Influence of Intra-Network Interference on Quality of Service in Wireless LANs

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I. CONTEXT AND OBJECTIVES

As the wireless medium is becoming more and more congested, a better use of the scarce frequency spectrum is needed to deliver the required Quality of Service (QoS) to clients. Especially in unlicensed bands, wireless systems suffer from intra-network interference, e.g., in professional wireless conferencing environments [1]. Therefore, cognitive solutions are being developed, both on radio and networking level [2, 3, 4, 5]. These cognitive solutions are based upon the use of a decision engine which can be either central or distributed. In order to guarantee a certain QoS, it is crucial to have insight in the link between the interference level observed at the receiver and the impact on the QoS.

In this paper, WiFi experiments in a pseudo-shielded environment will be discussed, i.e. an environment that is shielded from outside interference. The QoS decrease for a link under test will be assessed for interfering traffic at different power levels, for different degrees of channel overlapping between the link under test and the interfering traffic, and for different channel occupancy degrees of the interfering traffic. Knowledge about the impact of a particular interference source, allows improving QoS optimization algorithms for decision engines in cognitive systems.

The outline of the paper is as follows. Section II describes the environment where the experiments are conducted. In Section III, the interference experiments are discussed, followed by an analysis of the results in Section IV. Section V describes a cognitive framework in which the obtained results will be implemented in the future, and finally, Section VI summarizes the conclusions of this paper.

II. TEST ENVIRONMENT: LIVING LAB W-ILAB.T

All experiments are conducted in a pseudo-shielded testbed environment [6] in Ghent, Belgium. The nodes in the testbed are mounted in an open room (66 m x 20.5 m) in a grid configuration with an x-separation of 6 m and a y-separation of 3.6 m. Fig. 1 shows the ground plan of the living lab with an indication of the location of the nodes. The 60 installed nodes are represented by the blue locations on the picture.

Each node has two WiFi interfaces (Sparklan WPEA-110N/E/11n mini PCIe 2T2R chipset: AR9280) and on each WiFi card, two antennas are connected (2x2 MIMO (Multiple-Input Multiple-Output) is supported). Furthermore, an RM090 sensor node and a USB 2.0 Bluetooth interface (Micro CI2 - v3.0 EDR) are incorporated into each node.

III. DESCRIPTION OF INTRA-NETWORK INTERFERENCE EXPERIMENTS

The impact on the QoS over a link under test will be investigated for different interference scenarios. As QoS-parameter, the physical throughput is considered. Firstly, the living lab configuration for the execution of the different scenarios is explained. Secondly, the two interference scenarios will be discussed individually and thirdly, the setup of a single experiment will be described.

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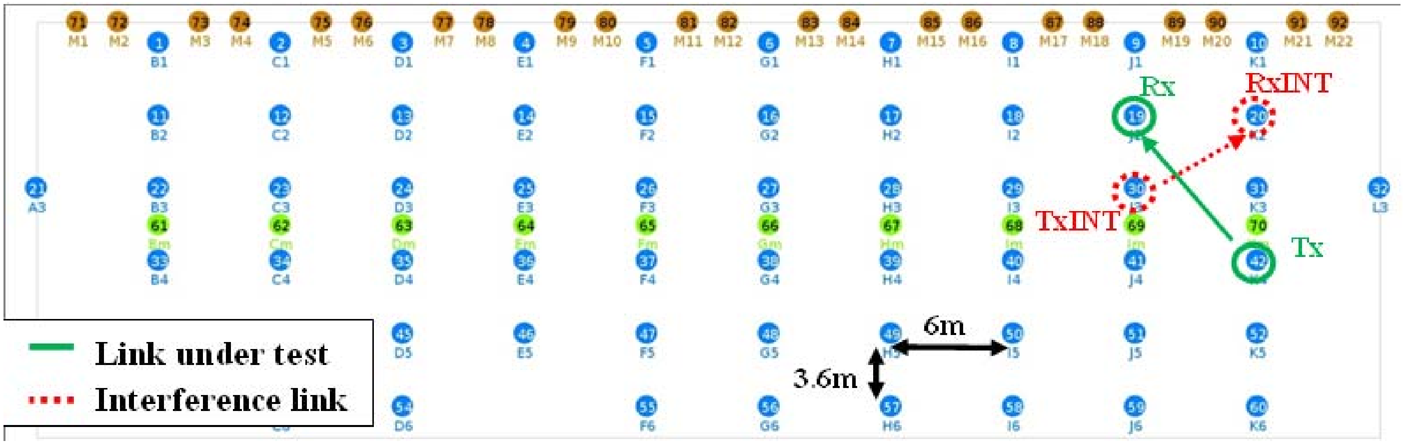

Fig. 1: W-iLab.t living lab test environment (66m x 20.5m) with indication of the nodes and the connection links used for the experiments.

