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Multi-rate multicast routing in multi-gateway multi-channel multi-radio wireless mesh networks

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With increasing popularity of group communication applications, it is necessary to design efficient multicast routing algorithms. One important challenge in respect to multicasting is the bandwidth heterogeneity of the receivers, which limits the rate of data delivery to the receivers by the slowest one. In this paper, we study this problem in the context of Multi-gateway Multi-Channel Multi-Radio Wireless Mesh Networks (M^3 WMNs). We design an efficient algorithm, which employs the well-established multi-rate technique for handling the bandwidth heterogeneity of the receivers. The proposed algorithm, namely Multi-Gateway Multi-Rate multicast routing (MGMR), aims at maximizing the total of the achieved data rates by the receivers while preserving fairness between them. We also formulate the optimal model of the problem to compare the outcomes of MGMR with the optimum. The simulation results demonstrate that MGMR yields high throughput results in a reasonable time.

1. Introduction

Wireless mesh networks (WMNs) have emerged as a practical network technology for broadband internet access in recent years. They provide connectivity for enterprise, campus, and metropolitan areas. The popularity of these networks is due to their desirable characteristics, including easy deployment and maintenance, low cost installation, high flexibility, and robustness. The backbone of a WMN consists of mesh routers and gateways, which are connected to each other with wireless links. In this architecture, data is exchanged with wired internet via gateways. The routers provide internet access for the mesh clients by forwarding their traffic to the Q2 gateways (Akyildiz et al., 2005).

Multicast service is becoming a key requirement of WMNs supporting multimedia applications. The bandwidth saving of this technique makes it appropriate for such applications. Many commercial services, such as Online TV, video conferencing, distance learning, and online games are examples of multicast-based applications, which have become more popular in recent years. These applications typically require high network resources. Hence, it is critical to design algorithms to enhance the performance of the network.

The network capacity degradation due to the interference between the links of the WMNs, makes multicast routing a challenging problem. With the recent progression in physical layer technologies, an effective approach to enhance the network capacity is to employ Multi-Channel Multi-Radio (MC-MR) WMNs. A wide range of research has studied channel assignment problem in this networks (Crichigno et al., 2008; Si et al., 2010; Naveed et al., 2007; Li et al., 2009; Alicherry et al., 2006; Subramanian et al., 2008). In the MC-MR setting, each node is equipped with a number of radios and can transmit data using multiple channels. By this means, the interference in the WMN is reduced and consequently, the achieved data rates by the multicast receivers are increased.

In the previous multicast routing algorithms in MC-MR WMNs, the source transmits data to all of the receivers at a single rate. This transmission rate is restricted by the slowest link between the source and the receivers. Due to bandwidth diversity of the receivers, it is desirable that they obtain data at different rates. This is achieved by multi-rate multicast routing. In this approach, the source can transmit data to the receivers at different rates based on their available bandwidths. Hence, the performances of the faster receivers are not restricted by the slower ones. The multi-rate multicast approach is employed by different applications such as MPEG-4 FGS video standard.

Multi-rate multicast routing has been well studied in wired and single-channel networks (Xiong et al., 2010; Sarkar 2005; Kakhbod and Teneketzis 2012; Kar et al., 2006; Bui et al., 2008). In the

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MC-MR setting, the multicast routing has to be integrated with channel assignment to obtain high-throughput results. Indeed, the obtained data rates by the receivers are determined by the way of performing channel assignment. The proposed solutions to channel assignment in multicast routing in MC-MR WMNs are inadequate. In these works, it is either assumed that the channel assignment is given (Liu and Liao 2010; Avokh and Mirjalily 2013; Li et al., 2011), or each node is equipped with two radios (Lim et al., 2011; Cheng and Yang 2011; Zeng et al., 2010). Moreover, the presented algorithms have not concerned multi-rate multicasting. Therefore, they are not appropriate for multi-rate multicasting in MC-MR WMNs. It is also worth mentioning that the existing multi-rate multicast algorithms assume that the multicast tree is given. Hence, the quality of their solutions are directly depends on the structure of the given trees.

In a WMN, the data traffic is delivered to the network via its gateways. Hence, we consider the multi-gateway characteristic of the WMNs in designing MGMR algorithm. Selecting proper gateways for the receivers reduces the interference of the network and therefore, the performance of the system is enhanced. Gateway selection in multicast routing has been studied in Zeng et al. (2010) and Zhao et al. (2010). The presented work in Zeng et al. (2010) selects the closest gateway to a given receiver as its gateway. In Zhao et al. (2010), Dijkstra's (1995) shortest-path algorithm is used to select a gateway in terms of each receiver. The generated outcomes by these approaches are inadequate in that they perform gateway selection according to the local evidences. In addition, the presented algorithm in Zeng et al. (2010), which studies MC-MR WMNs, does not take into account the impact of using multiple channels and radios while selecting the gateways of the receivers. Moreover, these algorithms do not take into account multi-rate multicasting while selecting the gateways of the receivers. Therefore, these works are not proper for M^3 WMNs.

