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# Information dissemination in unknown radio networks with large labels

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ABSTRACT

We consider the problems of deterministic broadcasting and gossiping in completely unknown ad-hoc radio networks. It is assumed that nothing is known to the nodes of the network about the topology of the network, that is even the size of the network is not known, except that $n > 1$. This lack of knowledge, about the value of $n$, is what distinguishes this setting from the vanilla model.

For this setting, protocols for the vanilla model, may be executed with multiplicatively large estimates, say $2^i$ in the $i$th phase, on the upper bound on the size of the network $n$. When the respective protocol with estimate $2^i \geqslant n$ on the size of the network is run, it will accomplish the task successfully. However, the problem that still remains is to determine when this process should terminate. Thus, to apply this design paradigm successful completion or incompletion of the process should be detected and this knowledge circulated in the network after appropriate number of rounds/phases of the protocol. In radio networks literature, this setting is known as the Acknowledged setting and broadcasting and gossiping problems for it are referred to as Acknowledged broadcasting and gossiping. An important feature of dynamic radio networks is that radio nodes can be dynamically introduced in the network from time to time and can be assigned labels in a much larger range, say polynomial in the size of the network, e.g. $[1, \ldots, n^c]$ for some constant $c$.

It is easy to see that protocols can be designed for the acknowledged setting only when the underlying communication network is strongly connected. We present the following results for these networks: (a) A deterministic protocol for Acknowledged broadcasting which takes $NRG(n, n^c)$ rounds, where $NRG(n, n^c)$ is the round complexity of deterministic gossiping for vanilla model. (b) A deterministic protocol for acknowledged gossiping, which takes $O(n^2 \lg n)$ rounds when collision detection mechanism is available. The schedule of the transmissions of nodes in the network, to enable them to infer collisions and discover existence of unknown in-neighborhood as a result, is abstracted as a family of sets of natural numbers which we call the Selecting-Colliding family. We prove the existence of Selecting-Colliding families using the probabilistic method and employ them to design protocol for acknowledged gossiping when no collision detection mechanism is available. Finally, we present a deterministic protocol for Acknowledged broadcasting for bidirectional networks, with a round complexity of $O(n \lg n)$ rounds.



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## 1. Introduction

Mobile ad-hoc radio networks play an important role in a large number of areas, ranging from agriculture and automobiles to hazardous environments and defense. Often enough, the connectivity of radio networks is not planned ahead precisely and there is no centralized system to coordinate the deployed radio nodes. Thus, radio networks form a classical distributed setting in which the nodes have to rely solely on the communication received by them from other nodes, their own label values (possibly knowledge of some other parameters) and environment stimulus to determine their action at any time. Complex communication activities rely in turn on fundamental communication primitives like broadcasting and gossiping.

In the *broadcasting problem*, a message from a distinguished source node is to be communicated to the rest of the nodes of the network, while in the *gossiping* problem each node of the network possesses a message which is to be disseminated to the entire network. Needless to say, gossiping can be achieved only on strongly connected networks. For both these primitives, the most important design consideration is the total time lapsed from initiation of a task to its completion. Typically, it is assumed, as in this work also, that nodes are synchronized with respect to a centralized clock and there are no faulty nodes. Nodes are also allowed to communicate messages of arbitrary sizes in a single time unit. Computation is organized in rounds. In every round, each node acts either as a transmitter or as a receiver but not both. Whether a node is actually able to receive a message or the message sent by it is received by an out-neighbor depends on the following characteristic of radio transmissions when no collision detection mechanism is available: *If two in-neighbors of a node transmit any message in the same round, then a collision occurs and the receiving node receives nothing. Furthermore, the receiving node cannot distinguish this event from the event when all of its in-neighbors are silent*. When collision detection mechanism is available then the node under consideration is able to detect the collision. In this work, we consider broadcasting and gossiping problems under both these assumptions.

The metric by which the complexity of broadcasting and gossiping protocols is measured is the round complexity. This metric is typically defined in terms of the number of nodes in the network $n$, the diameter of the network $D$ and maximum in-degree of a node $\Delta$. Also, the broadcasting and gossiping problems in radio networks have been studied under different assumptions about the knowledge of topology. In the centralized setting, the topology of the network is known to all the nodes. In a stronger model, nodes are given the labels of their immediate neighbors and in the more general setting the network is directed and nodes know only their own labels and the number of nodes in the network. *However, the ad-hoc nature of the radio networks is most closely modeled by the setting in which even the number of nodes in the radio network is not known*. Radio nodes have batteries which run for a short duration and whose life is largely restricted by the number of radio transmissions made by a node. Once the battery is consumed the radio node itself may be discarded or forgotten. Older nodes lying in the field for long duration are likely to die out, may be ignored and may stop participating in future computations. In a truly dynamic setting, nodes do not have any estimate of the size of the network to which they belong. Furthermore, a smaller range in which nodes are assigned labels may have been consumed by the unresponsive, undetected nodes in the field and cannot be reused. Thus, the ad-hoc nature of radio networks imposes the constraint that the nodes may be assigned labels in some large range say $[1, \ldots, n^c]$, where $c$ is a large constant (the reader is referred to [29] for a detailed motivation for studying the problem arising of large labels).

A protocol designed for the vanilla setting, in which nodes know the number of nodes in the network $n$, can be used for this setting as follows: Run the protocol for multiplicatively larger estimates on the upper bounds on the size of the network in a phase-wise manner, say estimate $2^i$ in the $i$th phase. However, a problem that still remains in this design methodology is that nodes cannot determine when a particular task has successfully completed. Hence, it is required that nodes receive some form of an ACK (acknowledgment) or NACK (negative acknowledgment) about the completion of certain task at the end of a phase. In the literature, these problems for completely *unknown networks* are called acknowledged broadcasting and acknowledged gossiping. They are known to be impossible to achieve for arbitrary values of $n$. If $n$ is guaranteed to be greater than 1, then possibility results are known [5,28]. The impossibility result in [14] rigorously formalizes the intuition that for acknowledged broadcasting, players must wake-up spontaneously[1] and start participating on their own. We stress that the wake-up in the spontaneous model happens synchronously i.e., all nodes wake up at the same time. In this work, we assume spontaneous transmissions and that number of nodes in the network $n$ is greater than 1.

The question of acknowledged broadcasting and gossiping was initially formulated and explored in [5]. Most recently, this problem has been considered in [30] and [14]. In [30] protocols have been given for acknowledged broadcasting (ARB) and acknowledged gossiping (ARG) for bidirectional and strongly connected networks. For *ARB* on bidirectional and strongly connected networks, protocols with round complexity of $O(n)$ and $\tilde{O}(n^{4/3})$ respectively are given. For ARG, the authors design protocols with a round complexity of $O(n\lg^3 n)$ and $\tilde{O}(n^{4/3})$ for bidirectional and strongly connected networks, respectively. For strongly connected networks, the round complexity of deterministic acknowledged broadcasting has been improved to $O(n\lg n\lg\lg n)$ rounds in [14].

Acknowledged protocols proposed in [5,28,30,14], for the setting of small labels, are quite inefficient if made to run for the setting when the nodes can take polynomially large labels. From a theoretical point of view, the assumption of

[1] It may be noted here that typically non-spontaneous model is considered in the literature in which it is assumed that a node should receive a message before participation in the broadcast protocol.