

Realistic Simulation and Experimental Validation of Adjacent-Channel Interference in Planning of Industrial Wireless Networks

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ABSTRACT

Interference is among of the most critical issues in wireless communication, especially in industrial application fields. Even though interference is rather well understood today, there is a lack of validated simulation models integrated with common network simulators. We present an integrated simulation and planning toolkit that allows us to estimate adjacent channel interference among multiple wireless networks such as IEEE 802.11 WLANs. We performed an extensive set of lab experiments not only to validate the presented simulation model but also to come up with quick lookup tables to be used for industrial network planning. The developed simulation framework provides very accurate physical layer modeling that is of utmost importance for WiFi planning in automation facilities. Not limited to the IEEE 802.11 protocols, the proposed interference model can be easily adapted for coexistence planning of WLANs and the IEEE 802.15.4 based WPANs in the 2.4 GHz band.

Categories and Subject Descriptors

C.2.1 [Computer-Communication Networks]: Network Architecture and Design—*Wireless communication*; C.4 [Performance of Systems]: *Performance attributes*

General Terms

Experimentation, Performance

1. INTRODUCTION

Looking at industrial wireless networks and applications focusing on application in automation facilities, both reliability and real-time communication represent the key requirements. In this paper, we concentrate on the reliability factor, that is influenced by appropriate network planning

functions. In particular, the following two issues need to be considered [20]: the quality of the signal at the physical layer, i.e., possible interference among different networks, and the channel access of the MAC protocol, i.e. the reduction of collisions on the channel. The latter one is addressed by many access techniques trying to avoid collisions while improving the throughput.

Interference mitigation is even more difficult in complex industrial settings. In most cases, network planning is used as a tool to manage frequencies and available bands to reduce interference. In our previous work [6], we developed a toolkit that supports a QoS-oriented network design using accurate physical layer modeling based on field measurements. This tool allows us to conduct either measurements or simulations to determine the signal distribution in a given environment considering any available machinery, walls, etc. Coupling this tool to our simulation framework, we finally get a highly precise physical layer model that we use to conduct performance evaluation studies. The final objective is to provide a toolkit that allows the planner to place nodes in a certain environment, to annotate application behavior and performance requirements, and finally to get statistical measures describing the feasibility of the current plan.

In this paper, we extend this work by studying adjacent-channel interference. In particular we concentrated on improving our simulation model to support evaluation of the performance degradation caused by adjacent-channel interference in deployments of multiple Wireless Local Area Networks (WLANs), with a particular focus on their applications in industrial automations. As pointed out in [12], proper use of partially overlapped channels can be beneficial to spectrum utilization and application performance.

The key contributions of this paper can be summarized as follows. We developed a simulation model for adjacent-channel interference in IEEE 802.11b networks. We carefully validated the model using experimental measurements in a lab environment. Our interference model implemented in the OMNeT++ simulation framework [18] supports network planning for industrial WLANs. Integrated with the simulation models of other wireless technologies, such as the one we developed for IEEE 802.15.4 protocols in OMNeT++ [7], this toolkit can be also used to plan for the coexistence of IEEE 802.11-based WLANs and IEEE 802.15.4-based Wireless Personal Area Networks (WPANs).

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The rest of this paper is organized as follows. Related work is discussed in Section 2. We present our approaches to modeling adjacent-channel interference in OMNeT++ in Section 3. Section 4 describes the detailed experimental settings for both hardware measurements and simulations. Some selected comparing results from the experiments are analyzed in Section 5. We finally conclude this paper in Section 7.

