A new dynamic co-channel interference model for simulation of heterogeneous wireless networks

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ABSTRACT

This paper presents an interference model of overlapping radio channels which allocate the same frequency band. The model is based on the INET Framework [12] of OMNeT++ [11] simulation engine and the raytracing tool Radiowave Propagation Simulator (RPS) [14]. By using our prediction model, we present a proposal for an easier integration of adaptive bit rate adjustment for wireless networks in OMNeT++. Since a few years, an increasing amount of technologies that use the public domain 2.4 GHz band like Wi-Fi, Bluetooth and ZigBee were launched into market which complicates a sophisticated coexistence. Therefore, we want to analyze a channel model that regards not only various Physical Layer specific circumstances but also the alignment of the different networks operating in their particular scenarios. Apart from other approaches, our simulation model uses a dynamic, coupled raytracing tool to compute Carrier-to-Interference (C/I) ratios directly out of the given ambient and alignment parameter set. Finally, the validity of the simulation implementation will be proven by applying a safety critical scenario in the area of rescue operations including monitoring of vital and ambient parameters.

Categories and Subject Descriptors

I.6.4 [**Simulation and Modelling**]: Model Validation and Analysis

General Terms

Performance, Design, Reliability, Experimentation, Verification

Keywords

Co-channel Interference, Channel Modeling, Wireless Local Area Network, ZigBee, OMNeT++, Radiowave Propagation Simulator

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1. INTRODUCTION

This paper presents an approach of modeling co-channel interference of adjacent networks accurately in OMNeT++. An external channel model calculated by the raytracing tool Radiowave Propagation Simulator (RPS) is the basic simulation approach, which has already been described in detail in [2] and [3]. The extensions made for this Multiscale Simulation model do not only rely on the prediction of channel influences like *path loss*, *fast and slow fading*, *delay spread* and *Doppler shift* but also take the analysis of the *interference between adjacent networks* into account. This analysis of interfering network traffic caused by different networks occupying the same frequency band and superposed with an additional movement of the participating nodes is calculated on demand during the protocol simulation in OMNeT++.

The employment of these C/I ratios together with the related received signal strength distributions allows a more realistic Physical Layer model.

The Multiscale Simulation approach differs from MiXiM [4] and Mobility Framework [5], as our approach adds an additional level of detail to the channel model. While the MiXim approach focusses on the identification of objects disturbing the line-of-sight between two nodes, our approach is based on a tightly coupled ray tracing tool allowing a detailed modeling of co-channel interference impacts. As a consequence, our approach permits to consider various channel effects like penetration, reflection, diffraction, polarization, specific antenna configurations and changing propagation models.

Important questions like: *How big is the influence of moving persons or objects on the wireless channel?* and *How is the behaviour of the system in dynamically changing environments?* can be answered by using the Multiscale Simulation framework.

By extending OMNeT++ with a sophisticated raytracing tool, which also includes an AutoCAD environment editor, the level of detail can be maximised. Although this approach is not open source - since ray tracing tools are only commercial available - the model does not rely on statistical path loss formulas. Even material parameters can be defined in the scenario to respect different reflection characteristics.

This paper presents a safety critical application scenario that uses different wireless network technologies. The project *Galileo4FireBrigades* deals with the employment of real time sensor data exchange between the whole hierarchical structure of the fire brigades. In order to ensure the security

FEC	Modulation	$\mathbf{SINR_{min}}$	$\mathbf{P_{emin}}$	R [Mbit/s]
1/2	BPSK	18 dB	-82 dBm	1
3/4	BPSK	21 dB	-81 dBm	2
1/2	QPSK	22 dB	-79 dBm	5,5
3/4	QPSK	25 dB	-77 dBm	11
1/2	16QAM	25 dB	-72 dBm	18
3/4	16QAM	32 dB	-70 dBm	36
2/3	64QAM	34 dB	-66 dBm	48
3/4	64QAM	35 dB	-65 dBm	54

Table 1: IEEE 802.11 b/g data rates depending on SINR and modulation technique [9]

of the field forces on location, a highly sophisticated and reliable parallel operation of different wireless technologies - most notably Wi-Fi and ZigBee - has to be established. Therefore, a basic channel model which considers the influences of different *transmit powers*, applied *antenna shapes*, *environment properties* and the *number of nodes* in the network on specific performance parameters was created. As these channel influences affect various parameters like reception level and available data rates, we extended this general model with an additional Carrier-to-Interference (C/I) ratio calculation that also takes the alignment of the different nodes in the network into consideration. The simulation model itself bases on a detailed modelled forest scenario.

