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# Beacon-based channel assignment and jammer mitigation for MANETs with multiple interfaces and multiple channels[☆]

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ABSTRACT

The capability of accessing multiple channels through multiple interfaces improve network capacity and is desirable for future Mobile Ad-Hoc Networks (MANETs). However, due to the presence of jammers as well as mobility and ad-hoc features, MANETs require distributed and efficient resource management for channel assignment. To address the channel assignment problem, which is a non-deterministic polynomial-time hard (NP-hard) problem, we propose a heuristic algorithm called Channel Assignment and JAmmer Mitigation (CA-JAM). The CA-JAM algorithm assigns a distinct channel for every interface of one station, and then all stations exchange the assignment information through beacon frames on every individual interface. When one station receives a beacon, the station organizes the information into tables. Therefore, each station, distributively, uses the table to reduce the number of neighboring stations using the same channel to avoid interference which in turn improves the throughput. The tables are also used to learn the disconnected neighbors due to jamming so as to mitigate the effect of jamming and maintain connectivity. CA-JAM is fully distributed with no use of control channel or central entity; thus, it improves connectivity and reduces interference by balancing stations over the available channels while mitigating jamming effects from multi channel multi interface MANETs. We confirm that CA-JAM outperforms existing protocols using the OPNET simulator.



## 1. Introduction

Mobile ad-hoc networks (MANETs) provide flexibility and scalability to set up a network compared to infrastructure networks. Such networks can be used in military combat, disaster relief or large construction sites. All MANET stations with a single interface or radio[1] should belong to the same service set on a single channel to stay connected, even if the interface can switch between channels [1]. As the number of MANET stations increases, interference and collision among them increase as well. This degrades network capacity, flexibility and scalability. Unlike other networks, MANETs are designed to have minimal manual configuration, low cost of hardware, and tolerance to jamming attacks and mobility [2].

Jamming is caused by high powered devices intentionally designed to attack a wireless network, which is referred to as intentional jamming. Also, jamming can arise unintentionally from non-compatible standards, e.g. 802.11 and 802.15.1 operating in the 2.4GHz ISM band, which is mostly referred to as interference. Another type of jamming in MANETs is caused by denial-of-service (DoS) attacks [3] where malicious stations transmit false messages to consume network resource and starve other stations. To mitigate jamming, first we need to detect it and then avoid using the jammed channel. Under the assumption that such jamming attacks are detectable, stations can dynamically switch from one channel to another [4] as in dynamic spectrum access, where stations search for a new channel when the current operating channel is unavailable.

Due to the reduction of radio cost, it is now easier to fit multiple interfaces in one station, as seen in Wi-Fi devices that work for both 2.4GHz and 5GHz. Therefore, our aim is to exploit this advantage to enhance the network capacity and flexibility of MANETs with the help of Multiple Interfaces of stations operating on Multiple Channels (MIMC) [5] by proposing a new channel assignment scheme. In addition, the channel assignment algorithm should overcome the jamming problem as well.

In this paper, we first formulate the channel assignment problem as graph partitioning problem that minimizes the number of adjacent vertices on the same partition, and then propose a distributed and heuristic channel assignment algorithm called Channel Assignment and JAmmer Mitigation (CA-JAM), because the problem is found to be non-deterministic polynomial-time hard (NP-hard). In CA-JAM, first, each station determines a distinct random channel for all of

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[1] Throughout the text, the terms interface and radio are used interchangeably.

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its interfaces and exchanges beacons on each interface for a simple rendezvous process. To enhance the rendezvous process, algorithms described in [6] and [7] can be used. Up on receiving beacons from neighbors, stations organize the information into two tables: an interface table and a neighbor table. To avoid interference, stations look up the number of neighbors per interface from its interface table and check whether it has multiple links with all neighbors on this interface. If these conditions are satisfied, the station switches to another channel to organize a less congested network and seek more connectivity.

When a channel is jammed, the following steps are performed: (1) neighbors that are exclusive to the jammed interface are selected, i.e., neighbors with a single link; (2) channel information about the unjammed interfaces of these neighbors is inferred; and (3) the channel that is shared among most neighbors is selected and assigned to the jammed interface. Then, the interface switches to the assigned channel to re-establish communication with its neighbors to recover the lost connection due to the jammer presence. CA-JAM is a beacon-based fully distributed channel assignment scheme resistant to jamming attacks, where there is neither control channel nor a central unit. To make our algorithm off-the-shelf 802.11-compatible, we only slightly modified the beacon type that was defined in the IEEE 802.11 standard.

The rest of the paper is organized as follows. In Section 2, related work is presented, and in Section 3, our problem statement is described. In Sections 4 and 5, the proposed CA-JAM algorithm and our simulation results are described, respectively. Our conclusion is presented in Section 6.

