Interference based Packets Recovery for Energy Saving in Cognitive Radio Networks

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Abstract—**In this paper, we propose to recover collided packets between Primary Users (PUs) and Secondary Users (SUs) in Cognitive Radio Networks (CRNs) for two scenarios. The PU's (or SU's) receiver considers the SU's (or PU's) transmitted packet's signals as an interference, and hence, cancels its effect in order to recover its corresponding received packet's signals. Recovering collided packets, instead of retransmitting them saves transmitters energy. In the first scenario, we assume PUs and SUs employ the standard Binary Phase-Shift keying (BPSK) and a 90 degree phase shifted version, i.e., orthogonal to BPSK, respectively, as their modulation techniques. In the Second scenario, we assume PUs and SUs employ BPSK and QPSK as their modulation techniques, respectively, or vice versa. In both scenarios, we propose protocols to recover the PU and SU collided packets, depending on the received phase shits. We show through numerical analysis that a significant fraction of collided packets can be recovered. We also derive an energy saving performance metric for our proposed mechanisms, in order to asses the saved energy due to recovering the collided packets. Our numerical analysis also shows that a high percentage of energy can be saved over the traditional scheme, in which our packets recovery mechanisms are not employed.**

I. INTRODUCTION

Due to the temporal and spatial underutilization of licensed spectrum bands, as well as the crowdedness of unlicensed bands, a new spectrum access paradigm has been recently proposed namely, Cognitive Radio (CR) [1]. CR enables users to adjust their transceivers' frequencies depending on the availability of licensed frequency bands which are otherwise unused by their licensees [2]. Thus, unlicensed wireless users, called Secondary Users (SUs) can dynamically and opportunistically access unused licensed bands in order to improve their throughput and service reliability. In this case, whenever the licensed, or the Primary Users (PUs) become active, SUs must vacate their bands. Cognitive Radio Networks (CRNs) operating according to these principles have many challenges such as spectrum sensing, management, mobility, allocation and sharing [3], [4].

In CRNs, PUs and SUs packets may collide when a PU becomes active while an SU is transmitting its packet. Recovering these collided packets can lead to performance improvement such as energy saving in some wireless networking environments, e.g., WiMAX wireless networks, cellular networks, and licensed wireless microphones. In this paper, we propose two recovery mechanisms, which we refer to as graceful handoff mechanisms 1 and 2. **These recovery mechanisms are based on canceling the effect of the interference that is caused by the collided signal which is not the receiver interest**. We assume PUs and SUs to be in the same locality in a wireless network, which employ BPSK or QPSK as their modulation techniques. BPSK and QPSK modulations are used in many wireless communication networks, such as a high-speed wireless access standards, e.g., WiMAX wireless networks, in which the spectrum bands range from 2 GHz to 66 GHz, and include both licensed and unlicensed bands, according to IEEE 802.16−2009 Standard [5]. A WiMAX user or subscriber (who pays for channel access) may change its modulation scheme based on the channel quality. For example, when channel's conditions are bad, a user employs low complexity modulation such as BPSK/QPSK, to increase data transmission reliability. However, when channel's conditions are good, higher complexity and higher bit rate modulation techniques are employed such as 16−QAM or 64−QAM in order to increase throughput. In this paper, we are interested in cases when a PU (WiMAX subscriber or BS) employs BPSK while transmitting over its licensed channel bands, and SUs modulation technique is QPSK, or vice versa. Or, both PUs and SUs employ BPSK. If an SU is transmitting over a channel, and the channel's PU becomes active, then a collision occurs between the SU and the PU packets. Our goal in this paper is to recover these collided packets.

Besides WiMAX networks, recent research has considered using licensed channels of cellular network to increase the capacity of SUs in CRNs [6], [7]. SUs opportunistically access cellular network channels, while its PUs are protected. CDMA2000, which is a 3G mobile standard networks that uses Code/Time Division Multiple Access multiplexing techniques for data and voice transmission in cellular networks, employs BPSK and QPSK modulation techniques for uplink and downlink data transmission, respectively [8]. Also, BPSK and QPSK modulation techniques are employed by licensed wireless microphones with low transmission power, as described in IEEE 802.22 standard [9].