A. *Network configuration*

During each interference scenario, two connection links were established, as displayed in Fig. 1. The first link, always operating on channel 6, is denoted as the link under test (LUT), with node 42 as transmit node Tx and node 19 as receiver node Rx (see Fig. 1). The second link was the interfering link, between node 30 (TxINT) and node 20 (RxINT) (see Fig. 1). The data generation rate of the transmitters is defined as the UDP (User Datagram Protocol) bandwidth of the Iperf application. All WLAN (Wireless Local Area Network) radio interfaces were set to transmit at a certain bit rate (Tx rate) and Iperf [7] was used as the traffic generator. The channel occupancy degree is here defined as the ratio of the data generation rate and the Tx rate. There is a transmit buffer that is filled by data at a rate equal to the data generation rate, while the interface transmits through this buffer at a rate equal to the Tx rate. The data generation rate is always smaller than or equal to the Tx rate.

$$\text{ChannelOccDegree}[\%] = \frac{\text{DGR}[\text{Mbps}]}{\text{Tx rate}[\text{Mbps}]} \qquad (1)$$

B. *Interference scenarios*

Two interference scenarios will be investigated in the paper. For each interference scenario, the influence of the received power from an interfering transmitter on the QoS over a link under test was assessed. Interference from node 30 in Fig. 1 was generated with different power levels within the supported range of 0 to 20 dBm, leading to a set of observed interference power levels [dBm] at node 19, the receiver of the link under test. However, in each of the scenarios, an additional parameter was also varied.

- In a first *interference scenario I*, also the influence of the **channel overlap** on the throughput over the link under test was assessed. A set of 70 experiments was executed, in which each of the experiments is characterized by the interference channel (5 channels) and by the generated interference level (14 levels) at node 19 (caused by interfering node 30). The channel of the interfering link was varied from channel 6 (full overlap with link under test) to channel 10 (smallest overlap with link under test). For each channel overlap, fourteen different interference power levels [dBm] were observed at node 19: [-51,-52,-53,-54,-56,-57,-59,-60,-62,-63,-66,-70,-71,-72]. The Tx rate for all WLAN interfaces was set at 2Mbps and the data generation rate of both transmitters at 1 Mbps, yielding channel occupancy degrees of 50%, using eq (1).
- In the second *interference scenario II*, also the influence of the **channel occupancy degree** on the throughput over the link under test was assessed. In total 140 experiments were executed, characterized by a varying channel occupancy degree (10 levels) and a varying generated interference level (14 levels) at node 19 (caused by interfering node 30). The channel occupancy degree was varied from 10% to 100% in 10%-intervals. For each channel occupancy degree, 14 different interference power levels [dBm] were observed at node 19: [-51,-52,-53,-54,-56,-57,-59,-60,-62,-63,-66,-70,-71,-72]. The data generation rate and Tx rate of the LUT were both set at 54 Mbps (channel occupancy degree = 100%). The Tx rate of the interfering link was set at 2 Mbps and operated at channel 6, the same channel as the LUT.

In the future, scenarios with multiple interferers will also be considered.

C. *Experiment Setup*

In each of the interference scenarios, a set of experiments is executed. Each experiment consists of two phases: a first phase where the QoS of the link under test was recorded without interference, and a second phase where interference was generated in the environment. Phase 2 of each experiment proceeds as follows: *(i) Start the interference transmission for 12 seconds (ii) Wait 1 second (iii) Start the link-under-test transmission for 10 seconds (iv) Wait 10 seconds (v) Stop all data transmissions*

During the execution of an experiment, the Iperf output stream containing the periodic throughput reports of the receiver was parsed and stored in a database at the experiment controller server of the testbed. For each record, we also logged the time stamp of the throughput report. Moreover, all physical-layer changes such as channel switching and transmit power modifications together with their time stamps were logged into the database. After running the experiments, the time stamps of the physical-layer changes were used in order to calculate the achieved throughput during each of the experiments in the total set.

IV. EXPERIMENT RESULTS

A. Interference scenario I: influence of channel overlap

Fig. 2 shows the achieved average throughput (in ten seconds) without interference, and the achieved average throughput as a function of the received interference power level, for interference on different channels. A higher channel number corresponds with less overlap (link under test operates on channel 6), i.e., for increasing channel separations, interference decreases. The interference level on the x-axis of Fig. 2 is defined as the power received from node 30 at node 19 (see Fig. 1). When there is no interference, the average throughput is 0.95 Mbps.

