

SDR-based frequency interference analysis test-bed considering time domain characteristics of interferer

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Abstract — In this paper, we suggested a software-defined radio (SDR)-based frequency interference analysis test-bed designed to consider both frequency and time domain characteristics of the interferer. Due to the versatile programming capability of universal software radio peripheral (USRP) and LabVIEW, performance degradation effects of victim receiver due to various interferer's parameters in both frequency and time domain can be analyzed intuitively. As an example, we demonstrated a frequency interference scenario consisting of Zigbee as a victim and three Wi-Fi nodes as interferers. From the measured results, it was verified that our test-bed can analyze easily actual interference environments in both frequency and time domain.

Keywords — frequency interference, frequency sharing, unlicensed band, LabVIEW, USRP, SDR.

I. INTRODUCTION

There is a growing need to utilize the frequency spectrum in various industrial fields and services, such as wireless broadband, supply chain management, education, health care, public safety, energy and environment, etc [1]. Moreover, the use of unlicensed devices will increasingly lead to congestion in the unlicensed frequency bands [2]. As a price for open access, the unlicensed wireless network may experience adverse interference from collocated wireless devices that are transmitting in the same unlicensed frequency band [3]. Therefore, when operating unlicensed devices in unlicensed frequency bands, it is of great importance to understand and analyze the frequency interference issues.

There are two main methods for assessing frequency interference. One is based on software, like the spectrum engineering advanced Monte Carlo analysis tool (SEAMCAT) which is widely used in frequency interference analysis, and the other is based on experiments using real hardware for the interferer and victim. The former usually shows results which are obtained from interference power, such as signal-to-interference-plus-noise ratio (SINR), and interference probabilities, etc. In other words, software simulation only calculates interference power by distribution of interferers. Hence, it is hard to get performance degradation effects

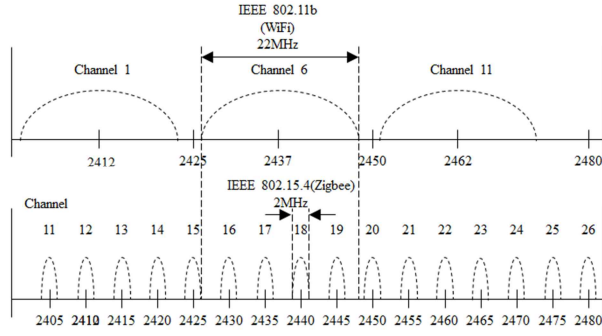
such as Bit Error Rate (BER) and Packet Error Rate (FER), in actual interference environments.

The latter approach is based on a hardware tool like [4]. To analyze the effect of frequency interference in the actual interference environment, we should use the real hardware. However, in the case of real hardware, it is difficult to change physical (PHY) and Media Access Control (MAC) layer parameters because they are commonly embedded in the modem chip. As an example, BER degradation at the PHY layer cannot be measured directly. Therefore, it is necessary to implement a frequency interference analysis test-bed which can reflect actual interference environment as well as adjust various frequency and time-domain interference parameters of interferers and a victim.

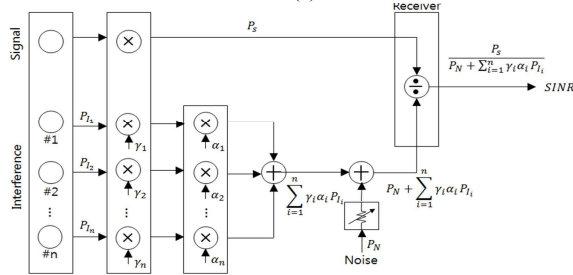
In this paper, we suggested a software-defined radio (SDR)-based frequency interference analysis test-bed which can model actual interference environments in both frequency and time domain. In our test-bed, frequency domain parameters are implemented by a universal software radio peripheral (USRP) and LabVIEW program. And time domain MAC parameters are implemented using the LabVIEW program. Due to the versatile programming capability of USRP and LabVIEW, we can easily set up the interference scenario representing a given interference environment. For example, we can adjust various frequency domain interference parameters (center frequency, spectrum mask, interference power, etc) and time domain interference parameters (packet size, duty cycle, collision time, back off time, etc). Accordingly, we can analyze victim's BER and FER degradation in realistic interference scenarios.

