Impact of omnidirectional and directive antennas on WLAN link performance under in-band interference

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***Abstract* — An experimental evaluation of 802.11g+n based wireless local area network (WLAN) devices with omnidirectional and directive antennas under interference is investigated in this paper. The performance of directive antennas is known to be better if the interference signal is coming from the sidelobes' directions. Here we studied the performance difference between directive and omnidirectional antennas when the interference signal is originated between a transmitter and a receiver.**

The measurement campaign was conducted in an anechoic chamber in order to be sure that other wireless devices operating in the same license free industrial, scientific and medical (ISM) 2.4 GHz band would not cause interference to the studied WLAN link. Interfering signal is a continuous wave that is generated with a signal generator. The interference is set to use the same bandwidth as the WLAN link uses for desired communication.

The results showed that the performance of the WLAN link with omnidirectional antennas is significantly better if compared to the directive antennas. Establishing the WLAN communication link with omnidirectional antennas was possible with 7 dBm more interference power than with directive antennas.

***Index Terms* — Anechoic chamber, continuous wave, experimental evaluation, interference location.**

I. INTRODUCTION

IEEE 802.11g+n [1] based wireless local area network (WLAN) devices have become popular, for example, in a home and an office environments in the recent years. Due to the vast increase in devices that operate in the industrial, scientific and medical (ISM) 2.4 GHz band, WLAN links are exposed to interference caused by Bluetooth and other WLAN devices. Interference has a significant impact to the WLAN performance, but for example in a home environment, interference can decrease throughput but it does not usually block communication completely [2]. Whereas in a case of intentional interference, or jamming, it can cause severe degradation in throughput and it can also block WLAN communication entirely.

Measurements of WLAN tolerance against jamming has been studied in many cases with cables between devices [3-5]. The objective has been to get rid of unwanted interference and effects of multipath channel in order to ensure stable environment for the measurements. But it prevents measuring the impact of location of interference source and what can be gained by using different antenna types. Despite the maturity of different WLAN technologies and extensive research done related to WLAN jamming, further studies are needed so the future devices would be more tolerant against interference.

This paper introduces a measurement scenario where interference source is between a transmitter (Tx) and a receiver (Rx). The objective of these measurements is to find out which antenna type, omnidirectional or directive, is more tolerant against interfering signal that comes between the Tx and the Rx.

This paper is organized as follows. Section II introduces the measurement setup. In Section III all the relevant parameters used in the measurements are introduced. Results are presented in Section IV and Section V concludes the paper.

II. MEASUREMENT SETUP

Measurements are conducted in an anechoic chamber to be sure that only intentional interference source is present and no other interference from other devices exist. There is an anechoic chamber at the University of Oulu having the measures of 11.5 m x 6.5 m x 6.5 m, 486 m^3. In these measurements, transmitted power is fixed and performance of the WLAN link is measured by using the Iperf network testing tool [6]. When the channel conditions are good, the modulation method in the studied WLAN link is 64-QAM (quadrature amplitude modulation) and the coding rate is 5/6. Therefore, the theoretical maximum data rate is 130 Mbps [1]. Under interference, WLAN module software automatically tries to keep communication link up by changing the modulation method, which reduces the data rate.

In the WLAN setup phase, a communication channel is

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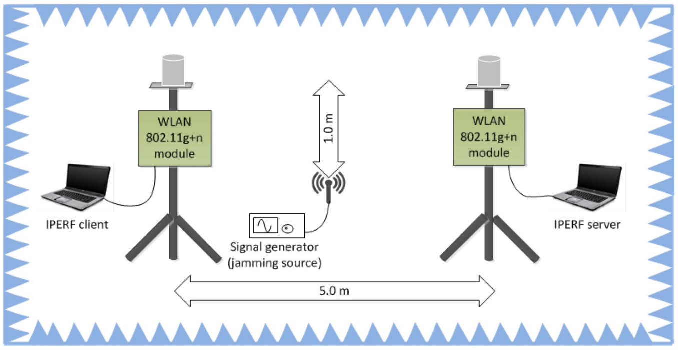

Fig. 1. Measurement setup with omnidirectional MIMO antennas.

selected. The selected channel has a minimum amount of interference caused by other devices. Even though the best channel is selected, it does not provide protection against intentional interference. After configuration, WLAN operates at that channel regardless of degradation of wireless link performance due to, for example, shadowing and changing interference level.

Analysis will focus on the performance degradation in a raw performance in a sense that in these experiments user datagram protocol (UDP) traffic is used, and thus, there is no degradation to throughput from recovery options or reliability and congestion control as in the transmission control protocol (TCP). Security features are not used in the measurements. Interfering signal is a continuous wave (CW) generated with a signal generator. The signal generator is E8257C by Agilent Technologies [7].

