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Detect and Avoid Mechanism for Ultra Wide-Band WiMedia: Experimental Evaluation of Detection Capabilities

Invited paper

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Abstract - **The Detect and Avoid (DAA) mechanism is a widely used technique in cognitive radios to support the coexistence of primary and secondary users operating in the same spectrum portion. In this paper we describe our experience in detecting WiMAX signal (operating as a primary user) in the 3.5 GHz range using the Ultra Wide-Band (UWB) test dongles from Wisair (operating as a possible secondary user of the spectrum). For this purpose a generic radiated test bed was prepared and two scenarios were considered in order to experimentally study the detection capability of DAA block within the WISAIR UWB devices. The detection results are presented in terms of the received signal strength and the sensitivity of the device.**

Keywords-ultra wide-band (UWB); detect and avoid (DAA); wireless communications; coexistence

I. INTRODUCTION

Ultra Wide-Band (UWB) technology opens up wide vista for broadband data transmission applications: home entertainment, automotive, public transport, and mobile communications. This high data rate, low power and short range technology enables devices to operate in frequency range from 3158 MHz to 10560 MHz [3]. Besides, various regulators in different countries define the UWB signal minimum bandwidth of 50 MHz [1], 500 MHz [2], 528 MHz [3].

Due to its large frequency span, UWB devices (also referred to as secondary users) can interfere with other wireless communication technologies, e.g. UMTS, GPS, WiMAX (primary users) [6], [8]. In order to avoid harmful interference with primary users (PU) the Detect and Avoid (DAA) mechanism can be applied [9], [10]. It provides spectrum sharing capabilities for primary and secondary users (SU) by allowing a SU to occupy the spectral band while a PU does not use it. However, in the case of detecting the transmitting PU, the SU must either stop its transmission or decrease its transmission power. In the present paper we focus our attention on WiMAX signal detection since it is expected to support future wireless local area networks.

For successful coexistence of primary and secondary networks, it is important that the availability of the PU signal is quickly detected by a SU [6]. To overcome the detection problem, various research groups and commercial companies have addressed this issue from experimental point of view. For instance, in [11] the DAA test bed for radiated measurements was implemented. In fact, this work outlines various issues on UWB radio frequency measurements and presents the implemented test bed in anechoic chamber without providing the results on WiMAX signal detection. The experimental analysis in [12] discusses the impact of 3.5 GHz WiMAX interference on UWB-WiMedia defined link. The experimental results of the victim signal (WiMAX and 3GPP LTE) detection by DAA UWB are presented in [13]. A vector generator generated the victim signal of various baseband. The victim signals were measured in terms of signal-to-noise ratios and detection time.

In this paper we experimentally evaluate the detection capabilities of DAA UWB device [14] provided by Wisair for two scenarios. For this evaluation we implement a generic test bed for radiated measurements of WiMAX signal which is generated by real WiMAX base station. The main idea of the present work is to explore the detection capability of DAA UWB device in real office conditions. In the beginning we model Tx-Rx channel and assess the value of path loss and derive path loss exponent for each of the scenarios. Afterwards we start WiMAX signal detection experiments. In each scenario we evaluate how detected signals depend on Tx power, Rx sensing sensitivity and Tx-Rx distance.

The rest of the paper is organized as follows: Section II presents the implemented test bed setup for radiated measurements. Two scenarios and channel modeling are described in Section III. DAA UWB device performance evaluation results for *in building line-of-sight* and *obstructed in building* scenarios are presented in Section IV. Finally, we conclude in Section V.

II. EXPERIMENTAL SETUP

In this section we describe the radiated test bed setup (see Figure 1) for the evaluation of detection capability of DAA UWB device. Since UWB technology is extensively used in domestic applications, e.g. personal connectivity, video streaming, the performance evaluation is implemented for two scenarios: *in building line-of-sight* and *obstructed in building*.