II. INTERFERENCE ANALYSIS MODEL

For verification of our test-bed, we assumed an interference scenario consisting of Zigbee as a victim and Wi-Fi as interferers as an example, because the 2.4 GHz unlicensed frequency band has worldwide usage, and previous studies have shown that Wi-Fi is the most significant interference source for Zigbee [5].



(a)



(b)

Fig.1. Frequency domain interference model: (a) Channel allocation of Zigbee and Wi-Fi; (b) Derived SINR concept considering only frequency and space domains.

In the frequency domain, as shown in Fig.1(a), Zigbee channels can overlap with Wi-Fi channels. Therefore we can consider the Wi-Fi signal to be partial band jamming noise for the Zigbee signal. With reference to Fig.1(b), extending to the situation of having N Wi-Fi interferers, SINR can be defined as

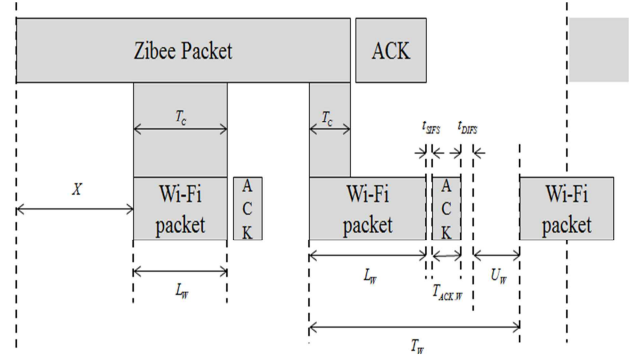
$$\text{SINR} = \frac{P_s}{P_N + \sum_{i=1}^N r_i \alpha_i P_{I_i}} \quad (1)$$

where P_s is the power of the desired signal at Zigbee receiver, P_N is the noise power, and P_{I_i} is received power from the i^{th} Wi-Fi node signal at the Zigbee receiver.

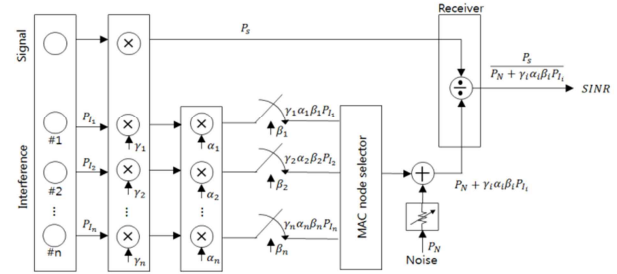
TABLE I

PARAMETERS IN TIME DOMAIN INTERFERENCE MODEL [7],[8]

Parameter	Definition	Value
T_w	Inter-arrival time between two WiFi data packets	Varying
L_w	Duration of WiFi data packet	1303μs
$t_{SIFS,w}$	Short interframe space of WiFi	10μs
$t_{DFS,w}$	Distributed coordination function interframe	50μs
$T_{ack,w}$	Duration of WiFi ACK packet	304μs
U_w	backoff time of WiFi	0~620μs
X	Time offset	Varying
T_c	Collision Time	Varying



(a)



(b)

Fig.2. Time domain interference model [6], [7]: (a) Packet of Zigbee and Wi-Fi; (b) Derived SINR concept considering frequency, space, and time domains.

Also, r_i is the spectrum overlapping factor of i^{th} Wi-Fi node and α_i is the path loss factor.

Next, we consider the time domain. The IEEE standards for both Zigbee (IEEE 802.15.4) and Wi-Fi (IEEE 802.11b) specify three methods of clear channel assessment (CCA) to determine the channel occupancy. The CCA default mode of Wi-Fi is a ‘carrier sensing mode’ in which a Wi-Fi node considers the channel free if no other Wi-Fi device is detected. And if we assume that both Wi-Fi and Zigbee devices operate in ‘carrier sensing mode’, they are essentially blind to each other’s transmissions. This assumption provides the worst case performance for Wi-Fi and Zigbee coexistence environments [6].

The time domain interference model is shown in Fig.2. Based on the assumption of blind transmission, the contention window is not modified even when Zigbee and Wi-Fi coexist. Let U_w represent the backoff time of Wi-Fi. U_w can be changed according to the number of node. From Fig.2(a), inter-arrival time between two Wi-Fi data packets is

$$T_w = L_w + t_{SIFS,w} + T_{ACK,W} + t_{DFS,w} + U_w \quad (1)$$

Let x be the time offset between Wi-Fi packets and Zigbee packets. Similar to [7], we can assume time offset x , and then collision time T_c can be changed by x and U_w . That

is, performance degradation according to frequency interference can be changed by x and U_w . Table I shows the parameters used in IEEE 802.15.4 and IEEE 802.11b standard.