In CRNs, SUs must detect the presence of PUs when they become active within a specified interval time, call it monitoring cycle, where its duration is dependent on the type of PUs, their applications nature, and QoS.

***Definition** 1.1: Monitoring Cycle*: is the time between the end of a sensing period and the end of the next sensing period for an SU, while the SU is transmitting its packet(s).

During the sensing period (which is part of monitoring) an SU conducts in-band sensing, to find out whether the PU of

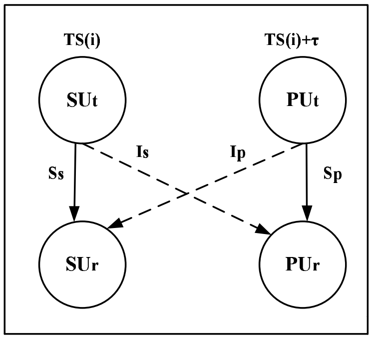

Fig. 1. System Model.

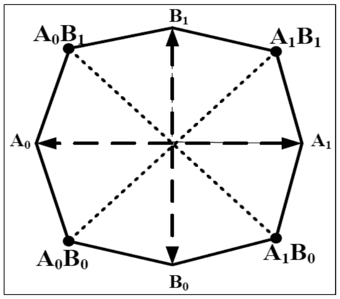

Fig. 2. Mechanism 1 constellation diagram for two transmitters A and B.

the channel that is being accessed by the SU became active or not. If a PU presence is miss-detected during the sensing period, as a result, all the SU transmitted bits during the following monitoring cycle collide with the PU's transmission. Even though, the SU receiver can recover these collided bits while receiving them one by one, by employing our proposed technique in this paper.

II. MOTIVATION

When a PU becomes active it does not sense its licensed channel to detect whether it is being used by an SU or not. Therefore, the PU just starts transmission over its assigned channel. As a result, if an SU has been using this channel at that time, a collision occurs between the head of the first packet transmitted by the PU and the tail of the last transmitted SU packet. To the best of our knowledge there is no proposed work in literature to recover these collided packets for the PU and the SU. Therefore, this problem motivated us to propose a new scheme, which we call graceful hand-off, and employ the additive nature of the electromagnetic (EM) waves as a coding operation for the simultaneously transmitted signals, in order to allow the PU and the SU receivers to recover their collided sub-packets. Our proposed scheme is energy efficient, because the recovered collided packets will not be retransmitted, and therefore, the transmission energy is saved for the PU and the SU transmitters.

In applications where PUs collisions can be tolerated, e.g., TV channels broadcast, only collided SUs packets may be recovered and the PU receivers do not have to change their operation.

III. SYSTEM MODEL

Figure 1 shows a sketch for our proposed model, a PU transmitter (PU_t) and its corresponding PU receiver (PU_r), and an SU transmitter (SU_t) and its corresponding an SU receiver (SU_r). We assume the MAC protocol is time slotted. Therefore, at the beginning of each Time Slot (TS), say TS i (TS(i)), the SU_t transmits only if senses the channel is idle (which means PUs are idle). However, if the a PU becomes active, call it PU_t, after τ time, a collision occurs between the head of the first packet transmitted by the PU_t and the tail of the last packet transmitted by the SU_t. Such that, $0 \leq \tau \leq T - \epsilon$, where T is the time slot time, and ϵ is a small time period, given that $\epsilon < T$. When the collision occurs the SU_r receives a superimposed signal of SU_t signal, call it S_s, and PU_t signal, call it I_p therefore, SU_r considers I_p as an interfered signal, and therefore, cancels its effect on its signal of interest, S_s, that transmitted by its corresponding SU_t, and that is based on the received bits' signals' phase shifts. On the other hand, in the same fashion the PU_r recovers its received bits signals, S_p, which is transmitted by its corresponding PU_t. Our proposed scheme will be explained in details, when we present our proposed graceful hand-off mechanisms 1 and 2 for packets recovery, in Sections V and VI, respectively.

