Experimental Validation of a Coexistence Model of IEEE 802.15.4 and IEEE 802.11b/g Networks

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***Abstract*—As IEEE 802.15.4 Wireless Sensor Networks (WSNs) and IEEE 802.11b/g Wireless Local Area Networks (WLANs) are often collocated, coexistence issues arise as these networks share the same 2.4 GHz Industrial, Scientific, and Medical (ISM) band. As a consequence, their performance may degrade. We have proposed a coexistence model of IEEE 802.15.4 and IEEE 802.11b/g networks, which addresses coexistence behavior and explains their coexistence performance. As an extension of the previous work, a compact testbed was developed and experiments on the coexistence issues between these networks were conducted. The experiments not only validated the theoretical model, but also provided more information and insights about the coexistence issues in the real-life environment.**

I. Introduction

IEEE 802.15.4 Wireless Sensor Networks (WSNs) are becoming increasingly popular. Because of their applications, e.g., in hospitals and home [1], WSNs are often collocated with IEEE 802.11b/g Wireless Local Area Networks (WLANs), which gives rise to coexistence issues as they both operate in the license-free 2.4 GHz Industrial, Scientific, and Medical (ISM) band.

There have been some studies about the coexistence issues between the IEEE 802.11b/g WLANs and IEEE 802.15.4 WSNs [2] [3] [5] [6]. Particularly, in [6], we presented a coexistence model of IEEE 802.15.4 WSNs and IEEE 802.11b/g WLANs. The model addresses the interaction between these two types of wireless networks and explains their coexistence performance. It focuses on two aspects, namely power and timing. These two aspects jointly impose different impacts on the performance of IEEE 802.15.4 WSNs and IEEE 802.11b/g WLANs, depending on the coexistence situations. To validate the model and get a better understanding of the coexistence issues in real-life situations, we conducted a number of experiments. The details of the experiments will be presented in this paper. The remainder of the paper is organized as follows: Section II gives an overview of the IEEE 802.11b/g standard, IEEE 802.15.4 standard and the coexistence model. Section III describes our testbed. The experimental results are presented in Section IV. Our conclusion is drawn in Section V.

II. Overview of IEEE 802.11b/g, IEEE 802.15.4 and a Coexistence Model

A. IEEE 802.11b/g

The IEEE 802.11b and IEEE 802.11g standards define the Medium Access Control (MAC) sublayer and the Physical (PHY) layer for WLANs. Both standards operate at 13 overlapping channels in the 2.4 GHz ISM band and the bandwidth of each channel is 22 MHz. The IEEE 802.11b/g MAC employs the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism. Clear Channel Assessment (CCA) is used in the physical layer to determine the channel occupancy [7]. CCA should perform Energy Detection (ED), or Carrier Sense (CS), or a combination of two, i.e., CCA shall report a busy channel upon detection of any energy above the ED threshold, or a signal with the known features, e.g., the modulation and spreading characteristics, or a known signal with energy above the ED threshold. Owing to involving only integrating the square of the received signal or signal envelop over a CCA duration, ED is a universal mechanism that can be deployed in all systems without requiring any knowledge of the type of underlying modulation scheme employed at the physical layer [8]. Therefore, in the heterogenous network environment, only ED can, though unreliably [8], sense the channel occupancy of other types of networks.

Before initiating a transmission, an IEEE 802.11b/g node senses the channel using either ED or CS (or both) to check whether it is busy because of the transmissions by other nodes. If the channel is sensed idle for a Distributed coordination function Inter-Frame Space (DIFS) time interval the node will transmit a packet. Otherwise, the node defers its transmission. As the channel becomes idle for a DIFS interval, the node will generate a random backoff delay uniformly chosen in a Contention Window (CW), i.e., $[0, W]$, where W is the size of the CW. The backoff timer decreases by one as long as the channel is sensed idle for a backoff time slot. The backoff counter will be frozen when a transmission is detected on the channel, and resumed when the channel is sensed idle again for a DIFS interval. When the backoff timer counts down to zero, the node transmits a packet. Immediately after receiving a packet correctly, the destination node waits for a Short Inter Frame Spacing (SIFS) interval and then sends an ACK back to the source node. If the source node receives the ACK, the