2. THE CHANNEL MODEL

2.1 Introduction

One of the main issues in modeling overlaying wireless networks is the fact that channels may overlap destructively in certain channel constellations. Furthermore, much disturbance is expected if a ZigBee network is used simultaneously with a Wi-Fi network in its environment. This difficulty results due to a parallel allocation of the same frequency and the usage of the same modulation technique (Direct Sequence Spread Spectrum (DSSS) in IEEE 802.11b [1]).

This parallel operation of different wireless networks within the same spectrum is not recognized in the INET Framework of OMNeT++ yet due to the one dimensional structure of the *ChannelControl*. However, in a real-world Wi-Fi network, an adaptive bit rate adjustment is applied to respect varying channel properties during operation. To model the influences of the Physical Layer on higher ISO-OSI layers in OMNeT++, Table 1 shows the implemented Signal to Interference plus Noise Ratios (SINR) and the minimum Reception Powers (P_e) together with the corresponding bit rates of IEEE 802.11. Applying these predetermined values for SINR and P_e a resulting Bit Error Rate (BER_{max}) value can be calculated to indicate the maximal threshold that is needed for a corresponding bit rate (R). To compute values which do not regard the applied Forward Error Correction rate (FEC), but only the modulation scheme, the following formulas mentioned below may be used. These formulas regard a distribution over an Additive White Gaussian Noise (AWGN) channel. The first one describes the bit error probability of a Binary Phase Shift Keying (BPSK):

$$P_{b|BPSK} = \frac{1}{2} erfc\left(\sqrt{\frac{E_S}{N_0}}\right) \tag{1}$$

If phasing of $\lambda = \pi/4$ and Gray-coding for QPSK (Quadrature Phase Shift Keying) is assumed, the symbol energy of QPSK splits up into an real and an imaginary part in equal shares. So we get:

$$\frac{E_b}{N_0} = \frac{1}{ld\,(M)} \cdot \frac{E_S}{N_0} = \frac{1}{2} \cdot \frac{E_S}{N_0} \tag{2}$$

Formula 2 is used to derive the bit error probability of the QPSK:

$$P_{b|QPSK} = \frac{1}{2} \cdot erfc\left(\sqrt{\frac{E_S}{2N_0}}\right) = \frac{1}{2} \cdot erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{3}$$

For consideration of QAM (Quadrature Amplitude Modulation), Formula 4 is used by neglecting decision errors between nearby signal points which occur in the constellation diagram of the modulation scheme:

$$P_{b|M-ASK} = \frac{2}{2ld\,(M)}\left(1 - \frac{1}{\sqrt{M}}\right) erfc\left(\sqrt{\frac{3ld\,(M)}{2\,(M-1)}\frac{E_b}{N_0}}\right) \tag{4}$$

Analyzing ZigBee we can use the bit error probability for the Minimum Shift Keying (MSK), because IEEE 802.15.4 uses an Offset-QPSK (O-QPSK) with half-sine impulse forming which is equivalent to the MSK (cf. [10]). ZigBee defines a minimal SINR of -10 dB and a minimal reception level of -85 dBm. We obtain Formula 5 for the computation of the BER in IEEE 802.15.4:

$$P_{b|MSK} = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{5}$$

Beside the consideration of the according reception levels, certain movement patterns, as well as possible asymmetrical up- and downlinks, have to be taken into account. This is important for extending the model to other wireless network technologies like 3GPP LTE (Long Term Evolution) or IEEE WiMAX. However, this paper concentrates on the analysis of the ISM band systems Wi-Fi (100 mW transmission power) and ZigBee (10 mW transmission power).

