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Routing protocol for *k*-anycast communication in rechargeable wireless sensor networks

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ABSTRACT

In this paper, a routing protocol for *k*-anycast communication based upon the anycast tree scheme is proposed for wireless sensor networks. Multiple-metrics are utilized for instructing the route discovery. A source initiates to create a spanning tree reaching any one sink with source node as the root. Subsequently, we introduce three schemes for *k*-anycast: a packet is transmitted to exact *k* sinks, at least *k* sinks, and at most *k* sinks, where, a packet can be transmitted to *k* or more than *k* sinks benefiting from broadcast technique without wasting the source energy for replicating it.

1. Introduction

Wireless sensor networks (WSNs), which are comprised of a large number of low-cost, low-power, small size, and multifunctional sensor nodes with finite battery life that can sense and process data and communicate with each other over a short distance [1,2], have been a topic of much interest to researchers due to their wide-ranging applications. For example, they have been used in military field [3], environmental field [4], health field [5], and smart home-field [6], to name a few. In these operations, sensors are utilized for collecting information on entities of their interest, where, efficient routing protocol and data transmission are usually required [7]. In WSNs, as the traffic of the network converges to the sink, nodes close to the sink consume their energy faster than farther nodes because they have to undertake the heavy workload for data forwarding and data collection.

Considering the packet delivery is restricted to the nodes around the sink and numerous packets will be accumulated in these nodes in a high data rate network, a solution to this problem is to deploy several sinks in a monitoring field, which poses a new challenge for routing protocol design. Currently, anycast becomes a very useful service for data transmission in multiple sinks. The paradigm of anycast communications [8,9], also termed one-to-any communications, is a newly designed communication service in IPv6, which is used to deliver a packet to any member of a group of designated recipients. Anycast technique plays an important role in the fields of DNS [10], etc. In WSNs, anycast technique can be used for neighbor and sink selection: when a sensor node produces data, it just needs to send it to any neighbor node or sink available.

In WSNs with multiple sinks deployed, for reliability, load-balancing and security purpose, it is then useful to ensure that at least *k* sinks receive a message whatever the *k* sinks, which is generally called *k*-anycast communication [11]. *k*-Anycast is an extension of anycast which delivers the packets sent by clients to at least or at most *k* member of an anycast group identified by an anycast address. *k*-Anycast communication technique is utilized for enhancing transmission reliability, load-balancing, and security purpose by collecting multiple copies of a packet from a source and verifying the information of monitoring field. Even though *k*-anycast scheme provides a high data transmission quality, it is easy for sensor nodes to deplete their energy due to limited and fixed energy supplement [12,13]. Note, it is generally accepted that the usefulness of a wireless sensor expires when its battery runs out. Therefore, there are scare works considering *k*-anycast communication for WSNs owing to the limited lifetime of sensor nodes.

Currently, an interesting approach to extend the lifetime of sensor nodes is to equip them with rechargeable technologies [14], which convert sources such as body heat [15], foot strike [16], finger strokes [17], and solar [18] into electricity. Assuming energy neutral operation [19], a sensor node can operate perpetually if the harvested energy is used at an appropriate rate. Note, a harvesting node is said to achieve energy-neutral operation if the energy used is always less than the energy harvested, and the desired performance level can be supported in a

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given harvesting environment. In these so called energy harvesting WSNs (EH-WSNs) or Rechargeable WSNs (R-WSNs), where sensors are equipped with rechargeable batteries or super-capacitor (in the order of a million recharge cycles [20]), although their lifetime is less of an issue, some new challenges appear due to the unique characteristics of R-WSNs.

For one thing, owing to the unpresentable nature of the environment and technology limitations, the available energy on nodes varies dramatically over time [21], which causes nodes to control energy utilization continually according to available energy. For another thing, the power storage capacity is limited [22], which means a node cannot be always beneficial to conserve energy when a network can harvest excessive energy from the environment [23]. In other words, reducing the power consumption below energy neutrality will not increase the lifetime further, but decrease the efficiency of the node utilization [24]. Since more energy can be extracted from the ambient environment, the harvested energy should be consumed as soon as possible in R-WSNs [25,26]. Therefore, rich power of sensors attribute to the application of *k*-anycast communication in R-WSNs.

In a nutshell, in the work, we propose a *k*-anycast routing protocol for data transmission. To the best of our knowledge, this is the first generic work that studies the routing protocol for *k*-anycast communication in R-WSNs. The remainder of this paper is organized as follows. In Section 2 we present a number of existing routing protocols about anycast and *k*-anycast communication, while in Section 3 the motivation is provided. In Section 4 we present our method and design. Section 5 contains experimental results. Conclusions are presented in Section 6.