Now, Eq. (1) can be modified to the situation of having multiple Wi-Fi interferer nodes. At this time, SINR which consider frequency and time characteristics can be defined as

$$\text{SINR} = \frac{P_s}{P_N + r_i \alpha_i \beta_i P_{I_i}}, \quad (2)$$

where β_i indicates transmission status of a i^{th} Wi-Fi node depending on collisions at the time domain. For example, if multiple Wi-Fi nodes have a value '1' at the same time, it undergoes a collision and has a random backoff time. If a Wi-Fi node has '1' alone, the Wi-Fi node transmits immediately without collision. That is, β_i can be changed by the type of network, data transmission and reception requirements of nodes, and MAC layer characteristics. Fig. 2(b) shows the contents and parameters described above.

III. TEST-BED SETUP

To evaluate the performance of Zigbee under Wi-Fi interference in a real environment as an example, we designed SDR-based frequency interference analysis test-bed as shown in Fig.3. At first, we implemented the IEEE 802.15.4 baseband modem and the BER measurement block using LabVIEW in the Host PC 1. Secondly, we connected this modem to USRP, which operated as a victim. The interference source was set to the RF band Tx signal by using Host PC 2 and USRP. Thirdly, the channel was a conductive system composed of a 3x1 power combiner ZFSC-2250-S+ model of Mini-circuit, the noise generator E4437B model of Agilent, and RF coaxial cable. Of course, we could experiment over the air (OTA), however, the conductive system is recommended for

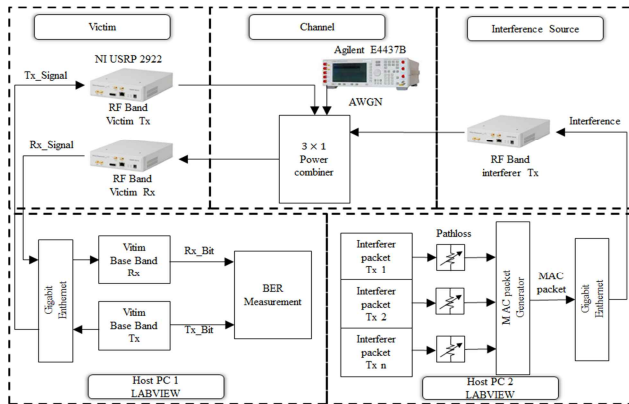


Fig.3. SDR-based frequency interference analysis test-bed setup.

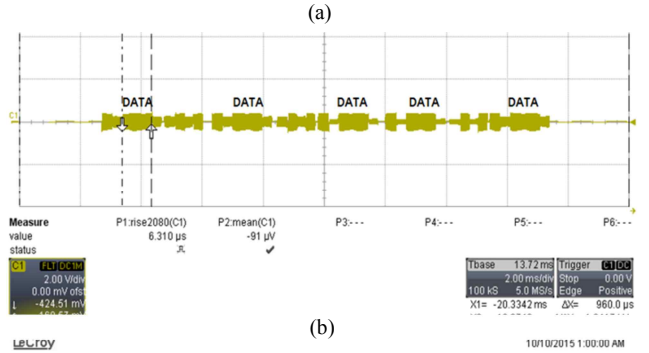
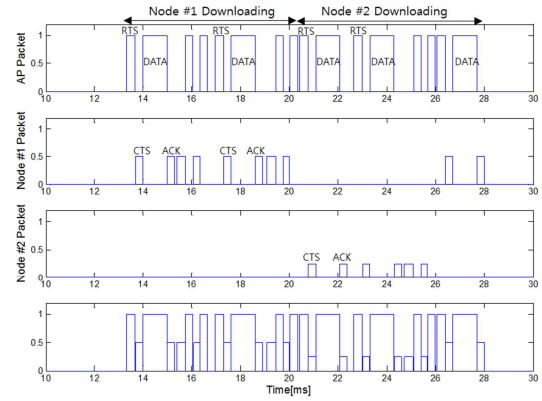


Fig.4. Time domain waveform of Wi-Fi interferers: (a) Simulated; (b) Measured

accurate verification of the suggested test-bed, because it is free from many unwanted emissions in a real environment. We connected the host PC to USRP with gigabit Ethernet cables for a fast interface and used a sync cable for synchronizing between two USRPs connected to the host PC 1. Backoff time can be changed in the MAC packet generator block. The Zigbee transmitter output power was set to 1 mW, and the Wi-Fi transmitter output power was set to 30 mW with reference to the standard. The output power of the noise generator and the interference power can be changed according to path loss. Using our test-bed, it is possible to analyze BER degradation due to interference in real time. In addition, it can be extended to different unlicensed frequency band devices or various interference environments simply by changing the software.