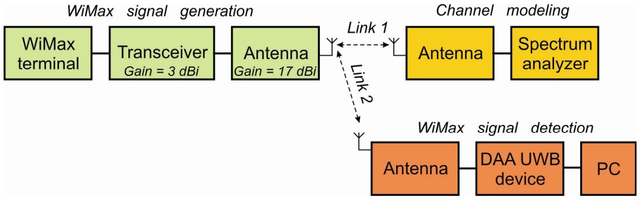

Figure 1. Experimental DAA UWB test bed setup

Besides, using this setup we perform Tx-Rx channel modeling and experimentally derive the values of path loss exponent for each scenario. Due to impedance compatibility and sufficient signal levels the antennas shown in Figure 1 can be connected to theirs respective devices directly.

The test bed presented in Figure 1 consists of three parts:

- *WiMAX signal generation* part comprises WiMAX base station AN-100U by Redline Communications which includes WiMAX terminal, transceiver with 3 dBi gain (G_t) (empirically determined), and antenna with 17 dBi gain (G_a). The parameters of WiMAX signal (see Table I) are set through the web interface of WiMAX terminal. The generated victim signal is transmitted to spectrum analyzer through *Link 1* in order to model the channel. Having modeled the channel we transmit victim signal to DAA UWB device which performs the environment scanning using four modes. Note, that total transmit power (P_{Tx}) in dBm is $P_{Tx} = P_t + G_t + G_a$ where P_t is nominal transmit power set at the terminal;

TABLE I. PARAMETERS OF THE WIMAX SIGNAL

Parameter	Value
Transmission mode	Time division duplexing, downlink only
Bandwidth, B	7MHz
Center frequency, f_c	3.4 GHz, 3.5 GHz, 3.6 GHz OFDM (256 FFT)
Signal power, P_t	[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12] dBm[a]
Frame duration	5 ms

a. It is the set of nominal power values of WiMAX terminal we used. Mind antenna and transceiver gain.

- *Channel modeling* part performs Rx power (P_r) measurement using vector network analyzer MS2036A by Anritsu. The network analyzer is configured in accordance with the standard described in [5]. Note, that for each scenario it is essential to model the channel from scratch;
- Having modeled Rx-Tx channel we start *Victim (WiMAX) signal detection* experiment. The victim signal is transmitted from WiMAX base station to DAA UWB device through *Link 2*. The DAA UWB device operates in a frequency band 3.1 – 3.6 GHz and supports a few scanning modes of environment with different scanning times. In this work we apply four modes of scanning: full, partial 25%, partial 12.5%, and partial 6.25%. Full DAA is done for 1 s period of scanning and partial modes are done for 2 s period of scanning. The sensitivity of Rx antenna of DAA UWB device is from –61 dBm to –31 dBm. The scale division of Rx sensitivity is 1 dB.

III. SCENARIOS AND CHANNEL MODELLING

In this section we briefly describe two scenarios implemented in this work and then present the results on channel modeling for both scenarios.

A. *Experimental Scenarios*

The experiments described in this paper were carried out at CREATE-NET, Italy. In this work we consider two scenarios: *in building line-of-sight* and *obstructed in building*. Both scenarios were implemented indoors and with normal everyday working conditions, e.g. passing people, turned on electronic devices.

In building line-of-sight scenario (also referred to as LOS link) was implemented at an office without obstructions between Rx and Tx parts. The Tx-Rx distance is 3.5 m.

For *obstructed in building* scenario (also referred to as NLOS link) we keep Tx part at an office and move Rx part to corridor. Rx and Tx parts are located in the shape of Cyrillic letter “Г” with the total perimeter distance of 8 m. We provide this description in order to give a reader an idea regarding the location of Rx and Tx parts during this scenario. However, before starting the experiments we model the channel for each scenario in order to estimate how physical processes modify the transmitted WiMAX signal.

B. *Path Loss Modelling*

We start path loss modeling with the Rx power (P_r) measurement using vector network analyzer as it is presented in Figure 1. Besides, we adopt path loss model for its implementation. The average large-scale path loss (PL) for an arbitrary Tx-Rx separation is given by the following:

$$\mathrm{PL(dB)} = \mathrm{PL}(d_0) + 10\cdot n\cdot\log(d/d_0) \qquad (1)$$

where d_0 is the close-in reference distance which is determined from measurements close to transmitter, n is the path loss exponent, and d is the Tx-Rx separation distance.

$$\mathrm{PL}(d_0) = 10\cdot\log(4\pi d_0 f_c / c) \qquad (2)$$

where c is the speed of light.