2. Related work

The concept of anycast was studied in multiple contexts, including network type [27], communications model [28], and purpose of usage [29], etc. originally, anycast technique was used in the TCP/IP networks. For instance, anycast technique is used for directing DNS queries to the closest root name server [30] and for server selection in distributed systems [31]. Though anycast is originally designed for Internet service, it has been applied to routing protocol design for wireless ad hoc and sensor networks. The anycast communication is a quite important technique in a sensor network with multiple sinks. There are some anycast routing protocols which were improved to support anycast service and mainly come from current routing protocol, such as, the AODV (Ad hoc on-demand distance vector routing) protocol is modified to support anycast service [32].

Anycast can be an important paradigm for a wireless sensor network in terms of resource, robustness, and efficiency for replicated service applications [33–35]. Anycast routing protocols based on the tree structure [9,36,37] is in accordance with the agreement, the extended model usually in the tree by hop count, physical interval or time intervals for unit, to build an anycast tree. A query is transported along the most fitting anycast tree. The anycast scheme is utilized to cope with sink selection in routing protocol design for WSNs and improve the performance of routing protocol widely, whose ultimate goal is to prolong the network lifetime. Even though multiple sinks are deployed in R-WSNs and sensor should also select one sink from the sink group to deliver packets, network lifetime is not a problem and unique characteristics of R-WSNs pose a high challenge for routing protocol design for R-WSNs.

k-Anycast strategy is the extension of anycast technique and first introduced in reference [38]. It is proposed as that packet is sent to any *k* members out of particular communication destinations. In reference [39], a *k*-anycast routing scheme is proposed in a MANET. *k*-Anycast tree method is adopted in reference [40], which *k* servers cooperate with each other to accomplish a task. The research on the *k*-anycast communication model is still limited and mainly focused on IPv6 networks. In these TCP/IP networks, TCP/IP, as the basic configuration, is needed to support these models and every member is provided with an IP address. In WSNs, TCP/IP can't be supported. Particularly, the energy and communication are limited for wireless sensor networks. Hence, the *k*-anycast protocols designed for TCP/IP networks do not adapt to sensor networks.

Different from earlier works, which either focus on the TCP/IP networks or static battery-powered network for anycast application, in this work, we present a routing protocol for *k*-anycast communication in R-WSNs. In summary, on observing the lack of *k*-anycast techniques consideration for data transmission in existing routing protocols, we introduce the first generic routing protocol algorithm of *k*-anycast scheme in R-WSNs.

3. Motivation

For WSNs with single sink, all packets generated by source sensors will be transmitted to the sink through one or multiple hop transmission. Due to the limited transmission radius, the sensors around the sink undertake the heavy workload for data forwarding and are easy to run out of their energy, which causes these sensors to be separated from the WSNs and the WSNs can no longer fulfill its role, as the example shown in Fig. 1. Especially, in a high-traffic network, it is a bottleneck for data flow to the sink, where the packet delivery is restricted to the nodes around the sink and numerous packets will be accumulated in their nodes.

As the network size grows, a packet has to be forwarded by more hop counts before reaching a sink and the E2E delay is intolerable. At the same time, it leads to packet dropped and retransmission seriously, which increase the E2E delay excessively in return. An interesting solution to this problem is to deploy several sinks in the monitoring field, and the monitoring area is divided into multiple regions depending on the sinks' distribution. For a source node, it just sends its packets to the nearest sink and the length of routing path can be reduced significantly. Therefore, multiple sinks deployment is recognized and used widely in WSNs, especially, in large-scale WSNs and high-traffic WSNs.

In WSNs with multiple sinks, for reliability, load-balancing, and security purpose, a source node tries to send its packet to as many as possible sinks (usually called *k*-anycast communication) benefiting from broadcast advantage. When a sensor broadcasts its signal, since all its neighbors can sense the information only if they locate in the sensor transmission radius, it doesn't need to use extra energy to replicate its packet to other neighbors, which is shown in Fig. 2. Therefore, in traditional-WSNs with the limited battery device, it doesn't waste the energy of source for *k*-anycast communication. However, more sensors have to join in the data transmission for *k*-anycast scheme, and more energy will be consumed.

Therefore, *k*-anycast communication is used prudentially in traditional-WSNs.

In R-WSNs, for the intermediate sensors, which only undertake data forwarding task and don't generate signals, since their energy can be

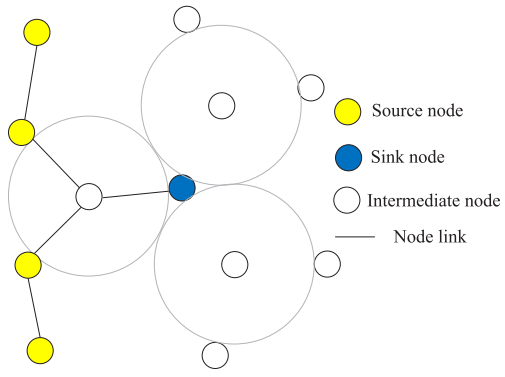

Fig. 1. Only one sink is deployed in a monitoring field.