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Broadcast scheduling in wireless sensor networks using fuzzy Hopfield neural network

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Abstract

In this paper we describe fuzzy Hopfield neural network (FHNN) technique to solve the TDMA (time division multiple access) broadcast scheduling problem in wireless sensor networks (WSN). We formulate it as discrete energy minimization problem and map it into Hopfield neural network with the fuzzy *c*-means strategy to find the TDMA schedule for nodes in a communication network. The broadcast scheduling problem for wireless sensor networks is an NP-complete problem. Each time slot is regarded as a data sample and every node is taken as a cluster. Time slots are adequately distributed to the dedicated node while satisfying the constraints. The aim is to minimize the TDMA cycle length and maximize the node transmissions avoiding both primary and secondary conflicts. The FHNN reduces the processing time and increases the convergence rate for Broadcast Scheduling Problem. Simulation results show that the FHNN improves performance substantially through solving well-known benchmark problems.

Keywords: Broadcast scheduling problem; Wireless sensor networks; Clustering; Fuzzy *c*-means; Hopfield neural network

1. Introduction

Effective broadcast scheduling is important to avoid any conflict and to use channel resource efficiently. The broadcast scheduling problem for wireless sensor networks (WSN) is an NP-complete problem. The time division multiple access (TDMA) technology has been used to share a radio channel among many users where a channel is divided into synchronized data packet transmission. A time slot has a unit time length required for a single packet to be communicated between adjacent nodes. The TDMA cycle length is the total number of time slots in a frame cycle. The transmission for each station must be scheduled to avoid any interference (Kanzaki, Hara, & Nishio, 2005).

The aim of the broadcast scheduling problem (BSP) is to find an optimal TDMA frame structure that satisfies to schedule transmissions of all nodes in a minimal TDMA length without any conflict (Peng, Soong, & Wang, 2004). Many researchers have investigated neural networks to solve the BSP. Baker and Ephremides (1981) first formulated the problem and proposed some ad-hoc algorithms. The problem of finding a TDMA cycle where all nodes can broadcast packets has been studied most intensively. Tassiulas, Ephremides, and Gunn (1989) had first proposed a Hopfield neural network for broadcast scheduling problem, where the decay term in the motion equation disturbs the system convergence on some conditions and provides poor solution quality. Even, Goldreich, Moran, and Tong (1984) proved that the TDMA cycle minimization problem is NP-complete. Besides, Funabiki and Takefuji (1993) proposed a parallel algorithm to find a conflict-free time slot assignment in a TDMA cycle. Their algorithm used the hysteretic McCulloch–Pitts model and three heuristics to increase the likelihood of the convergence to the global minimum. Meanwhile, Takefuji, Lee, and Aiso (1992) proposed a maximum neural network (MNN) model and applied it for several NP-complete problems. The MNN always guarantees a valid solution and greatly reduces the search space without the burden on parameter-tuning.

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Moreover, Chakraborty and Hirano (1998) used genetic algorithms with a modified crossover operator to handle large networks with complex connectivity. Additionally, Wang and Ansari (1997) proposed a mean field annealing (MFA) algorithm to find a TDMA cycle with the minimum delay time. Recently, Salcedo-Sanz, Bousono-Calzo'n, and Figueiras-Vidal (2003) proposed a hybrid algorithm HNN–GA which combines a Hopfield neural network for constraint satisfaction and a genetic algorithm for achieving maximal throughput. Yeo, Lee, and Kim (2002) proposed a two-phase algorithm based on sequential vertex coloring (SVC). They showed that their method can find better solutions. Furthermore, Shi and Wang (2005) proposed a two-stage hybrid method SVC–NCNN that combines a sequential vertex coloring (SVC) algorithm and the noisy chaotic neural network (NCNN). They use the SVC to obtain the minimal frame length in the first stage and the noisy chaotic neural network to obtain the maximal node transmissions in the second stage. Unfortunately, in the case of the BSP, the optimum choice of the parameters takes long calculation time. An inherent disadvantage of this approach is that it easily converges to local optima.

