Journal of Network and Computer Applications 57 (2015) 182–191

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

A collaborative multi-hop routing algorithm for maximum achievable rate

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ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form
29 March 2015
Accepted 1 June 2015
Available online 13 July 2015

Keywords:
Achievable rate
Collaborative routing
Optimal path
Multi-hop networks
Collaborative communication

ABSTRACT

This paper studies collaborative multi-hop communication technology in next generation wireless communications. We propose a collaborative multi-hop routing algorithm combined with clustering to improve network performance. To build the multi-hop routing with maximum achievable rate, a relation matrix is exploited to describe the possible coverage of network nodes. A clustering-based path strategy is presented to create the effective next-hop link. A collaboration strategy is proposed to construct collaborative matrix. And then by clustering and collaboration, a multi-hop routing with maximum achievable rate is successfully built. The effectiveness and the feasibility of the proposed methods are verified by simulation results.

1. Introduction

Collaborative multi-hop routing has received much attention due to its importance for performance improvement. Mathematical modeling and branch-and-cut framework are often used to jointly optimize relay node assignment and flow routing for cooperative communications in multi-hop networks (Sharma et al., 2010, 2012). In Naghshvar et al. (2012), the routing and scheduling methods of optimal throughputs in multi-hop wireless networks are investigated, and some routing policies of optimal throughputs are proposed. Collaborative relaying schemes are presented in Lin et al. (2009) to achieve the cooperative diversity of the physical layer. A hybrid multi-hop routing algorithm via mixing flat multi-hop routing and hierarchical multi-hop routing is studied (Abdulla et al., 2012). Additionally, the feasibility and impacts of the multi-hop routing on sensor networks are analyzed in Rao and Biswas (2012). Therefore, to achieve better performance improvement, it is necessary to introduce collaboration to the multi-hop routing, but how to build effectively collaborative multi-hop routing is an open problem.

To solve this problem, Jung and Ingram (2013) used linear programming to optimize a cooperative routing in multi-hop wireless sensor networks. They found out some important factors and behaviors for achieving the optimal cooperative routing (Jung and Weitnauer, 2013). Kwon and Shroff (2012) studied the energy-efficient routing problem in multi-hop wireless networks, and proposed an energy-efficient routing scheme by considering transmission power, interference, remaining energy, and energy replenishment. Tang et al. (2012) investigated the availability and stability of links in multi-hop and multi-flow mobile ad hoc cognitive networks, and proposed a cross-layer distributed approach to improve network throughput using mobility prediction. Liang et al. (2012) studied how to choose candidate nodes and how to determine the prioritization metric about them for the opportunistic routing in multi-hop wireless mesh networks, and then presented the cooperative opportunistic routing. Gohari and Rodoplu (2012) studied the end-to-end delay estimation in mobile multi-hop wireless networks. Liu and Sherali (2012) proposed a second-order distributed Newton's method to design the joint multi-path routing and perform flow control. Yue et al. (2012) studied the coding-aware routing metric in multi-hop wireless networks. Bhattacharjee and Bandyopadhyay (2013) proposed an energy efficient routing algorithm to balance data traffic among network nodes and improve network lifetime.

Additionally, Tao et al. (2012) presented a flow-balanced routing protocol for multi-hop clustered wireless sensor networks to achieve power efficiency and coverage preservation. Ong and Motani (2010) studied the routing in cooperative multiple-terminal wireless networks and proposed an algorithm to construct optimal routes. Rondinone and Gozalvez (2013) exploited a

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http://dx.doi.org/10.1016/j.jnca.2015.06.010

multi-hop connectivity metric to estimate the capability of forwarding paths and proposed a contention-based broadcast forwarding protocol to select forwarding paths. Wong et al. (2013) proposed a distributed greedy algorithm to attain maximum gain cost ratio for each node. Kuo and Lin (2012) proposed a multi-hop multicast routing scheme for wireless multi-hop relay networks. Ranjitkar and Ko (2010) presented a collaborative routing protocol to help relaying nodes without employing forward data packets. Zhang and Jia (2013) proposed an analytical model of network throughput to consider traffic demands of clients. Chen et al. (2012) analyzed the energy balance problem of cooperative routing and proposed a routing scheme to balance the energy among nodes and attain the maximum network lifetime. James et al. (2011) proposed an adaptive rate transmission scheme to optimize network throughput. Lakshmanan and Sivakumar (2013) proposed an adaptive diversity routing protocol to determine the cooperating node number for each link and the corresponding cooperation strategy. Nordio et al. (2013) presented several analytical bounds to the achievable data rate for nodes' full-duplex and half-duplex radios. Dynamic spectrum access problem for multi-hop networks (Jiang et al., 2015a) and networks' energy efficiency (Jiang et al., 2015b,c) were also researched.