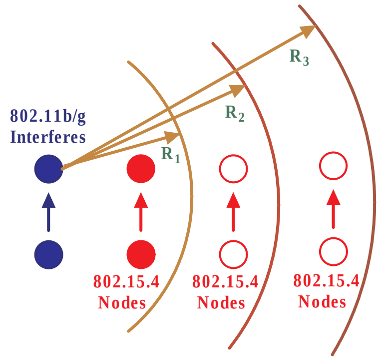

Fig. 1. Coexistence regions of IEEE 802.15.4 and IEEE 802.11b/g

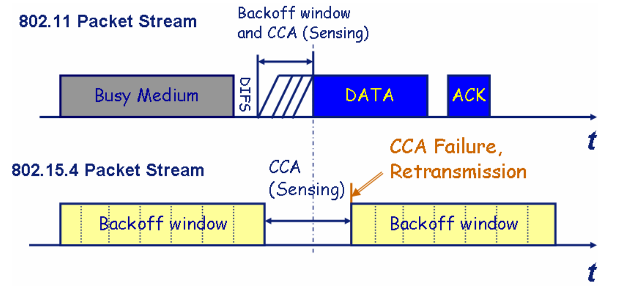

Fig. 2. In R1, the shorter timing gives IEEE 802.11b/g nodes priority over IEEE 802.15.4 nodes to access the channel and therefore causes unfairness to the IEEE 802.15.4 nodes

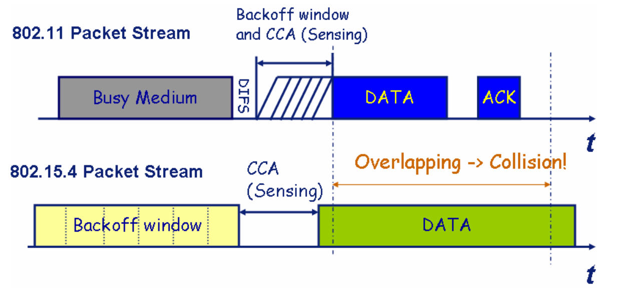

Fig. 3. In R2: IEEE 802.11b/g nodes fails to sense IEEE 802.15.4 nodes

size of CW remains the same value; otherwise, it doubles.

B. IEEE 802.15.4

The IEEE 802.15.4 standard defines the MAC sublayer and the PHY layer. Its operational frequency bands include the 2.4 GHz ISM band. Like IEEE 802.11b/g WLANs, IEEE 802.15.4 WSNs also employ CSMA/CA for the medium access control. There are two versions of IEEE 802.15.4 CSMA/CA: slotted and unslotted. In this paper, we discuss only the popular unslotted one. In IEEE 802.15.4 WSNs, the channel is sensed only during a Clear Channel Assessment (CCA) period rather than during both a CCA and a backoff period like in IEEE 802.11b/g WLANs. Moreover, when the channel is sensed busy during a CCA period, the size of CW in IEEE 802.15.4 WSNs doubles, and when the number of the channel access attempts exceeds *macMaxCSMABackoffs*, the maximum number of backoffs the CSMA-CA algorithm will attempt before declaring a channel access failure [9], the pending packet is discarded.

C. A Coexistence Model of IEEE 802.11b/g and IEEE 802.15.4 networks

The coexistence model of IEEE 802.11b/g and IEEE 802.15.4 networks in [6] includes two aspects, namely power and timing, which are described as follows:

1) Power Aspect: The transmit powers of IEEE 802.11b/g nodes and IEEE 802.15.4 nodes are typically 100 mW [7] and 1 mW [9], respectively. In case of comparable CCA thresholds, the significant difference in the transmit power can result in three distinct regions, R1, R2 and R3 as follows:

R1: a region in which IEEE 802.15.4 nodes and IEEE 802.11b/g nodes can sense each other;

R2: a region in which IEEE 802.15.4 nodes can sense IEEE 802.11b/g nodes, but not *vice versa*;

R3: a region in which neither can sense the other, but IEEE 802.15.4 nodes could still suffer IEEE 802.11b/g interference.