Our scheme is different from Physical layer Network Coding (PNC) [10] and Analog Network Coding (ANC) techniques [11], because we recover the packets at the receiver nodes without using a relay node as shown in Figure 1, while PNC and ANC techniques requires the a relay node. Our proposed scheme requires synchronization as in PNC, however, ANC does not require it. Our scheme requires synchronization between SUs and PUs, in [12] a cross-layer based opportunistic multi-channel time-slotted MAC protocol for CRNs is proposed, in which time slots for the licensed channels and the Common Control Channel (CCC) for SUs have the same time length and are synchronized.

In our proposed packets recovery mechanisms, SUs modulation technique selection is based on the modulation technique employed by PUs. Let M_1 be a BPSK modulation scheme that is represented by A_1 and A_0 symbols with phase shifts 0 and π, respectively. Also, let M_2 be a BPSK modulation scheme that is represented by B_1 and B_0 symbols with phase shifts $\frac{\pi}{2}$ and $\frac{-\pi}{2}$, respectively, as shown in Figure 2. The QPSK, when employed, is represented by 4 symbols, such that each symbol codes two transmitted bits. As shown in Figure 3 symbols A_{11}, A_{01}, A_{00}, and A_{10} correspond to $'11'$, $'01'$, $'00'$, and $'10'$ bit combinations, respectively.

IV. MODEL ASSUMPTIONS

We introduce the following common assumptions:

- ○ The Medium Access Control (MAC) protocol is time slotted.
- ○ The modulation schemes for PUs and SUs are BPSK and QPSK.
- ○ Our proposed scheme mainly depends on phase shifts rather than received energy in order to recover the received signals.
- ○ SUs' transmissions are synchronized with each other. This is a requirement for our proposed mechanisms 1 and 2.

Simple and effective techniques for synchronizing a group of transmitters to a receiver have been proposed in [13], [14], [15].

- SUs and PUs are synchronized [12], as we explained in our system model, Section III.
- The SUs can detect and recognize the modulation technique employed by PUs. Many methods have been proposed in literature, as in the survey in reference [16], to detect different modulation techniques.
- Mechanism 1 is employed when PUs use $M_1(M_2)$ and SUs use $M_2(M_1)$, as shown in Figure 2.
- Mechanism 2 is used when one of the PUs and SUs uses QPSK, and the other uses BPSK, as shown in Figure 3.

V. GRACEFUL HAND-OFF MECHANISM 1

This Section presents PUs' and SUs' packets recovery protocols for collided packets.

A. SUs' Packets Recovery Protocol:

This subsection explains our proposed protocol for packets recovery at the SU side, when a collision occurs with the PU's packet head. Define SU_t and SU_r to be the transmitting and the receiving SUs, respectively. The steps for SU's packet tail recovery are as follows:

1) For the sake of exposition, let us assume SUs determined that the PU of the channel uses the M_1 BPSK modulation technique (as explained in Section III), and let us call these symbol values A_0 (phase=π) and A_1 (phase=0). Therefore, the SU uses the M_2 modulation technique (with symbol values B_0 (phase=$\frac{-\pi}{2}$) and B_1 (phase=$\frac{\pi}{2}$)), which is orthogonal to M_1.
2) When SU_r receives a corrupted packet, due to an overlap between the tail of the received SU packet and the head of the PU packet, the corruption will be in the phase shifts of the received packet's tail bits, because their signals do not match SUs demodulation technique (neither $\frac{\pi}{2}$ nor $\frac{-\pi}{2}$).
3) To recover the corrupted symbols, SU_r checks if the tail bits match any of the phase shifts corresponding to two transmitters, as shown in Figure 2 and Table I, to recover the corrupted signal. For example, if the phase shift for a received bit signal is $\frac{\pi}{4}$ or $\frac{3\pi}{4}$, then SU_r concludes that SU_t transmitted the B_1 bit symbol.
4) SU_r repeats the process in step 3 for all collided bit signals within the received packet's tail.

