Estimation of expectable network quality in wireless mesh networks

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Abstract. Our work aims to improve the usability of wireless mesh networks as communication layer of smart office environments. While wireless mesh networks are well-suited for this task in general, the negative impact of interference, fading, and saturation makes the communication basically opportunistic. Our goal is to develop a system which allows a short-term estimation of network quality in terms of throughput, packet loss and latency. The estimation is based on channel measurements and detected high-level activities. With the estimated quality, we expect a significant improvement to user assistance and a speed-up of device integration. In this work-in-progress paper, we define the fundamental problem and its background and design a system that is suitable to solve the problem. We also present some preliminary results from ongoing experiments we carry out in a custom indoor test bed.

Keywords: wireless mesh network, network quality, prediction, smart environments

1 Introduction and Background

The work presented in this paper is part of a larger research project which focuses on user assistance in *smart environments* (SE). These environments are composed of an ensemble of various devices, many of them mobile or portable. The application scenario covers instrumented rooms—referred to as *smart meeting rooms*—that support teams in tasks such as knowledge exploration and knowledge integration. The present devices include laptops, smart phones, projectors, lights, motorized blinds and canvases, sensors for light intensity and temperature, cameras, microphones and indoor positioning systems.

These devices need to cooperate spontaneously in order to assist the user. The assistance is based on the user's inferred intentions. For achieving their joint goal, it is inevitable that the devices form a network and communicate among each other. According to [7], network concepts suitable for the task must provide

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[⋆⋆] Postal address: Universität Rostock, Fakultät für Informatik und Elektrotechnik, Institut für Informatik, Lehrstuhl für Informations- und Kommunikationsdienste, D-18055 Rostock a flexible and robust communication layer which (I) does not depend on a central infrastructure, (II) supports device mobility within the network, (III) integrates new devices seamlessly, and (IV) allows the discovery of devices and services.

Wireless mesh networks (WMN) based on IEEE 802.11 Wireless LAN fulfill almost all of the requirements and are therefore well-suited for this task [1]. The technology is commonly available and achieves a throughput which is comparable to Fast Ethernet when using 802.11n. WMN require routing mechanisms that compensate for the inherent properties of wireless communication such as time-varying quality of links as well as movement, arrival, and disappearance of devices. Numerous different approaches exist which implement the mesh functionality either on the network layer (such as OLSR-LQ) or on the link layer (such as 802.11s).

The link quality of the wireless links has a significant effect on the network quality in terms of packet loss, throughput, and latency. Therefore, the applied routing metric must take the current link qualities into account in order to find optimal routes. As to that, numerous cost functions have been developed in the past [2]. The main reasons for the variations in link quality are (a) fading due to attenuation and multipath propagation, (b) interference caused by non-WLAN devices, and (c) transmissions of neighboring WLAN devices.

The 2.4 GHz and 5 GHz frequency bands which are used for WLAN are also utilized by various other wireless systems which normally cannot decode WLAN transmissions (b). Thus, cooperative sharing of the wireless channel does not work here. Additionally, transmissions of other WLAN devices can degrade the link quality significantly (c) because of collisions and the shared medium access.

To enforce certain service qualities in wireless networks, different methods have been proposed. Both or either of prioritization (such as in 802.11e) or reservation (such as in [3]) are commonly used. However, these approaches work neither in the presence of interference caused by non-WLAN devices nor in case of WLAN stations which do not support the corresponding protocols. In the context of our work, we therefore consider the communication in WMN to be basically opportunistic.

2 Goal

Our research project aims at improving the usability of WMN for smart office environments. In these environments, devices execute autonomously planned action sequences. In order to execute a particular action, the network requirements of this action must be met. For the reasons stated in § 1, we can neither use reservation nor prioritization to guarantee this. Our goal therefore is to estimate the short-term network quality. For this, we need to create empirical models that allow us to determine the expectable network quality in terms of throughput, packet loss, and latency.

The estimated values will be used as an input to the strategy synthesis. The main challenge of the strategy synthesis component is to generate device action sequences which are then executed by the devices of the ensemble. Generated sequences need to be validated in order to decide whether they are executable. The estimation of network quality is a valuable input in this validation process.

