Computer Communications 32 (2009) 1613–1630

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

An efficient bow-based on-demand QoS routing protocol for MIMO ad hoc networks ☆

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ARTICLE INFO

Article history:
Received 24 November 2008
Received in revised form 25 May 2009
Accepted 28 May 2009
Available online 21 June 2009

Keywords:
Quality-of-service
MIMO
Ad hoc network
Rate-link
Range-link

ABSTRACT

The multiple inputs multiple output (MIMO) architecture supports smart antennas and MIMO links is now a popular technique for exploiting the multi-path, spatial multiplexing, and diversity gain to provide high spectral efficiencies and performance improvement in wireless ad hoc networks. In this work, we propose a new multi-path on demand quality-of-service (QoS) routing architecture, looked like a bow and called as *bow* structure, in MIMO ad hoc networks. A bow-based MIMO ad hoc networks routing protocol, named as BowQR, is also proposed to support QoS requirement and to improve the transmission efficiency. Each *bow* structure is composed of rate-links and/or range-links on demand to provide multi-path routing and satisfy the bandwidth requirement. Two types of transmission links, the rate-link and range-link, exploit the spatial multiplexing and spatial diversity to provide extremely high spectral efficiencies and increase the transmission range. Finally, the simulation results show that our BowQR protocol achieves the performance improvements in throughput, success rate, and average latency.

1. Introduction

In recent years, the multiple inputs multiple output (MIMO) system is a rapid growth technology in wireless communications [1,7–9,14,19]. MIMO systems contain multiple antennas for both transmitter and receiver, as shown in Fig. 1. The usage of the MIMO mechanism increases the transmission data rates of wireless systems without any additional power consumption and bandwidth usage. A MIMO link employs multiple element arrays (MEAs) at both ends of the end-to-end communication. Such links provide two types of gain, the diversity gain and multiplexing gain, which are two options for the operating mode in the MIMO system [11,24]. In the operation of spatial multiplexing, the transmission link is denoted as the rate-link [21] and the incoming data are demultiplexed into some distinct streams on the same number independent antennas. Each stream is simultaneously transmitted out of an independent antenna in the same channel. Specially, the usages of multiple parallel streams achieve higher capacity on each point-to-point link. In the operation of diversity, the transmission link is denoted as range-link [21] and the data streams of the link are transmitted by multiple antennas simultaneously. The characteristics of multiple antennas contain the increase of the transmission range, the decrease of the bit-error rate (BER), and the decrement of the signal to noise ratio (SNR) or multi-path fading of the link. The usages of MIMO links are exploited in the WLAN and WiMAX standards, such as IEEE 802.11n and 802.16 standards, and become more extremely popular in many currently researches [2,10,18,20–22].

In this work, we focus on the QoS supporting and performance enhancing for the MIMO links furnished the MIMO ad hoc network. The MIMO ad hoc network is different from the traditional ad hoc network that each mobile node equips multiple antennas and operates in the same channel. Specially, the QoS routing problem in MIMO ad hoc networks is also an important issue [4–6,14]. The QoS routing protocol supports mobile applications to guarantee their bandwidth requirement. A QoS routing protocol with bow-based architecture, namely BowQR, is developed in our MIMO ad hoc networks to enhance the transmission efficiency. A QoS satisfied the bow-path will be constructed after our BowQR protocol executed. It simultaneously takes two operations of MIMO link into consideration, that are spatial multiplexing and spatial diversity, to guarantee the QoS and improve the performance. In addition, a special multi-path structure, looked like a bow and called as *bow* structure, is identified in our MIMO ad hoc networks. Each *bow* composes of rate-links and/or range-links on demand and is identified to satisfy the QoS requirement.

☆ This work was supported by Grants NSC-96-2213-E-194-007 and NSC-97-2221-E-305-003-MY3 from the National Science Council of the ROC.

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doi:10.1016/j.comcom.2009.05.018

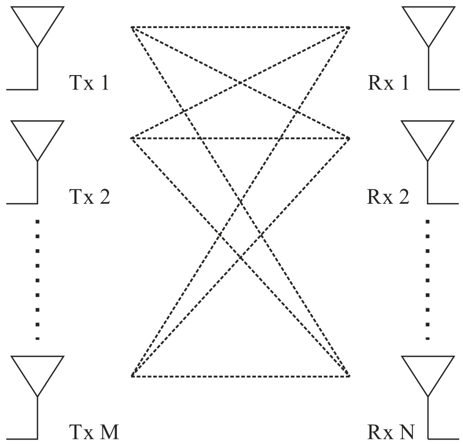

Fig. 1. MIMO illustration.

The rest of this paper is organized as follows. Some related works are discussed in Section 2. Section 3 presents the system model and basic idea of our QoS routing protocol. Section 4 gives the performance analysis of our work, which has higher throughput and better success rate but with more overhead. Finally, Section 5 concludes this paper.