This paper proposes a collaborative multi-hop routing algorithm with maximum achievable rate to raise the performance of next generation wireless networks. Firstly, we analyze the system model including transmission model of nodes and multi-hop transmission model with collaboration. Our problem can be mathematically modeled as an optimization problem. Next, a relation matrix is defined to describe the possible coverage of network nodes. We cluster network nodes to include possible collaborative nodes, and then build possible paths from source node to destination node. A clustering-based path strategy is presented to build the neighbor node matrix and create the effective next-hop link. A clustering path algorithm is proposed to create the multi-hop path set from source node to destination node. Next, a collaborative strategy is proposed to create the collaborative matrix, where the optimal object is to maximize the maximum achievable rate. By calculating the maximum achievable rate of each path in the path set, the path with maximum achievable rate is selected to construct the optimal path set. In doing so, we can find the shortest path with the maximum achievable rate. Finally, a collaborative multi-hop routing with the maximum achievable rate is successfully built by clustering and collaboration.

The rest of this paper is organized as follows. Section 2 is the system model and problem statement. Section 3 is to derive our collaborative method. Section 4 is simulation analysis. Finally, our work is concluded in Section 5.

2. System model and problem statement

In this section, we discuss the network model of this paper, including transmission model of nodes and multi-hop transmission model.

2.1. Transmission model of nodes

In multi-hop wireless networks, to attain link or path rate as large as possible, the achievable rates of nodes or paths need to be maximized. To reach this aim, we employ the transmission model of nodes shown in Fig. 1 where c_u and c_v denote, respectively, the transmission and receiving nodes with omni-directional antennas, d_{uv} is the distance from c_u to c_v, and θ_{uv} denotes the effective receiving angle of c_v to receive the c_u's signal. According to the wireless communication theory, in the wireless network in Fig. 1, there exist many statistically independent reflection and scattering paths for channel filter taps. The kth tap $h_k[m]$ follows the cyclic symmetry Gaussian distribution with the zero mean value and variance ζ_k. Generally, due to the dense barriers such as building in a city, there is not the line of sight between the sending node and the receiving node. Thereby, the kth tap's module $y=|h_k[m]|$ is well described with Rayleigh distribution and its density function can be denoted as

$$p_k(y)=\frac{y}{\zeta_k^2}\exp\left(-\frac{y^2}{2\zeta_k^2}\right),\quad y\geq 0 \tag{1}$$

And the $x=h_k[m]^2$ meets the exponential distribution, namely

$$p_k(x)=\frac{1}{\zeta_k^2}\exp\left(-\frac{x}{2\zeta_k^2}\right),\quad x\geq 0 \tag{2}$$

According to the wireless communication theory, the transmission channel can be modeled into the Rayleigh Fading channel. For the Rayleigh Fading channel, the channel gain from node c_u to node c_v can be expressed as

$$g_{uv}=\frac{1}{(d_{uv})^{\alpha}} \tag{3}$$

where α is the path loss exponent and generally holds the value from 2 to 4.

The received power of node c_v can then be represented by

$$P_v^r=P_u^s\times g_{uv}=P_u^s\times(d_{uv})^{-\alpha} \tag{4}$$

where P_u^s denotes the transmitting power of node c_u. Only when the Signal-to-Interference and Noise Ratio (SINR) of the receiver exceeds a certain threshold, the receiving node can correctly receive the signal, namely

$$\delta_v\leq\frac{P_v^r}{\eta_v+\varphi_v} \tag{5}$$

where η_v is the noise power and φ_v indicates the interference power.

Therefore, to achieve the communication between nodes c_u and c_v, the transmission power of c_u should be

$$\begin{aligned}P_u^s&\geq\frac{\delta_v\times(\eta_v+\varphi_v)}{g_{uv}}\\&=\delta_v\times(\eta_v+\varphi_v)\times(d_{uv})^{\alpha}\end{aligned} \tag{6}$$

2.2. Multi-hop transmission model

To build an effective multi-hop routing, clustering and collaboration are used in the multi-hop transmission model, as shown in Fig. 2 where the network nodes are randomly distributed in the wireless network, the solid and dot lines denote the relaying and collaborative paths, respectively, R_1, R_2, R_3, and R_4 are relaying nodes, C_1, C_2, C_3, and C_4 are collaborative nodes, s and d, respectively, denotes source and destination nodes. The multi-hop transmission is exploited to build the feasible path from

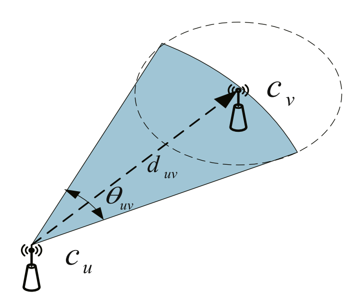

Fig. 1. Transmission model of nodes.