Multipath Extension of the ZigBee Tree Routing in Cluster-Tree Wireless Sensor Networks

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ABSTRACT
Wireless Multimedia Sensor Networks (WMSNs) are one of the most challenging applications of WSN. They require large amounts of data to be transmitted with high reporting rates which consume an order of magnitude of resources, such as storage, computation, bandwidth, and energy. On the other hand, the ZigBee standard was originally specified for low data rate, low power consumption, and low cost wireless personal area networks (WPANs), making it suitable to WSN. However, handling high data rate applications, such as video surveillance in WPANs, is a challenge. Simultaneous multipath routing is one solution to increase the available bandwidth in a ZigBee network. In this paper, we proposed Z-MHTR (ZigBee Multipath Hierarchical Tree Routing), a node disjoint multipath routing extension of the ZigBee tree routing protocol in cluster-tree WSNs. Extensive simulations were performed and showed that the proposed multipath routing enhances application performance in terms of packet delivery ratio, end to end delay, and network lifetime even under heavy data rates.

Keywords: Cluster-Tree Topology, IEEE 802.15.4/ZigBee, Multipath Hierarchical Tree Routing, NS2 Simulations, Wireless Sensor Networks

INTRODUCTION
ZigBee is a robust wireless communication standard managed by the ZigBee Alliance (ZigBee, 2006) and based on the IEEE 802.15.4 physical and MAC layer standard (IEEE, 2006). It defines a network layer, application framework as well as security services. ZigBee aims at handling low data rate, low cost devices and long-life batteries making it very suitable to wireless sensor networks (WSNs) (Akyildiz, Su, & Cayirci, 2002). It can be embedded in a wide range of products and applications. Nowadays, the availability of low-cost CMOS cameras and microphones, Wireless Multimedia Sensor Networks (WMSNs) (Akyildiz, Melodia, & Chowdhury, 2007) gained more interest and research effort. In a WMSN, the scalar WSN
is strengthened by introducing the ability of retrieving richer information content through image and video/audio sensors (Rahimi et al., 2005). This can significantly enhance a wide range of applications like object detection, surveillance, recognition, localization, and tracking.

ZigBee supports three types of network topologies namely: star, peer-to-peer and its special case cluster tree topologies. The routing algorithm specified by the network layer of ZigBee depends on the topology used in the ZigBee sensor network. In the simple star topology, there is no routing, data is assumed to be directly transmitted in one-hop to the destination. In the tree topology, a Tree Routing (TR) protocol (Kim, Kim, Yoo, & Lopez, 2007; Nefzi & Song, 2007) is used. Data is routed along the parent-child links established as a result of join operations. Peer-to-peer topology uses a table driven routing basically similar to the Ad hoc On demand Distance Vector (AODV) routing protocol (Baronti et al., 2007; Perkins & Royer, 2003; Karthikeyan, 2010; Ran, Sun, & Zou, 2006). For these two latter topologies, devices can communicate with each other in a multi-hop manner.

ZigBee technology suffers from its limited bandwidth (250 kbps at 2.4 GHz) and extending it to meet WMSN requirements is a real challenge. In the literature, few works already considered multimedia applications over IEEE 802.15.4. In order to guarantee transmitting such dataflow, the authors in (Garcia-Sanchez, Losilla, & Garcia-Haro, 2008) made use of the Guaranteed Time Slot (GTS) (IEEE, 2006) (part of the ZigBee standard). In Deshpande (2006) the GTS mechanism is not used, streaming metrics such as packet loss and latency are analyzed in 802.15.4 networks using the NS2 simulator (Information Sciences Institute, n.d.). A cross-layer solution is proposed in Garcia-Sanchez, Garcia-Sanchez, and Losilla (2010) where the feasibility of transmitting streaming video flows is evaluated. It uses application-level QoS parameters to tune the MAC and physical layers.

In this paper, we explore the use of multipath routing to handle high data rate applications. We chose the cluster-tree topology (IEEE, 2006) of ZigBee and made extensions of the Tree Routing (TR) protocol to allow the formation of multiple disjoint paths. This choice is motivated by the fact that the tree-based topology is efficient, easy to establish and to maintain.

Multipath routing has been one of the most important current directions in the area of routing. It is known for its benefit to Ad-hoc and WSNs. Multipath routing allows the establishment of multiple paths between source and a destination node. According to the application goal, multipath routing may be proposed in order to increase the reliability of data transmission (i.e., fault tolerance) or to provide load balancing and higher aggregated bandwidth. In fact, numerous research investigations on the performance and benefit of multipath routing technique have shown that the use of such routing can improve throughput, reduce end to end delay, increase reliability, ensure security and also mitigate network congestion (Vlajic & Stevanovic, 2010).

Depending on application requirements, the established paths can be used alternatively where only one path is used at a time or simultaneously by using more than one path at the same time. The former approach is more suitable to ensure failure tolerance while the latter may allow load balancing. A multipath routing protocol can fall in one of the following three classes depending on paths disjointness: link disjoint paths, non-disjoint paths and node disjoint paths. However, ZigBee specification does not define the multipath routing mechanism; this limitation has motivated us to propose a solution to this important routing technique in ZigBee WSN which represents the main contribution of this paper.

This paper is structured as follows. The next section presents the related work. Introduced briefly in this section is IEEE 802.15.4/ ZigBee standard and its tree routing scheme. Our proposed ZigBee multipath routing protocol is then described and simulation results are
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