Theoretical Computer Science 562 (2015) 453–475

Contents lists available at ScienceDirect

Theoretical Computer Science

www.elsevier.com/locate/tcs

Data gathering and personalized broadcasting in radio grids with interference ☆

Jean-Claude Bermond [a,b,*], Bi Li [b,a,c], Nicolas Nisse [b,a], Hervé Rivano [d], Min-Li Yu [e]

[a] Univ. Nice Sophia Antipolis, CNRS, I3S, UMR 7271, Sophia Antipolis, France
[b] INRIA, France
[c] Institute of Applied Mathematics, Chinese Academy of Sciences, Beijing, China
[d] Urbanet Inria team, Université de Lyon, Insa Lyon Inria CITI Lab, France
[e] University of the Fraser Valley, Dpt of Maths and Statistics, Abbotsford, BC, Canada

ARTICLE INFO

Article history:
Received 29 December 2012
Received in revised form 8 October 2014
Accepted 21 October 2014
Available online 27 October 2014
Communicated by G. Ausiello

Keywords:
Gathering
Personalized broadcasting
Grid
Interference
Radio networks

ABSTRACT

In the *gathering* problem, a particular node in a graph, the *base station*, aims at receiving messages from some nodes in the graph. At each step, a node can send one message to one of its neighbors (such an action is called a *call*). However, a node cannot send and receive a message during the same step. Moreover, the communication is subject to interference constraints, more precisely, two calls interfere in a step, if one sender is at distance at most d_I from the other receiver. Given a graph with a base station and a set of nodes having some messages, the goal of the gathering problem is to compute a schedule of calls for the base station to receive all messages as fast as possible, i.e., minimizing the number of steps (called *makespan*). The gathering problem is equivalent to the *personalized broadcasting* problem where the base station has to send messages to some nodes in the graph, with same transmission constraints.

In this paper, we focus on the gathering and personalized broadcasting problem in grids. Moreover, we consider the non-buffering model: when a node receives a message at some step, it must transmit it during the next step. In this setting, though the problem of determining the complexity of computing the optimal makespan in a grid is still open, we present linear (in the number of messages) algorithms that compute schedules for gathering with $d_I \in \{0, 1, 2\}$. In particular, we present an algorithm that achieves the optimal makespan up to an additive constant 2 when $d_I = 0$. If no messages are "close" to the axes (the base station being the origin), our algorithms achieve the optimal makespan up to an additive constant 1 when $d_I = 0$, 4 when $d_I = 2$, and 3 when both $d_I = 1$ and the base station is in a corner. Note that, the approximation algorithms that we present also provide approximation up to a ratio 2 for the gathering with buffering. All our results are proved in terms of personalized broadcasting.

☆ This work is partially supported by Project STREP FP7 EULER, ANR Verso project Ecoscells, ANR GRATEL and Region PACA.

* Corresponding author at: Univ. Nice Sophia Antipolis, CNRS, I3S, UMR 7271, Sophia Antipolis, France.
E-mail addresses: jean-claude.bermond@inria.fr (J-C. Bermond), bi.li@inria.fr (B. Li), nicolas.nisse@inria.fr (N. Nisse), herve.rivano@inria.fr (H. Rivano), joseph.yu@ufv.ca (M.-L. Yu).

http://dx.doi.org/10.1016/j.tcs.2014.10.029

1. Introduction

1.1. Problem, model and assumptions

In this paper, we study a problem that was motivated by designing efficient strategies to provide internet access using wireless devices [8]. Typically, several houses in a village need access to a gateway (for example a satellite antenna) to transmit and receive data over the Internet. To reduce the cost of the transceivers, multi-hop wireless relay routing is used. We formulate this problem as gathering information in a Base Station (denoted by BS) of a wireless multi-hop network when interference constraints are present. This problem is also known as data collection and is particularly important in sensor networks and access networks.