2. RELATED WORK

In the last few years, there has been much work on evaluating and characterizing the network performance in presence of co-channel interference [10, 15, 16]. Not touching the adjacent-channel interference issues, these studies made efforts to derive an analytical Physical Layer (PHY) model that predicts the delivery ratio or the throughput capacity of a given link under given traffic loads with a certain number of interferers on the same channel. A common method of these works is to use the measurement-based RF profiling of a realistic network. This modeling approach has also been used in our work. We deploy a network planning tool [4] with its site survey function to perform RF measurements. Based on the obtained measurements, a lookup table is created to map transmit power to receive power. An earlier work of using ray tracing, Markov chains and experimental data for realistic indoor radio propagation modeling in the Network Simulator Version 2 (ns-2) was presented in [9].

A study dedicated to adjacent-channel interference was presented in [19]. The authors focused on estimating the throughput of the source network under various configurations of interfering traffic on different adjacent channels using analytical methods. We adopted this scheme in our model; the key difference lying in the estimation of the Packet Error Rate (PER) and the throughput. In [19], the PER is directly estimated from the utilization of the interfering network, whereas the throughput is calculated from this PER. In our model, the PER is calculated on a per-packet basis according to a series of Signal to Interference Noise Ratio (SINR) measures obtained from the simulation as a result of multiple interferences in different phases of receiving one signal packet. The throughput is naturally obtained from packet-level simulation.

Interference in multi-radio systems can be more severe due to the close proximity of the different transceivers. In [8], the effect of adjacent-channel interference on the performance of dual-radio multi-hop IEEE 802.11a networks has been quantified using both in-lab and field measurements on selected testbeds. More detailed measurements on Direct-Sequence Spread Spectrum (DSSS) and Orthogonal Frequency Division Multiplexing (OFDM) in both 2.4 GHz and 5 GHz bands including a simulation model were presented in [13]. This interference model was implemented as an extension to the existing radio model in JiST/SWANS.

In [11], the authors presented a co-channel interference model for the OMNeT++/INET framework, which integrates a commercial ray tracing tool for accurate prediction of the radio propagation in complex environments. The proposed method can show the dynamic distribution of the signal strength and the achievable data rate for multiple 2.4 GHz-based WiFi networks operating on the same channel. The major problems of the ray-tracing technique are its high computational complexity and the need for detailed environmental models. In addition, this work did not sufficiently consider the mutual interference between IEEE 802.11 and

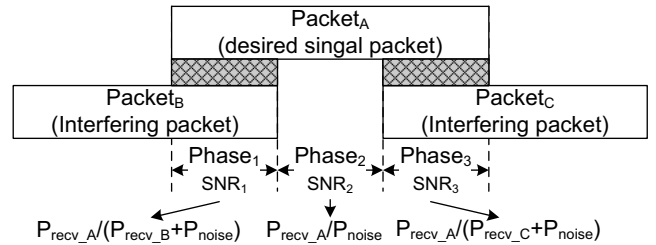


Figure 1: Generic interference model

IEEE 802.15.4 networks by taking the Power Spectral Density (PSD) of two standards into account, as, for example, presented in [17].

3. INTERFERENCE MODELING

In this section, we first describe the existing interference model and then present our enhancements that enable accurate simulation of adjacent-channel interference. Without loss of generality, we focus on introducing our modeling concept by taking the IEEE 802.11b protocols as an example.

3.1 Legacy Interference Model

Most network simulation frameworks, including the most recent version of OMNeT++, use simple radio models based on the widely used collision model, which is illustrated in Figure 1. They are only able to handle packet collisions on the same channel (co-channel interference). In this model, judging whether a received packet is corrupted due to collision or biterror is determined by the following conditions.

Condition 1.

Consider an interfered reception of a signal packet $Packet_A$ at the receiver of $Node_A$. The receiving power P_{recv} of both the signal packet and the interfering packet is calculated using the well-known pathloss propagation equation, which takes the transmit power P_{tran} (in mW), the distance between the sender and the receiver d , the pathloss exponent α , the speed of light c , and the carrier frequency f as input parameters:

$$P_{recv} = \frac{P_{tran}}{d^\alpha} \left(\frac{c}{4\pi f} \right)^2 \quad (1)$$

Condition 2.