B. PUs' Packets Recovery Protocol:

As stated above, PUs' packets recovery is optional as it may require changes to the operation of the PU. PUs which can tolerate some loss, e.g., TV receivers, do not need to implement this procedure. The protocol for packets recovery at the PU's receiver, when a collision occurs with the tail of the SU packet, is similar to SU's packet recovery which is explained in previous subsection. For example, assume PUs use M_1. If the phase shift for a received bit signal is $\frac{\pi}{4}$ or $\frac{-\pi}{4}$, then the PU receiver concludes that the PU transmitter transmitted A_1 bit symbol.

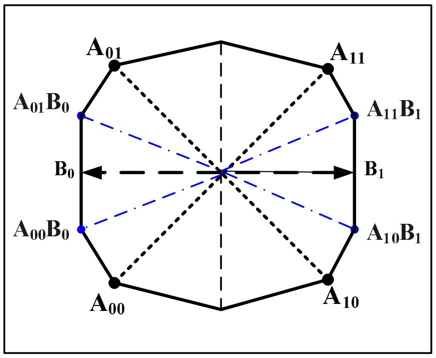

Fig. 3. Mechanism 2 constellation diagram for 2 transmitters A and B, where A and B employ QPSK and BPSK (M_1) modulation techniques, respectively.

TABLE I
SIGNALS CODING AND DECODING FOR TWO TRANSMITTER NODES AND ONE RECEIVER NODE IN PNC SCHEME.

A	B	PNC Signal	Decoded Signals
0	0	signal with the phase difference $e^{j(-\frac{3\pi}{4})}$	A_0,B_0
0	1	signal with the phase difference $e^{j(\frac{3\pi}{4})}$	A_0,B_1
1	0	signal with the phase difference $e^{j(-\frac{\pi}{4})}$	A_1,B_0
1	1	signal with the phase difference $e^{j(\frac{\pi}{4})}$	A_1,B_1

TABLE II
SIGNALS CODING AND DECODING FOR TWO TRANSMITTER NODES IN PNC SCHEME, WHERE TRANSMITTER A USES QPSK, AND TRANSMITTER B USES BPSK.

A	B	PNC Signal	Decoded Signals
11	1	signal with the phase difference $e^{j(\frac{\pi}{8})}$	A_{11},B_1
01	0	signal with the phase difference $e^{j(\frac{7\pi}{8})}$	A_{01},B_0
00	0	signal with the phase difference $e^{j(-\frac{7\pi}{8})}$	A_{00},B_0
10	1	signal with the phase difference $e^{j(-\frac{\pi}{8})}$	A_{10},B_1

It is worth mentioning that the bit error rate (BER) for this mechanism, as shown in Figure 2, is similar to that of QPSK.

VI. GRACEFUL HAND-OFF MECHANISM 2

In this section, we extend our work in the previous Section where PUs and SUs employ QPSK and BPSK, respectively, or vice versa. In Figure 3, assume that the PU uses QPSK modulation which is represented by symbols A_{11}, A_{01}, A_{00}, and A_{10}. Also, assume that the SU uses BPSK modulation technique which is represented by B_1 and B_0 symbols (M_1). Therefore, the possible received phase shifts when the PU and the SU transmit their signals simultaneously are represented by the four dash-dotted lines in Figure 3 and explained in Table II. For example, when the received phase shift is $\frac{\pi}{8}$, this means that a collision has occurred such that a PU transmitted symbol A_{11} and an SU transmitted the B_1 symbol.

The packets recovery steps, either by the PU or the SU receiver node, when collisions occur between a PU and an SU packets, are similar to the steps presented in the previous section, except that the PU or SU receiver node needs to use Table II to recover the collided packets.

In Figure 3, the minimum received phase shift difference at the receiver is $\frac{\pi}{8}$ which is similar to the $16-$PSK modulation scheme. Therefore, 16-PSK BER can serve as an upper bound for the BER under this mechanism.