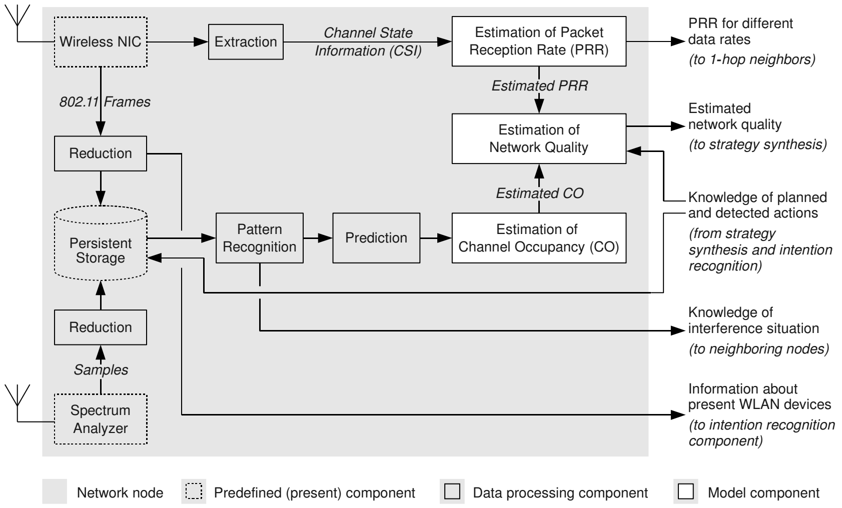

Fig. 1. Overview of the designed system. One node of the mesh network is shown. The labels on the right side indicate information exchange with other nodes of the WMN and other components of the smart environment.

For example, a remote user wants to participate in a meeting which takes place in a smart meeting room. With respect to the user experience, the system should only offer a video chat with the remote user if the network conditions currently allow a stable video transmission. Otherwise, the system may offer only an audio transmission. Also, it is possible to exclude certain actuators during planning if it is known that control commands will not reach these actuators reliably because of high packet loss conditions.

Moreover, the models to be developed will help us to reduce the time needed to integrate a new device into the network. Currently, routing protocols commonly measure the link quality be sending and counting test packets. We can omit this time-consuming process if we can estimate the link quality after only a few exchanged packets. Finally, the experiments we carried out in order to create and validate the empirical models are also helpful to understand the real-world patterns of interference and network usage in smart office environments.

3 System Description

Based on the requirements outlined in § 1 and § 2 we designed a system which allows us to estimate the quality of a link in the mesh network from (i) knowledge about the intensity and frequency of interference, (ii) the activity of all neighboring WLAN devices, (iii) information about detected user activities, and (iv) the current channel state. If such information is available for all links within a path between two communicating devices, we can estimate the quality for the entire path. For (i–iii), we consider not only the current conditions, but use also recorded, historic data for prediction. For (iv), we consider only the current state since even minor movement of devices or obstacles can influence the channel significantly due to the strong effects of multipath propagation in indoor environments. A prediction is therefore not promising here.

We designed the system in respect to the possibilities of commercial off-the-shelf hardware to allow straightforward prototypic implementations. Also, we intend the system to work decentralized, as routing in mesh networks is usually organized in a distributed manner. Therefore, one instance of the system is required to run on each network node. Figure 1 shows one instance. Both the wireless network interface card (NIC) and a separate spectrum analyzer serve as data sources. For each received frame, we extract and store the 802.11 frame type, source address and duration[1]. Additionally, we extract the channel state information similar to [5]. To detect interference and non-WLAN spectrum users, we use a simple spectrum analyzer (Ubiquiti AirView). It detects the signal energy across the entire 2.4 GHz ISM[2] band with a resolution bandwidth of 500 kHz. Existing solutions [8] show that this step may be done as well solely with a wireless NIC.

In the recorded data about interference and WLAN activity, we extract patterns and use them for prediction, resulting in a probabilistic estimation of the channel occupancy. In this step, we combine methods of time series analysis with machine learning methods such as Hidden Markov Models. Our goal is to combine information from both observations of spectrum use and knowledge of the user's activities. We classify activities into e.g. ”lecture“, ”group meeting“, and ”empty room“. Eventually, we can describe the channel occupancy rate such as shown in [6], [9] and [4]. We use the current channel state information (CSI) to estimate the probability of a successful frame reception for each 802.11 data rate[3]. Since models for this purpose already exist, this step is not in our focus.

From the estimations of packet loss, channel availability and information about planned or ongoing activities for which the impact on the network is known, we can finally estimate the short-term network quality and supply this information to the strategy synthesis component. Moreover, we are able to provide information about the number and type of currently present wireless devices to the intention recognition component of the SE.

Next to the information exchange between a node and components of the SE there is an exchange among the nodes of the network. First, neighboring nodes can share their knowledge about current and past interference conditions and channel occupancy since we can assume that the conditions are similar for nodes spatially close to each other. Such an exchange is also helpful for new nodes joining the network in that they can benefit from the knowledge acquired by nodes which are already on-site. We have to develop a metric which allows us to decide whether knowledge from a neighboring node is applicable to another node. Secondly, each node can provide the results of the packet loss estimations to its direct neighbors in order to allow them to select an optimal 802.11 data rate for their transmissions.