$Packet_B$ is treated as noise at the beginning if its P_{recv} is lower than a specified sensitivity value (e.g., -85 dBm). $Packet_A$ with its P_{recv} above the threshold will be taken as a signal packet, interfered by $Packet_B$ in $Phase_1$. $Packet_C$ is also identified as noise because it arrives during the receiving of $Packet_A$. The receiving power of the interfering packets will contribute to the noise level at the receiving node, and it will reduce the Signal to Noise Ratio (SNR) of $Packet_A$. The SNR describes the noise as the sum of the thermal background noise and the power of all interfering packets, including those from concurrent packet transmissions on the same and neighboring channels.

Condition 3.

The reception of $Packet_A$ can be divided into three phases with different SNR values due to its overlap with $Packet_B$

and $Packet_C$. If, at the end of $Packet_A$'s reception, the minimum value of all SNRs is below a threshold (e.g., 4 dB), the corruption of $Packet_A$ due to the collision is evaluated. We call it collision judgment Rule 1.

Condition 4.

If Rule 1 does not apply, Rule 2 with Bit Error Rate (BER) and PER calculations is used to make a final decision. The BER is calculated as a function of bitrate and SNR using dedicated theoretical formulas for different modulation types, which can be found in the textbook [14]. The current OMNeT++ implementation distinguishes the different bitrate applied at the PHY header and the MPDU, as defined in the IEEE 802.11 standard. However, only a single minimum SNR value is used, which can lead to different BERs compared to evaluating all phases with different SNRs. The PER is then inferred by multiplying the BER with the corresponding bit length. In the simulation, the correct packet reception is then modeled as a random process taking the calculated PER into account.

It is to note that, first of all, simulation of adjacent-channel interference is not yet supported. Secondly, the used pathloss model is not accurate enough to model the complex radio propagation properties in real industrial environments, for example, the receiving power must be estimated with a high accuracy as it has a significant impact on the final results.

3.2 Enhanced Interference Model

We introduce our improvements again using the example shown in Figure 1. We assume that both $Packet_A$ and $Packet_C$ are transmitted on the same channel a . $Packet_B$ is transmitted on an interfering channel b that overlaps channel a in the power spectrum. To distinguish the interference sources, we use P_{inter_B} to represent the interfering power that is received by $Node_A$ on channel a . If the channel distance $n = |a - b| \neq 0$, P_{inter_B} is clearly smaller than P_{recv_B} , i.e. the value if the packet was received on channel a .

3.2.1 Adjacent-channel interference model

The first step is to quantify P_{inter_B} received by $Node_A$ on channel a . According to the power spectrum of IEEE 802.11 DSSS, the receiving power will be attenuated in both *spacial* and *frequency* domains, if both systems are operating on two partially overlapping channels. The attenuation in the spacial domain can be estimated using an adequate radio propagation model such as the pathloss model deployed in the original co-channel interference model or a measurement-based method that we will introduce later. To accurately quantify the attenuation in the frequency domain, the PSD of the IEEE 802.11 DSSS signal and the spectral mask applied at both systems needs to be considered. This attenuation value is also referred to as spectrum factor that represents the combined effects of transmitter and receiver masks and the frequency offset [1]. We used the model from [19] to compute such attenuation values and to calibrate them by comparing the simulation results with lab measurements (Table 1). As can be seen, at larger channel distances, i.e. 4 and 5, the realistic values are much higher compared to the theoretical ones. With the calculated P_{inter_B} , we get $SNR_1 = P_{recv_A} / (P_{inter_B} + P_{noise})$. SNR_2 and SNR_3 remain the same as depicted in Figure 1.

