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A heuristic algorithm for optimum transmission schedule in broadcast packet radio networks

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Abstract

Packet Radio networks are to provide data communications among a set of nodes distributed over a wide region. Transmission from nodes is broadcast in nature. Where direct communication between two nodes is not possible, connection is established in multiple hops. A time division multiple access (TDMA) protocol is adopted for conflict free communication among different nodes. The goal is to find a *conflict free transmission schedule* for different nodes at different time-slots of a fixed length time frame, called TDMA cycle. The optimization criterion is primarily to (1) minimize the TDMA cycle length, and then to (2) maximize the number of transmissions. The problem is proved to be NP-complete. A randomized algorithm is proposed, which is very efficient to achieve the first optimization criterion. The results are shown to be superior compared to other recently reported competitive algorithms.

Keywords: Packet radio network; Time division multiple access; Optimum transmission schedule

1. Introduction

Packet Radio networks (PRNET) are widely used for wireless communication over a wide geographical area, where direct radio or cable connection is impractical. A host of papers, published during 1984–1987, contain nice survey about this problem and its variations [1–6].

The radio frequency band, available for use to a network system, can be allocated to the different nodes in different ways: frequency division [5,7], time division [8], code division, and spatial reuse. When a single radio channel is used, the communication can be facilitated either by broadcasting, or by activating a subset of network links in proper sequence [9–11]. In general, when nodes transmit packets in broadcast mode using omnidirectional antennas, network management is simple if all nodes are tuned to the same channel frequency, and use time division and spatial reuse [12–14]. By spatial reuse we mean, a set of nodes can transmit the same channel at the same time, if that does not cause any interference, due to their far away geographical locations. For example, using the UHF band for ground mobile operation, where the radio range is inherently short, rendering spatial reuse is a natural outcome. Sometimes directional antenna or low transmission power is used to facilitate spatial reuse of channel [15,16]. Since all nodes cannot directly communicate, due to distance or other obstructions, nodes act as store-and-forward repeaters facilitating multi-hop connection. The PRNET model we assume here uses time division multiplex with spatial reuse.

A PRNET can be modeled by an undirected graph, where the nodes represent the transreceiver stations. A link between two nodes is present when they can transmit and receive packets directly. An example of a network with six nodes is shown in Fig. 1(a). Here, node 1 can communicate directly with nodes 2 and 3, but not with the remaining nodes. When node 1 has to transmit a packet to node 5 say, it has to use nodes 3 and 4 as intermediate repeaters.

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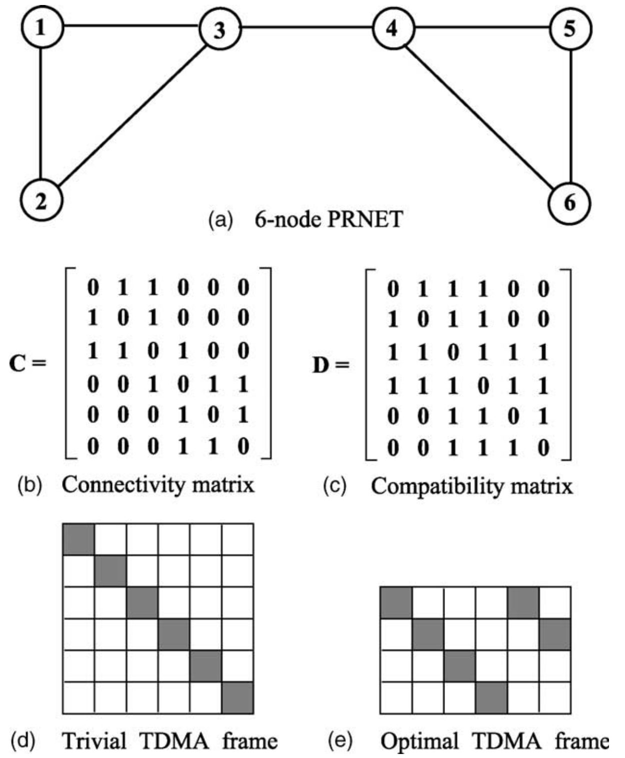

Fig. 1. Example of a (a) 6-node network, corresponding (b) **C** matrix and (c) **D** matrix, with (d) trivial TDMA schedule and (e) optimal TDMA schedule.

In the PR network, each station can transmit or receive, which is controlled by its control unit. When a node transmits, all its neighbors connected by direct link in the graph, can receive. The neighboring node/s could absorb the packet, if it is so designated. Else, it may store it to transmit it later, in which case it acts as an intermediate repeater.

We consider a fixed topology PRNET, where a single wide band Radio channel is used by all nodes. A time division multiple access (TDMA) protocol is used [4]. The transmissions of packets are controlled by a single clock. The time is divided into distinct frames consisting of fixed length time-slots. A time-slot equals to the total transmission time required for a single packet to be transmitted and received by a pair of neighboring nodes. Many nodes may transmit simultaneously at the same time-slot without conflict, if they are far apart. In one TDMA frame, all the nodes must be able to transmit at least once. This is termed as *no-transmission* constraint.

The basic optimization objective is to get the smallest length TDMA frame, where many nodes are allowed to transmit simultaneously in a single time-slot in a conflict free manner. The secondary objective is to maximize the number of such transmissions for maximum utilization of the channel. Depending on the traffic distribution over the network, it is possible that some nodes may need more transmissions than others in a single TDMA frame. At first, we will not consider that situation and assign single transmission for each node in a TDMA frame, and minimize the TDMA frame length. In Section 3.2, we will modify the algorithm to accommodate situation, where the traffic demand at different nodes are different.

When multiple transmissions per node are scheduled in a TDMA frame, the number of transmissions for individual nodes should conform to their traffic demand [9]. Sometimes, even though traffic demands from different nodes are considered to be the same, the number of transmissions in the TDMA frame is maximized without considering uniform transmission allocation. In that case, one objective could be the fairness of allocation, where divergence of transmission allocations for different nodes should be as small as possible. In addition, one should ensure that the waiting time between transmissions for each node should be concentrated towards the average waiting time—another measure of fairness. These fairness objectives are not considered in any algorithm reported so far.

In addition to *no-transmission* constraint, there are other constraints, namely the *primary conflict* and the *secondary conflict*. *Primary conflict* says that a particular node cannot transmit and receive in the same time-slot. In other words, two neighboring nodes cannot transmit simultaneously. A *secondary conflict* occurs when two or more packets arrive at a node in a single time-slot. This will occur when two nodes at a distance of two hops are allowed to transmit simultaneously. Then the intermediate node will receive two different packets from two directly connected nodes, at the same time-slot. The transmission schedule in the TDMA cycle should be such that the *primary* and the *secondary conflicts* are avoided.

We propose a simple and fast randomized algorithm to find a pool of valid solutions of the problem. Though the optimization criterion is not considered while generating solutions, the best in the pool is the optimum solution for all the problems tried. Simulations were done with problems of various complexities and the results compared with recent works including one using neural network [17,18] and the other using mean field annealing [19].

The remainder of the paper is organized as follows. A formal introduction of this scheduling problem and the terms used in the paper are explained in Section 2. In Section 3, we describe the algorithm. In Section 3.2, an extension of the algorithm to consider non-uniform traffic demand at different nodes, is explained. The pseudocode and the complexity analysis of the algorithm are available in Appendix A. The details of simulation and results, and comparison with earlier works are in Section 4. Section 5 is the conclusion including discussions of possible extensions of this work.

2. The problem

PR network can be represented by a graph $G=(V,E)$, where $V=\{v_1,v_2,\ldots,v_i,\ldots,v_N\}$ is the set of nodes