TABLE II. AVERAGE PATH LOSS EXPONENTS FOR IN BUILDING LINE-OF-SITE AND OBSTRUCTED IN BUILDING SCENARIOS

Central frequency, GHz	Average path loss exponent	
	in building line-of-site	obstructed in building
3.4	3.68	4.06
3.5	3.80	4.14
3.6	3.94	4.26

Experimental path loss evaluation is carried out for three various central frequencies (3.4 GHz, 3.5 GHz, 3.6 GHz). The evaluation results are shown in Figure 2 and Figure 3 for *in building line-of-sight* and *obstructed in building* scenarios respectively. Average path loss exponents, n, for two scenarios and three central frequencies shown in Table II are derived from (1):

$$n = (\mathrm{PL} - \mathrm{PL}(d_0)) / 10\cdot\log(d / d_0). \qquad (3)$$

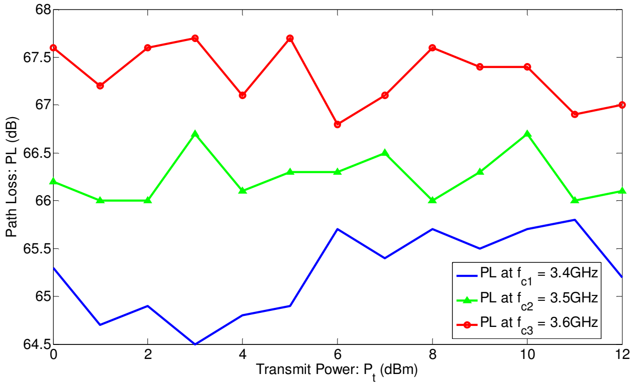

Figure 2. Experimental path loss evaluation for in building line-of-site scenario

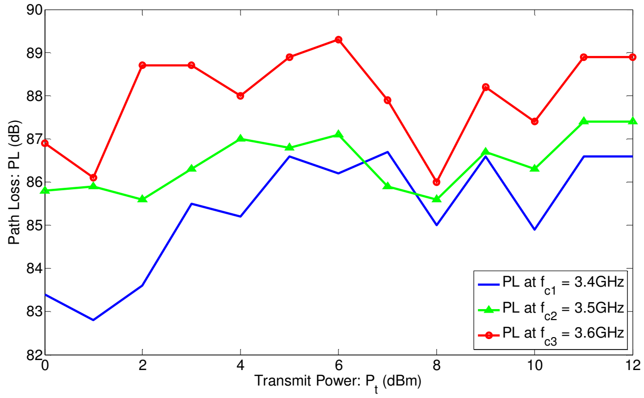

Figure 3. Experimental path loss evaluation for obstructed in building scenario

We should note that asymmetrical shape of the curves depicted in Figure 2 and Figure 3 as well as path loss exponents values are caused by environmental conditions in the office during the experiment.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A number of measurement runs were carried out to evaluate the performance of DAA UWB device under different conditions [1], e.g. WiMAX signal power, Rx sensitivity, Tx-Rx distance. WiMAX signal was generated in accordance with parameters shown in Table I.

The software used for WiMAX signal detection with several DAA modes indicates how many times the victim signal was detected and how much time was spent for these detections. For our convenience we introduce the *average WiMAX signal detection per second* in order to study the performance of the DAA module in the UWB device. This metric is simply defined by dividing the number of detections by time spent for the detections. We note here again that the detection performance in all experiments depends on scanning time which is 2 s for partial modes and 1 s for full mode.

A. *WiMAX Signal Power*

During the first experiment we explored how average WiMAX signal detection by DAA UWB device depends on transmitted power. The central frequency, Rx sensitivity and distance were fixed at 3.5 GHz, –61 dBm (maximum value), 3.5 m respectively. For each detection mode we changed nominal transmitted power at WiMAX terminal from 0 dBm to 12 dBm. Note, that there is also the total gain of 20 dBi in the Tx part.