The measurement setup with omnidirectional antennas is shown in Fig. 1. Naturally, the setup is the same for directive antennas, antennas are just switched from omnidirectional to directive. Tx and Rx antennas are five meters apart from each other. Tx and Rx antennas are located two meters above the floor. The antenna of an interference source is located one meter lower than the Tx and Rx antennas, but on the same direct line. Therefore, the distance between the antenna of the interferer and both desired antennas is 2.46 m. The Tx and the Rx both have capability for multiple inputs multiple outputs (MIMO) communication, i.e. they are equipped with two antennas. Both antenna types are commercial-of-the-shelf. Omnidirectional antenna's radiation pattern is shown in the Fig. 2. It produces 6 dBi gain. Directive antenna is shaped as a shark fin as typically seen in modern vehicles. Those antennas are highly directive as shown in the Fig. 3, which shows the antenna radiation pattern. Fig. 4 shows the radiation pattern in the elevation plane. The antenna produces 14.2 dBi gain.

Iperf network testing application [6] is used to generate the transmitted data and it calculates throughput, jitter and packet loss ratio. Iperf client and Iperf server are running in the transmitter and in the receiver, respectively. Maximum transmission unit (MTU) is 1500 bytes at the network layer. In order to avoid fragmentation, UDP packet size is set to 1470 bytes at the Iperf client. By setting packet size smaller than the MTU, a lost datagram equals to lost packet. Laptops and the signal generator are placed behind radio frequency (RF) absorption material so they do not cause reflections.

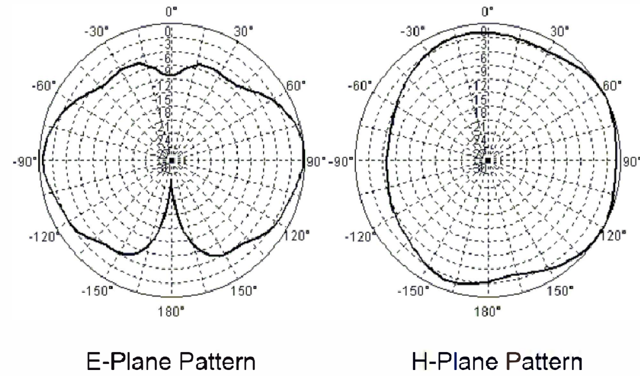

Fig. 2. Radiation pattern of omnidirective antennas at 2400 MHz.

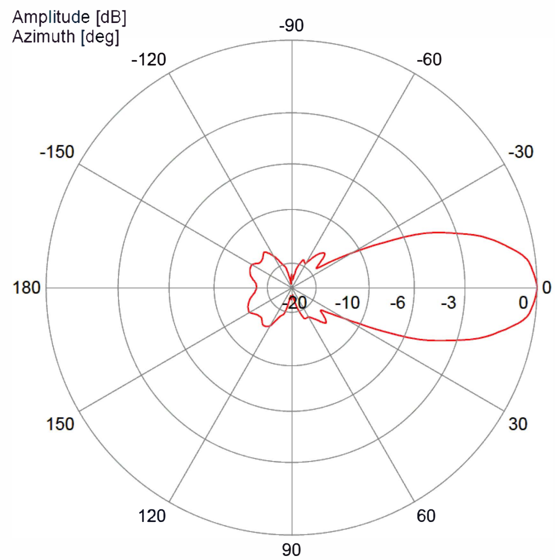

Fig. 3. Radiation pattern of directive antennas at 2450 MHz, with ground plane.

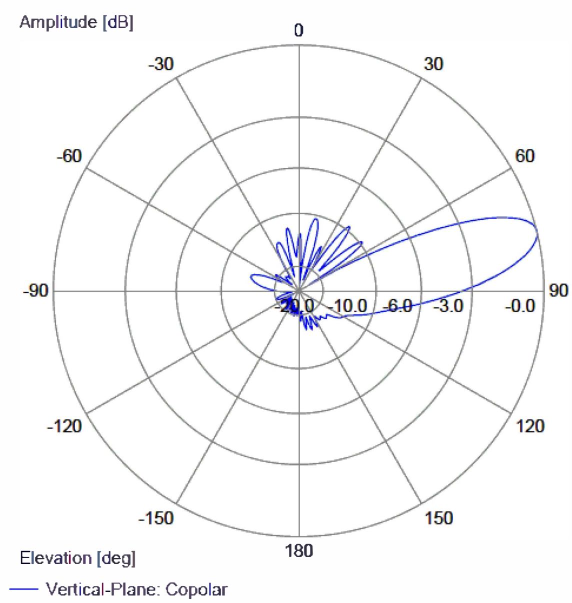

Fig. 4. Elevation pattern of directive antennas at 2450 MHz, with ground plane.

