External Interference-Aware Distributed Channel Assignment in Wireless Mesh Networks

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***Abstract*—Interference is one of the major causes for performance degradation in wireless networks. Channel assignment algorithms have been proven successful to decrease the network-wide interference by using non-overlapping channels for otherwise interfering links. However, external co-located networks and devices are usually not considered in the channel assignment procedure, since they are not under the control of the network operator and their activity is therefore hard to capture. In our work we fill this gap by additionally considering the interference resulting from external devices. The novelty of this approach is that not only co-located IEEE 802.11 networks are captured, but also other sources of interference that utilize the same frequency band. We present the spectrum sensing component DES-Sense, a software solution for 802.11a/b/g that detects congested channels and does not require any changes to the drivers. We present a first algorithm for external interference-aware channel assignment and show proof-of-concept results from the DES-Testbed, a wireless mesh network with 120 multi-radio nodes.**

***Index Terms*—channel assignment, spectrum sensing, dynamic frequency selection, wireless mesh network**

I. Introduction

Multi-radio mesh routers allow the communication over several wireless network interfaces at the same time. However, this can result in high interference of the wireless transmissions leading to a low network performance. Channel assignment for multi-transceiver *wireless mesh networks* (WMNs) attempts to increase the network performance by decreasing the interference of simultaneous transmissions. The reduction of interference is achieved by exploiting the availability of fully or partially non-overlapping channels.

With the success of IEEE 802.11 technology, there is a dense distribution in urban areas of private and commercial network deployments of WLANs. These co-located networks compete for the wireless medium and can interfere with each other, thus decreasing the achievable network performance in terms of throughput and latency. Additionally, non-IEEE 802.11 devices, such as cordless phones, microwave ovens, and Bluetooth devices, operate on the unlicensed 2.4 GHz and 5 GHz frequency bands and can further decrease the network performance. It is therefore an important issue for efficient channel assignment, to also address the external interference. This task is not trivial, since the external networks and devices are not under the control of the network operator.

In this paper, we present a method to monitor the activity of external devices that utilize the same wireless channel. We achieve this, by directly accessing the carrier sensing statistics of the wireless network interface. We show a way to distinguish between traffic from our own network and the channel usage of external devices. This allows to identify heavily congested channels which should be avoided for our own network. We present an algorithm that considers the channel usage in order to calculate a truly external interference-aware channel assignment. We present proof-of-concept results for our sensing component DES-Sense in the DES-Testbed, a WMN with more than 120 multi-radio mesh routers [1].

The remainder of this paper is structured as follows. In Section II we present related work and Section III presents the spectrum sensing component DES-Sense for the real-time measurement of the channel usage. The paper concludes with an outlook on future work.

II. Related Work

Although channel assignment is still a young research area, many different approaches have already been developed [2]. In distributed approaches each mesh router calculates its channel assignment based on local information. In contrast, centralized approaches rely on a central entity, usually referred to as *channel assignment server* (CAS), that calculates the channel assignment for the entire network. Distributed approaches are considered more suitable once the network is operational and running, since they can react faster to topology changes due to node failures or mobility [2].

A main trade-off in this field exists between the channel-diverse assignment and the network connectivity, since only interfaces that are tuned to the same channel can communicate with each other. One solution is to switch a dedicated interface to a common channel to preserve the network connectivity [3]. Link-based channel approaches preserve the network topology by assigning channels to links instead of interfaces [4][5], thus being completely transparent to the routing layer. Another solution is to have one interface per node on a fixed channel for receiving and dynamically switch to the channel of the receivers fixed interface for sending [6]. The *Skeleton Assisted Partition Free* (SAFE) algorithm uses *minimal spanning trees* (MSTs) to preserve the network connectivity [7]. However, in these algorithms only the network-internal interference is addressed.

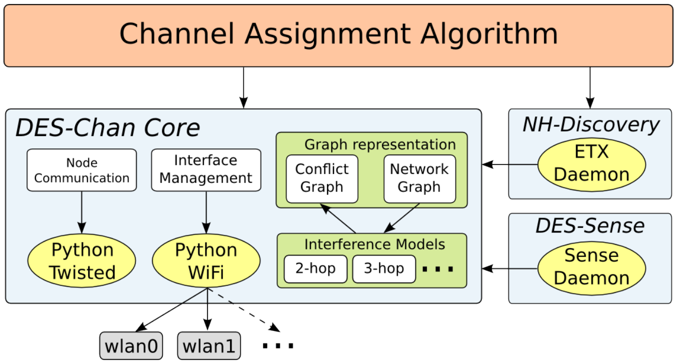

Figure 1. Architecture of DES-Chan with DES-Sense. The DES-Chan framework comprises common services required by a wide range of different algorithms. The DES-Sense module provides the channel occupancy statistics to the algorithms.