Most schemes employed to solve BSP problems concentrate on the applications of linear programming, graph coloring algorithm (Yeo et al., 2002), annealing (Wang & Ansari, 1997), neural networks (Bertsekas & Gallager, 1987; Funabiki & Takefuji, 1993; Shi & Wang, 2005; Tassiulas et al., 1989), and genetic algorithms (Chakraborty & Hirano, 1998; Salcedo-Sanz et al., 2003). No attempt has been made to solve BSP by applying a fuzzy clustering technique. This paper aims to find a conflict-free time slot assignment in a TDMA cycle. The problem of fuzzy clustering is to find a fuzzy c-partition and the associated cluster centers. In this paper, we proposed fuzzy Hopfield neural network (FHNN) clustering technique to solve the BSP. The proposed algorithm integrates fuzzy c-means clustering strategies into learning procedures (Bezdek, 1981). The FHNN algorithm is a numerical procedure for finding membership grade, which minimizes the energy function. Therefore, the BSP is considered as the problem of minimizing an energy function. The FHNN algorithm is used to obtain the net value, then the fuzzy state updating procedure is applied to obtain the solution. Time slots are adequately distributed to the nodes while satisfying the interference constraints. The FHNN finds the minimal TDMA frame length with transmission scheduling and maximize channel utilization for broadcast scheduling problem. This approach includes a new objective function and its minimization distance by Lyapunov energy function is based on unsupervised two dimensional fuzzy Hopfield neural networks. After applying FHNN method on the sample time slots at different number of nodes, there is an increase in the converge rate and a decrease in the number of iterations.

The rest of this paper is organized as follows. Section 2 describes the broadcast scheduling problem Section 3 describes the fuzzy Hopfield neural network (FHNN) algorithms applied to the broadcast scheduling problem and the energy function derived. Section 4 shows the simulation results. Finally, conclusions are presented in Section 5.

2. Broadcast scheduling problem (BSP)

In a TDMA ad-hoc network, time is divided into unit-length slots. Each frame consists of a fixed number of time slots. The goal of the BSP is to find a transmission schedule with the shortest TDMA frame cycle length which satisfies listed below constraints, and the total transmissions are maximized (Lloyd, 2002). Packets can be transmitted in successive frames. We are concerned with the fixed assignment of transmission for stations in a frame. We summarize the constraints in the BSP in the following two categories (Chakraborty & Hirano, 1998; Peng et al., 2004):

(1) *No-transmission constraint*: Each node should be scheduled to transmit at least once in a TDMA cycle.
(2) *No-conflict constraint*: It excludes the primary conflict (a node cannot have transmission and reception at the same time) and the secondary conflict (a node is not allowed to receive more than one transmission at the same time).

Network connectivity is described in an $n \times n$ symmetric binary matrix for an n-node network, where an element $d_{ij} = 1$ if there is connectivity between node i and node j. Any two connected or neighboring nodes can communicate with each other. Fig. 1 shows the system representation for the problem, where a six-nodes network and seven links are given in Fig. 1a. Figs. 1b and c show the connectivity matrix and the compatibility matrix, respectively. An optimum TDMA cycle solution of four time slots with seven transmissions for this BSP instance is described in Fig. 1d. The black square and the white square indicate the nonzero output and the zero output of the processing element, respectively.

3. FHNN for broadcast scheduling problem

3.1. Fuzzy Hopfield neural network (FHNN)

The Fuzzy c-means (FCM) clustering is based on the "sum of intra-cluster distances" criterion in which each data point belongs to a cluster for fitting a degree specified by membership grades (Windham, 1983). Let $Z = \{z_1, z_2, \ldots, z_n\}$ be a given finite unclassified data set, where z_x, $x = 1, 2, \ldots, n$, represents an n-dimensional training sample. A fuzzy c-partition of Z is denoted by $P = \{A_1, A_2, \ldots, A_c\}$, where c is a predetermined number of clusters. The membership grade μ_{xi} indicates the degree of possibility that z_x belongs to the ith fuzzy cluster. The membership grade is a value between zero and one which satisfies $\sum_{i=1}^{c} \mu_{xi} = 1$, for $x = 1, 2, 3, \ldots, n$ and $0 < \sum_{x=1}^{n} \mu_{xi} < n$, for $i = 1, 2, 3, \ldots, c$. The cluster center v_i of fuzzy partition A_i is calculated as