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Optimal *k*-Anycast Routing Algorithm for Sleep-Wake Scheduling Wireless Sensor Networks

Xin Xu, Yun-li Gu, and Ya-ping Cheng
Jiangsu Engineering Center of Network Monitoring,
Nanjing University of Information Science & Technology, Nanjing 210044, China
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Abstract. Finding optimal *k*-anycast routing paths for sleep-wake scheduling wireless sensor networks(WSN) is a NP-complete problem. Most previous research work only attends to optimizing the time delay during a hop or a single path. But in terms of the performance of the end-to-end delay, this scheme is not optimal. In this paper, an optimal *k*-anycast routing algorithm for sleep-wake scheduling WSN is proposed to solve the problem. In the proposed algorithm, base stations apply AODV-based multipath routing protocol to acquire *k*-anycast routing information, then genetic algorithm is applied to search the optimal *k* routing paths between nodes and bases stations. Since the proposed algorithm has the feature of global optimization ability, in contrast to previous algorithms, experiment results show that the proposed algorithm can reduce end-to-end delay more efficiently.

Keywords: *k*-anycast, genetic algorithm, wireless sensor networks, routing algorithm.

1. Introduction

In a large-scale WSN, if all sensor nodes send their monitoring data to only one base station (or sink node), the base station would become a bottleneck. A solution to this problem is to deploy multi base stations in a monitoring field. And for reliability, energy-consuming-balancing, load-balancing and security purpose, it is useful to ensure that each sensor node should send its monitoring information to any *k* of all base stations. This communication model is generally called *k*-anycast.

In the literature, only a few algorithms have been designed for *k*-anycast routing [1-7]. The work in [1-2] proposed a *k*-anycast model in a mobile Ad hoc network and described the implementation scheme. Then Wang [3] proposed a *k*-anycast communication model for wired networks, which maintains a *k*-anycast tree according to the "join" and "leave" requests of the member nodes. Dow [4] also established an anycast tree based on the clustering and virtual backbone to discover *k* services. The work in [5] proposed a distributed geographic *k*-anycast routing (GKAR) protocol for WSN, which can efficiently route data from a source sensor to any *k* destinations. Subsequently, Gao [6] proposed a *k*-anycast routing protocol for WSN based upon an anycast tree scheme. In the scheme, a source initiates to create a spanning tree reaching any one sink with source node as the root. In the work [7], *k*-anycast is applied in publish/subscribe-based information-centric network(PS-ICN).

Sleep-wake scheduling is an effective mechanism to prolong the lifetime of energy-constrained sensor networks. In this scheduling, sensor nodes periodically or aperiodically exchange information with their neighboring nodes. Such as Hsu[8] and Naveen[9] appropriately arrange sensor nodes to sleep when data transmission or reception is not needed. In sleeping state, the communication module of a sensor node is turned off; so the energy consumption is fairly low. Thus, sleep-wake scheduling is suitable for WSN.

But according to sleep-wake scheduling, nodes are not always under working state, and senders often have to wait the next stop node to wake, thus leading much sleeping delay. In a multi-hop WSN, sleeping delay in each hop will accumulate, thus ultimately leading a bad performance of end-to-end transmission delay. The objective of the study is to find *k* routing paths which have the optimal performance of end-to end delay.

2. Problem description

We model a WSN by a directed graph $G(V,E)$, where *V* is the set of *n* vertices, and *E* is the set of *m* edges. We denote *N* by sensor nodes number; *S* is the source node; $G(A)$ is *k*-anycast group (base stations) and $A_1, A_2, \cdots, A_M$ are *k*-anycast members; r_i represents the wake-up rate of node *i*. Wake-up rate means the number of rounds a node from start working to end sleeping in a unit time. In each sleep-wake cycle, each node should promise at least Δt working time. We represent $r = (r_1, r_2, \cdots, r_N)$ the wake-up rate vector of WSN. For energy balancing purpose, *k*-anycasts paths are disjoint with each other. That means, each node joins at most one *k*-anycast path to prevent the node's energy draining too fast.

k-anycast routing is a NP-complete problem. That means, we cannot find a finite polynomial solution. According the algorithm in [3], they would select the best path one by one (best path first scheme, BPF) until they find k paths. But in fact it is not the optimal solution. As shown in Fig. 1, assuming *k*=2, path $P_1 = S, n_1, n_2, n_3, A_1$ will be selected firstly according [3], then since node n_1 and node n_3 are used by path P_1, $P_2 = S, n_7, n_8, n_9, A_3$ will be selected as the second path (*k*-anycast paths must be disjoint paths). Obviously, the end-to-end delay performance of $P_3 = S, n_4, n_2, n_3, A_1$ and $P_4 = S, n_1, n_5, n_6, A_2$ is better than P_1 and P_2. Therefore, BPF scheme is not the best scheme.