With the standardization activities for IEEE 802.11h [8], the *dynamic frequency selection* (DFS) mechanism was introduced and research on algorithms that consider external interference expanded. 802.11h was mainly introduced as a regulation in Europe since the 5 GHz unlicensed spectrum is also used for radar technology. An external interference-aware algorithm for infrastructure WLANs has been proposed in [9], which is realized by monitoring the utilized channel for beacons and data traffic of other WLAN networks.

Outside of IEEE 802.11, spectrum sensing is a fundamental part of cognitive radios [10]. Spectrum sensing is required for *secondary users* that operate in a licensed spectrum to detect if *primary users* are present and depending on the result retreat or utilize the wireless channel [11]. The SpiderRadio is an implementation of a cognitive radio with spectrum sensing in 802.11a/b/g [12]. SpiderRadios are equipped with one radio and the focus is on the detection of primary users. To realize this approach, changes to the network interface drivers have been carried out.

In our work, we present a novel approach to combine the spectrum sensing with distributed channel assignment algorithms for IEEE 802.11 networks. The goal is to enrich the DES-Testbed, a 120 multi-radio wireless mesh network with a software solution for spectrum sensing that detects congested channels and does not require any changes to the drivers.

III. DES-Sense

We developed the sensing component DES-Sense for real-time measurement of the channel usage. It has been implemented as a module for DES-Chan, a framework for empirical research on distributed channel assignment [13][14]. DES-Chan eases the development process of channel assignment algorithms by providing several services, that are common to a wide range of approaches. The architecture of DES-Chan comprising DES-Sense is depicted in Figure 1.

A. Components

DES-Sense consists of the following two components:

- *Sensing component* - The sensing component is a daemon that periodically retrieves statistics about the channel occupancy. This is achieved by retrieving the carrier sensing statistics of the wireless network card via the driver. Based on the statistics we are able to determine the percentage of a certain interval the medium was sensed busy and therefore could not have been used for wireless transmissions. We can efficiently determine the channel usage and predict the future activity of external networks and devices by using the statistics as input for corresponding models. The sensing component can be configured dynamically with the set of channels $C = \{c_1, c_2, .., c_k\}$ that will be monitored and the duration $T = \{t_1, t_2, .., t_k\}$, each channel is monitored.
- *IPC interface* - For the integration into DES-Chan, an *inter process communication* (IPC) interface is provided that allows algorithms to retrieve the channel usage statistics to fuse them into their channel assignment decision. The algorithms can query the daemon via the interface to update their channel usage statistics.

B. Challenges

Several challenges had to be addressed to efficiently use this method. The carrier sensing statistics are retrieved via the `ath5k` driver for Atheros-based interfaces [15], which is one of the few drivers for the Linux system that currently provide these statistics. However, from the carrier sense statistics alone, it can only be derived that the channel has been utilized, but not by which station. It is therefore hard, to distinguish between traffic from our own network and external networks and devices. To solve this problem, the monitoring interface can be set in *monitor mode* and thus capture and analyze the received packets. This way, we can distinguish between internal and external traffic and can treat the channel usage of our network different than that of other networks.

In order to assess the channel usage, we need to perform periodic measurements on the available channels. With multi-radio mesh nodes, this can either be solved with a dedicated interface, that permanently monitors the channel usage. The drawback of this approach is that the dedicated interface can not be utilized for data transmissions. Another method is to perform the monitoring measurements event-based, in case a change of the link quality is observed, for example, when the throughput drops. With this method, a traffic flow must be stopped and can only be resumed after a less congested channel is found and switched to. This will lead to a higher delay for this particular flow.

Another challenge results from the fact, that a wireless interface can monitor only one channel at a time. This means, that simultaneous monitoring of all available channels is not possible with one wireless interface. The duration for monitoring all channels is:

$$T_M = \sum_{k=1}^{k} t_i \qquad (1)$$

Depending on the values for t_i, the risk exists that bursty traffic might not be monitored on a particular channel. However, with periodic measurements, we aspire to gather enough data to derive realistic estimations of the future channel usage time.

C. Algorithm

Our first approach that incorporates the channel usage data is the *external interference-aware channel assignment* (EICA) algorithm. EICA assigns channels to links and is therefore topology preserving. A conflict graph is used to formulate the problem so that the number of edges in the conflict graph shall be minimized. Each link is owned by the node with the higher ID and only this node can change the channel of the link. The node ID can be any unique identifier, such as IP address, MAC address, or host name.

