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Predictable Energy Aware Routing based on Dynamic Game Theory in Wireless Sensor Networks ☆

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ABSTRACT

A routing algorithm named Sub-Game Energy Aware Routing (SGEAR) modeled by Dynamic Game Theory is proposed in this paper to make better routing choices. SGEAR takes the residual energy of the nodes and the energy consumption of the path into consideration and achieves Nash Equilibrium using Backward Induction. Compared with Energy Aware Routing, SGEAR can provide stable routing choices for relaying nodes and the energy of the network can still burn evenly. Moreover, this algorithm is more suitable for being combined with sleeping scheduling scheme and thus prolongs the lifetime of Wireless Sensor Networks. Simulation results show that, combined with sleeping scheduling scheme, SGEAR has an increase of 20% in energy saving compared with Energy Aware Routing.

1. Introduction

Severe energy limitation is one of the most important differences between traditional network and Wireless Sensor Networks (WSNs). It is not feasible to supply energy with new battery to the sensor nodes because there are plenty of very cheap sensors deployed in a wide and complex area, some of which human cannot reach. So how to prolong the lifetime of the WSN is a challenging job researchers now face. A lot of work has been done to solve this energy-awareness problem, the principal goal of which is the efficient use of energy [1–4].

In this paper, energy efficient technologies are analyzed first and then the deficiency of the Energy Aware Routing is pointed out, leaving topics for further investigation. We assume that an ideal network model is adopted which means nodes' detecting neighbors is supported [5]. We set a simple example to illustrate the deficiency and also give a guidance of the improvement. Because the process of the routing scheme proposed in this paper is just a mapping of Dynamic Game Theory model, Dynamic Game Theory is therefore used in order to give a more persuasive conclusion and the strategies are given to choose and adjust path in finding the solution of sub-game Nash Equilibrium. Moreover, simulations show that the solution has a more predictable feature which endows itself with the advantage of combining with sleep scheduling mechanism.

2. Analysis on energy efficient technologies of WSN

In the year 2002, Deborah Estrin et al gave a guest report in the international conference of Mobicom [6], which showed an important result that decreasing the working time of the radio component [7–9] is a very important way for energy saving.

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In recent years, a lot of researchers have focused on diminishing the network energy consumption. Such work can be illustrated from micro and macro perspectives respectively. In micro aspect, coding [10], data compression [11–15] and data aggregation [14,16] can be used to reduce the power consumption by transmitting less data. Meanwhile, the nodes can be arranged to get into the sleep mode when there is no transmission task, which can be called sleep scheduling [17,18]. These researches from micro angle have laid a solid foundation for the energy saving issue, and furthermore, sleep scheduling plays a very important role especially when the scenario has a low frequency of data transmission. But in the micro aspect, the schemes have only considered the energy consumption of individual nodes or path, which has a feature of centralization, that is, the feature of burning the energy of the nodes along those paths. This leaves the network with a wide disparity in the energy levels of the nodes, eventually leading to disconnected subnets [19,20], and thus the network loses the ability to serve. To avoid this, alternative paths are chosen to balance the lifetime. Therefore, how to schedule the routing is the main subject of lifetime issues, the goal of which is to develop an optimal schedule strategy so that the energy of the nodes can burn evenly and furthermore to use the energy efficiently [20–23]. Although clustering is another hot topic achieve energy efficiency [24,25], the routing schemes among clusters and within a cluster still have to face the challenges stated above. So we do not mention clustering technologies in this paper.

Among the energy efficient technologies, Energy Aware Routing is a typical macro scheme [19]. It chooses the forward path based on the available energy of the nodes and the request energy of the path. The power available (PA) of the nodes is the energy left at present. The request energy of the path can be calculated using different radio propagation models [7–9].

Energy Aware Routing does make great progress in solving the disconnected-subnet problem. However, it does not focus on the lifetime of WSN. A scheme is proposed in [19] ensuring that the optimal path will not always be chosen so that the network degrades gracefully as a whole rather than getting partitioned. To achieve this, multiple paths are found between source and destinations, and each path is assigned a probability of being chosen, depending on the energy metric. In the scheme, paths are randomly chosen depending on the probabilities. This means that none of the paths is used all the time, preventing energy depletion. However, the scheme is based on the probability and it can only give an average result, furthermore it is not easy to combine with sleep scheduling mechanism. In literature [20], the Energy Aware Routing in [19] has been modified in the lifetime point of view. The new scheme chooses the path according to proportion of the path cost and the min power available value. It draws a balance between the lifetime of the network and the lifetime of single path. But in fact, the path cost has been allocated in each node, not in the minimum-power-available node, so this approach cannot prevent the occurrence of disconnection. Furthermore, it can draw the result of irregular changing. For convenience, we give the following two definitions before illustrating the irregular changing scenario.

Definition 1. If node *A* sends data to node *B*, then *A* is called up-direction node, *B* is called down-direction node.

Definition 2. Let *c* be the total energy consumption of the path *L*, let *a* be the minimum power available value among the nodes in path *L*, define *a*/*c* as the path survivability factor.

Theorem 1. *The path survivability factor can gain an irregular change when some new node is added to the path.*

Theorem 1 can be demonstrated by Fig. 1. Let the energy consumption of path L_1 be c_1, the minimum power available value among the nodes in path L_1 be a_1; let the energy consumption of path L_2 be c_2, the minimum power available value among the nodes in path L_2 be a_2; the power available value of node *S* be as ($a_s > a_1$; $a_s > a_2$), the energy consumption of one hop of node *S* be c_s. According to literature [17], when it comes to the path choice of *M*, *M* choose the path from L_1 and L_2 that satisfy max (a_1/c_1, a_2/c_2), When it comes to the path choice of *S*, *S* choose the path between L'_1 and L'_2 that satisfy max ($a_1/(c_1 + c_s)$, $a_2/(c_2 + c_s)$). Unfortunately there does exist a scenario that satisfies $(a_1/c_1) < (a_2/c_2)$ and $a_1/(c_1 + c_s) > a_2/(c_2 + c_s)$, for example, $a_1 = 3$, $c_1 = 5$, $a_2 = 2$, $c_2 = 3$, $c_s = 2$. That means node *M* will choose path L_1 while node *S* will choose path L'_2. A further analysis shows that node *S* has no other choice but to send data to node M which chooses path L_1, though node *S* would have chosen path L_2'. Therefore, the actual path is L'_1. We call this scenario an irregular change, and node *M* is called irregular changing node.

Theorem 2. *The choice of irregular changing node has nothing to do with that of the up-direction nodes.*

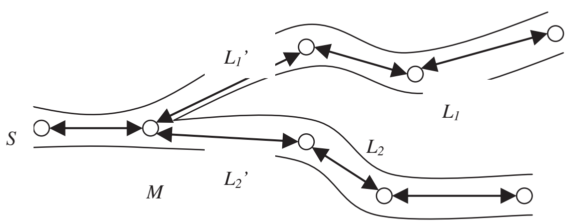

Fig. 1. Irregular change in path choosing.