IV. EXPERIMENTAL RESULTS

For verification of the suggested test-bed, firstly, we generated interferer's data packets using the LabVIEW program. Fig.4(a) shows the simulated time domain waveform of Wi-Fi interferers using NS-2 event simulation which is composed by one Wi-Fi Access Point (AP) and two Wi-Fi nodes. As shown in Fig.2(b), we

apply the individual path loss according to distribution of nodes and transmission point per node was determined in specific interference environment. As shown in Fig.4, if the shortest separate distance between the victim (Zigbee) receiver and AP, AP has the smallest path-loss, so it has the highest amplitude. AP sends ready to send (RTS) before sending information data. And one of two nodes informs AP using clear to send (CTS) that it is possible to receive data and AP sends data. Then, the node sends acknowledge (ACK) when it received the data without problem. It is similar to the described above when another node downloaded data. By checking the measured USRP output waveform using oscilloscope as Fig. 4(b) and by comparison of Fig. 4(a), it is verified that our testbed can generate time domain packets of W-iFi interferers in real time. All parameter except for center frequency followed the Wi-Fi standard but center frequency was set to 400 MHz because of the limitations of the oscilloscope.

Next, we measured the BER performance of Zigbee under Wi-Fi interference and compared with the theory. The theoretical BER equation at PHY layer analysis given in [8] is

$$BER = \frac{8}{15} \times \frac{1}{16} \times \sum_{k=2}^{16} -1^K \binom{16}{k} e^{(20 \times SNR \times (\frac{1}{k}) - 1)}. \quad (3)$$

Fig.5 shows the BER curve of a victim Zigbee receiver as a function of noise and Wi-Fi interference power level variation. Without any interference, the BER performance is a function of Signal to Noise Ratio (SNR) only. In this experiment, the interference power is fixed to two times (3dB) larger than the signal power. Therefore, in the region lower than -3dB SNR, noise power becomes dominant. On the other hand, in the region larger than -3dB SNR, interference power becomes dominant.

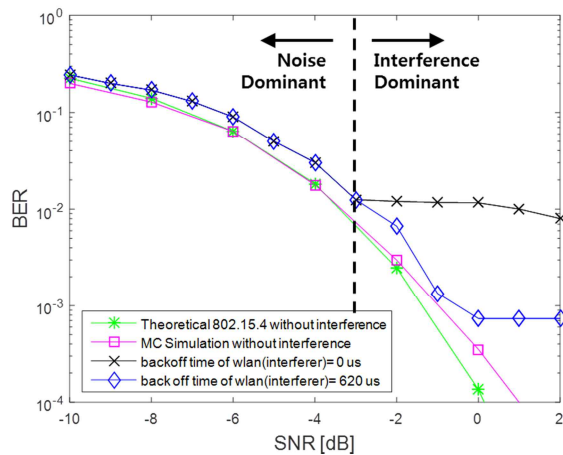


Fig.5. BER curve of Zigbee as a function of noise and Wi-Fi interference power level variation.

Therefore, if U_w is zero, interference power is always 3 dB larger than the signal power. Therefore BER curve shows almost flat characteristics in the region larger than -3dB SNR. But, if time domain characteristics are considered, BER curve varies as a function of collision time. Because the collision time T_c is varied with backoff time U_w , we tested BER performance as a function of U_w within the range of IEEE 802.11b specification. From the measurement results, the larger U_w value is, the less the probability of collision is, and then the better BER performance can be achieved. As a result, it was verified that our testbed can model various interference scenarios considering time domain characteristics.

V. CONCLUSION

In this paper, we suggested a SDR-based frequency interference analysis test-bed. Due to the versatile programming capability of USRP and LabVIEW, actual frequency interference environments can be easily modeled. For verification of our test-bed, we demonstrated a frequency interference model between Zigbee and Wi-Fi. We believe that our test-bed can be used for assessing interference problems between various devices.

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