At the network initialization, all links are assigned to the same channel. Each node then iterates over all owned links and changes the channel of the link which results in the largest decrease of interference in the local neighborhood. The largest decrease is achieved with the combination of link u and channel k that removes the highest numbers of edges in the local conflict graph. Additionally, we use the *busy ratio of the medium* (BROM), with $\mathrm{BROM} \in [0, 1]$. The BROM is defined as the ratio of the monitoring time t_i and the channel busy time of c_i in t_i. A BROM value of 0.5 would mean that the channel has been sensed busy for 50% in t_i. With this, we derive the metric of the *expected throughput* (ET), which is calculated using the bandwidth B of the wireless link as follows:

$$\mathrm{ET} = (1 - \mathrm{BROM}) \cdot B \tag{2}$$

The channel, which achieves the largest decrease in network-wide interference with the highest (ET) is then selected. The channel switch is executed using a 3-way handshake. This procedure is repeated until the local interference cannot be reduced any further, i.e., all possible (u, k) combinations have been tried. In order to ensure the termination of the algorithm, each combination is only tried once. The total number of iterations is $O(|V_c|K)$, where $|V_c|$ is the number of vertices in the conflict graph (of the whole network) and K is the number of available channels.

D. Current state

As a proof of concept, we validated DES-Sense on the mesh routers of the DES-Testbed at the Freie Universität Berlin [1]. The DES-Testbed comprises 120 multi-radio mesh routers and is deployed in an unshielded environment over the computer science faculty buildings where several co-located WLANs exist to provide Internet access to the students and research staff.

For a first evaluation of the sensing component, we ensured that no frames were sent by the DES-Testbed nodes, so that we only capture the activity of external devices. We activated one wireless interface on each testbed node and started the monitoring phase of the available channels on the 2.4 GHz frequency band. The results of the channel usage measurements for one particular node is shown in Figure 2. The figure shows the BROM for the channels 1 to 12 of the 2.4 GHz band. As can be seen, the channels 1, 6, 11 are already utilized up to 40%. This complies very well with our knowledge that the co-located faculty WLANs used by students and research staff are using exactly these channels.

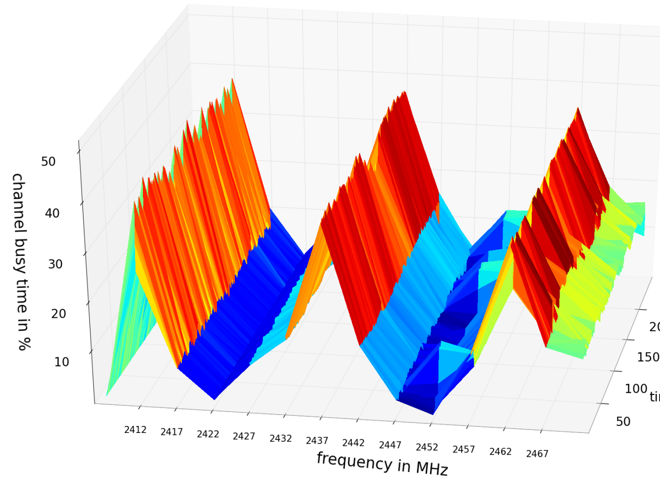

Figure 2. Channel busy ratio on the 2.4 GHz frequency spectrum. The channels 1, 6, 11 are already utilized up to 40%, which implies that the channels are already highly congested. Co-deployed to the DES-Testbed, the APs of the university WLAN use exactly these channels.

It is interesting to note, that the BROM for all channels has only little deviation. A further analysis of the captured packets traffic revealed, that at the time of the monitoring mostly beacon frames were received, which are sent periodically from the APs of the co-located networks.

IV. Conclusion and Future Works

In this paper, we presented DES-Sense, our approach to efficiently sense the channel occupancy with off-the-shelf IEEE 802.11 hardware. Our distributed channel assignment algorithm EICA will incorporate the measured BROM results in order to calculate a truly external interference-aware channel assignment. We showed a proof-of-concept for the measurement of the BROM on the DES-Testbed, a static wireless mesh network at the Freie Universität Berlin.

As this is work-in-progress, we are currently in the implementation and experimental evaluation process of the algorithm. The DES-Testbed, with more than 120 multi-radio mesh routers, presents an ideal playground for the experimental study, since many diverse scenarios can be created and mesh routers can be also used as desired as noise generators. In a large series of experiments, we will compare our algorithm to the link-based [5] and interface-based [3] channel assignment algorithms, which have already been implemented and tested at the DES-Testbed.

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