VII. PERFORMANCE ANALYSIS

In this section, we introduce two performance metrics to evaluate the efficiency of our proposed protocols for mechanisms 1 and 2. First metric, the probability of successfully recovering the collided packets between the SU and the PU transmitters. Second metric, energy saving due to recovering the collided packets by their receivers, instead of retransmitting them again. Let us introduce the following notations:

- N: is the number of transmitted bits by an SU.
- K: duration (in bits) of monitoring cycle.
- $p_t(i,K)$: the probability for a PU to start its transmission at bit i of the K bits during the monitoring cycle, given that the PU became active.
- p_e: the probability that at least one bit cannot be recovered in the SU packet, which is also the probability that the SU packet will be corrupted due to collision.
- p_s: the probability of recovering the collided PU and SU sub-packets successfully, and it is equal to $1-p_e$.
- p_a: is the probability for a PU to become active during a monitoring cycle, and corresponds to a geometric distribution.
- BER: represents the Bit Error Rate for the modulation schemes which are employed by PUs and SUs in the network.
- e: is consumed energy to transmit one bit (Joule).
- E_{ws}: consumed energy for bits transmitted by an SU, while one of our proposed mechanisms is employed by SUs (with energy saving, since the collided SU packets bits with the PU are recovered).
- E_{ns}: consumed energy for bits transmitted by an SU, while neither of our proposed mechanisms is employed by SUs (no energy saving, since the collided SU packets bits with the PU can not be recovered).
- ρ: energy saving percentage compared to the traditional scheme, in which neither of our proposed mechanisms is employed by SUs.

A. *Probability of successful collided packets recovery:*

The probability of successfully recovery the collided packets performance metric, p_s, is shown in equation (1).

$$p_s = \sum_{i=1}^{K}(1-BER)^{K-i+1}p_t(i,K). \tag{1}$$

This corresponds to the probability of success in packet recovery. The $(1-BER)^{K-i+1}$ term in equation (1) represents the probability of recovering the $(K-i+1)$ collided bits for both the PU and the SU, such that the PU has started its transmission at the i^{th} bit of SU packet which is being transmitted. We assume that $p_t(i,K)=\frac{1}{K}$, $\forall i$, which corresponds to a discrete uniform distribution.

B. *Energy saving:*

In traditional wireless networks more than two users packets may collide at the same time, e.g., slotted Aloha MAC protocols However, in CRNs when packets collision occurs, it happens between an SU which is transmitting and one PU at most that becomes active[1], our proposed mechanisms 1 and 2 are customized for this collision scenario in CRNs.

TABLE III

NUMERICAL RESULTS PARAMETERS: MONITORING CYCLE TIMES AND LENGTHS, WHEN DATA RATE = $1\ Mbps$.

monitoring cycle time (ms)	monitoring cycle length (K)
4.09 ms	$512*8$ bits
12 ms	$1,500*8$ bits
20 ms	$20,000$ bits
50 ms	$50,000$ bits
100 ms	$100,000$ bits
160 ms	$160,000$ bits
2 sec	$2*10^6$ bits

Let us focus on the saved energy by SU in this subsection, the total number of monitoring cycles is equal to $\frac{N}{K}$. Every some monitoring cycles a PU becomes active, and the average number of these cycles is equal to $\frac{1}{p}$. Since the probability for the PU to become active, p_a, follows a geometric distribution where its average is equal to $\frac{1}{p}$. Therefore, the number of times the PU becomes active equals $\frac{\frac{N}{K}}{\frac{1}{p}}$. In equation (2), in the RHS, $K\frac{1}{p_a}$ in the first term represents the number of transmitted bits by the SU when it is able to successfully recover the collided bits with a probability equals to p_s at the last monitoring cycle in every $\frac{1}{p_a}$ monitoring cycles, at which the PU becomes active and collides with SU packet bits. However, the SU receiver may not be able to recover these collided bits in the last monitoring cycle successfully with a probability equals to $(1-p_s)$, and therefore, retransmits these bits, as a result, the total transmitted bits are $K\ (\frac{1}{p_a}+1)$ as shown in the second term in the RHS of equation (2). However in equation (3), since the collided packets are not recovered, the SU transmitter retransmits the collided bits. Therefore, the total number of transmitted bits equals to $(\frac{1}{p_a}+1)$. Equation (4) represents the saved energy percentage due to employing one of our proposed mechanisms for packets recovery.