These regions are illustrated in Fig. 1.

2) Timing Aspect: In R1, an IEEE 802.11b/g node and an IEEE 802.15.4 node can sense each other via ED and therefore both of their CSMA/CA mechanisms work, i.e. as one is transmitting, the other has to be waiting. IEEE 802.15.4 nodes, however, typically have a 10-30 times longer timing than IEEE 802.11b/g nodes, e.g. the backoff slot unit is 320 μs, 20 μs and 9 μs for IEEE 802.15.4, IEEE 802.11b and IEEE 802.11g, respectively, shown in Table I. The shorter timing gives IEEE 802.11b/g nodes priority over IEEE 802.15.4 nodes to access the channel and therefore causes unfairness to the IEEE 802.15.4 nodes in R1. This is illustrated in Fig. 2.

In R2, IEEE 802.15.4 nodes can sense IEEE 802.11b/g nodes but not *vice versa* given the comparable CCA thresholds, because the transmit power of IEEE 802.11b/g nodes is much higher than that of IEEE 802.15.4 nodes. As a consequence, when IEEE 802.11b/g nodes are transmitting, IEEE 802.15.4 nodes have to be waiting, whereas when IEEE 802.15.4 nodes are transmitting, IEEE 802.11b/g nodes are not aware and thus simply proceed to transmit, probably causing an overlapping in packet transmissions. This is shown in Fig. 3.

In R3, neither IEEE 802.15.4 nodes nor IEEE 802.11b/g nodes can sense the other. However, IEEE 802.15.4 nodes may still suffer from the IEEE 802.11b/g interference in case of very weak IEEE 802.15.4 links, as we will show in Section IV.

In order to validate this model, to see how it works in practice and more importantly, to get more insights about the coexistence issues, we carried out a number of experiments using off-the-shelf hardware. The details about the experiment testbed and our findings are presented in the following sections.

III. Testbed

We set up a compact testbed to check if the three regions described in Section II-C exist in reality. Note that we use

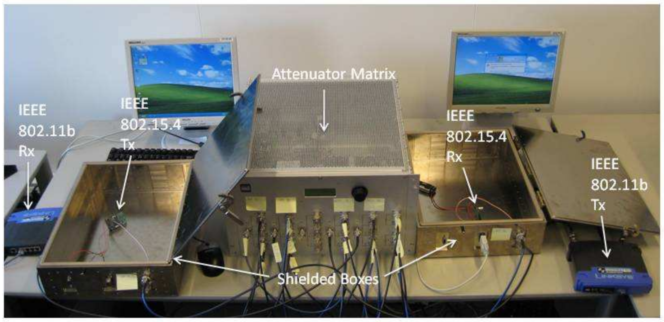

Fig. 4. Testbed of the coexistence model of IEEE 802.11b and IEEE 802.15.4 networks

only IEEE 802.11b mode in the test, but the result is also applicable to IEEE 802.11g. As shown in Fig. 4, the testbed consists of the following items:

- two IEEE 802.11b nodes (Linksys WRT54G): a Tx and an Rx;
- two IEEE 802.15.4 nodes (AquisGrain [10]): a Tx and an Rx;
- two RF shielded isolation boxes;
- one attenuator matrix box;
- two PCs with testing software.

The antennas of IEEE 802.11b nodes and IEEE 802.15.4 nodes are connected by cables via the attenuator matrix, the attenuation values of which can be adjusted to emulate the physical distance in a wireless environment. To isolate from other RF interference in the environment, IEEE 802.15.4 nodes were put into the RF shielded isolation boxes. In this way, we got a controlled RF environment, making the measurements repeatable.