2.2 Interference Modeling

For an accurate simulation of the Physical Layer, varying antenna gains, different transmitter powers and changing environmental propagation models are regarded. Hence, we can observe fluctuant reception levels and C/I ratios caused by co-channel interferers moving relatively to one another. To respect this high dynamic effect within the simulation model, our *Multiscale Network Simulation Environment (MNSE)* [2], which basically consists of the INET Framework and the raytracing tool RPS, is used. First we start with an illustration of network nodes which are placed in a 3D scenario containing an applied environment model (cf. Figure 1).

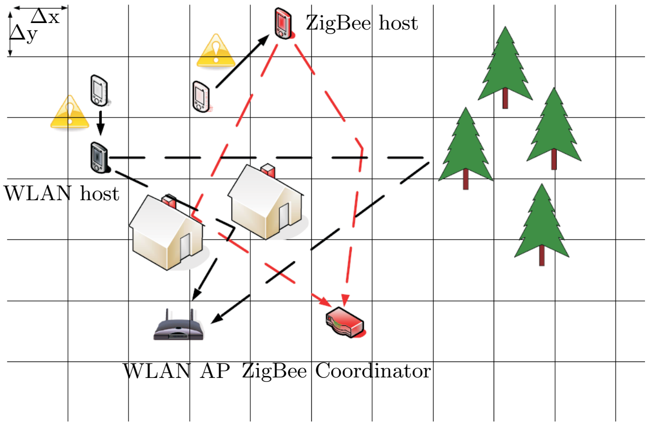

Figure 1: Triggering of recalculations of reception levels and C/I ratios

Each node is located in a raster and communicates with its Access Point (AP), respectively its ZigBee coordinator, whereas the communication link is established by multiple propagation paths. As reception levels and C/I ratios do not diverge significantly within short distances and a recalculation is quite computationally intensive, the radio field distribution is updated in intervals of Δx and Δy. This caching method is applied only for communications within the same network. Generally, the C/I computation can be divided into five major cases (shown in Figure 2). The illustrated network is exemplary for the purpose of an easier demonstration of the different cases. Thus, the considered network is shaded and all possible interferer nodes are marked with a lightning-cloud.

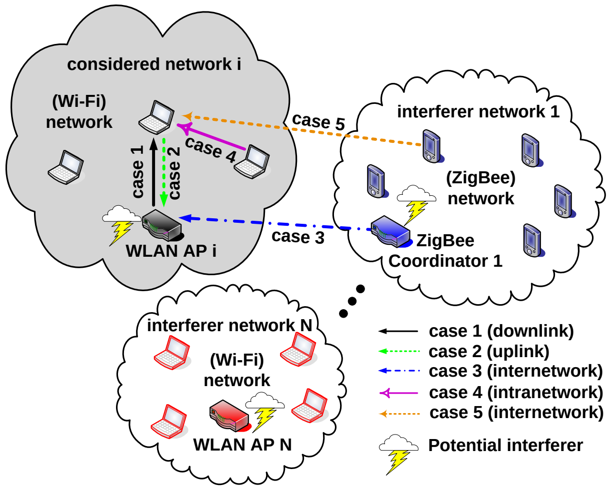

Figure 2: Five possible variations of communication incidences regarded by the Interference Model

- In the first case we analyze the downlink in which the AP sends a message to one of its nodes. As we have N networks (in this example only three of them occur in the picture) all of the N-1 adjacent networks interfere with the considered one (network i). This is approximated in our simulation by respecting the potential highest interference power of a network (which is in generalized cases always the AP/coordinator of a network) in order to calculate the accumulative interference power. Furthermore, we always assume that there is only one interferer per interfering network, because the applied Carrier Sense Multiple Access/Collision Avoidance CSMA/CA techniques in IEEE 802.11 and IEEE 802.15.4 avoid a simultaneous transmission of more than one network participant. In addition to that, all potential interferer networks must allocate the same frequency as the considered one. This may be configured in the *omnetpp.ini* separately. For case 1 the C/I ratio (i = considered network) is considered as:

$$\frac{\mathrm{C}}{\mathrm{I}}_{\mathrm{case1}} = \frac{P_{AP_i}}{\sum\limits_{j=1}^{N} P_{AP_j}} \; \{j \mid j \neq i \wedge ch(j) = ch(i) \forall j\} \tag{6}$$