TABLE I
MEASUREMENT PARAMETERS

Parameter	Value
Radio protocol	802.11g+n
Center frequency (data)	2452 MHz †
Data rate	10 Mbps
UDP packet size	1470 B
Transmitted power, P_{tx}	10 dBm
Omnidirectional antenna gain	6 dBi
Directive antenna gain	14.2 dBi
Number of antennas	2 x 2 (MIMO)
Transmission time	120 s
Tx and Rx antenna height	2 m
Distance between Tx and Rx	5 m
Distance between interference source and Rx	2.46 m
Interference source antenna height	1 m
Interference center frequency	2452 MHz
Interference bandwidth	20 MHz

† Channel 9.

III. MEASUREMENT PARAMETERS

WLAN modules are configured to use 802.11g+n frequency channel 9. The center frequency of that channel is 2452 MHz. The interference source is set to the same center frequency, having a bandwidth of 20 MHz.

The WLAN Tx transmission power is 10 dBm. The actual output power is then amplified with the antenna gain. Therefore, the transmitted power with omnidirectional antennas is 16 dBm and 24.2 dBm with directive antennas. 24.2 dBm is more than the allowed maximum power in the 2.4 GHz band regulated by the European Union [8]. In the USA, Federal Communication Commissions (FCC) regulates the maximum equivalent isotropic radiated powers (EIRP) in the license free bands. The maximum allowed power is 21 dBm when the maximum antenna gain is less than 15 dBi [9]. Therefore, the maximum EIRP can be 36 dBm. Transmit power is intentionally set high, because the WLAN module automatically tries to fight against interference by changing the modulation method, as mentioned earlier. 64-QAM is more vulnerable to interference and jamming than, e.g., 16-QAM or binary phase shift keying (BPSK), because with less constellation points, error vector magnitude (EVM) can be larger. Therefore, the results presented in this paper do not describe in an unambiguous way what is the interference/jamming power level needed to corrupt a WLAN link since the modulation method is automatically controlled and it cannot be monitored during measurements.

Before the actual measurements, the power level of the interference source where communication link is not able to make connection is empirically searched and by decreasing interference/jamming power (P_{JAM}) with 1 dBm, communication link barely works. P_{JAM} is decreased step by step until interference does not have significant impact to the link anymore. All the relevant parameters are summarized in the Table I.

TABLE II
RESULTS

Antenna	Interference/jamming power (P_{JAM}) [dBm]	Avg. throughput [Mbps]	Avg. jitter [ms]	Avg. packet loss [%]
Omnidirectional	5	✘	✘	100
	4	0.48	66.58	95.06
	2	0.82	38.12	92.46
	0	7.27	2.94	27.33
	-2	9.95	1.31	0.46
	-4	9.99	0.89	0
Directive	-2	✘	✘	100
	-3	0.11	126.8	98.93
	-4	1.3	152.1	87.03
	-5	2.84	8.91	71.45
	-6	2.26	12.76	77.21
	-7	2.05	10.56	79.39
	-8	9.75	1.82	2.43
	-9	9.99	0.41	0.03

IV. RESULTS

Table II presents the results obtained from the Iperf network testing tool for both antenna types. The impact of interference can be seen by analyzing throughput, jitter and packet loss ratio. Free space path loss is used to calculate received power which is used to define signal-to-jamming-ratio (SJR).

A. Connectivity and throughput

Both measurement cases were started with 10 dBm interference/jamming power. The WLAN modules were not able to make connection to each other. Then the P_{JAM} was decreased by 1 dBm until the connection was established. With omnidirectional antennas, at P_{JAM} level of 4 dBm, connection started to work. As can be seen from Table II, the throughput is only 0.48 Mbps, whereas, with directive antennas, P_{JAM} was decreased to -3 dBm in order to establish a connection and 0.11 Mbps throughput was measured.

By decreasing interference power again by 1 dBm, throughput improved moderately in both cases. When the P_{JAM} was decreased by 6 dBm, impact of interference was minor.

The limit between good and poor performance is very small, within 2 dBm range. The WLAN connection with omnidirectional antennas achieved only 0.82 Mbps throughput when the P_{JAM} = 2 dBm, but 7.27 Mbps with P_{JAM} = 0 dBm.