A functional diagram of the testbed is depicted in Fig. 5. The attenuation losses among those nodes are as follows,

- x_1: between IEEE 802.11b Tx and IEEE 802.15.4 Tx;
- x_2: between IEEE 802.11b Rx and IEEE 802.15.4 Tx;
- y_1: between IEEE 802.11b Tx and IEEE 802.15.4 Rx;
- y_2: between IEEE 802.11b Rx and IEEE 802.15.4 Rx.

x_1, x_2, y_1 and y_2 are adjustable, from 32 dB to 212 dB. Moreover, we set both the attenuation losses between IEEE 802.11b Tx and Rx and between IEEE 802.15.4 Tx and Rx as 70 dB, so that the two links have a very good quality, i.e. the packet loss ratio of the IEEE 802.15.4 link is close to zero and the throughput of the IEEE 802.11b link is 6.82 Mbps, the maximum value achievable in our case given the parameter values in Table I.

IV. Experiments

In this section, a number of experiments are carried out to check if the three regions described in Section II exist in practice and to get more insights about the coexistence issues. The parameter values used in the experiments are shown in Table I.

In our experiments, the IEEE 802.15.4 Tx constantly sends only broadcast packets and the IEEE 802.15.4 Rx does not

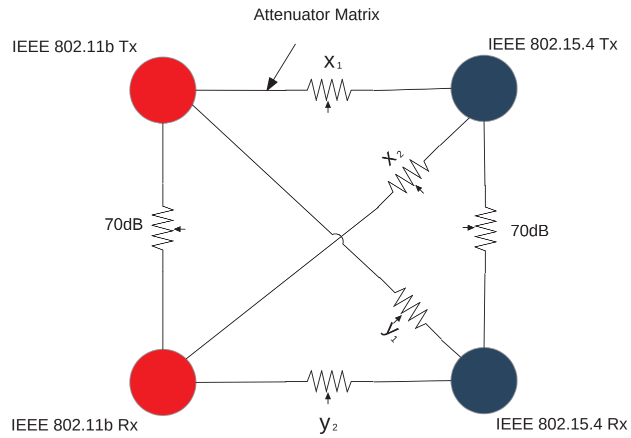

Fig. 5. Functional diagram of the coexistence testbed

TABLE I
IEEE 802.15.4 and IEEE 802.11b/g System Parameters and Additional Parameters Used in Experiments

	IEEE 802.15.4	IEEE 802.11b	IEEE 802.11g
Transmit power	0 dBm	17 dBm	17 dBm
Receiver sensitivity	-85 dBm	-76 dBm	-82 dBm
Bandwidth	2 MHz	22 MHz	22 MHz
Data rate	250 kbps	11 Mbps	54 Mbps
Backoff unit T_{bs}	320 μs	20 μs	9 μs
SIFS	192 μs	10 μs	10 μs
DIFS	N/A	50 μs	28 μs
CCA duration	128 μs	$\leq$ 15 μs	$\leq$ 4 μs
CCA threshold	-85 dBm	-84 dBm	-84 dBm
CW_{min}	7	31	15
Center frequency	2410 MHz	2412 MHz	2412 MHz
Payload size	30 bytes	1500 bytes	1500 bytes
ACK	No	Yes	Yes
Transmit intensity	Every 20 ms	Saturated	Saturated

send any packets including ACKs. The IEEE 802.11b Tx generates a saturated packet stream and the IEEE 802.11b Rx sends ACKs only. Moreover, we made the IEEE 802.11b Tx and the Rx have the same impact to the IEEE 802.15.4 Tx and to the IEEE 802.15.4 Rx, respectively. We therefore always set the same values for x_1 and x_2 , and y_1 and y_2, respectively. For brevity sake, we let $x = x_1 = x_2$ and $y = y_1 = y_2$.

Before carrying out the experiments, let us calculate R1, R2 and R3, given the parameter values in Table I.

• R1: Given the IEEE 802.15.4 transmit power of 0 dBm and the IEEE 802.11b CCA threshold of -84 dBm, when $x \geq$ 84 dB, the IEEE 802.11b nodes will not be able to sense the IEEE 802.15.4 nodes, i.e., R1 is the region where $x <$ 84 dB.

• R3: Although the IEEE 802.11b transmit power is 17 dBm, only 16.946% falls into the 2 MHz band of IEEE 802.15.4 [4], i.e. 9.3 dBm. Given the CCA threshold of -85 dBm, the IEEE 802.15.4 nodes will not be able to sense the IEEE 802.11b nodes when $x \geq$ 94.3 dB, i.e., R3 is the region where $x \geq$ 94.3 dB.