## 2. Related work

The use of multiple interfaces incurs a channel assignment issue. There exist several studies about channel assignment in literature each from different perspective; in this section we assess previous works in this issue. In [8] and [9], the authors provided approaches on how graph theory can be used for channel assignment in MANETs. In [10], graphs are substantially applied to the channel allocation. First, the topology is determined based on the connectivity and interference graph. The interference graph is used to determine link interference, and an optimal algorithm is formulated based on the connectivity graph to reduce the multichannel link interference. Finally, authors proposed an approximation algorithm, because the coloring solution for the formulated graph is NP-hard. Moreover, interference among users is considered when designing channel allocation schemes. In [11], a centralized multi-radio conflict graph is used to model interference among stations, where a channel is assigned using station intelligence to minimize interference throughout the network. In [12], another form of conflict graph called Multi-Dimensional Conflict Graph (MDCG) is proposed to find a possible non-interfering channel assignment.

In [13], the authors proposed a static channel assignment algorithm, where each interface is assigned a distinct channel and that will determine the topology. The assignment strategy is to allocate interfaces in a common neighbor with as many distinct channels as possible such that the interference among connections is minimized. The authors of [16] suggested that one of the multiple interfaces is static while others are dynamic. In this method, HELLO messages are exchanged among the stations over the static interface and the information extracted from this message is used to mitigate interference among stations.

The proposed scheme in [36], strives to minimize interference with the help of channel assignment. This is a greedy assignment which requires all the links in the network as an input. The goal is to maximize the number of links that operate simultaneously. First each link is mapped with the first channel then the upper and lower bound SINR of each link while using that channel is obtained. Following that links are prioritized based on the upper and lower bound SINR on that channel; the link with highest priority will be assigned to that channel and the rest of the links are mapped to the next channel. This process is repeated until all the links are mapped to channel.

Adaptive Dynamic Channel Allocation protocol (ADCA) is a hybrid channel assignment protocol proposed in [25]. Like [16], one interface of each station is static while the others are dynamic. The purpose of the static interface is to enhance throughput between a station and central node whereas the dynamic interfaces are designed to work in on-demand mode. Time is divided into fixed intervals, each having a control and data interval. In the control interval dynamic interfaces negotiate a channel and choose the “least congested channel”. Each station has a queue associated with its neighbors and in the data interval the algorithm takes the queue length into consideration to choose to which group of neighbors it should communicate first. In [15], IEEE 802.11 stations obtain neighbor information through scanning and beacon broadcast. Then, they form a local coordination group based on similarity of available channels. The group votes on channels to select one channel as a coordination channel for future channel assignment.

The work in [21] suggests a group-based channel assignment (GCA) algorithm based on a divide and conquer approach. In GCA, stations are classified into a master and slaves, where the master is responsible for gathering new link formation and channel assignment. When a slave node joins the network it will send a request to its neighbors who acknowledge with a reply. However, it is the job of the master station to decide whether the new station’s link should be activated or not. If it decides to activate the new link, the master will send a broadcast message to all neighbors about the activation of the new link. In GCA, links are grouped based on the bandwidth requirement, and the groups are organized to form components. Then, links of each component are assigned to different channels. The first and second procedures guarantee a balance whereas the last procedure enhances throughput and fairness.

Another group based channel assignment is found in [33]. In this scheme, stations that are fully connected to one another belongs to one group. Stations that overhear other groups communication are called bridge stations. First each group will be assigned one channel in such a way that there is no collision between neighboring groups. One interface of each station in the group will use that for communication. Bridge stations will form fully connected group on their second interface and that group will be assigned a channel in the same manner. When stations communicate with in the group a Latin square based scheduling is implemented to avoid collision. When stations would like to communicate members of other group than its own then it will forward its data to the bridge station; the group made of bridge stations also employ Latin square method to avoid collision.

The authors in [14] investigate the joint effect of topology control and channel assignment in two stages; first, every station adjusts and checks its link until an undirected graph is constructed; second, every station is assigned a transmission channel. In [17], a joint channel assignment and routing protocol is proposed to minimize the maximum number of $l$-hop neighbors that share the same channel. Each station builds the network topology from periodical HELLO messages sent through the common control channel (CCC). Stations detect active neighbors using the request-to-send (RTS)/ clear-to-send (CTS) through CCC. Then, they choose a channel that is available for both stations from their list. Other stations update their available channel list upon listening to the RTS/CTS. The use of a CCC and 802.11-like MAC protocol is also found in [18].

Unlike [17], to detect channel availability, stations use spectrum sensing in addition to HELLO messages. One transceiver is used for a CCC whereas others are used for data exchange; Data Transmission reServation (DTS) is used for control packet transmission in order to announce spectrum reservation and transmit power to neighbors.