$$E_{ws} = \frac{\frac{N}{K}}{\frac{1}{p_a}}[p_s K\frac{1}{p_a}e + (1-p_s)K(\frac{1}{p_a}+1)e]. \tag{2}$$

$$E_{ns} = \frac{\frac{N}{K}}{\frac{1}{p_a}}[K(\frac{1}{p_a}+1)e]. \tag{3}$$

$$\begin{aligned}\rho &= \frac{E_{ns}-E_{ws}}{E_{ws}} * 100\% \\ &= \frac{(\frac{1}{p_a}+1)-(p_s\frac{1}{p_a}+(1-p_s)(\frac{1}{p_a}+1))}{\frac{1}{p_a}+1} * 100\% \\ &= \frac{p_s}{\frac{1}{p_a}+1} * 100\%.\end{aligned} \tag{4}$$

VIII. NUMERICAL RESULTS AND DISCUSSION

In this section, we evaluate the performance of our two proposed mechanisms, using the performance metric introduced in the previous section, which is the probability of successful recovery for collided sub-packets, p_s. In our numerical results, we considered two data rates 1 Mbps and 6 Mbps with

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[1] In this paper, we assume there is only one PU assigned to each licensed channel.

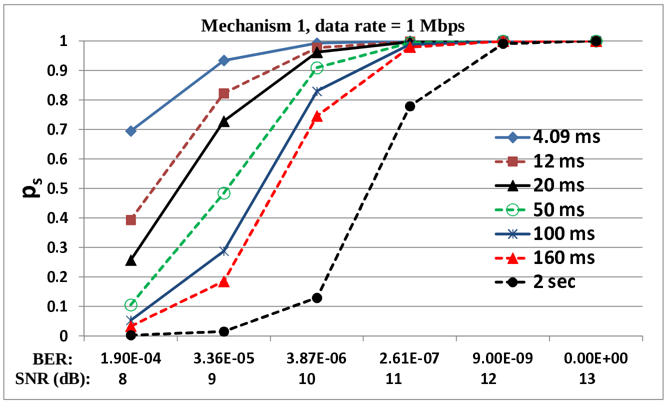

Fig. 4. p_s for mechanism 1, where data rate = 1 Mbps.

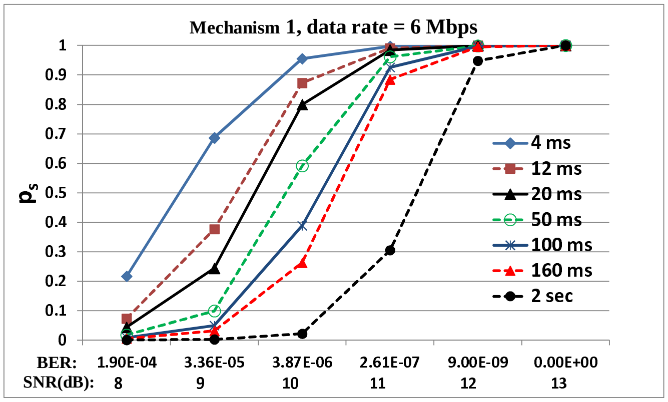

Fig. 5. p_s for mechanism 1, where data rate = 6 Mbps.