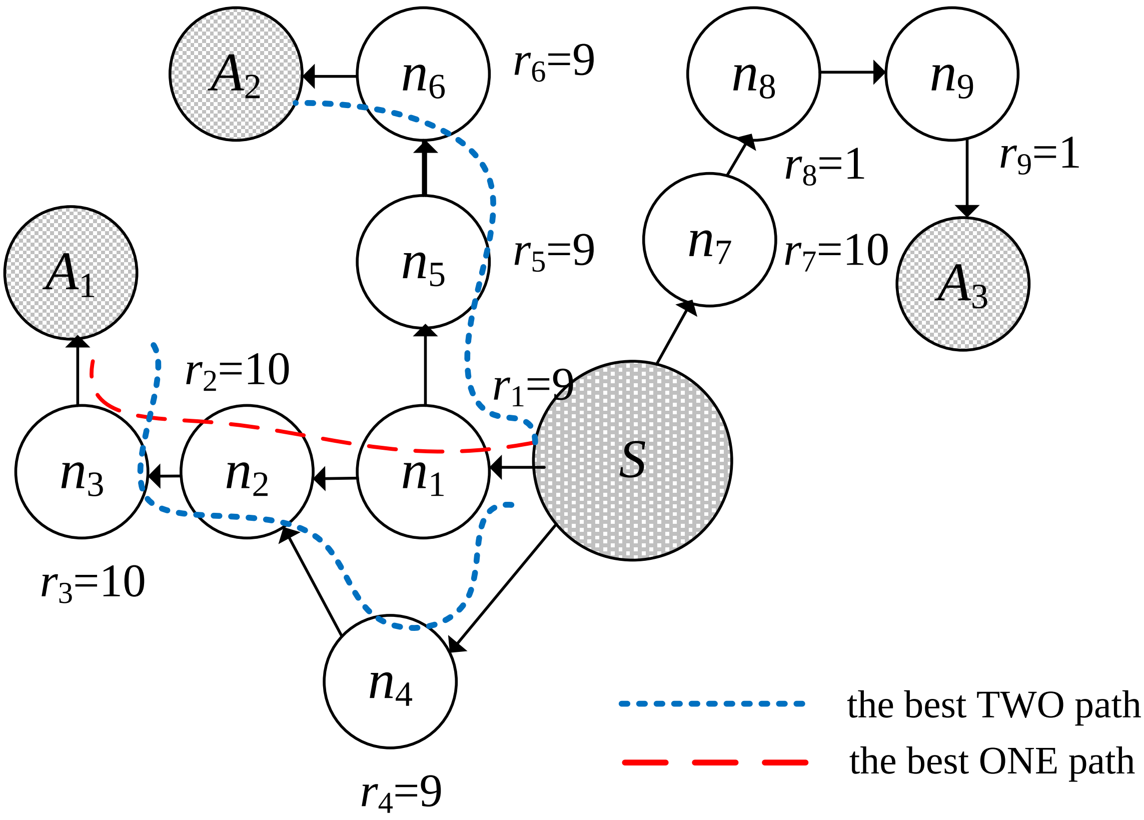

Fig 1. Illustration of *k*-anycast routing

Since *k*-anycast routing is a NP-complete problem, Kim [10-11] developed a delay-optimal anycast scheme. In the scheme, all nodes must follow a fixed sleep-wake scheduling and all source node must follow a fixed report task scheduling, and it turns the scheme into not practical (because the events such as nodes fall failure; select another path for energy balancing; clock drift; and so on). So in this paper, we propose an optimal *k*-anycast routing algorithm for sleep-wake scheduling WSN, and the proposed algorithm doesn't need the restriction on fixed report task scheduling.

3. Network model

For a *k*-anycast path $P = S, n_0, n_1, \cdots, n_L$, we have the end-to-end delay D_P as follows:

$$D_P = \sum_{i=0}^{L} (D_t(n_i) + D_s(n_i)) \tag{1}$$

Where, S is the source node, $n_L \epsilon G(A)$, $D_t(n_i)$ represents the transmission delay at node n_i, and $D_s(n_i)$ represents the waiting delay at node n_i. As we know, while a node is in wakeup state, the waiting delay is 0; otherwise; while a node is in sleeping state, the average waiting delay is $(1 - r_i \Delta t)/2r_i$. Thus, we have the expected value of $D_s(n_i)$ as follows:

$$D_s(n_i) = (1 - r_i \Delta t)^2 / 2r_i \tag{2}$$

While $r_i \in [0, 1/\Delta t]$, we know that $D_s(n_i)$ is monotone decreasing. And from Eqs.1, we also know that increasing the wake-up rate of a node can decrease the average waiting delay at that node.