B. Jitter

Jitter is the variation in the delay of received packets. Jitter is important parameter especially in applications that require synchronized timers, such as transporting and rendering audio or video streams [1].

Larger jitter values are experienced with directive antennas, over 100 ms with P_{JAM} -3 dBm and -4 dBm. Jitter values are improved significantly when P_{JAM} is decreased only by couple of dBm.

C. Packet loss ratio

The packet loss ratio has a correlation with the throughput. But the packet loss ratio describes clearly how many percent of the packets were lost without need to know transmitted data rate. As can be seen from average percent of packet loss, interference has a major impact to the WLAN performance. When P_{JAM} = -4 dBm with directive antennas, which is much smaller than the transmitted power (24.2 dBm), is enough to cause loosing 87.03 % of the packets.

D. Signal-to-jamming-ratio

The path loss can be estimated with Friis transmission equation [10]

$$P_{\mathrm{rx}} = P_{\mathrm{tx}} G_{\mathrm{tx}} G_{\mathrm{rx}} \left(\frac{\lambda}{4\pi d}\right)^2, \qquad (1)$$

where P_{rx} and P_{tx} are received and transmitted power, respectively. G_{rx} and G_{tx} are antenna gains, λ is wavelength and d is the distance between Tx and Rx. The P_{tx} is fixed to 10 dBm. By calculating how much power is received from Tx and interference source, the SJR can be deducted.

Fig. 5 shows a comparison between omnidirectional and directive antenna. It also includes a reference measurement performed with coaxial cables. Fig. 5 shows packet error ratio (PER) as a function of SJR. It is clearly seen that the WLAN performance with omnidirectional antennas is much better than with directive antennas. Results of the coaxial cable measurements show the worst performance because the interference/jamming signal is added to the desired data signal with a combiner.

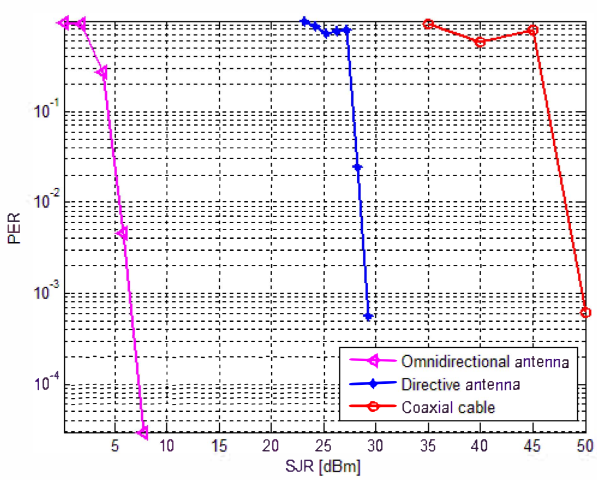

Fig. 5. Packet error ratio as a function of signal-to-jamming-ratio.

E. Comparison of measurement streams

In this section is shown a comparison between entire measurement streams of WLAN performance with omnidirectional and directive antennas with different interference powers. In the figures, one data point is averaged from 1 s time period. First is shown a comparison of P_{JAM} where connection was established for both antenna types. For omnidirectional antenna, Fig. 6 shows the throughput and the jitter when P_{JAM}=4 dBm. The standard deviation (σ) of the throughput is 0.74 Mbps. For directive antenna, at -3 dBm interference power the Tx and the Rx were able to communicate. However, the connection was lost during measurement run at 86 s. The data stream is shown in Fig. 7.

In Fig. 8 is shown a data stream of omnidirectional antenna performance with P_{JAM} = -4 dBm. The link is operating almost at full data rate and throughput's σ is 0.05 Mbps. With directive antennas at P_{JAM} = -7 dBm, throughput σ is 0.81 Mbps, as can be seen from Fig. 9.

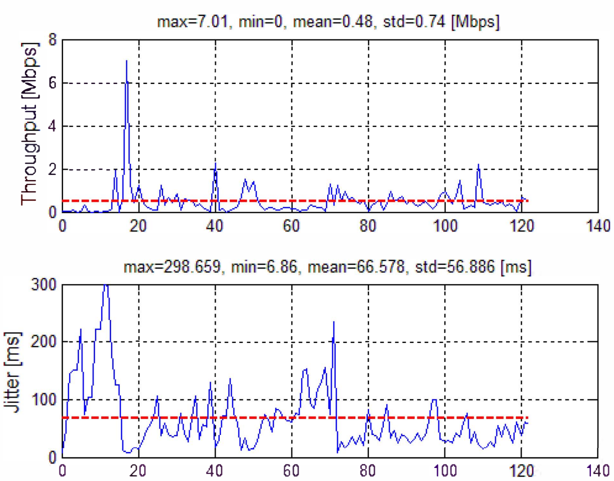

Fig. 6. Iperf output data stream, omnidirectional antenna, P_{JAM} = 4 dBm.