• R2: By definition, R2 is in between R1 and R3, i.e., R2 is the region where 84 dB $\leq x <$ 94.3 dB.

Now let us carry out the experiments to identify these re-

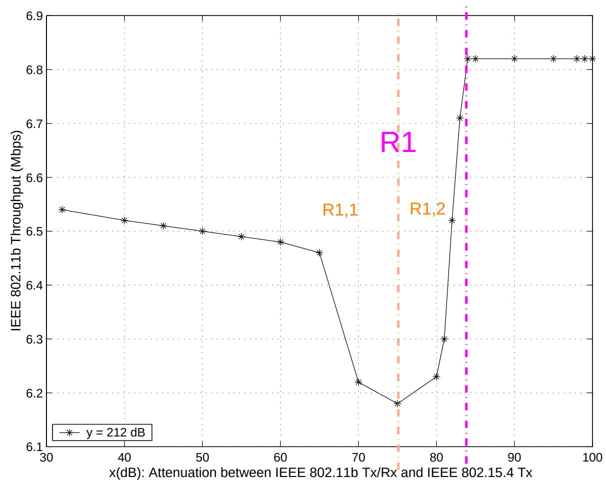

Fig. 6. In R1: IEEE 802.11b/g nodes can also sense IEEE 802.15.4 traffic

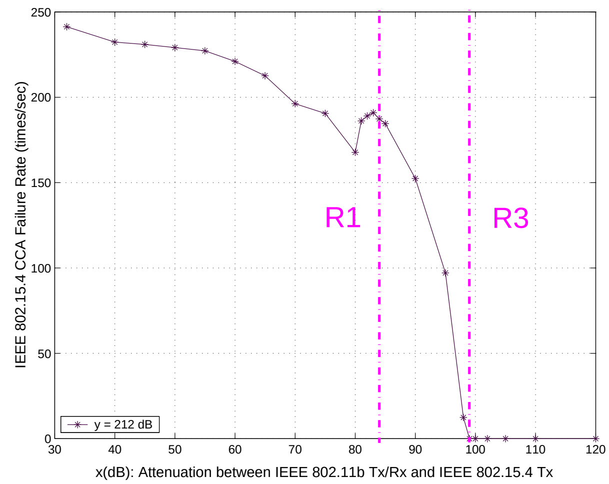

Fig. 7. IEEE 802.15.4 Tx CCA Failure Rate

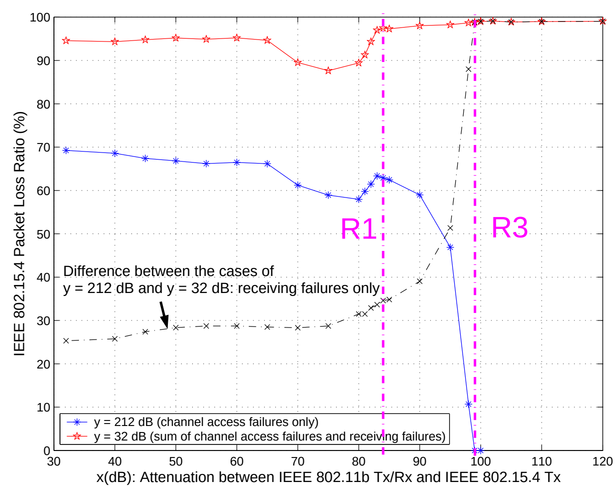

Fig. 8. In R3: neither can sense the other, but IEEE 802.15.4 nodes could still suffer IEEE 802.11b/g interference

gions. For convenience, we start with identifying R1, followed by R3 and R2.

A. *R1 Identification*

To identify R1 and to investigate details of the coexistence behavior of IEEE 802.11b and IEEE 802.15.4 networks, we measure the IEEE 802.11b throughput and the IEEE 802.15.4 packet loss ratio in the following two cases.