Figure 4 and Figure 5 present the diagrams of average signal detection versus Tx power for *in building line-of-sight* and *obstructed in building* scenarios respectively. Both diagrams show that full mode of DAA UWB device detects less signals per second.

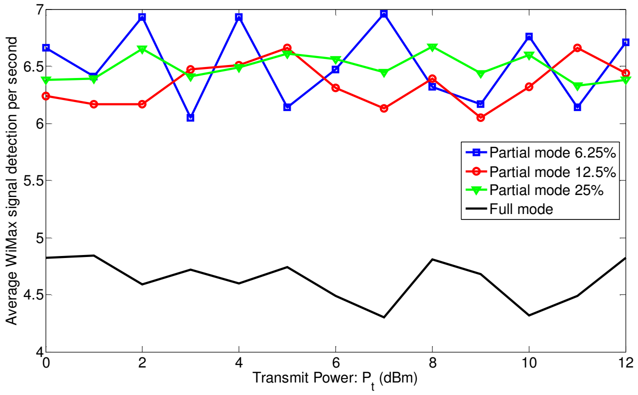

Figure 4. Average WiMAX signal detection per second using four scanning modes for in building line-of-sight scenario(f_c = 3.5 GHz, d = 3.5 m, sensitivity = –61 dBm).

Figure 4 shows that average number of the signal detections for each mode does not fluctuate much. Therefore, it does not depend on transmit power with current settings.

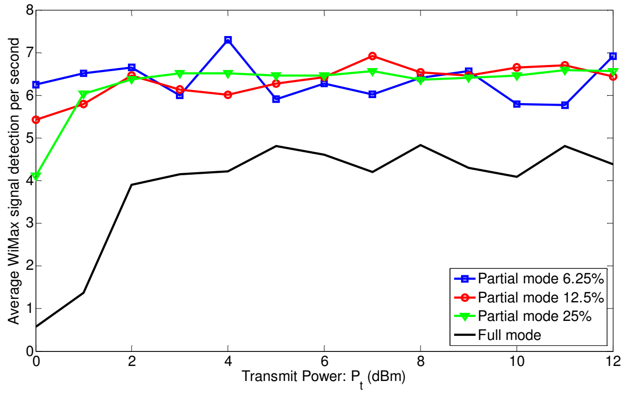

Figure 5. Average WiMAX signal detection per second using four scanning modes for obstructed in building scenario (f_c = 3.5 GHz, d = 3.5 m, sensitivity = –61 dBm).

However, in the case of *obstructed in building* scenario (Figure 5) full mode detection capability is drastically decreased for 0 dBm and 1 dBm values of nominal Tx power. The detection capabilities of other detection modes do not change significantly.

B. Rx Sensitivity

Figure 6 shows how average WiMAX signal detection per one second depends on Rx sensitivity in *in building line-of-sight* scenario. The Tx-Rx distance is 3.5 m, central frequency is 3.5 GHz. We set low threshold of Rx sensitivity equal to –41 dBm because DAA UWB device can not detect victim signals below this level. It is shown that average number of detections for all *partial modes* do not vary drastically and is around six detections per second. However, this number varies from approximately one to approximately five detections for *full mode*.

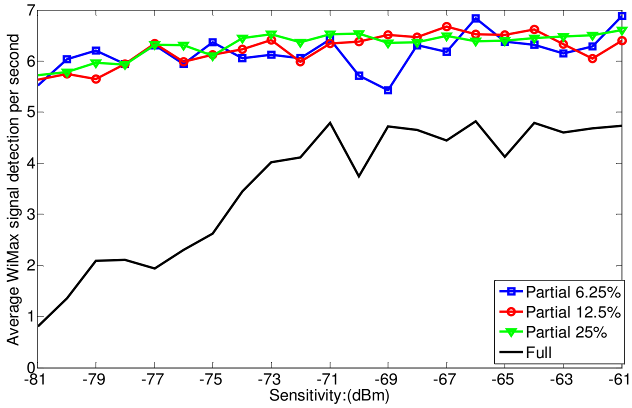

Figure 6. Average number of WiMAX signal detections per second vs. sensitivity for line-of-sight scenario (d = 3.5 m, f_c = 3.5 GHz)