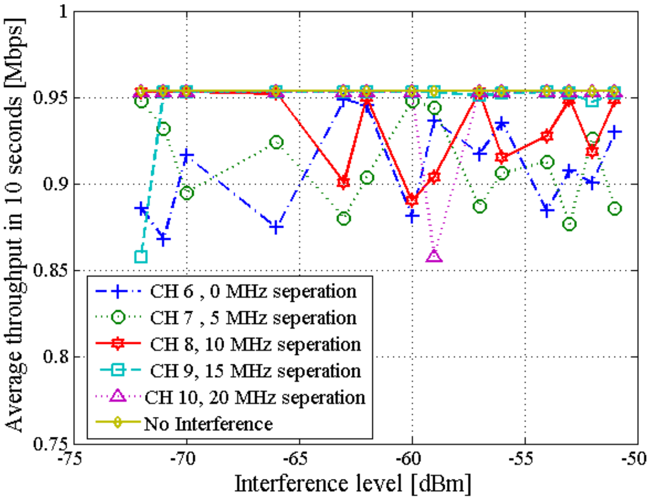

Fig. 2: Average throughput over link under test in a ten-second timeframe as a function of received interference power level, under the absence of interference and for interference with different channel overlaps.

Table 1 lists the corresponding throughput reduction in terms of percentages, due to the interference level and for different channel overlaps. Firstly, Fig. 2 and Table 1 show that the interference power level does not have an influence on the throughput reduction percentage: the throughput is not more impacted when the interference power is higher. Secondly, Fig. 2 and Table 1 show that interference does not influence the throughput much when the channel separation is at least 3 channels (channel 9 and 10): the throughput is mostly not affected at all (0% reduction). Thirdly, when the interfering link and the link under test operate on the same channel (channel 6), the MAC (Medium Access Control) protocol efficiently tackles interference using the CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) mechanism: the throughput is affected, but not dramatically. The throughput is reduced by 4.1% on average and by 8.4% at most (see Table 1). Fourthly, when interference occurs on channel 7, the throughput is equally affected compared to channel 6 (3.9% vs. 4.1%), and slightly less for channel 8 (1.8% vs. 4.1%).

Inter-ference level [dBm]	**Throughput reduction [%] due to interference on (CH 6 is link under test)**				
	CH 6	**CH 7**	**CH 8**	**CH 9**	**CH 10**
-72	6.3	0	0	9.5	0
-71	8.4	2.1	0	0	0
-70	3.2	6.3	0	0	0
-66	8.4	3.2	0	0	0
-63	0	7.4	5.3	0	0
-62	0	0	0	0	0
-60	7.4	1.1	6.3	0	0
-59	1.1	6.3	5.3	0	9.5
-57	3.2	4.2	0	0	0
-56	1.1	4.2	3.2	0	0
-54	7.4	4.2	2.1	0	0
-53	4.2	7.4	0	0	0
-52	5.3	2.1	3.2	0	0
-51	2.1	6.3	0	0	0
Average	4.1	3.9	1.8	0.7	0.7

Table 1: Average throughput reduction (over 10 s) due to interference for different interference power levels and for different channel (CH) overlaps, channel 6 is link under test.

B. Reproducibility of scenario I

Fig. 3 shows the results of a second iteration of the channel overlap experiment, with experiment settings identical to the ones in Section IV-A. The figure confirms previous findings. The 70 measurement points have an average absolute deviation of 2.3% (throughput reduction) with a standard deviation of 2.9% (comparison of scenario I with reproduced scenario). Average throughput reductions for CH6, 7, 8, 9, and 10 are 2.8%, 2.9%, 2.3%, 0.7%, and 0.7%, respectively. These values are also in line with the ones listed in Table 1. We can conclude that the experiments are reproducible.