In this paper, we study multicast routing in Multi-gateway Multi-channel Multi-radio (M^3) WMNs. It has been shown in Subramanian et al. (2008) that performing channel assignment with the aim of minimizing the interference in the WMN, is reduced to solving the max K-cut problem in the correspondent conflict graph. As max K-cut problem is proved to be NP-hard in Frieze and Jerrum (1997), our problem, which includes channel assignment, is also NP-hard. Therefore, we design an efficient algorithm, namely Multi-Gateway Multi-Rate multicast routing (MGMR), to solve the problem. MGMR yields high-throughput outcomes in that it considers the reciprocal relationship between gateway selection, channel assignment, and multi-rate multicasting. In the proposed algorithm, the aim is to maximize network throughput while preserving fairness between the receivers. The problem is also formulated as a Mixed Integer Programming (MIP) model to obtain optimal solutions. As it will be shown in the simulations, our algorithm generates efficient results in a sensible time.

MGMR decomposes the problem into three phases of gateway selection, channel assignment, and rate allocation. In the gateway selection phase, the multi-rate multicasting property and MC-MR architecture of the proposed network model are considered while selecting the gateways of the receivers. Using the multi-rate technique, the obtained data rate by a receiver, is restricted by the transmitted data rates of its ancestor links. As we aim at maximizing network throughput, the links which transmit data to more receivers are more effective in enhancing the network performance. In this way, the number of descendant receivers of the links is considered while selecting gateways of the receivers. Moreover, the performance of the system depends on the number of the radios of the nodes, and the number of the channels. Therefore, these parameters are considered in gateway selection as well. In the channel assignment phase, the multi-rate multicasting scheme is taken into account via including the number of descendant receivers of a given link in computing its observed interference. In this algorithm, less-loaded channels are assigned to the end nodes of the links which are prone to more interference. By this way, the amount of interferences of different channels throughout the WMN will be balanced. Hence, more room will be available for enhancing the obtained data rates by the receivers. After accomplishing these phases, the obtained data rates by the receivers are determined in the rate allocation phase.

The rest of the paper is organized as follows: Section 2 categorizes the related works to our research. The network model used in this paper is described in Section 3. The optimal model of the problem is presented in Section 4. In Section 5, we explain MGMR algorithm in details. In Section 6, we study the performance of MGMR under different scenarios. Finally, Section 7 concludes the paper.

2. Related work

Multicast routing has been extensively studied in the literature. In these studies, both uni-rate and multi-rate techniques have been employed for data transmission. The focus of the uni-rate multicasting algorithms in Liu and Liao (2010), Ruiz and Gomez-Skarmeta (2005), Wang et al. (2010) and Zhang et al. (2009) is on minimizing the amount of bandwidth usage. Some studies, such as Wang et al. (2010) and Zhang et al. (2009), have also guaranteed QoS requirements of applications. Roy et al. (2008), Zhao et al. (2007), Koutsonikolas et al. (2012) and Zhao et al. (2011) considered the quality of wireless links to provide high throughput multicast routing metrics. The multi-rate multicast technique has been employed in wired and single-channel networks in Xiong et al. (2010), Sarkar (2005), Kakhbod and Teneketzis (2012), Kar et al. (2006) and Bui et al. (2008). In these works, it is assumed that the multicast tree is given a priory. Hence, the results of these algorithms are unsatisfactory as they cannot adapt to the network configuration.

The proposed algorithms for multicast routing in MC-MR WMNs have used uni-rate multicasting approach. The aim of the presented algorithms in Li et al. (2011), Lim et al. (2011), Cheng and Yang (2011), Zeng et al. (2010), Nguyen and Nguyen (2009) and Jahanshahi et al. (2011) is to reduce the interference between the links of the multicast tree. In Li et al. (2011), Lim et al. (2011), Cheng and Yang (2011) and Jahanshahi et al. (2011), tree construction and channel assignment are performed jointly. The optimal model for joint tree construction and channel assignment was given in Jahanshahi et al. (2011). The presented algorithm in Lim et al. (2011) adopted a button-up approach for solving the problem. The aim of Cheng and Yang (2011) was to satisfy delay requirements of the multicast applications, while minimizing the interference between the links of the tree. In Li et al. (2011), multicast routing metrics for MC-MR WMNs were designed and incorporated in the well-known MAODV algorithm. A call acceptance algorithm was presented in Chiu and Yeung (2010). In this work, the multicast tree is constructed such that the traffic loads of different nodes and channels are balanced. An optimal model for the problem was also presented to show the effectiveness of the proposed heuristic. The algorithm in Chiu and Yeung (2010) was improved in Avokh and Mirjalily (2013) through enhancing its objective function.

In the multicast routing in multi-channel multi-radio WMN literature, data have sent to all the receivers at the same rate. Therefore, the rate of multicast session has to be adjusted to the slowest receiver. Thanks to the multi-rate technique, it is practicable to send data to each receiver at a rate commensurate with its available bandwidth. Using this approach, our work increases the obtained data rates by the receivers compared with the existing solutions.