1) y = 212 dB*:* Given such a high attenuation loss, the IEEE 802.11b Tx and Rx have actually no impact on the IEEE 802.15.4 Rx but only the Tx. Therefore, in this case, the IEEE 802.15.4 packet loss is due to only channel access failures at the Tx rather than receiving failures at the Rx. As the IEEE 802.15.4 Rx does not send any packets including ACKs in our experiments, only the IEEE 802.15.4 Tx could affect the throughput of the IEEE 802.11b network. Thus, we can adjust x and observe the impact of the IEEE 802.15.4 Tx on the IEEE 802.11b Tx and Rx.

As an example, in Fig. 6, we can see that as $x = 32$ dB, the IEEE 802.11b throughput is approximately 6.54 Mbps, less than its maximum, i.e. 6.82 Mbps, which suggests that the IEEE 802.11b network is suffering, though not very seriously, from the IEEE 802.15.4 traffic.

As x increases, we expected the IEEE 802.11b throughput to increase as well because of the weakening IEEE 802.15.4 Tx impact. However, we surprisingly found in Fig. 6 that as x increases until about 75 dB, the IEEE 802.11b throughput actually decreases, which suggests that the impact of the IEEE 802.15.4 Tx on the IEEE 802.11b network actually increases. By further investigation, we found that this happens because, as x increases, the missed probability of the IEEE 802.15.4 ED increases and consequently, more often the IEEE 802.15.4 Tx senses the channel idle and then sends out more packets than it should, which lowers the channel occupancy of the IEEE 802.11b traffic and thus the throughput of the IEEE 802.11b network. As addressed in [8], with a high missed probability, ED is not a reliable CCA method. Especially, as the detected signal weakens, the missed probability of ED goes even higher. We call this the "imperfect CCA effect", which can also be observed in Fig. 7 and in Fig. 8. We can see in Fig. 7, for 32 dB $< x <$ 80 dB, as x increases, the IEEE 802.15.4 CCA failure rate decreases, which confirms that more IEEE 802.15.4 packets were sent out indeed and thus the IEEE 802.15.4 packet loss ratio decreases.

In Fig. 6, for 75 dB $< x <$ 84 dB, as x increases, the IEEE 802.11b throughput increases, which suggests the influence from the IEEE 802.15.4 Tx is getting less. It is because the IEEE 802.11b Tx/Rx are leaving the region where they are able to sense the IEEE 802.15.4 Tx.

For $x \geq$ 84 dB, as x increases, the IEEE 802.11b throughput keeps constant at its maximum, i.e. 6.82 Mbps, suggesting that the IEEE 802.11b Tx/Rx are not able to sense the IEEE 802.15.4 Tx and therefore not affected by the IEEE 802.15.4 Tx anymore. On the other hand, from the Fig. 8 we see that in the region of $x <$ 84 dB, the IEEE 802.15.4 Tx has a high packet loss ratio, which suggests it can sense IEEE 802.11b traffic there. **We therefore conclude the region where** $x <$

84 dB is R1. We may further divide R1 into two subregions as R1,1 (x < 75 dB) and R1,2 (75 dB < x < 84 dB), illustrated in Fig. 6. R1,2 is the transition region, where the IEEE 802.11b Tx is leaving the region in which it is able to sense the IEEE 802.15.4 nodes.

Note that the curve of y = 212 dB case in Fig. 8 is not monotonic. We see that when $x \geq 80$ dB, there is a "hump", i.e., the IEEE 802.15.4 packet loss ratio goes up first until $x = 83$ dB and then goes down again till to zero at $x =$ 98 dB. The "hump" is because the IEEE 802.11b Tx and Rx are leaving R1, as shown in Fig. 6, and therefore getting less influence from the IEEE 802.15.4 traffic, which results in more IEEE 802.11b packets sent out and therefore more IEEE 802.15.4 channel access failures. For $x \geq 83$ dB, as x increases, although more IEEE 802.11b packets are sent out, these packets cause only decreasing IEEE 802.15.4 channel access failures because of their weakening power. For $x \geq 98$ dB, the IEEE 802.15.4 packet loss ratio equals zero, which means that IEEE 802.15.4 Tx cannot sense IEEE 802.11b traffic anymore and therefore does not suffer from the channel access failures. It is confirmed in Fig. 7, where we can see that the IEEE 802.15.4 CCA failure stays zero for $x \geq 98$ dB.

