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An efficient multipath structure for concurrent data transport in wireless mesh networks ☆

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Abstract

Multipath routing is employed extensively in wireless mesh networks for fault tolerance, throughput enhancement, and load balancing purposes. Most existing multipath routing methods tend to establish link-disjoint or node-disjoint paths with minimal path costs. As paths created by these methods are typically close to each other, they may cause serious inter-path interference when serving for concurrent data transmissions. In this paper, we first introduce an AODV-based decoupled multipath routing protocol named AODV-DM. AODV-DM builds an insulating region around each established path to prevent new paths from being formed in the neighborhood of the established path. Multiple paths formed by this means are "isolated" from each other; thereby they are very suitable to serve for concurrent data transmissions. We also investigate the transport-layer route-coupling problem, and conclude that a path-aware SCTP scheme is a very good match to our AODV-DM protocol. The path-aware SCTP scheme enables the transport layer to make the most of the capacity provided by decoupled multipath. We simulate the AODV-DM protocol and integrate it with the path-aware SCTP protocol. The simulation results demonstrate that AODV-DM, combined with the path-aware SCTP, significantly boosts end-to-end throughput of multihop data transmissions. This decoupled multipath structure is especially beneficial to concurrent transmissions of time-constraint data in wireless mesh networks.

Keywords: Wireless mesh networks; Multipath; Route-coupling; Throughput enhancement; SCTP

1. Introduction

Multipath routing is one of the distinguished features of wireless mesh networks. It can be used for various purposes. For example, a source device can establish a primary path as well as several backup paths toward a desired destination. Once the primary path breaks, the source can switch the on-going traffic to backup paths, instead of shutting down the end-to-end connection. In resource-constrained networks, a source-destination pair may evenly use the resources of multiple paths, instead of exhausting one path. Besides, when a single path cannot provide sufficient capacity to support traffic demands, a source may create additional paths and simultaneously deliver data through these paths. The focus of this paper is to design a concurrent multipath structure for bandwidth aggregation and throughput enhancement.

Traditional multipath routing algorithms incline to build multiple link/node-disjoint paths with minimized path costs. Although these paths do not share common links or nodes, they are usually located around the shortest path, and stay very close to each other. When all these paths are utilized simultaneously to transmit data, they will heavily affect each other and cause route-coupling problem [1]. Ascribed to the broadcast nature of wireless medium

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and the hidden/exposed terminal problems, the route-coupling problem suppresses concurrent data transmissions through adjacent paths, and may make multipath routing perform worse than single path routing. In order to achieve throughput enhancement by using multiple paths, we need to seek ways to remove route coupling.

In this paper, we introduce AODV-DM, an AODV decoupled multipath routing protocol, to efficiently establish multiple node-disjoint paths that are separated far enough to avoid inter-path interferences. In brief, a primary path is built like any other single-path routing protocol first; and then a region is defined around the primary path for insulating purpose. Finally, a secondary path is selected outside the region. Since the primary path and the secondary path are spaced out by the insulating region in view of radio coverage, they do not contend for the same piece of medium. Moreover, the AODV-DM algorithm is optimized to reduce the length of the secondary path. The two-path formation mechanism can be easily extended to establish three or more decoupled paths.

AODV-DM provides a good multipath structure at the network layer. However, as the transport layer controls the inputs to these paths, the network layer shall seek support from the transport layer in order to work more efficiently. Unfortunately, the traditional TCP is designed for single-path routing and cannot adapt to the network layer multipath structure. We propose to employ a path-aware SCTP scheme [2,3], which possesses the abilities to identify congestions occurring in different paths, and independently control traffic rate of each path.

By integrating the multipath modules crossing the network and transport layers, we are able to derive an efficient multipath structure for concurrent data transfer in wireless mesh networks. Simulations verify the feasibility of our designs and show that our protocols can achieve much better performances than the single path and coupled multipath protocols.

The rest of this paper is organized as follows. Section 2 gives a brief overview of related work. Sections 3 and 4 describe the AODV-DM protocol as well as the path-aware SCTP scheme, respectively. Section 5 presents our simulation results. Lastly, Section 6 concludes the paper.

2. Related work

Multipath routing in wireless ad hoc networks has been studied extensively in recent years [1,4–8]. Most multipath routing algorithms address the ways to construct link-disjoint or node-disjoint paths. While link-disjoint multipath is mainly utilized to tolerate link failures, node-disjointed multipath can not only protect transmissions from link and node failures, but also enable balanced usage of network resources. Therefore, node-disjoint multipath is more favored in error-prone and resource-limited wireless networks. There have been quite a few papers regarding the creation of multiple node-disjoint paths in wireless ad hoc networks. For example, Lee and Gerla present a split multipath routing algorithm (SMR) [4] to build maximally disjoint paths. EDSR, an extended dynamic source routing scheme [5], discovers node-disjoint paths by marking them with different colors. AODVM [6] is an AODV-based node-disjoint multipath routing protocol. We will discuss more about AODVM in Section 3.

Although node-disjoint paths do not share any relay nodes, they may lie close to each other and generate serious inter-path interferences. This phenomenon is called route coupling. In order to resolve the route-coupling problem, Pearlman et al. proposed to use multiple channels to construct contention-free paths [1]. In [7], Saha et al. suggested using directional antennas to reduce radio interferences between different paths. Although these approaches can decouple adjacent paths, they require extra resources, which may not be practical in low-cost wireless mesh networks.

A DSR based decoupled multipath scheme was proposed in [8]. In this scheme, each route reply (RREP) message carries not only the information of a newly discovered path, but also the neighborhood information of the path. With sufficient topology information supplied by RREPs, source node is able to pick out multiple decouples paths. One concern about this scheme is that the topology reporting through RREPs may cause large control overhead especially in large and dense networks.

Some recent researches indicated that traditional TCP does not work well over concurrent multipath routing [9,10]. One reason is that TCP cannot conduct congestion control in each individual path. Also, TCP ascribes disordered packet delivery to path congestion, however, for multipath routing, many out-of-sequence cases are caused by path diversity, which should not trigger the reduction of data transmission rate. A new transmission layer protocol, stream control transmission protocol (SCTP) [11], was proposed recently to enhance end-to-end transmission performances especially for multi-stream, multipath applications. SCTP inherits the major features of TCP, such as connection setup, reliable transmission, and congestion control etc. In addition, it provides some new functions, like multi-streaming, multi-homing, and four-way handshake. The multi-homing scheme is particularly beneficial to the establishment and maintenance of multiple paths. Al et al. [2] and Ye et al. [3] improved the SCTP congestion control mechanism by making source-destination pairs respectively handle congestion control in different paths. This improvement shows significant advantage in concurrent multipath data transport.

Some researchers declare that unless we establish a large number of paths, which is costly and infeasible, multipath routing does not improve load balancing at all [12]. They reach this conclusion under the assumption that every node in the network incessantly sends messages to any other node via the shortest paths. If all nodes aggressively occupy network resources and keep the network busy, using additional paths would not benefit much. However, under normal operating conditions, much of network resources may become available in terms of time and space. By using