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An adaptive channel assignment in wireless mesh network: The learning automata approach☆

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ABSTRACT

In wireless mesh networks, random changes in the environment can increase the complexity of the multi-channel assignment. In this work, a new channel assignment scheme based on learning automata is proposed, which adaptively improves the network's overall performance by predicting network dynamics. First, we use a practical utility function that reflected the user's preference regarding the signal-to-interference-and-noise ratio is applied. In the multi-automata learning algorithm, each user evaluates a channel selection strategy by computing a utility value in a stochastic iterative procedure. The utility function that potentially reflects a measure of satisfaction is used by every node as an environmental response to the current selected strategy. In the proposed algorithm, by changing network traffic pattern, the channel allocation varies adaptively with dynamic conditions of the network. Extensive simulation-based evaluation of our algorithm demonstrates that the proposed algorithm converges to an equilibrium point, which is also optimal for channel assignment policy.

1. Introduction

Wireless Mesh Network (WMN) is an emerging new technology that is in the process of being adopted as the wireless Internetworking solution in the near future. Characteristics of WMN—such as rapid deployment and self-configuration—make it suitable for transient on-demand network deployment scenarios such as disaster recovery, hard-to-wire buildings, conventional networks, and friendly terrains.

WMN architecture can be established from mesh clients and mesh routers. The mesh clients are often laptops, cell phones, and other wireless devices—either fixed or mobile. The mesh routers make a multi-hop infrastructure for wireless backbone, to ensure forward traffic from the mesh clients to the gateways to provide connectivity to the Internet. The mesh routers relay all the wireless network traffic on behalf of clients that may be outside of the communication range of their destinations. Some of the mesh routers act as a gateway to provide connectivity to the Internet or other wired networks. This functionality in mesh gateways increases the interoperability of wireless mesh networks and other types of wireless networks, such as cellular networks, MANETs, WSNs, Wi-Fi, and WiMAX.

Simultaneous communication on 802.11 radios may be lead to capacity degradation when the operation is within the same interference range [1]. Fortunately, the IEEE 802.11 specification in physical layer makes multiple orthogonal channels

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available. For example, the 802.11b/g standard provides three such channels while the 802.11a standards allow up to 12 non-overlapping frequency channels that can be used simultaneously within the neighborhood. Accordingly, to achieve high throughput, wireless mesh routers can be equipped with multiple radios and operate on multiple orthogonal frequency channels which arises to the advantage of a self-managing and high capacity wireless mesh network [2].

In the context of learning, learning automata is an adaptive, distributed approach to solve a wide range of engineering problems, especially in communication networks in which the automata are located at the network's nodes. Learning automata—as a stochastic optimization framework—has been used to model the uncertain aspects of network dynamics. This mechanism has been widely used to predict the unknown probability distribution in some challenging problems, such as dynamic channel assignment [3], link scheduling [4], and routing [5]. In this paper, some network characteristics related to the performance and the network feedback used to train the learning automata are represented by an abstract environment model for which only a few functional properties are assumed. An environment model in which the penalty probabilities are unchanged is unsatisfactory, because the observed evolution of the process is not memoryless.

To the best of our knowledge, this work is the first study on utilizing learning method for multi-radio channel assignment under the Signal-to-Interference-Plus-Noise-Ratio (SINR) model for interference that can be implemented in a distributed fashion. In this work, a game of automata-based channel assignment scheme that does not require any knowledge about network topology and configurations, and that can be implemented in a fully distributed fashion under a more realistic model of physical interference, was developed and adapted. The rest of the paper is organized as follows: Related studies on the channel assignment problem are summarized in Section 2. Sections 3 and 4 focus on the system model, which consists of the stochastic learning method used in learning automata and proposes a distributed multi-radio channel assignment based on leaning automata that gradually learn the stochastic behavior of the network. The final section provides some simulation result and conclusions.

2. Channel assignment problem

Channel access mechanisms provided by the MAC layer protocol are developed for coordinating access to the shared medium and alleviating conflicts. These methods, especially in wireless networks, are schedule based such as frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA) or contention-based, such as carrier-sensing multiple access with collision avoidance (CSMA/CA).

Using more than one radio in each wireless mesh router is an effective approach for improving the performance of wireless mesh networks. IEEE 802.11a provides 12 non-overlapping channels that can be used simultaneously for communication within a neighborhood when different radios are tuned to use non-overlapping channels [IEEE]. The more radios are assigned to the same channel, the more connectivity is achieved, but the more interference is induced as well [6]. Consequently, increase in connectivity and decrease in interference tradeoff should be balanced.

Channel allocation is faced with some constraints. First, two communicating nodes require a shared distinct channel to establish a communication link. Second, the traffic load imposed on the wireless links should not exceed the nominal capacity of the channel. Third, the number of available channels is fixed. Fourth, the number of channels used by each node is limited to the number of radio transmitters that belong to that node [7]. According to these restrictions, it has proven that the problem of optimal channel assignment can be mapped to multi-constraint graph coloring problem and arises as NP-Hard problem [8].

Channel assignment schemes can be classified in terms of the implementation as centralized and distributed. Most of the centralized approaches follow the graph model to solve multi-constraint graph coloring problem. Marina [9] has developed a topology control approach called "Connected Low Interference Channel Assignment (CLICA)." This approach uses a greedy heuristic algorithm based on unit disk graph to enable a feasible topology formation control. Although this approach ensures the network connectivity and avoids link revisits, it does not take into consideration the impact of traffic on optimal channel assignment. Tang et al. propose the use of INSTC as an interference-aware channel assignment and routing algorithm. In their study, the authors formally define and present an effective heuristic for the minimum interference survivable topology control (INSTC) problem, which seeks a channel assignment for the given network, such that the induced network topology is interference-minimum among all K-connected topologies of the given unit disk graph [10]. Like CLICA, INSTC suffers from sacrificed fairness problem when it chooses a channel for a wireless link in a locally optimal manner. C-HYA—another centralized channel assignment scheme for wireless mesh networks based on Hyacinth—is proposed in Raniwala et al. [8]. Their proposed algorithm assigns channels to ensure network connectivity and meet the capacity limitation of the link. It estimates the expected traffic load on each wireless link based on current and past offered traffic. Then, it traverses links in decreasing order of estimated traffic load and assigns channel in a greedy manner. Although this scheme presents a method for channel allocation that incorporates connectivity and traffic patterns, the assignment of channels on links may cause a ripple effect.

In dynamic assignment, channels are assigned to radios for a short time period; the radio interfaces should frequently switch between channels per-packet or per-flow [11]. In this paper, each node uses a pseudo-random sequence mechanism to switch channels synchronously, so that all neighbors meet periodically in the same channel. Another distributed and dynamic channel assignment algorithm called D-HYA is proposed in Raniwala et al. [12]. This algorithm assigns channels according to traffic load, in order to achieve load balancing and improve aggregate throughput.