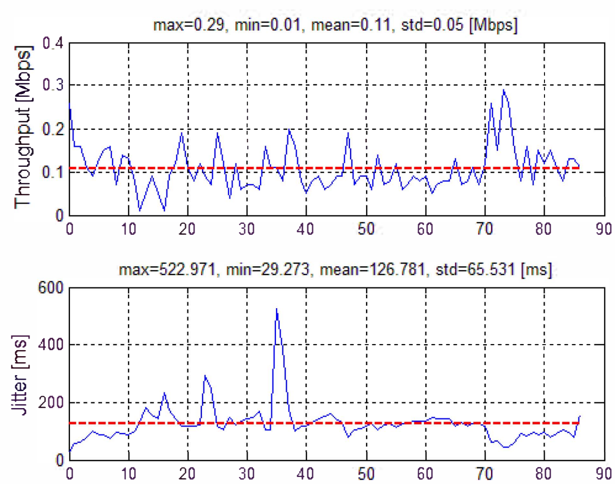

Fig. 7. Iperf output data stream, directive antenna, P_{JAM} = -3 dBm.

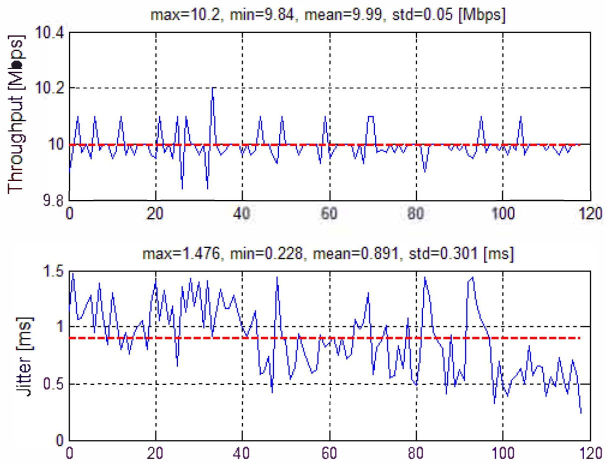

Fig. 8. Iperf output data stream, omnidirectional antenna, P_{JAM} = -4 dBm.

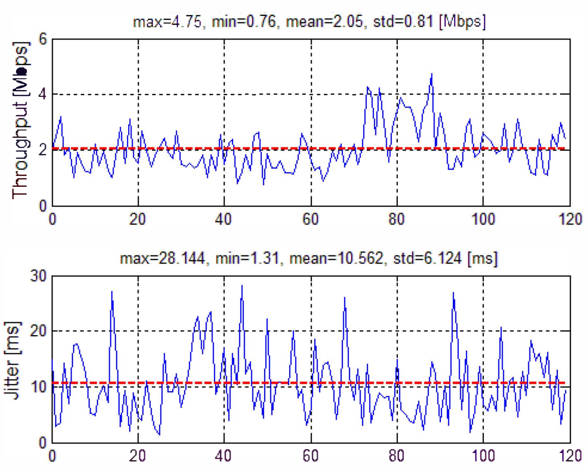

Fig. 9. Iperf output data stream, directive antenna, P_{JAM} = -7 dBm.

V. Conclusion

WLAN is very common nowadays and therefore it is important to know how well it operates under interference/jamming with different antennas. Use of directional antennas is a potential method to fight against interference and jamming. This is because the sidelobes of the directional antennas are minor and therefore the interference coming from either sidelobe or back does not have that major impact to the Tx/Rx. This paper presented the results from experimental measurement campaign to compare omnidirectional and directive antenna performance under interference that is coming between the antennas. Iperf network testing tool was used to measure throughput, jitter and packet loss ratio. In all interference measurement cases, a signal generator was used to create the interference signal, which was a CW. Although the signal generator is an expensive tool, it is expected that similar results are achieved with a cheap (30 – 50 €) commercial jammer. Using a commercial jammer in the measurements was considered, but they are assumed to be illegal and therefore the signal generator was used instead.

The results showed that the WLAN link with omnidirectional antennas is significantly more tolerant against interference compared to the WLAN link with directive antennas. The WLAN link with omnidirectional antennas was established when P_{JAM} = 4 dBm whereas with directive antennas P_{JAM} had to be decreased to -3 dBm in order to establish a connection. Therefore, omnidirectional antennas should be used instead of directive antennas if potential jammer or interference source can be located between the Tx and the Rx.

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