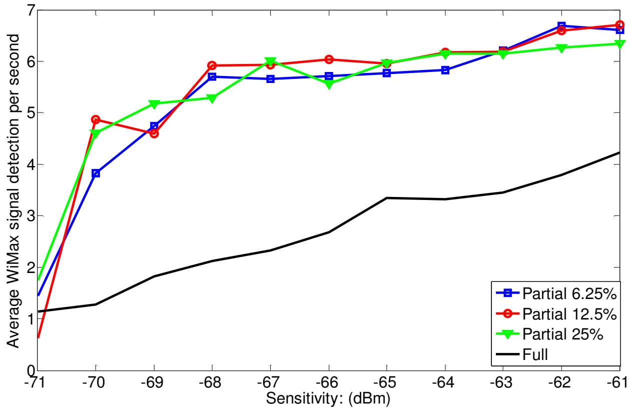

Figure 7. Average number of WiMAX signal detections per second vs. sensitivity for obstructed in building scenario (d = 3.5 m, f_c = 3.5 GHz)

We keep the same setup adjustments for *obstructed in building* scenario. In fact, we have changed only the low Rx sensitivity threshold because WiMAX signals below –51 dBm sensitivity could not be detected. Figure 7 presents experimental results for this case. In contrast to *in building line-of-sight* scenario where the average detection curves for *partial modes* depended almost linearly on sensitivity the average number of detections for *partial modes* varies from approximately one to approximately seven detections per second. The curve for *full mode* did not change significantly.

C. Rx-Tx Distance

Finally, we investigated how the average number of victim detections depends on the Tx-Rx distance. For this purpose we kept all the adjustments as in *in building line-of-sight* scenario. We fixed the Rx sensitivity equal to –61 dBm but changed the Tx-Rx distance meter by meter starting from 1 m and finishing at 8 m.

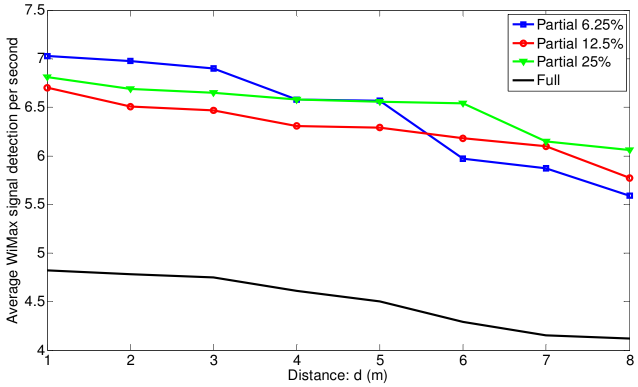

Figure 8. Average signal detection per second vs. distance for in building line-of-sight scenario

The results of this experiment are shown in Figure 8. The curves for all detection modes have the similar shape but obviously differ in number of detections.

V. CONCLUSION

In this paper we presented some experimental results on the detection performance of a detect-and-avoid mechanism implemented on an UWB device designed by Wisair. The wireless channel for the considered indoor LOS and NLOS channels were initially modeled resulting in the experimentally derived path loss exponents for both scenarios for three center frequencies 3.4 GHz, 3.5 GHz, 3.6 GHz over a given bandwidth. The detect-and-avoid analysis was then performed by detecting the WiMAX signals in order to evaluate how average signal detection depends on the Tx power, Rx sensitivity and Tx-Rx distance. The detection results were presented for full and partial scanning for the detect and avoid technique.

ETSI TS 102 754 [5] defines the avoidance options which fall in four major categories: power reduction, spatial avoidance, frequency avoidance, time sharing. Though we have focused our attention at the detection capability of DAA, the results of this paper may be used for analyzing what avoidance option is applicable in each particular case.

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