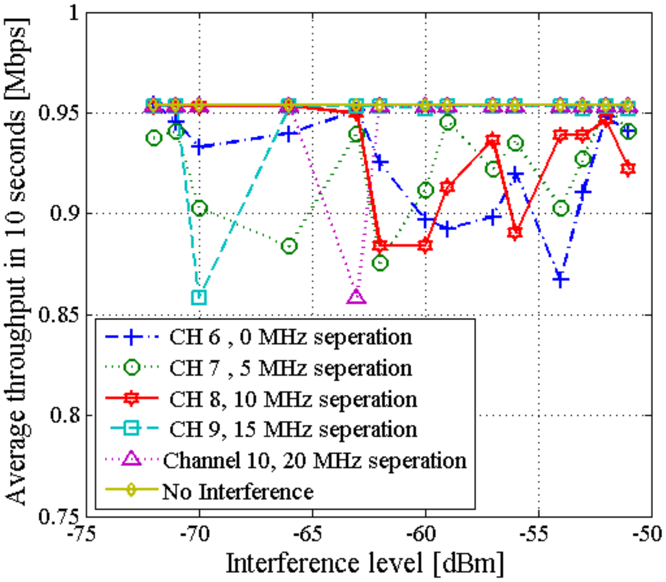

Fig. 2: Average throughput over link under test in a ten-second timeframe as a function of received interference power level, under the absence of interference and for interference with different channel overlaps (reproducibility test).

C. *Interference scenario II: influence of channel occupancy degree*

Fig. 4 shows the achieved average throughput (in ten seconds) without interference, and the achieved average throughput as a function of the received interference power level, for interference with varying channel occupancy degrees. The figure shows again that the observed interfering power level has no significant influence on the QoS. As could be expected, the throughput is more impacted for higher channel occupancy degrees. It should be noted that even without interference, the intended throughput of 54 Mbps is not attained.

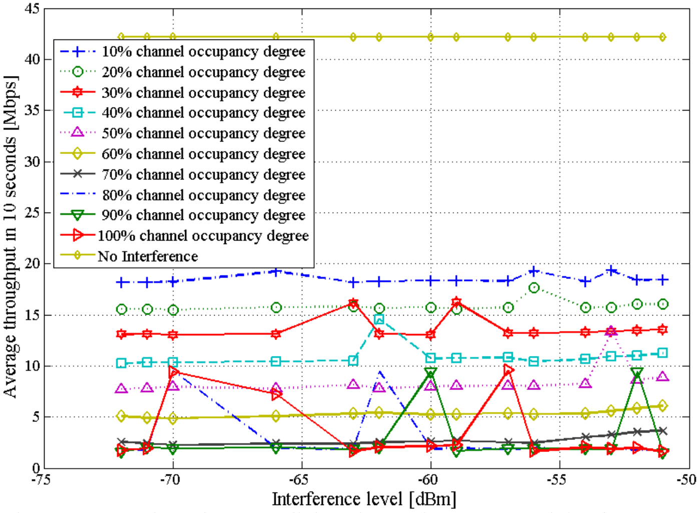

Fig. 4: Average throughput over link under test in a ten-second timeframe as a function of received interference power level, under the absence of interference and for interference with different channel occupancy degrees.

Table 2 lists the average throughput reductions (over 10 s) due to interference for different channel occupancy degrees, averaged over the different interference power levels. The average throughput reduction increases from 56.1 % to more than 93 % when the channel occupancy degree is varied from 10% to 70%. For higher channel occupancy degrees, the throughput remains more or less constant.

Channel occupancy degree [%]	**Throughput [Mbps]**	**Throughput reduction [%]**
0 (no interference)	42.17	-
10	18.50	56.1
20	15.85	62.4
30	13.64	67.7
40	10.92	74.1
50	8.46	79.9
60	5.34	87.3
70	2.73	93.5
80	2.94	93.0
90	2.93	93.1
100	3.36	92.0

Table 2: Average throughput reduction (over 10 s) due to interference for different channel occupancy degrees.

V. APPLICATION: IMPLEMENTATION INTO COGNITIVE NETWORKING SYSTEM

In case the interference is known, the obtained results can be used to estimate the performance of a connection link or to reconfigure the network in order to optimize the network or at least to achieve a desired throughput. To that end, the results can be incorporated into a cognitive wireless networking system. Such a system is implemented and tested in the test lab described in Section II. Fig. 3 shows the global architecture of the system, consisting of a database, an environment map, the network itself, and a decision engine.