Transmission model We adopt the network model considered in [2,4,9,11,16]. The network is represented by a node-weighted symmetric digraph $G = (V, E)$, where V is the set of nodes and E is the set of arcs. More specifically, each node in V represents a *device* (sensor, station, ...) that can transmit and receive data. There is a special node $BS \in V$ called the *Base Station (BS)*, which is the final destination of all data possessed by the various nodes of the network. Each node may have any number of pieces of information, or *messages*, to transmit, including none. There is an arc from u to v if u can transmit a message to v. We suppose that the digraph is symmetric; so if u can transmit a message to v, then v can also transmit a message to u. Therefore G represents the graph of possible communications. Some authors use an undirected graph (replacing the two arcs (u, v) and (v, u) by an edge $\{u, v\}$). However *calls* (transmissions) are directed: a call (s, r) is defined as the transmission from the node s to node r, in which s is the *sender* and r is the *receiver* and s and r are adjacent in G. The distinction of sender and receiver is important for our interference model.

Here we consider grids as they model well both access networks and also random networks [14]. The network is assumed to be synchronous and the time is slotted into *steps*. During each step, a transmission (or a *call*) between two nodes can transport at most one message. That is, a step is a unit of time during which several calls can be done as long as they do not interfere with each other. We suppose that each device is equipped with a half duplex interface: a node cannot both receive and transmit during a step. This models the near-far effect of antennas: when one is transmitting, it's own power prevents any other signal to be properly received. Moreover, we assume that a node can transmit or receive at most one message per step.

Following [11,12,15,16,18] we assume that no buffering is done at intermediate nodes and each node forwards a message as soon as it receives it. One of the rationales behind this assumption is that it frees intermediate nodes from the need to maintain costly state information and message storage.

Interference model We use a binary asymmetric model of interference based on the distance in the communication graph. Let $d(u, v)$ denote the distance, that is the length of a shortest directed path, from u to v in G and d_I be a nonnegative integer. We assume that when a node u transmits, all nodes v such that $d(u, v) \leq d_I$ are subject to the interference from u's transmission. We assume that all nodes of G have the same interference range d_I. Two calls (s, r) and (s', r') do not interfere if and only if $d(s, r') > d_I$ and $d(s', r) > d_I$. Otherwise calls interfere (or there is a collision). We focus on the cases where $d_I \leq 2$. Note that in this paper we suppose $d_I \geq 0$. It implies that a node cannot receive and send simultaneously.

The binary interference model is a simplified version of the reality, where the Signal-to-Noise-and-Interference Ratio (the ratio of the received power from the source of the transmission to the sum of the thermic noise and the received powers of all other simultaneously transmitting nodes) has to be above a given threshold for a transmission to be successful. However, the values of the completion times that we obtain lead to lower bounds on the corresponding real life values. Stated differently, if the completion time is fixed, then our results lead to upper bounds on the maximum possible number of messages that can be transmitted in the network.

Gathering and personalized broadcasting Our goal is to design protocols that efficiently, i.e., quickly, gather all messages to the base station BS subject to these interference constraints. More formally, let $G = (V, E)$ be a connected symmetric digraph, $BS \in V$ and $d_I \geq 0$ be an integer. Each node in $V \setminus BS$ is assigned a set (possibly empty) of messages that must be sent to BS. A multi-hop schedule for a message is a sequence of calls used to transmit this message to BS. As no buffering is allowed, this schedule is defined by the step of the first call and the path that the message follows in order to reach BS. The *gathering problem* consists in computing a multi-hop schedule for each message to arrive the BS under the constraint that during any step any two calls do not interfere within the interference range d_I. The completion time or *makespan* of the schedule is the number of steps used for all messages to reach BS. We are interested in computing the schedule with minimum makespan.

Actually, we describe the gathering schedule by illustrating the schedule for the equivalent *personalized broadcasting problem* since this formulation allows us to use a simpler notation and simplify the proofs. In this problem, the base station BS has initially a set of *personalized* messages and they must be sent to their destinations, i.e., each message has a personalized destination in V, and possibly several messages may have the same destination. The problem is to find a multi-hop schedule for each message to reach its corresponding destination node under the same constraints as the gathering problem. The completion time or *makespan* of the schedule is the number of steps used for all messages to reach their destination and the problem aims at computing a schedule with minimum makespan. For any personalized broadcasting schedule, it is always possible to build a gathering schedule with the same makespan. Hence these two problems are equivalent. Indeed,