- The second case deals with the calculation of the uplink which is analog to the previous case in terms of interferers. We get with $node_i$ equals the sending node, a C/I ratio of:

$$\frac{\mathrm{C}}{\mathrm{I}}_{\mathrm{case2}} = \frac{P_{node_i}}{\sum\limits_{j=1}^{N} P_{AP_j}} \; \{j \mid j \neq i \wedge ch(j) = ch(i) \forall j\} \tag{7}$$

- Case three considers a communication between APs/ coordinators of two adjacent networks. All APs/ coordinators that do not participate in the specific communication process are interferers. In this case it's essential to regard the transmission directions as well as the different powers. With i equals receiver network and j equals sender network:

$$\frac{C}{I}_{case3} = \frac{P_{AP_j}}{\sum\limits_{x=1}^{N} P_{AP_x}} \; \{x \mid j \neq x \neq i \wedge ch(x) = ch(i) \forall x\} \tag{8}$$

- The fourth case is a direct communication between two nodes within the same network. Interferers are all APs/coordinators of the whole scenario because regular Wi-Fi/ZigBee networks usually apply star topologies. As a consequence of that two nodes would normally exchange data packets via an AP. That means, the two nodes aren't logged onto the network yet and we observe beacon traffic between the two nodes. Furthermore, the network coordinator/AP may send a beacon at the same time, too. With $node_i$ equals transmitting node results:

$$\frac{\mathrm{C}}{\mathrm{I}}_{\mathrm{case4}} = \frac{P_{node_i}}{\sum\limits_{j=1}^{N} P_{AP_j}} \; \{j \mid ch(j) = ch(i) \forall j\} \tag{9}$$

- The last case is an inter-network exchange between two nodes, which is nearly similar to the previous one. Here it is important to regard the different transmission powers once again when interchanging packets between two different wireless technologies (beacon traffic). The C/I ratio with j equals transmitting node is:

$$\frac{\mathrm{C}}{\mathrm{I}}_{\mathrm{case5}} = \frac{P_{node_j}}{\sum\limits_{i=1}^{N} P_{AP_i}} \; \{i \mid ch(i) = ch(j) \forall i\} \tag{10}$$

3. IMPLEMENTATION ASPECTS

3.1 Interface between OMNeT++ and RPS

The main objective of the present paper is to realize a mobile architecture of a new *RPS ChannelControl* module. Therefore, all connections between the nodes are evaluated dynamically (in terms of reception level and SINR) regarding the relative distances to one another as well as the physical characteristics of each node. The motion of the nodes is supported by a mobility submodule separately. In contrast to the conventional *ChannelControl* of INET in which a certain interference radius is calculated statically, the new *RPS ChannelControl* examines the whole scenario for potential interferences. To achieve the dynamic and physical computations of reception levels and C/I ratios, the architecture shown in Figure 3 is applied.

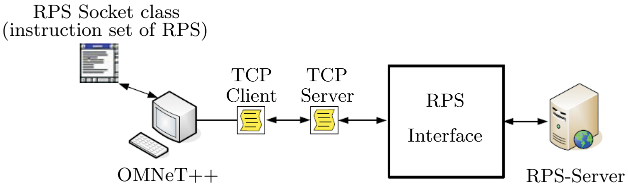

Figure 3: Interface between OMNeT++ and RPS

All instructions supported by the RPS Client are deposited in the *RPS Socket Class* at the local OMNeT++ Client to grant full access to the RPS functionality via a transparent TCP connection. In Oder to support this dynamic model, we modified the existing ChannelControl to generate a central control unit permitting a global view on the scenario. This simplifies to keep track of node positions, channel allocations and positions of objects that do not participate in any communication process (e.g. pedestrians, cars, etc.).