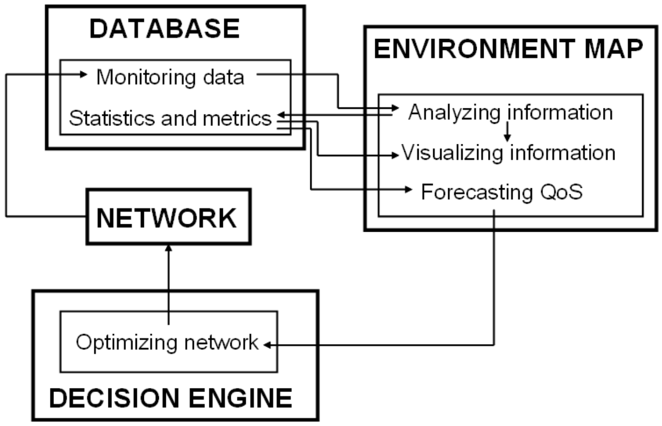

Fig. 3: Architecture of cognitive wireless networking system

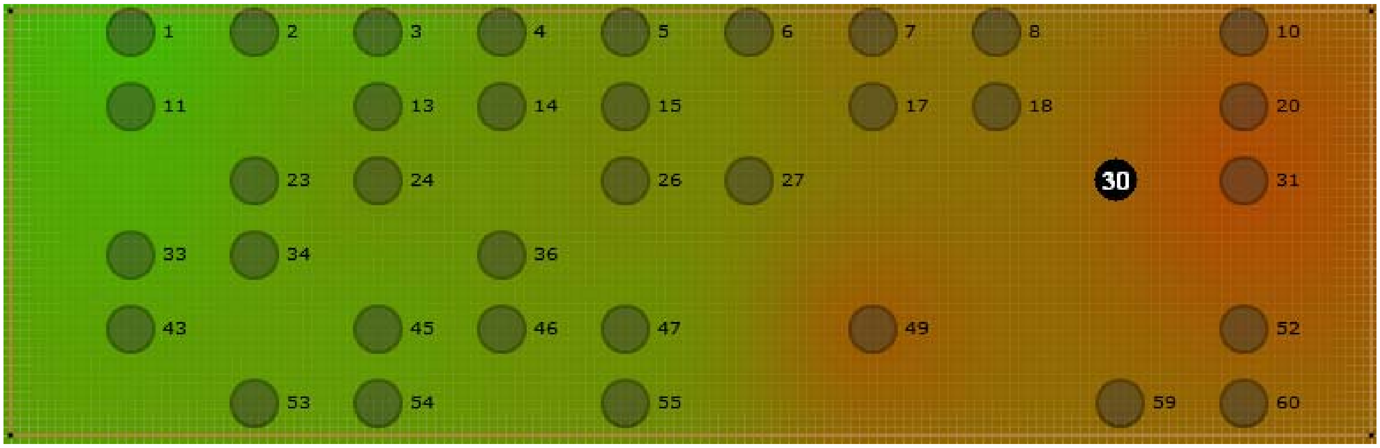

Fig. 4: Environment map of RSSI values in W-iLab.t living lab test due to traffic generated at node30.

As traffic is being generated, all network information (e.g., RSSI, delay, channel overlapping,…) is monitored (see Section III), and stored in a database. Based on the information in the database, a map of the environment is then created, visualizing QoS parameters (e.g., throughput) or interference (channel occupancy, RSSI) metrics. Fig. 4 visualizes RSSI values measured in the environment of Fig. 1, where node 30 (interferer) generates traffic. The values are monitored at the locations of the nodes indicated on the map. Other values are obtained by applying interpolation techniques. A red color indicates high RSSI values, a green color indicates lower values. Real-time updates of this map allow a quick assessment of the channel occupancy. The results of this study allow making models for forecasting the new QoS in case changes to the network configuration are made. Out of multiple network parameter adjustments, the decision engine is then able to select the best option and to reconfigure the network accordingly, which then, ideally, provides a better overall QoS in the network. The experimental results obtained in this paper are indispensible for reliable QoS forecasts.

VI. CONCLUSIONS

In this paper, the influence of intra-network interference on the QoS in WLANs has been assessed.

The QoS decrease for a link under test has been assessed for interfering traffic at different power levels and for different degrees of channel overlapping between the link under test and the interfering traffic. For channel separations of 3 channels or more, the throughput is hardly affected. Interference on the same channel as the link under test is efficiently coped with by the CSMA/CA mechanism and only causes throughput reductions of maximally 8.4 % for the considered experiment. The average throughput reduction is around 4% for interference on the same channel, irrespective of the interference power level. Throughput is equally reduced by interference on adjacent channels (3.9% on average) and slightly less (1.8%) affected by interference on channels that are 2 channels apart (from the channel of the link under test). Average throughputs are increasingly reduced for higher channel occupancy degrees: from 56.1 % to more than 93 % when the channel occupancy degree is increased from 10% to 70%. Results of these and other experiments can be used to model QoS impact in WLANs. The models can then be used in a cognitive optimization system that automatically adapts its parameters for QoS optimization.

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