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Efficient design of wireless mesh networks with robust dynamic frequency selection capability

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ABSTRACT

Wireless Mesh Networks (WMN) operating in the 5 GHz band must implement Dynamic Frequency Selection (DFS) capabilities to cope with the presence of radar systems operating in the same frequencies. In particular, upon detection of a radar event, WMN devices must switch to a different channel within a given time specified by radio regulations. This is not only mandatory to avoid interference to radar systems, but is also convenient since radar pulses are a source of interference to the WMN itself. In this work we propose a solution for the deployment of WMNs using channels co-located with radar systems in an efficient and reliable manner. Our contribution is two-fold. First, we specify a distributed coordinated channel change procedure which reacts efficiently to radar events. We then formulate an optimization problem to find the best channel allocation which explicitly takes DFS into account, and provide a heuristic algorithm to solve it. We assess the proposed approach numerically and by simulation. Evaluation results motivate our work by confirming that DFS, which has been disregarded in previous work on WMN channel assignment, may have a significant impact on the performance of the network, and show that our solution is effective in finding a good trade-off between channel spatial reuse and DFS management.

1. Introduction

Given the shared nature of wireless links, a significant performance degradation in Wireless Mesh Networks (WMNs) is due to the intra-network interference between concurrent transmissions. The use of multiple radios and channels in such networks has been shown to effectively mitigate such effect and thus improve the network throughput dramatically [1]. When operating in licensed bands, however, incumbent external sources of interference cannot be avoided and may severely affect the WMN performance. As an example, the IEEE 802.11 standard [2], which is the most common wireless communication technology adopted for infrastructure WMNs, allocates 19 and 21 non-overlapping channels in the 5 GHz band in EU and US, respectively, for its OFDM PHY (also known as IEEE 802.11a). However, a substantial subset of them (15 and 12, respectively, according to EU and US radio regulations) are co-located with systems like weather radars and other military applications. Such systems typically operate in a sporadic manner but, whenever on, they take precedence over other devices using the same channel. Therefore, devices operating in such *co-located* channels must implement *Dynamic Frequency Selection* (DFS) capabilities in order to avoid interference with primary systems.

DFS capabilities are specified in detail by regulatory bodies, e.g., FCC in US [3] and ETSI in EU [4], in terms of procedures to both detect radar activity and switch to a

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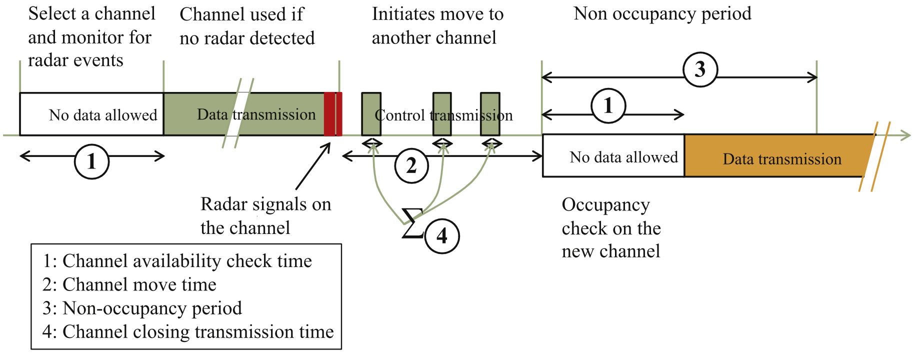

Fig. 1. DFS procedure.

new channel. Time constraints are associated to each step of these procedures in order to minimize interference to primary systems while channel switching is carried out. More specifically, Fig. 1 illustrates the DFS requirements specified by [4]. When a radar pulse is detected, the device has to leave the channel in use within 10s (*channel move time*). The channel which experienced the radar event has to remain unused for at least 1800s (*non occupancy period*). If the new selected channel is also subject to DFS, a channel availability check (CAC) has to be performed, i.e., the device has to monitor the channel for 60s to possibly detect radar pulses (*minimum channel availability check time*). If no pulse is detected, data transmission can then be resumed on the new channel.[1]

As mentioned above, the use of multiple channels in a WMN is key to achieve good performance: the more the allocated channels, the less the spatial reuse and therefore the intra-network interference. However, if channels subject to DFS are also allocated to maximize the set of used channels, the WMN becomes then subject to temporary link disruptions because of DFS channel availability checks. Even if the topology provides for alternative paths, the time it takes for the routing algorithm to repair the route is usually long, and may be unacceptable for delay-sensitive traffic. Moreover, the temporary or permanent switch of one or multiple radios to a new channel may both alter the planned WMN topology and/or make the WMN operate in a sub-optimal manner (with respect to the original channel allocation plan).

The objective of this work is to provide a solution for efficiently deploying a multi-channel multi-radio WMN with network-wide DFS capabilities. Our contribution is twofold. First, we devise a *coordinated channel change procedure* which is compliant to current radio regulations in the special case when there is at least one node which is one-hop away from any other node in the network (we refer to this case hereafter as a single *neighborhood*). Secondly, we define an optimization problem, and propose a heuristic algorithm to solve it, to find a suitable partitioning of the WMN into a number of neighborhoods, and allocate a subset of channels to each of them with the purpose of running the proposed channel change procedure in a fully distributed manner.

Though the problem of dynamic channel assignment has been widely investigated in the field of multi-radio multi-channel WMNs, to the best of our knowledge this is the first work which tackles the problem by explicitly taking DFS regulations into account. We show by numerical and simulation results the impact that DFS may have on the performance of a WMN, and demonstrate the effectiveness of our proposed solution.

The rest of the paper is organized as follows. We review the state of the art in Section 2. In Section 3 we describe the coordinated channel change procedure and formulate the channel allocation problem addressed as part of this work, for which we propose a heuristic solution in Section 4. Performance evaluation is carried out in Section 5. We finally draw some conclusions in Section 6.

2. Related work

Previous work on channel assignment in WMNs is vast; for the sake of brevity we refer the reader to [5] for a comprehensive survey.

Static channel assignment provides a fixed allocation of channels to radio interfaces according to some optimization function. As an example, in [6] Subramanian et al. propose a heuristic algorithm that aims at finding a minimum-interference channel assignment. The algorithm is guaranteed to be topology preserving, i.e., all links that would be established in the single channel network are preserved by the multi-channel allocation. On the other hand, in [7] the authors present a graph-theoretic formulation of the problem and demonstrate that the resulting optimization problem is NP-complete. They then develop a greedy heuristic, called CLICA, to create low interference topologies. Network topology strongly affects traffic routing, therefore some previous work tackled the problem of topology design, channel allocation and routing through a holistic approach. For instance, in [8,9] solutions are proposed that aim at maximizing the overall network end-to-end throughput.

[1] To reduce the impact of the CAC, an *off-channel channel availability check* is allowed, i.e., the CAC can be performed with a spare radio interface different form the one used for data transmission. In this case, however, the CAC time is increased to at least 360s. We will take advantage of this opportunity in the solution proposed in this work.