We keep using Rule 1 as described to judge corruption conditions, but a new Rule 2 with more accurate BER and

Table 1: Spectrum factor of IEEE 802.11 DSSS (attenuation values in dB)

Channel diff.	0	1	2	3	4	5
Theoretical	0	0.28	2.19	8.24	25.50	49.87
Calibrated	0	0.28	2.19	8.24	53.00	high

PER estimation will be applied. Instead of using only the minimum SNR in the BER calculation, the BER will be computed for each phase with its corresponding SNR value. The PER can finally be calculated as

$$PER = 1 - \prod (1 - BER_i)^{bitlength_i}, i \in [1, numPhase] \quad (2)$$

where BER_i represents the BER of $Phase_i$ and $bitlength_i$ is the number of bits transmitted in $Phase_i$. The operation of products computes the probability of the packet transmission without any bit error.

In this paper, we implemented the formulas for bitrates of 1, 2, 5.5, and 11 Mbit/s according to the IEEE 802.11b DSSS specifications. Not constrained on this protocol version, our concept of adjacent-channel interference modeling can be quickly applied in other models developed in the OMNeT++/INET framework for various wireless standards, such as IEEE 802.11g and IEEE 802.15.4. For example, to evaluate the mutual interference between the IEEE 802.11b WLANs and the IEEE 802.15.4 WPANs, we can upgrade the model presented in [5] with the same access methodologies described previously, by using the BER calculation formulas presented in the standard specifications [2] and recalculating the spectrum factors correspondingly.

3.2.2 Radio propagation model

The pathloss radio propagation model provides satisfactory accuracy only, if the investigated communication environment can be approximated as a free space model. Due to the complexity of radio propagation characteristics in indoor environments, empirical models are usually developed based on a large set of data collected for specific scenarios.

In previous work [6], we proposed a simulation framework that couples the planning tool SINEMA E [4] with the OMNeT++ network simulator for evaluating the performance of industrial applications. SINEMA E allows us to conduct either measurements or simulations with its powerful environmental modeling functions to determine the signal distribution for a specific scenario. A typical application is an automation environment that exhibits very complex structures resulting in a non-uniform signal distribution. The collected signal strength and the network settings such as topology and device configurations can be directly imported into OMNeT++. Instead of using a free space radio model, for each packet transmission, the PHY model performs lookup in the database to determine the expected signal strength at the receiver. Integrating this statistical radio propagation modeling approach can further increase the accuracy of our proposed interference model.

4. EXPERIMENTAL SETUP

To validate the proposed interference model, we compared a set of measurements in a realistic lab network using off-the-shelf products with the simulation results. Particular atten-

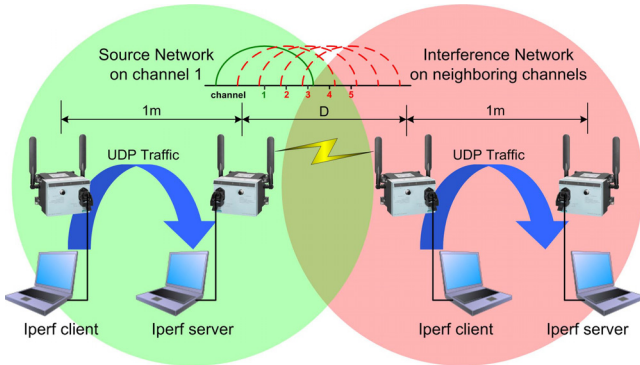


Figure 2: Experimental network setup

tion has been paid to mapping the parameters of the hardware experiments exactly to the simulation models.

4.1 Measurement Platform and Tools

The used testbed is illustrated in Figure 2. We deployed four Siemens SCALANCE W-780 access points [3] and organized them in two sub-networks that were placed on one line. Each subnet consists of two devices operating in infrastructure mode, one in Access Point (AP) mode and the other in client mode. We strictly isolated the communication between two subnets by allocating different SSIDs and IP addresses. The distance between two devices in the same subnet was fixed at 1 m, while the distance D between the two subnets was varied in the experiments. In order to generate traffic and to collect statistics, each device was connected to a dedicated laptop using the integrated Ethernet port. The SCALANCE devices allow us to configure the device and to monitor statistics either via a command line interface or via a web interface.