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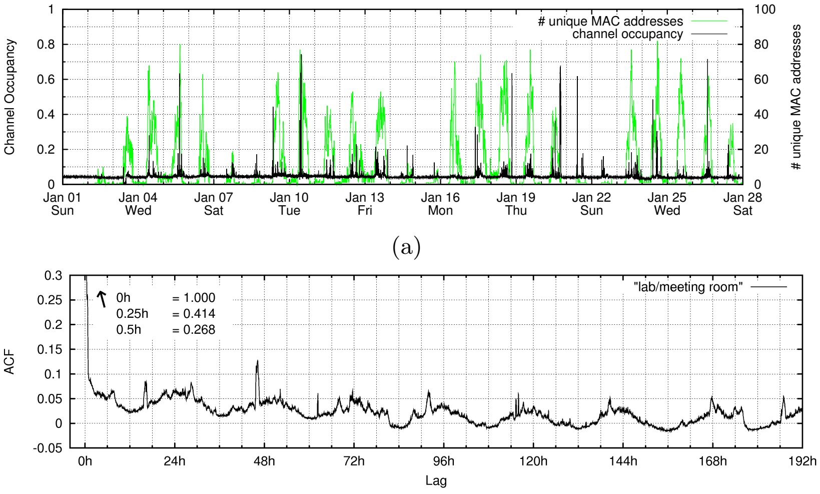
[1] Computed from frame length, data rate and preamble type.

[2] Industrial, Scientific and Medical

[3] e.g. each combination of modulation, forward error correction and antenna configuration



(a)

(b)

Fig. 2. Time-series data from our indoor test bed. (a) shows probability of occupation for a single channel and the number of active WLAN clients. (b) shows the autocorrelation of the channel occupation from (a). Please refer to § 4 for further details.

4 Intermediate Results

Based on a commercial router platform, Ubiquiti RouterStation Pro, we built a test bed with ten prototypic network nodes and deployed them in a typical office environment at our university department building. We conducted long-term experiments in this test bed to explore patterns in channel occupancy, network usage, and interference. We also assessed the impact of multipath propagation on current wireless consumer hardware in a typical office environment.

In Fig. 2a we show some measurements from the test bed about channel occupancy of WLAN channels in the 2.4 GHz ISM band. We took data collected from one of our network nodes which is located in a lab room at the department. The room is occasionally used for meetings as well. The black graph shows the channel occupancy of a single WLAN channel on 28 consecutive days in January 2012. We computed the channel occupancy by taking the samples collected with the spectrum analyzer. We observed a span of 20 MHz around 2.412 GHz (channel 1), which is the channel used by most clients in this room. We applied a threshold of $\gamma = -96\,\text{dBm}$ to distinguish between "idle" and "occupied" channel states and finally computed the average occupancy in 60 s windows. For Fig. 2b we took the time series data from 2a and computed the autocorrelation function (ACF) with a lag of up to 192 h (8 days).

It can be seen that the channel occupancy is very low during the night (ca. 5 %, mainly caused by beacon frames) and moderate to high during the working hours. It can also be seen that different days show different patterns of usage. The ACF shows that there is a periodicity of 24 h, but the low values imply that a prediction of consecutive days and even of consecutive weeks is not promising. We found similar results also for other network nodes in our test bed. These nodes are placed in lecture halls, labs, and meeting rooms. We conclude therefore, that prediction of channel occupancy solely with time-series data is not sufficient, because it will not be accurate enough to predict overall network quality. Our approach is therefore to increase the accuracy of prediction by combining time-series data with external information about user activities.

Figure 2a (green graph) shows the number of active WLAN devices nearby our network node, computed by observing WLAN channels 1–13 using a sequential pattern (”channel hopping“). We consider only data frames originating from a wireless station and compute the number of unique MAC addresses occurring within a 10-minute window from that. The high number of active devices observed can be explained by the fact that transmissions from adjacent offices and corridors, and a from small lecture room were also received by our test-bed node. It can be seen in the raw data that a high number of present WLAN devices at a particular point in time indicates a high channel occupancy at this time[4].

5 Conclusion and Outlook

In § 1 and § 2, we outlined the general problems with the use of wireless mesh networks as communication layer for smart office environments. Instead of reservation or prioritization, our goal was an estimation of network quality. Based on our findings we developed the system model described in § 3.

As a next step, we will develop the estimation models for channel occupancy and overall network quality and verify them in our test bed. In the final step, we will deploy the network nodes in the *smart meeting room* and evaluate the overall prediction accuracy in real-world use cases.

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[4] Please note that in Fig. 2a the channel occupancy is only computed for channel 1, while the number of active clients is computed for channels 1–13.