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Opportunistic communications based on distributed width-controllable braided multipath routing in wireless sensor networks

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A B S T R A C T

Multipath routing, especially braided multipath routing (BMR), has become a powerful tool to provide reliable and energy-efficient packet transmissions against wireless links losses and node failures. In previous literatures, most of the construction methods of braided multipath routes are centralized and inefficient. By exploiting the broadcast nature of wireless mediums, opportunistic routings proposed recently bring much more reliability and efficiency for wireless communications. In this paper, with the idea of opportunistic routings, we propose a distributed width-controllable braided multipath routing (WC-BMR) based on local neighbor's information for data collections in wireless sensor networks. By only attaching a little information to data packets, the transmission direction can be restricted near the main route. Heterogeneous widths, namely, different widths on different hops from the source to the sink can also be supported to adapt to the dynamic and heterogeneous wireless links. Then, to avoid packet collisions, a novel time schedule strategy is given. In terms of the reliability, delay and transmission overhead, the performance of WC-BMR is analyzed theoretically. In addition, a kind of less cooperative topology (LC-Topology) in the WC-BMR is found, which brings no or less reliability gain. And modified cooperative WC-BMR (MCWC-BMR) with the detection algorithm for LC-Topology is proposed to maintain the high reliability and efficiency, which allows parents nodes to choose the best main route locally and dynamically. Using TOSSIM platform, WC-BMR and MCWC-BMR are both evaluated with some previous baseline approaches. Simulation results reveal that both WC-BMR and MCWC-BMR, especially the latter, can achieve higher reliability and efficiency, as well as keep lower delay under various network settings.

1. Introduction

Since early 2000, wireless sensor network (WSN) has drawn worldwide attentions from both academics and industrials, and become one of the key technologies for information obtaining in information age. Consisting of numerous smart wireless sensor nodes, WSNs can be used in various applications [1,2], such as intelligent buildings, modern agriculture, factory automation, military reconnaissance, wild environmental monitoring, etc. Every node in the network should accomplish data acquisitions, and transmit its data to the sink cooperatively. All uploaded sensor data will be processed to obtain useful information in the sink or in the network distributively for advanced applications.

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As one of the fundamental issues, the research about data collections in WSNs has been studied for many years [3]. From several practical projects like VigilNet [4], OASIS [5] and GreenOrbs [6], some related interesting findings have been discovered as follows:

(1) the packet loss rate over wireless links is much higher, and tremendous retransmissions are required to guarantee the reliability of multihop communications, thus leading to energy efficiency much lower;
(2) asymmetric wireless links may exist due to the diversity of hardware modules and unbalanced loads;
(3) packet collisions may happen when two or more neighbor nodes are sending packets at the same time;
(4) owing to the varying wireless links and random node failures in extreme situations, a predictable and stable path may never exist, the network connectivity is intermittent, and the rare upload opportunity and unpredictable node disruptions often result in packet loss.

Those bottleneck problems above are hindering further practical applications of WSNs. Therefore, the research about reliability issues for data collections in WSNs in order to increase disaster tolerance, data survivability and network lifetime has become of great significance.

Related works have been carried out in numerous literatures. There have been several transmission models, such as collection trees [7], clustering [8] and mobile sinks/mules [9,10]. Multipath routings [11] have been proposed for end-to-end communications, including disjointed routings [12–19] and braided routings [15–17,20–23], which exploit the redundancy of wireless links to improve the reliability. By exploiting the broadcast feature of wireless channels and the spatial diversity among neighbor nodes, opportunistic routings [24–32] allow that more than one forwarder overhears the transmission of the node on the previous hop, and only one best forwarder will be selected to forward the packet, which can decrease the number of retransmissions and transmission delay, and increase network reliability and throughput. Moreover, some coding methods have also been used for reliable transmissions, such as source coding [33], erasure coding [34], and network coding [35].

However, some problems in multipath routings and opportunistic routings still exist, remaining the design space for performance improvement. (1) The construction methods for multipath routings in most existing schemes like [13–16,20,21] are still inefficient, which need the whole link information attached in the control message, leading to high resource consumptions and complexity, and do not provide the scalability. (2) Node-disjoint multipath requires dense networks, where nodes should own many upstream neighbors. When the network gets sparser, network performance cannot be guaranteed. (3) In existing braided multipath routings [15–17,20–23], the transmission path width, namely, the size of local forwarding list on next hop, has not been explored to adapt to the varying and heterogeneous wireless links. (4) For opportunistic routings, diverging paths may exist [24–26,30], and forwarding set does not adapt to varying links, and only depends on network deployment [24–32]. (5) Some random or improper backoff strategies are utilized, which cause the interferences among two hops transmissions and cut down the reliability gain; (6) Most of existing schemes [12–16,20,21,23–32] are only designed for one source-destination pair communication, which cannot meet the requirement of many-to-one communications in WSNs.

In this paper, we propose a width-controllable braided multipath routing (WC-BMR) and a modified cooperative WC-BMR (MCWC-BMR) to increase the resilience to link dynamics for reliable and efficient data collections in WSNs. Our design inherits the advantages of braided multi-path routings and opportunistic routings by exploiting the broadcast nature and spatial diversity of wireless mediums. Both of proposed WC-BMR and MCWC-BMR incorporate four components to achieve high reliability and efficiency: a) the distributed construction of multiple parent cooperative topology (MPCT), b) the calculation of heterogeneous parent number, c) distributed WC-BMR packet transmission and its modified version MCWC-BMR, and d) time schedule strategy (TSS). Our major contributions are as follows in detail.

(1) First, MPCT topology is built in a distributed and iterative way to lay the foundation for cooperative packet delivery. It is not just for end-to-end pattern but for the many-to-one pattern, one of the popular communication patterns in the WSNs. In MPCT, every node has more than one potential parent to forward its packet to achieve the reliability. Diverse cooperative relationships may be absorbed in MPCT under different network densities and link losses.
(2) Then, the heterogeneous path width, namely, the parent number along the transmission route, can be calculated locally, which allows different widths on different hops to adapt to the dynamic and heterogeneous links.
(3) Next, based on MPCT, the WC-BMR packet delivery scheme is proposed to control the transmission direction on or near the main route locally during packet transmissions by only attaching a little information to the data packet. And a distributed TSS is given to avoid packet collisions among two hops transmissions.
(4) Besides, a kind of less cooperative topology (LC-Topology) during MPCT construction is found, which brings no or less reliability gain. The modified MCWC-BMR allows nodes to determine which main route will be followed dynamically to achieve much higher reliability and efficiency.
(5) At last, in terms of the reliability, delay and transmission overhead, the performance of WC-BMR is given theoretically. Compared with some related schemes, both of WC-BMR and MCWC-BMR are evaluated using TOSSIM platform. It is validated that both two proposed schemes, especially the latter one, can achieve better network performances.

The rest of this paper is organized as follows. In Section 2, the related works are given first. Then, MPCT construction, WC-BMR transmission and time schedule strategy are proposed respectively in Section 3. In Section 4, the performance of WC-BMR is analyzed theoretically. In Section 5, we present a local detection algorithm for LC-Topology and a modified cooperative WC-BMR. Compared with several existing schemes, our proposed schemes are evaluated in