To produce interference traffic, the commonly used network testing tool Iperf was deployed in our experiments. In each subnet, an Iperf client running on one laptop generated UDP packets and transmitted them to an Iperf server on the other one over the wireless link. We specified one subnet as the source network and the other as the interference network. We measured the performance in terms of the Packet Delivery Ratio (PDR) on the source network under various interference scenarios.

4.2 Measurement Environment

We used a lab of $5 \times 7 \text{ m}^2$ located in the basement of the computer science building providing a relatively clean electromagnetic environment. The only fixed interfering source was an IEEE 802.11g/b WLAN repeater operating on channel 11, which we were not allowed to turn it off. To avoid additional interference from this source, we configured the source network on channel 1 and the interference network on channel 6.

To further detect unexpected interfering sources that might suddenly appear during the experiments, e.g. from mobile devices, we used the spectrum analyzer Wi-Spy 2.4x and the software Chanalyzer. With this commercial toolkit, we can monitor and analyze the activities of wireless signals in the 2.4 GHz ISM band. As shown in Figure 3, the Chanalyzer software can display information such as the signal strength and its frequency distribution. We used this toolkit not only

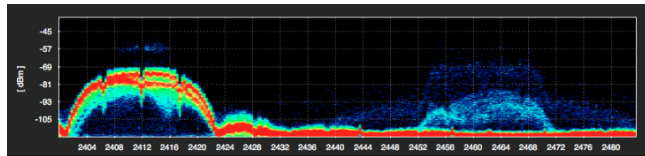


Figure 3: Spectrum visualization in Chanalyzer: IEEE 802.11b source network on channel 1 (left) and IEEE 802.11g repeater on channel 11 (right)

Table 2: Parameters settings

SCALANCE W-780	
Protocol version	IEEE 802.11b
Operation mode	infrastructure mode
Bit rate	1, 2, 5.5 Mbit/s
Transmit power	17 dBm
RTS/CTS	inactive
Fragmentation	inactive
Retransmission	5
AP's beacon interval	1 s
Channel difference	0-4
Iperf	
Transport protocol	UDP
Bandwidth	from 250 Kbit/s to 3.75 Mbit/s
Packet size	64, 1000 Byte
Running time	1000 s
Simulation model	
Radio sensitivity	-85 dBm
SNIR threshold	4 dB
Attenuation values	calibrated values in Table 1
Propagation mode	pathloss
UDP traffic pattern	settings as used in Iperf
Simulation time	1000 s

to detect external interfering signals, but also to verify the channel and power settings of the SCALANCE devices.

4.3 Performance Metric

A direct consequence of interference is the increased bit error rate, which is usually evaluated and counted in simulation experiments. A second choice is to measure the PER at link layers. The deployed SCALANCE devices provide some error statistics such as the number of FCS errors and CRC errors that are detected among all received MAC frames. Those statistics are useful for diagnosing the network configuration, however, they cannot directly be used to validate our interference model.

We realized in our experiments that the number of collisions produced by the simulations differs quite a lot from the error statistics collected by the hardware, especially in interference situations. We believe that the huge deviation is mainly caused by the different error detection mechanisms implemented in real hardwares and in simulation models. Thus, we have finally chose PDR that is measured at the application layer as the performance metric in our experiments. The comparison results described later show a good approximation between both the measured and the simulated PDR values.