2. Related works

The usage of MIMO mechanism can increase the data rates of wireless systems without any additional power consumption and bandwidth usage. The usage of MIMO system grows rapidly in wireless communications. Some medium access control (MAC) and routing protocol for MIMO ad hoc networks are developed in [1,7–9,14,18,19,21].

In [18], Sundaresan and Sivakumar present a MAC protocol for MIMO ad hoc networks that leverages the physical layer capabilities of MIMO links with the focus being predominantly on the spatial multiplexing capability of MIMO links. They identify several advantages of MIMO links and discuss several key optimization considerations to realize an effective MAC protocol for such an environment. Contiguously, Sundaresan and Sivakumar present a first routing protocol in ad hoc network with MIMO links in [21]. They make three following works. First, they identify the capabilities of MIMO links and capture the relevance to their routing protocols. Then, they analyze the relative tradeoffs of exploiting the different capabilities of MIMO links. Finally, they propose a reactive routing protocol with MIMO links, namely MIR, whose components are built on the insights gained from the analysis results, and hence leverage the characteristics of MIMO links in their operations to improve the network performance [21]. The MIR protocol proposed by Sundaresan and Sivakumar [21] is the first proposed routing protocol in MIMO ad hoc networks, but it is only an uni-path (they choose the best one from several available routing paths by their definition) result. Each transmission in the MIR protocol considers only the uni-path rate-link or range-link. The high latency transmission problem occurred on the condition that the rate of one link in the path is too slow. To overcome this problem, our work focuses on developing a multi-path QoS routing protocol for MIMO ad hoc networks. Several QoS routing protocol in ad hoc networks are developed in [3–5,13,14]. In [14], Lin and Lin calculate the end-to-end path bandwidth to develop an on demand QoS routing protocol in a mobile ad hoc network (MANET). Under their routing protocol, the source sends the calculated message and QoS available to the destination in the mobile network. Further, Liao et al. [13] propose an on demand protocol for searching a multi-path QoS route from a source host to a destination host. Their basic idea is distributing a number of tickets from a source and allowing a ticket to be further partitioned/split into sub-tickets to search for a satisfactory multi-path. A dynamic route switching protocol (DRSP) to locate useful and longlived routing paths is proposed in [17]. The DRSP considers both node mobility and energy consumption. To reduce the possibility of unsuccessful delivery, expired backup paths are erased automatically. The transmission power is adjusted according to the mobility prediction.

More recently, Chen et al. [5] develop an on demand link-state multi-path QoS routing protocol on the wireless mobile ad hoc network. Their protocol collects the bandwidth information of whole links from the source to the destination in order to construct a network topology with the information of each link bandwidth. They offer a multi-path route when the single route of the network contains insufficient bandwidth and offer a uni-path route when the network contains sufficient bandwidth. The destination eventually determines the QoS multi-path routes and replies the source host to perform the bandwidth reservation. Besides, Chen and Ko propose a lantern-tree-based QoS multicast protocol with a reliable mechanism for MANETs in [4]. They identify a lantern-tree in a MANET to provide an on demand QoS multicast protocol to satisfy the certain bandwidth requirements from a source to a group of destination nodes. The lantern-tree is a tree whose sub-path is constituted by the lantern-path, where the lantern-path is a kind of multi-path structure.

To summarize above, several QoS routing protocols in ad hoc networks under time division multiple access (TDMA) model are developed [3–5,12,13,15,16]. Our approach simultaneously takes the rate-link and range-link into consideration so as to maintain a QoS multi-path route in MIMO ad hoc networks and utilizes the concept of multi-path route to develop a new multi-path structure, named as the *bow* structure. Further, we propose a bow-based QoS routing protocol to enhance the MIR protocol [21] in MIMO ad hoc networks. The simulation results show that our work improves the success rate, the average latency, and the throughput when the QoS routes are constructed. Nevertheless, the high success rate causes some overheads in our work. In the following section, we will propose our system model and basic idea under the time division multiple access (TDMA) model.

3. System model and basic idea

In this section, we discuss the definitions of our system model and basic idea. Our system model works on the ad hoc network with MIMO links and the MAC sub-layer is implemented by the TDMA channel model. We introduce the enhancements by using different operations of MIMO links. Our basic idea contains some various operations of the MIMO link in each TDMA cycle and is described as follows.

3.1. System model

Our works base on two operations of MIMO link, rate-links for spatial multiplexing and range-links for spatial diversity. In the following, we introduce the enhancements between two operations of MIMO link and omni-antenna link [1,8,21], as shown in Fig. 2. Fig. 2(a) illustrates the MIMO operations of the omni-antenna that contains the values of the transmission rate W, the bit error rate (BER) p, and the communication range r. By the way, the notation tuple of each link on omni-antenna is denoted as (W, p, r). Further, we focus on the strategies of the other three MIMO operations, spatial multiplexing (MUX), diversity to increase reliability (REL), and transmission range (RANGE). In the operation of spatial multiplexing, the incoming data are demultiplexed into K distinct