It is worthy of noting that according to [2] [3] [5], IEEE 802.15.4 WSNs has little impact on the IEEE 802.11 WLANs performance. This conclusion is true in general, but may not hold in some cases. For example, in Fig. 6, we see that for 70 dB $< x <$ 80 dB, the IEEE 802.11b throughput is about 6.2 Mbps, approximately 10 % less than its maximum, i.e. 6.82 Mbps. In case of poor quality IEEE 802.11b links and a heavier IEEE 802.15.4 traffic, the IEEE 802.11b throughput will get even lower.

Although R1 has been identified, to reveal more details of the coexistence behavior of IEEE 802.11b and IEEE 802.15.4 networks, with an emphasis on the impact from the IEEE 802.11b traffic on the IEEE 802.15.4 network, we further measured the IEEE 802.15.4 packet loss ratio in the following case.

2) y = 32 dB: In this case, the IEEE 802.11b Tx and Rx influence not only the IEEE 802.15.4 Tx but also the IEEE 802.15.4 Rx. As a consequence, the IEEE 802.15.4 packet loss is not only due to channel access failures at the IEEE 802.15.4 Tx but also to receiving failures at the IEEE 802.15.4 Rx. Because of the imperfect CCA effect described in Section IV-A1, as x increases, the channel access failures decrease (The only exception happens for 80 dB $<$ $x <$ 84 dB, which will be discussed later.) and the receiving failures increase. More specifically, as x increases, more often the IEEE 802.15.4 Tx senses the channel idle and therefore transmits more packets than it should be and the channel access failures therefore decrease. However, on the other hand, most of these packets will collide with IEEE 802.11b packets and the receiving failures therefore increase. Whether the overall IEEE 802.15.4 packet loss ratio increases or decreases, depends on which change is dominant, the decrease in the channel access failures at the IEEE 802.15.4 Tx or the increase in the receiving failures at the IEEE 802.15.4 Rx.

From the curve of y = 32 dB case in Fig. 8, we can see that for 32 dB $< x <$ 65 dB, as x increases, the IEEE 802.15.4 packet loss ratio keeps approximately constant, which suggests that the decrease in the channel access failures at the IEEE 802.15.4 Tx and the increase in the receiving failures at the IEEE 802.15.4 Rx are comparable, shown as the curve of y = 212 dB case (channel access failures only) and the curve of "Difference between the cases of y = 212 dB and y = 32 dB" (receiving failures only). Besides, representing the receiving failures only, the curve "Difference between the cases of y = 212 dB and y = 32 dB" also shows that there are 25% - 35% IEEE 802.15.4 packets lost because of the receiving failures even in R1, which is due to the imperfect IEEE 802.11b/g CCA. That is, given a perfect IEEE 802.11b/g CCA, as IEEE 802.15.4 nodes seize the channel and send packets, IEEE 802.11b/g nodes always defer and therefore do not cause any transmission collision. In practice, however, although thanks to continuously sensing the channel in very short duration ($\leq$ 15 μs and 4 μs for IEEE 802.11b and IEEE 802.11g, respectively), the performance of IEEE 802.11b/g CCA is better than that of IEEE 802.15.4, it is still likely to fail to detect some of IEEE 802.15.4 transmissions.

For 65 dB $< x <$ 75 dB, the IEEE 802.15.4 packet loss ratio decreases since the channel access failures decrease sharply, while the receiving failures keep almost constant.

For 75 dB $< x <$ 80 dB, the dominant receiving failure increase accounts for the increase in the IEEE 802.15.4 packet loss ratio.

For 80 dB $< x <$ 84 dB, the channel access failures increase rather than decrease as usual. It is because the IEEE 802.11b Tx and Rx are leaving R1, shown in Fig. 6, and getting less influence from the IEEE 802.15.4 traffic, much more IEEE 802.11b packets are therefore sent out, causing a sharp increase in the channel access failures at the IEEE 802.15.4 Tx. Moreover, the receiving failures also increase. Therefore, the IEEE 802.15.4 packet loss ratio increases.