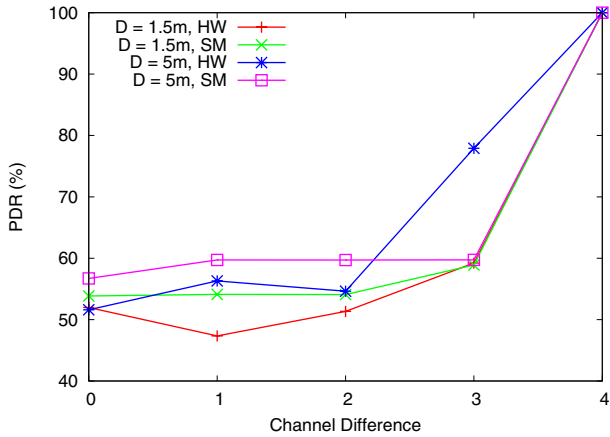


Figure 4: PDR vs. channel difference: IEEE 802.11b at bit rate of 1 Mbit/s, UDP traffic generated at 250 kbit/s in both source and interference networks

4.4 Parameter Settings

The parameters used for the measurements and the simulations are summarized in Table 2. We tried to use the same settings in both the simulation and the lab hardware. We noticed that at the highest bit rate of 11 Mbit/s, the hardware rate selection function often scaled down the speed in case of bad signal quality caused by strong interference. This function cannot be turned off in the SCALANCE devices and has thus not been implemented in the models as well. For these reasons, we only tested bit rates at 1, 2, and 5.5 Mbit/s. All the experiments have been carried out five times for each configuration to produce statistically significant results.

5. EXPERIMENTAL RESULTS

We present in this section the results of our comparative experiments in selected scenarios. We validated the enhanced interference model by comparing the measured PDR values with those from the simulations that we conducted using identical settings.

5.1 PDR at 1 Mbit/s

In this scenario, the PDR was measured for an increasing channel difference ($0, \dots, 4$) at the bit rate of 1 Mbit/s. The UDP packet size was set to 64 Byte in both networks. The UDP traffic in the source network was generated at 250 kbit/s, so that the source network reaches highest bandwidth utilization without losing packets in case of non-interference. Correspondingly, the interference network was configured to maximize the generation of interfering traffic, i.e. the UDP client generates at least at 250 kbit/s. We first placed the two networks 1.5 m apart and then moved them to a larger distance of 5 m. The obtained results are shown in Figure 4.

As we can observe in both the measurement and the simulation results, that, at 1.5 m distance and with the channel differences smaller than 4, the source network can only deliver about half the number of the packets compared to the non-interference case. At an interfering distance of 5 m, the performance is slightly improved due to the weakened interfering power caused by the spacial attenuation. The experiments also show that only settings of the channel difference

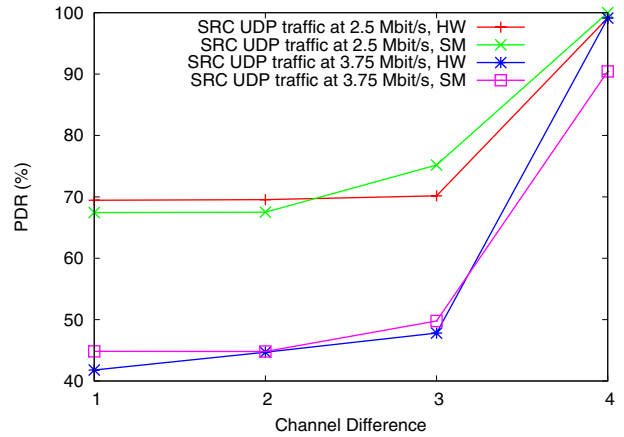


Figure 5: PDR vs. channel difference: IEEE 802.11b at bit rate of 5.5 Mbit/s, UDP traffic generated at 2.5 Mbit/s in the interference network

larger than 3 can eliminate the inter-channel interference under such extensive interfering conditions.

Generally speaking, the simulation results have shown the right trend as expected and provided a good approximation to the measured results. However, we notice that the simulated results are more optimistic than the measured values, especially at smaller channel differences. This could be caused by a SINR threshold deployed in the simulations that is smaller than the actual value in the hardware. One exception can be found in the graph at 5 m distance with channel difference 3, where the measured PDR is higher than the simulated value. Considering that this does not occur at the shorter distance of 1.5 m, we conclude that the deviation is caused by the fact the actually received interfering power at 5 m would have been much more attenuated by our lab environment compared to the pathloss model. However, at smaller distances such as 1.5 m, the pathloss model can provide satisfactory accuracy. Such issues can be solved by deploying a more accurate radio propagation model, such as our proposed SINEMA E-based model [6].