3.2 Multidimensional Data Structure

In this section we would like to give a brief introduction into the underlying data structure of our new *RPS ChannelControl* that facilitates an application of the proposed channel modeling. Generally, the multidimensional data structure consists of two basic classes called *Networklist* (description of the specific network properties) and *Node* (description of the different node attributes). The architecture of this multidimensional data structure is shown in Figure 4. Supported by the class *Networklist* an array containing the different networks of the scenario and their general data is created. This general data is:

- the particular AP/coordinator of a network
- the OMNeT++ ID of the AP/coordinator
- a counter for the amount of the current nodes participating in the considered network
- the applied channel number and technology (Wi-Fi or ZigBee)
- the base station ID (BSID) of the AP/coordinator in RPS
- a pointer to an attached node-list embedded in each *Networklist* element

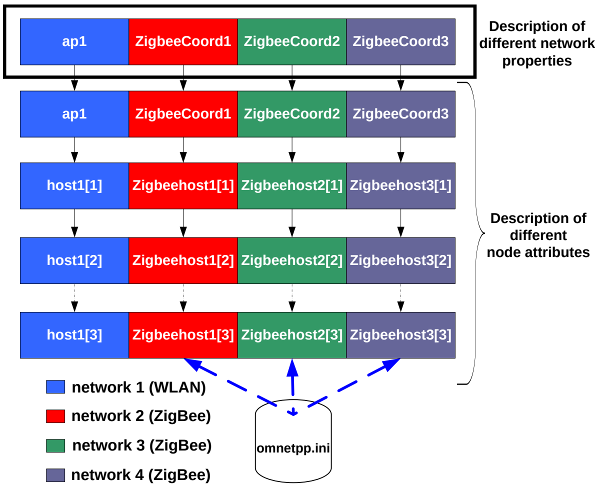

Figure 4: Multidimensional data structure of RPS ChannelControl

Thus, we observe a linked list that contains information about all nodes in a certain network within each *Networklist* element. In contrast to the *Networklist* class, class *Node* describes the most important properties of a node respective an AP/coordinator. These properties are:

- the ID of the device in OMNeT++
- the current and last position
- the reception level (from AP to node) in dBm
- the C/I ratio in dB
- the channel number of the current link

To calculate a C/I ratio we divided the computation into two parts. First we calculate the received power for each node which is needed for the calculation with RPS. After that, we compute the resulting C/I ratio regarding the five cases in RPSChannelControl.

4. PERFORMANCE EVALUATION

This section describes some exemplary results of radio field distributions in a real-world application. We are going to analyze a specific fire brigade outdoor scenario in the scope of forest fire suppression. Hence, an adaption of the special fire brigade communication hierarchies in our simulation model is needed. To ensure the safety of the action forces on field, one of the main intention of this section is to demonstrate the influence of the scenario and the motion profile on the radio characteristics. The applied communication hierarchy is shown in Figure 5.

Up to five fire fighters are organized in a subgroup and wear ambient sensors. This group forms a wireless Personal Area Network (PAN) which is able to transmit measurement data via ZigBee to the according fire brigade leader. Each fire brigade leader collects the sensor data and forwards it to the C-Service, which represents the middle management layer on location. In this example, motion of the AP is neglected, as this high model of dynamics cannot be illustrated in a 3D-plot. Instead, rather one possible example of a radio

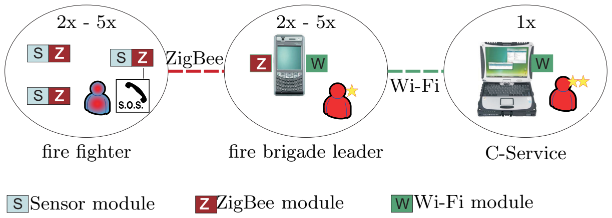

Figure 5: Communication Hierarchy of the Safety Critical Scenario

field distribution is shown, which contains the relative movement of two fire fighter brigades based on a typical motion sequence.

