in $O((D + \log n) \log^2 \frac{n}{D} \log^3 \log \frac{n}{D})$ time.

1.2 New results

We present a randomized algorithm for broadcasting in blind (directed or undirected) networks without collision detection which succeeds with high probability within time $O(D \log \frac{n}{D} \log^2 \log \frac{n}{D} + \log^2 n)$. This improves over the running time of [4] and comes within a poly-log log factor of the $\Omega(D \log \frac{n}{D} + \log^2 n)$ lower bound [1, 6]. We also present an $O(D \log \frac{n}{D} \log\log\log \frac{n}{D} + \log^2 n)$-time algorithm for directed networks with collision detection.

2 Algorithms

The main idea of our randomized algorithms in blind radio networks is as follows: when considering a particular node v we wish to inform, all of its active in-neighbors will be transmitting with some probability. We wish to make the sum of these probabilities approximately constant (say $\frac{1}{2}$), since then we can show that v will be informed with good probability. However, we do not know the size of v's active in-neighborhood, so choosing appropriate probabilities is difficult. To do so, we have the source node generate a global random variable from some distribution Y for each time-step, which will function as a 'guess' of in-neighborhood size. By appending these variables to the source message, we can ensure that all active nodes are aware of them. Then, based on these global variables and upon local randomness, the active nodes decide whether to transmit.

By choosing and analyzing the distribution Y we can obtain some bound on the probability that a node with active neighbors is informed, in each time-step. We then show a recipe for converting these probabilities to a running time for broadcasting.

Algorithm 1 Broadcast Framework.

for $t = 1$ to ∞ **do**
  let $T = 2^t$.
  for each $j \in [T]$, s generates a random variable x_j from distribution Y.
  s appends variables x_j to the source message.
  for j from 1 to T, in time-step j, **do** active nodes v transmit with probability 2^{-x_j}.
end for

2.1 Blind radio networks without collision detection

In networks without collision detection, we take Y to be the sum of two *components*, which account for different network conditions. Under most circumstances, we use **General-Broadcast**; where the source "guesses" a neighborhood size from 1 to ∞ in each time-step, with a probability that decreases in neighborhood size in order to converge. In low diameter networks, we improve upon this with **Shallow-Broadcast** component, which quickly informs networks of low diameter using T to approximate in-neighborhood size.

▶ **Theorem 1.** *Broadcasting can be performed in networks without collision detection in* $O(D \log \frac{n}{D} \log^2 \log \frac{n}{D} + \log^2 n)$ *time, succeeding with high probability.*

2.2 Directed blind radio networks with collision detection

When collision detection (and a global clock) is available, nodes can learn their exact distance d_v from the source node within $O(D)$ time, via a process known as *beep waves* [2]. The local transmission probabilities that nodes use during our broadcasting algorithm can then depend on d_v, as well as T and the global randomness provided by the source. We add two new components to the two already defined which exploit this: **Deep-Broadcast**, which quickly informs nodes far from the source, and **Semi-Shallow-Broadcast**, which removes a running-time bottleneck when D is small.

▶ **Theorem 2.** *Broadcasting can be performed in networks with collision detection in* $O(D \log \frac{n}{D} \log \log \log \frac{n}{D} + \log^2 n)$ *time, succeeding with high probability.*

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