Computers and Electrical Engineering 48 (2015) 203–213

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

Cooperative packet-forwarding mechanism for throughput improvement in multi-channel wireless networks ☆

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ARTICLE INFO

Article history:
Received 19 June 2014
Received in revised form 2 August 2015
Accepted 3 August 2015
Available online 19 August 2015

Keywords:
Cooperative communication
Direct path
Fairness
Channel assignment
Path selection

ABSTRACT

Typical MAC protocols for IEEE 802.11-based ad hoc networks employ a direct transmission strategy whenever the transmitter can directly reach the receiver (one-hop transmission). While such a design enjoys simplicity, it limits the number of admitted transmissions in a given neighborhood. Due to the performance anomaly of 802.11-based wireless networks, transmission with low data rates occupy the shared medium for longer periods of time. Occupying the transmission medium for a longer period of time results in less available transmission time for other nodes, which consequently reduces the number of transmitted packets during the same period of time, leading to a reduction in network throughput. To improve the overall network throughput, we present a cooperative multi-channel MAC protocol for single-hop wireless mobile ad hoc networks that attempts at computing the path with the minimum required transmission time for a given source–destination pair (including the channel assignment along that path). The proposed protocol attempts at improving network performance by means of cooperative communications. According to our approach, if the one-hop (direct) path between communicating nodes supports low data rate (requires longer transmission time), the source selects a multi-hop path to the destination such that the total amount of required transmission time is minimized. Through simulations, we show that our proposed protocol achieves significant throughput and fairness improvement compared to the standard IEEE 802.11-based protocol.

1. Introduction

Due to the growing demand for wireless applications and services, increasing their supported capacity and performance has become a challenging issue. A Wireless mobile ad hoc network (MANET) consists of a group of nodes that work together in a distributed manner and are capable of movement. These nodes are connected via wireless links without the use of the existing network infrastructure or centralized administration [1]. Ad hoc networks are used in areas where infrastructure is not presented or when using infrastructures is impractical. Wireless MANETs are used in different applications, such as military, civilian, personal, and emergency applications.

☆ Reviews processed and approved for publication by the Editor-in-Chief.

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http://dx.doi.org/10.1016/j.compeleceng.2015.08.002
0045-7906/

Typically, MAC protocols designed for IEEE 802.11-based MANETs utilize the direct path between the transmitter–receiver pair (one-hop transmission) to deliver data packets, irrespective of the supported data rate (e.g., [1–10]). Although such a mechanism is simple, however, it limits the total number of accepted transmissions in a given period of time, which decreases the overall network performance. This is because when the direct path has low date rate, the transmitter reserves the communication channel for a longer period of time preventing neighboring nodes from accessing the channel until its transmission is completed. This negatively affects network throughput and results in short-term fairness. Therefore, new cooperative MAC protocols are needed to effectively utilize the available resources and maximize network performance.

In this paper, we propose a cooperative channel assignment and packet forwarding protocol that uses cooperative communication with the multi-channel capability of wireless nodes in a single-hop MANET. Our proposed protocol aims at improving network performance by reducing the required transmission time for a given transmission that suffers from low-data rate direct link through selecting a multi-hop path (including channel assignment) with the minimum total required transmission time even through a direct one-hop path between the communicating pair exists. Specifically, when the direct path between the source and destination has lower data rate than the other possible paths, the source collaborates with other nodes to deliver its data packets to the destination. Through such collaboration, several nodes (called helper nodes) participate in forwarding the data from the source to the destination. According to the mechanism used in the proposed protocol, the source selects the path that guarantees the minimum transmission time (including channel assignment and helper selection) to deliver data packets. The source, destination and helper nodes form a multi-hop path from the source to the destination. Such cooperation between source, destination and helper nodes decreases the overall needed transmission time by selecting a higher data rate path. This preserves more channels and time for potential future transmissions (allows those transmissions to proceed earlier and to access the channels more frequently), which consequently improve network throughput and fairness. According to our proposed protocol, the source selects the path that guarantees the minimum transmission time (including channel assignment and helper selection) to deliver data packets. To evaluate the performance of our proposed protocol, we conduct simulations for both single-channel and multi-channel mobile ad hoc networks. Simulation results show that our protocol significantly improves the network throughput over the standard IEEE 802.11b protocol. The results also indicate that our protocols preserve fairness.

The rest of the paper is organized as follows. In Section 2, the related work is reviewed. Section 3 introduces the system model, and Section 4 provides the SNR and transmission time analysis. The proposed cooperative packet-forwarding protocol is described in Section 5. Simulation results and discussions are presented in Section 6. Finally, Section 7 provides concluding remarks.

2. Related work

Recently, several studies proposed solutions to the fairness problem in 802.11b wireless networks with the target of improving network throughput. In [2], the authors discussed the performance anomaly of an 802.11b network. They showed that the throughput of the network will be significantly decreased when at least one mobile node has lower bit rate. This is because this node will capture the channel for a long period of time. This will delay other nodes form accessing the channel. Their calculations and measurements proved that the probability of accessing the channel for all users is the same. This privileges low rate nodes over high rate nodes. In [3], the authors reduced the effect of the fairness problem by adjusting the packet size according to the transmission bit rate. They derived expressions to show that the channel utilization time for slow and fast nodes is fair. Then, all nodes in the network will have the same opportunity to access the channel. In [4], the authors proposed a novel approach to solve the performance anomaly by the means of packet aggregation. Packet aggregation is done using a dynamic time interval, when the channel occupancy time is larger than the transmission time of the nodes packet. In [5], the authors introduced the transmission probability p_t, to 802.11b protocol, as new parameter to solve the performance anomaly problem. When this new protocol adjusted according to the bit rate, it gives all the nodes in the network identical channel utilization probability. Hyogon and others in [6] set the CW_min (Contention Window) for each transmission such that the CW_min is inversely proportional to the supported bit rate. To increase network capacity and throughput, several studies (e.g., [7–17]) have proposed different cooperative MAC protocols. In [7], the authors introduced the first cooperative MAC protocol "CoopMAC". They defined two alternative solutions CoopMac I and CoopMac II. In CoopMac I, three new fields in the RTS packet were introduced; one of them is used to announce the MAC address of the selected helper. Because of the hardware complexity of adding new fields; the authors used "address 4" field in the IEEE 802.11 frame format in CoopMac II to indicate the helper's address. CoopMAC I and II are basically based on the operation of the Distributed Coordination Function of the IEEE 802.11. Korakis [8] extended the work in [6] to be deployed in MANETs. In this protocol, the transmitter accesses the rate information in the Cooperation table and decides whether it's better to send data through the one hop route or the two hop depending on the route rates. When it chooses to transmit via the two-hop path, the transmission time will be shorter compared to the one-hop path. In [10], Chou et al. presented a solution to perform cooperative communication in distributed wireless networks. The authors claimed that only one relay must participate in the cooperative transmission. In order to select the relay node among its neighbors, they developed mechanisms such as a busy tone and a special RTS (Relay-RTS). Kim and Lee [11] proposed a cooperative MAC protocol. They assumed that the operation of the protocol is performed by the existence of three elements; a low rate station, an AP (access point) and a higher rate station. The low rate sender station uses the path through the high rate station to forward data to the AP. Active