5.2 PDR at 5.5 Mbit/s

We also evaluated a higher bit rate at 5.5 Mbit/s on partially overlapping channels with the difference in the range between $[1, \dots, 4]$. During the measurements, we monitored the actually utilized bit rate of the SCALANCE devices in order to guarantee that the experiments were carried out at the specified data rate without being scaled down to a lower speed by the adaptive rate selection function. The interfering distance was fixed at 1.5 m. We configured the UDP traffic in both networks at 2.5 Mbit/s using a packet size of 1000 Byte and then increased the UDP traffic in the source network to 3.75 Mbit/s. The results are presented in Figure 5.

As we can see for channel difference 4, the source network can transmit almost all the generated packets without suffering from interference. The PDR drops as the channel difference decreases, because the interference gets more intensive. The worse results at the higher source UDP traffic are mainly caused by the fact that more packets are dropped in the queue.

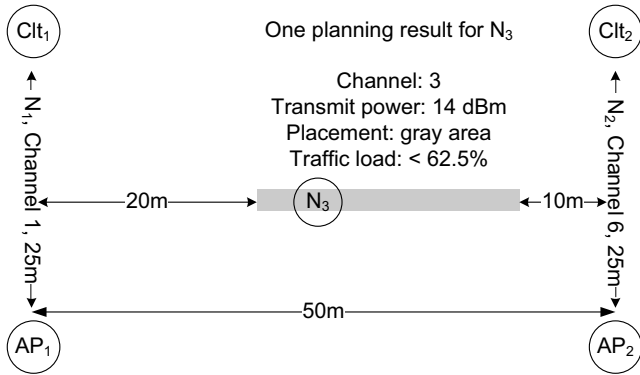


Figure 6: Planning an extra N_3 in an environment with two existing WLANs

6. NETWORK PLANNING

With the proposed enhanced interference model, the QoS-oriented integrated network planning scheme [6] can now be extended to evaluate deployment of multiple adjacent-channel WLANs. Consider the following example: there are two IEEE 802.11b WLANs on channel 1 and 6, respectively, as shown in Figure 6. There is no mutual interference between each, thus, they are configured to transmit UDP traffic at 75 % of the maximum goodput (application level throughput) with a PDR of 100 % (considering a packet size of 64 Byte and a bitrate of 1Mbit/s). We now introduce an additional network N_3 in both spatial and frequency domains. It is required that the PDR of the existing networks must not drop below a specific threshold value (e.g., 95 %). Depending on the practical conditions and requirements, four parameters need to be determined: the channel allocation (2, 3, 4 or 5), the spacial placement (on the central horizontal line of 50 m), the transmit power (17, 14 or 11 dBm), and the network traffic load (percentage of maximum goodput).

The planning process is started with a 3D environmental modeling, device placement, and parameter configurations. Besides the integrated simulation function providing a rough estimation of the signal distribution, this tool can be used to perform on-site RF measurements, which is especially meaningful for planning networks in a complex industrial environment. The created RF profile together with the device parameters and the topology information can be directly imported into the OMNeT++ simulation.