For 84 dB $< x <$ 98 dB, the receiving failures are slightly dominant, which accounts for the slightly increased IEEE 802.15.4 packet loss ratio.

For $x \geq 98$ dB, the IEEE 802.15.4 packet loss ratio keeps a high value close to 100%. In this case, only the receiving failures exist as there are no channel access failures anymore.

Given the detailed discussion about the coexistence behavior of IEEE 802.11b and IEEE 802.15.4 networks above in R1, the identification of R3 and R2 is straightforward as follows.

B. R3 Identification

From the curve of x = 212 dB case in Fig. 8, we see that as $x \geq 98$ dB, the IEEE 802.15.4 packet loss ratio owing to the channel access failures goes down till to zero, which means that IEEE 802.15.4 Tx cannot sense IEEE 802.11b traffic and therefore does not suffer from the channel access failures anymore. It is confirmed in Fig. 7, where we can see that the IEEE 802.15.4 CCA failure rate goes down till zero as $x \geq 98$ dB. We therefore conclude that in the region where $x \geq 98$ dB, neither IEEE 802.15.4 nodes nor IEEE 802.11b

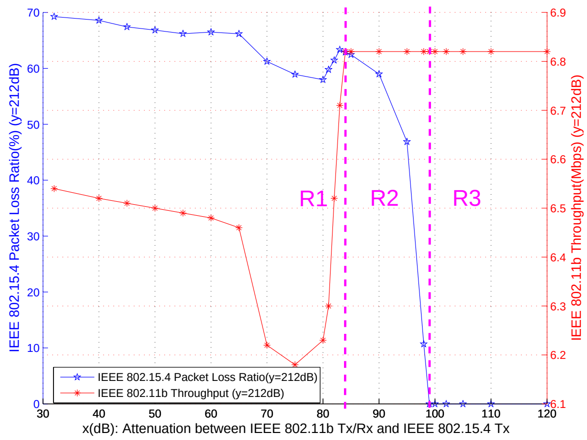

Fig. 9. In R2: IEEE 802.15.4 nodes can sense IEEE 802.11b/g nodes, but not *vice versa*

nodes can sense the other, but IEEE 802.15.4 nodes may still suffer from the IEEE 802.11b interference, which is exactly what R3 defines. Note that R3 $\geq$ 98 dB here is 3.7 dB more than that we have calculated, i.e., 94.3 dB and this difference may be attributed to the errors in the measurement and/or the hardware implementation.

C. R2 Identification

For convenience, Fig. 6 is superimposed on Fig. 8, resulting in Fig. 9. We can see that in the region between R1 and R3, i.e., 84 dB $< x <$ 98 dB, there are still some IEEE 802.15.4 packets loss owing to the channel access failures, which suggests in that region, IEEE 802.15.4 Tx can still sense the IEEE 802.11b Tx/Rx, while not *vice versa*. This is exactly the region which R2 defines.

Upon till now, all R1, R2 and R3 are clearly identified and the coexistence model in [6] is validated by our experiments.

V. Conclusion

As an extension of the previous work, experiments on the coexistence issues between an IEEE 802.11b WLAN and an IEEE 802.15.4 WSN were conducted. The experiments clearly validated the coexistence model we proposed before and therefore confirmed its usefulness in the explanation and prediction of the coexistence behavior of IEEE 802.11b/g and IEEE 802.15.4 networks. Furthermore, we gained more insights on the coexistence issue from the experiments, for example, the imperfect CCA effect, which could cause both IEEE 802.11b/g and IEEE 802.15.4 nodes to fail to detect the ongoing packet transmission in the channel and therefore cause the transmission collision. For another example, the experiments showed that in some cases, IEEE 802.15.4 WSNs may have a non-negligible impact on the performance of IEEE 802.11b/g WLANs. We believe that based on such a thoroughly understanding about the coexistence issue, our coexistence model is helpful for researchers to resolve the coexistence issues between IEEE 802.11b/g WLANs and IEEE 802.15.4 WSNs.

VI. Acknowledgement

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