Each brigade consists of three fire fighters who wear various ZigBee ambient sensor kits and one brigade leader who is the ZigBee coordinator of the particular PAN. The fire brigade leader has a hybrid communication device, which collects the sensor information over ZigBee and forwards relevant information over Wi-Fi to the C-Service.

To gain a more realistic analysis of the radio distribution in this certain area, a relative movement is applied in this scenario. Furthermore, the fire fighters observe a forest area shown in Figure 6. In addition to that, a traffic generator cares for the needed constant data stream between C-Service and fire brigade leaders. The C-Service is situated at the coordinates (200m,-204m) and both brigades move funnel-shaped from their indicated starting points into the forest area (that's the reason why the result plots look funnel-shaped as well). The question at this point is, if an interruption of the communication link between the considered fire brigade leader menaces somewhere in our scenario. At the points where the links may be interrupted a so called Dropped Unit [7] (battery-powered Wi-Fi repeater) has to be placed by the fire forces to extend the coverage of the Wi-Fi network.

4.1 Received Signal Strength Distribution

In Figure 7 the calculated received signal strength distribution between one fire brigade leader and C-Service is shown from top view. Here a Wi-Fi connection link is considered which requires an Received Signal Strength Indication (RSSI) of at least -82 dBm for a data rate of 1 Mbit/s. If a data rate of 54 Mbit/s is desired, the RSSI has to be higher than -65 dBm. By examining Figure 7, we recognize two zones with quite homogeneous signal strength distributions. In the plane field area, we observe an excellent reception level which would guarantee a data rate of 54 Mbit/s by neglecting interferences. In contrast to that, there are more oscillating received signal strengths within the forest area due to constructive/destructive interferences. The most significant reception level drops are caused by line of sight losses due to some big trees in the forest. Nevertheless, a quite good reception direct behind the edge of the forest is achieved by multipath propagation. As multipath propagation seems to be the key role for RSSI computations, it is obvious that the distance between the considered fire brigade leader and C-Service, scenario profile, antenna gains and transmission powers influence this calculation, too. However, this is just the first step for an adequate analysis of radio field constellations, which does not regard the influence of *co-channel interferers* yet. Furthermore, the important relative movement between the two brigades was neglected here.

