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Geographic energy-aware non-interfering multipath routing for multimedia transmission in wireless sensor networks

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A B S T R A C T

Wireless Multimedia Sensor Networks (WMSN) have been drawing considerable attention and discussion in recent years due to its potential applications in various fields. For WMSN, how to increase the throughput in constrained environments has become the main challenge. Multipath routing is a promising solution because it can improve the channel utilization rate, reduce transmission delay and balance the transmission load. To pursue high efficiency for a multipath routing scheme, we need to take the characteristics of wireless environments and sensor networks into careful considerations. Based on such considerations, this paper introduces a Geographic Energy-Aware non-interfering Multipath (GEAM) routing scheme which divides the whole network topology into many districts and simultaneously forwards data through these districts without interfering with each other – to achieve interference-free transmissions. Our scheme will adjust the load of each district according to the energy status of their nodes; it does not establish fixed paths in advance and will hence maintain high performance even when the topology changes rapidly. We meanwhile employ a simple way to deal with the hole problem. Simulation results show that, when compared with related routing schemes, our GEAM can achieve higher performance at real-time transmission and meanwhile distribute transmission loads more evenly to most of the nodes in the network.

1. Introduction

Recent technological advances in microelectrical–mechanical systems (MEMS) have helped reduce the cost and sizes of processors, memory and transceivers and, as a result, made producing cheap and tiny sensors possible. The numerous sensors spread in an assigned area can organize themselves into a wireless sensor network (WSN) [3] and report the observed phenomenon via multi-hop transmission to the sink node. In the past, WSN was usually dispatched to collect small-sized scalar data (such as temperature and moisture), however, with the maturity of miniaturization technologies, we are now able to install small, inexpensive cameras or microphones in sensor nodes and facilitate the development of wireless multimedia sensor networks (WMSN) [2,10].

WMSN can be utilized in such practical applications as video home care, road surveillance and health monitoring, but how to *efficiently* transmit the large amount of collected multimedia information (especially the real-time streaming video) by the bandwidth-limited wireless channels is a challenging task. Before routing starts, it is desirable to reduce the transmission load by compressing the captured images and videos. The problem is: sensor nodes – equipped with low-power CPU and limited memory – do not fit coding schemes proposed for high computational complexity, like MPEG [29] or APP [28]. We need to lessen the data rate using distributed video coding (DVC) [5,8,15,22], the low-complexity image compression algorithm which compresses massive real-time information into a much more succinct file.

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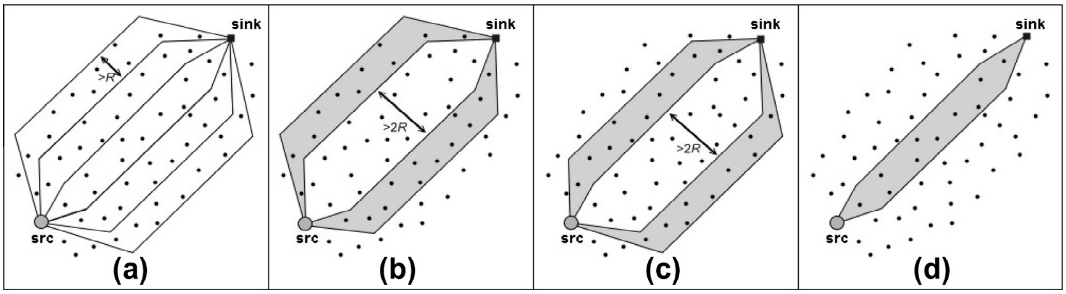

Fig. 1. The concept of GEAM.

Even aided by the DVC algorithm, involving limited bandwidth to transmit compressed real-time images remains a challenge as these data usually require tens to hundreds of kbps – depending on the image size, frame per second (FPS) and required peak signal-to-noise ratios (PSNR). Realizing these energy-limited, low-cost sensor nodes are prone to exhaust or error, we must take the following key factors into careful consideration in order to achieve efficient transmission for WMSN.

Key factors for real-time multimedia transmission:

1. *Low transmission delay:* For real-time transmission, data should arrive as fast as possible as much delayed data may become obsolete and useless.
2. *Balanced energy distribution:* As battery-powered sensor nodes are likely to exhaust energy when transmitting massive real-time information, we should distribute transmission burdens to more nodes in the network – to keep certain nodes from overwork or early exhaustion of their irreplaceable power.
3. *Duplicated paths:* When the cheap, error-prone sensor nodes are affected or destroyed by unpredictable disturbances or events, transmission paths may break down. When a broken path emerges, real-time transmission will break off to reconstruct a new path – causing transmission delay and also degrading network performance. To maintain reliable data transmission and favorable network performance, duplicated paths are indispensable.

As of consequences, multi-path [14,24] becomes a crucial feature in developing WMSN. Unlike traditional shortest-path schemes, multi-path schemes will construct multiple transmission paths from each source–sink pair and – by evenly sending data packets through these multiple paths – spread the transmission burden to more nodes to prolong the life time of nodes and the network. Node-disjoint paths which share no common nodes are of particular interest because they can prevent some nodes from relaying more packets than others or keep multiple paths from simultaneous breakdown when their common nodes fail. It is also important to see that, in wireless communication, bandwidth is shared between neighbor nodes and a node may interfere with geographically close nodes, thus degrading the throughput. To ensure real-time transmission efficiency for WMSN, it is therefore desirable to transmit data through paths that will not interfere with each other.

Taking these factors into account, this paper introduces a Geographic Energy-Aware non-interfering Multipath (GEAM) routing scheme to facilitate data transmission in WMSN. The proposed GEAM scheme divides the whole topology into several districts (Fig. 1a) and the districts into three groups (Fig. 1b–d). The distance between any two districts in the same group will be set more than twice the transmission radius R – except for the nodes in the proximity to the source and sink – to keep the districts from interfering with each other as possibly as can be. To send a packet, GEAM will assign the packet a district boundary and send it through the district by the greedy algorithm to the sink. By such a transmission mechanism – i.e., sending packets through different districts in the same group, GEAM can easily achieve non-interfering multipath transmission. Our scheme also performs well in the error-prone sensor environments because it does not construct routing paths in advance. Besides data, the energy and location information of nodes will also piggy-back during packet transmission. That is, the sink will report the information to the source which then, based on the report, adjusts the load of each district to balance the transmission burden and prolong the lifetime of the network. The results of the conducted experimental evaluation show that, when compared with related routing schemes, our GEAM yields better performance at real-time transmission as it is able to achieve more balanced energy consumption and load distribution for nodes and the network, in most situations.

This paper is organized as follows. Section 2 provides a succinct survey on the interference problem in wireless environments and also on related schemes about geographical routing or multi-path routing. Section 3 introduces the proposed GEAM routing scheme. Experimental performance evaluation on GEAM and other schemes is given in Section 4. Section 5 concludes the paper.

2. Background study

2.1. The interference problem

Multipath routing protocols can construct, maintain and use multiple paths to transport the sensed data. Despite multipath routing has many advantages, it may incur the so-called inter-path interference or route coupling problem [21] in