The next step is using OMNeT++ to conduct simulations with all combinations of the configurable parameters. Considering the four-dimensional parameter space resulting in too many combinations to be examined in the simulations, we can reduce the number of simulations using the following method. The mentioned four parameters can be classified into two categories. The traffic load is in the first category and has a major impact on the frequency and probability of interference occurring at the source network. Such effects can be investigated via simulations that are based on a detailed 802.11b model. The second category contains the rest three parameters, which determine the interfering power received at the source network in the following equation.

$$P_{inter} = P_{tran} - A_{cd} - A_{sd} \quad (3)$$

The attenuation values of different channel settings (noted as A_{cd}) and spatial distance (noted as A_{sd}) are obtained from

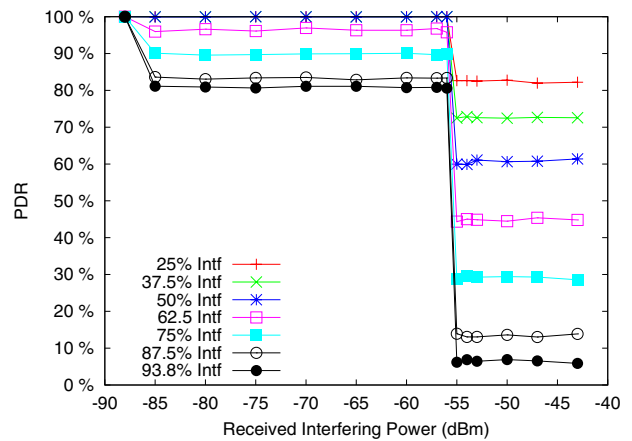


Figure 7: PDR under various interfering power and traffic load

Table 3: Maximum and Minimum values of P_{inter}

	P_{inter}	P_{tran}	A_{cd}	A_{sd}
Max	-37.28 dBm	17 dBm	0.28 dB	60 dB (12.5 m)
Min	-88.5 dBm	11 dBm	25.5 dB	74 dB (51.5 m)

Table 1 and using Equation 1, respectively. We can use a single P_{inter} to represent the three planning parameters in the simulations. Deploying this simplified method is reasonable for planning cases where each node on the same source network can be assumed to receive the same interfering power from the interfering network. Furthermore, considering the use of only different channels in the two source networks, we only need to simulate two networks i.e. N_1 and N_3 . In addition, we modified the model to let N_3 run as an independent interfering source, which is not interfered by N_1 . The purpose is to exactly control the amount of interfering traffic constantly applied at N_1 . In this way, the obtained planning results can provide a certain degree of tolerance, because the actual impact on the source network in real-world deployments would be less due to the mutual interference.

Applying the above modifications, the simulations can be conducted in a much simplified way by taking only two parameters, the traffic load of N_3 and the attenuated interfering power P_{inter} . To decide the range of P_{inter} , its maximum and minimum values are calculated in the investigated parameter space and listed in Table 3. The simulation results with a set of selected P_{inter} values in the calculated range and different traffic loads represented as the percentage of maximum goodput can now be plotted in one graph, which is shown in Figure 7.

The next step is to determine in the graph the parameter range where performance requirement is satisfied. The requirement of at least 95% PDR can be guaranteed when the interfering traffic is set below 62.5% and $P_{inter} < -56$ dBm. The three planning parameters w.r.t interfering power need to be explored for each of their combinations within the identified range of P_{inter} in consideration of the two source networks. This process requires only solving a 3D system of equations including Equation 3 and some constraint equations describing the distance or channel difference relations

between N_1 and N_2 . In case of more than one matching combination being found, decision can be made by following a certain priority rule, such as preferring a larger transmit power to increase the coverage and signal quality of N_3 itself.

For example in the discussed scenario, if a maximum transmit power of 17 dBm is desired, the channel allocation can only be at 2 or 5 for N_3 , with which N_3 has to be placed at least 45 m away from the source network that it has only one channel difference between them. If lowering the power to 14 dBm, we will have more options, for example allocating channel 3 for N_3 and putting it at any place in the gray area in Figure 6.

7. CONCLUSION

We proposed a simulation model to support accurate modeling of adjacent-channel interference. This model extends our previous work on network planning support for industrial applications, focusing on automation facilities. We validated the simulation model using an extensive set of lab experiments. The shown results clearly outline the accuracy of the proposed model. We were also able to confirm that the integrated use for network planning is feasible.

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