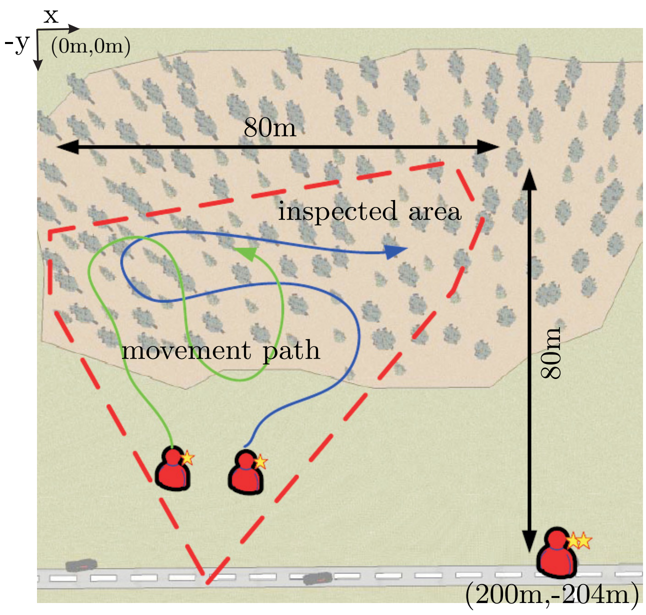

Figure 6: Forest Fire Scenario: Simulation Setup

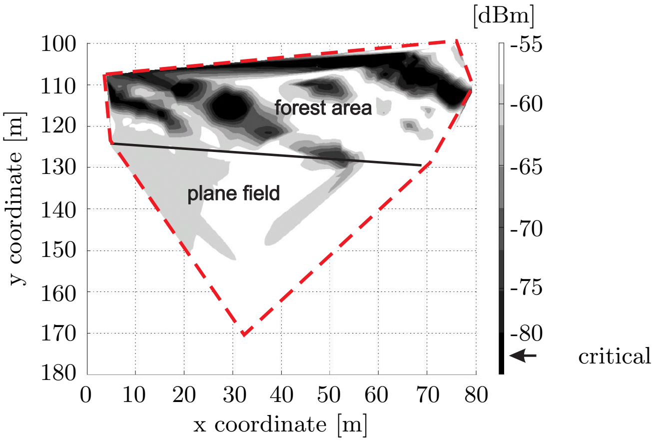

Figure 7: Distribution of Received Signal Strength

4.2 Resulting Data Rates for a non interfering System Setup

Based on Table 1 we can perform an analysis to calculate a distribution of data rates on location. Therefore, we use the RSSI results of Section 4.1 and combine them with a Signal to Noise Ratio (SNR). A typical SNR value is derived by using the Johnson Nyquist noise formula [15] for the description of thermal noise:

$$U_{R,eff} = \sqrt{4 \cdot k_B \cdot T \cdot R \cdot \Delta f} \qquad (11)$$

With $R = 1\,\Omega$, $\Delta f = 22\,\text{MHz}$ and $T = 293K$ we get a root mean square voltage of $0.5968\,\mu\text{V}$. If we assume a considered resistor of $1\,\Omega$ once again, we get an effective thermal noise power of 3.236^{-10} mW. The resulting SNR is computed by neglecting co-channel interferences.

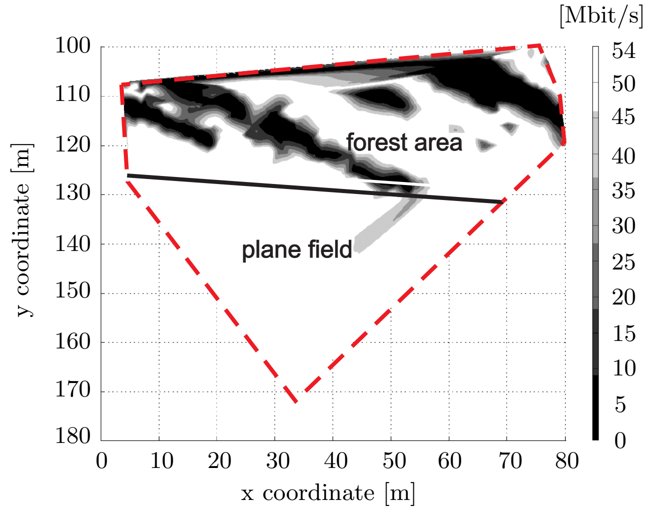

Figure 8: Distribution of Data Rates for a non interfering System Setup

Figure 8 describes an error-free setup that implies a correct channel allocation of the different networks. As a consequence of that, the resulting data rates reflect a best-case scenario.

4.3 Carrier to Interference Ratio Distribution for Co-channel Interference

In contrast to the previous reception level and data rates analysis, the C/I level which results by considering fully overlapping Wi-Fi and ZigBee channels, seems to be very destructive (see Figure 9). As mentioned before, the C/I ratio depends not only on the relative motion of the two brigade leaders to one another but also on varying transmit powers (Wi-Fi 100 mW; ZigBee 10 mW) and fluctuant distances between nodes. Furthermore, we only regard the other fire brigade leader as an interferer, because this ZigBee coordinator applies the highest transmission power in the network (in generalized cases; cf. Section 2.2). By considering Figure 9, it is important to recognize that bright marked areas do not indicate an excellent connection, but that the distance between the interfering fire brigade leader and the considered one is sufficient. In contrast to that, darker marked areas show that either the interfering fire brigade leader is close or that no direct line of sight to the AP is available. These line of sight losses affect a decreasing influence of the Wi-Fi AP (C-Service), whereas disturbance of the interfering fire brigade leader increases.

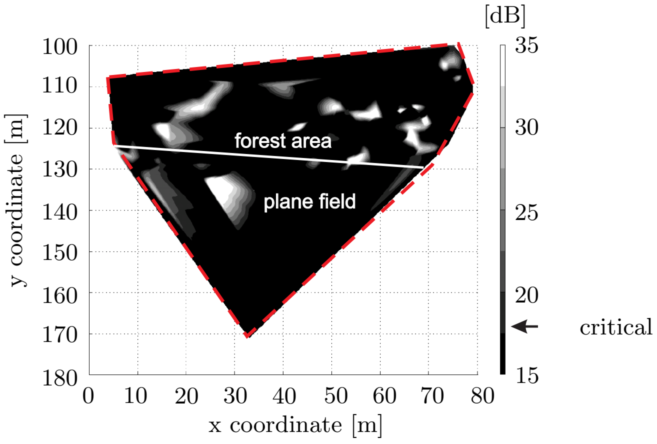

Figure 9: Distribution of Carrier to Interference Ratios for overlapping Radio Channels

4.4 Data Rate Distribution for overlapping Radio Channel System Setup

As the last step of our analysis we combine the results of the previous sections to receive an adequate approach of the radio distribution in this scenario. Based on Figure 7 and 9, one could ask once again for the available data rates that can be achieved with overlapping channels in the analyzed region. The calculation has already been discussed in Chapter 2. Although, the Carrier-to-Interference ratios look quite destructive in Figure 9, Figure 10 is more docile if we combine the RSSI and the C/I based on Table 1. There are many regions in which a data rate of at least 11 Mbit/s can be achieved. This verifies that the partial, dynamic oscillations of the C/I ratio in Figure 9 have a great influence on the resulting data rate in this scenario. Although, the received signal strength distribution in Figure 7 seemed to be sufficient for high data rates (Figure 8), Figure 10 shows that many data rate break-ins are caused by co-channel interference only. As a consequence of that, we clarified that a ZigBee network is able to disturb a Wi-Fi connection significantly in certain circumstances.

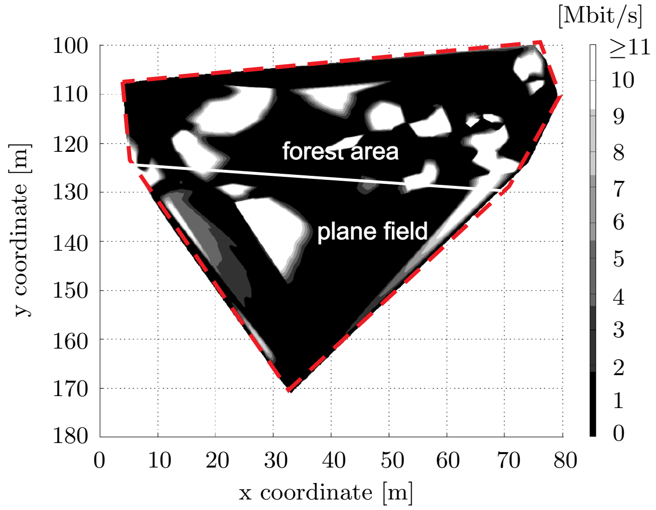

Figure 10: Distribution of data rates for co-channel interference system setup

5. CONCLUSION AND FUTURE WORK

In this paper we presented a proposal to analyze the current problem of an increasing coexistence of wireless networks in the 2.4 GHz band. We discussed various channel properties that influence the maximal reachable data rate. Furthermore, we discussed a channel model which considers the alignment of nodes separately for each communication path. After that, a safety critical scenario was examined that needed an adaption of the network hierarchy, which showed the expandability of the present implementation to other fields of application. In addition to that, we noticed that only a dynamic evaluation of the radio field distribution allows a precise quantitation of the mobile radio channel. Hence, we could first recognize a fluctuant and dynamically changing C/I level as we started to take varying distances of the fire brigades to the C-Service combined with a certain relative movement of the two brigades to each other. Furthermore, this implementation permits an adaptive bit rate adjustment of wireless networks in the INET Framework. Finally, this model can be extended to different wireless network technologies like 3GPP LTE or IEEE WiMAX as the channel model already regards different transmission powers and antenna gains.

6. ACKNOWLEDGMENT

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