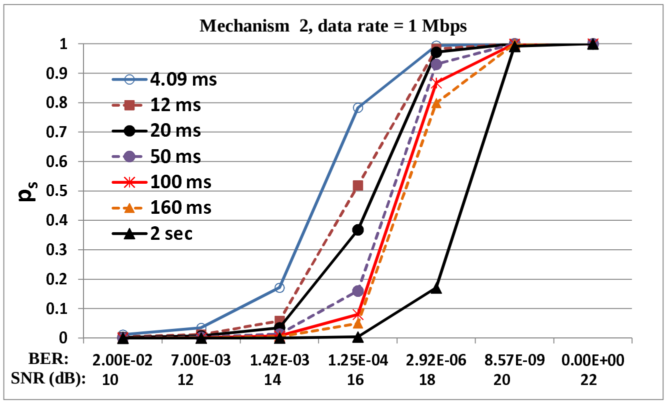

Fig. 6. p_s for mechanism 2, where data rate = 1 Mbps.

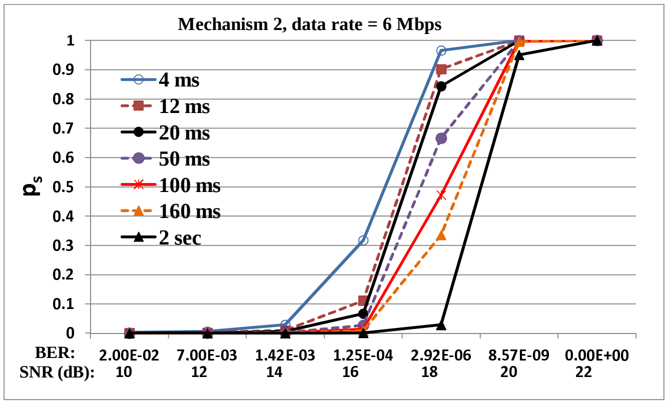

Fig. 7. p_s for mechanism 2, where data rate = 6 Mbps.

different monitoring cycle lengths. As an example, Table III shows the monitoring cycle times and lengths for 1 Mbps. It is worth mentioning that in IEEE 802.22 WRAN cell [17], the base station superframe size = 160 ms, and the Maximum Detection Time (MDT) frame to detect the PU when it becomes active should not exceed 2 sec. However, in public safety and cellular networks spectrum, MDT frame must be much less than 2 sec, due to the nature of the applications, in which the PU's sensitivity to interference by SUs is higher than that in TV spectrum. Therefore, the monitoring cycle length is dependent on the type of PUs and the applications. In our numerical analysis, we varied the monitoring cycle length from 4.09 ms to 2 seconds in order to study its effect on packet recovery efficiency, under different application requirements.

The maximum tolerable BER is dependent on the applications nature, and their *QoS* requirements. Therefore, in our numerical analysis, we evaluated the performance of our proposed packets recovery mechanisms 1 and 2 with different values of BER. In general, increasing Signal-to-Noise Ratio (SNR) decreases BER. We obtained the QPSK and 16−PSK theoretical BER values from the BER analysis tool in Matlab communication toolbox, where the channel type is AWGN.

A. *Probability of successful collided packets recovery results:*

As stated earlier in mechanism 1, the BER rate is similar to that of QPSK modulation. Figures 4 and 5 show p_s with respect to the BER for QPSK (and its corresponding SNR (dB)) for data rates 1 Mbps and 6 Mbps, respectively, with different monitoring cycle times. The probability of recovering the collided PU and SU sub-packets successfully, p_s, increases by increasing SNR. Results show that with a small increase in SNR, p_s increases significantly. For example, when the monitoring cycle time is 20 ms and data rate is 1 Mbps, p_s is 0.73 and 0.97 when SNR equals to 9 and 10, respectively, and therefore, p_s is increased by 32% when SNR is increased by just 1 unit.

As stated earlier, in mechanism 2 the BER rate is upper bounded by the BER of 16−PSK modulation. Figures 6 and 7 show p_s with respect to the BER of 16−PSK (and its corresponding SNR) for data rates 1 Mbps and 6 Mbps, respectively, with different monitoring cycle times. The probability of recovering the collided PU and SU sub-packets successfully, p_s, increases by increasing SNR. Similar to mechanism 1, results show that with a small increase of SNR, p_s increases significantly. For example, when the monitoring cycle time is 50 ms and data rate is 6 Mbps, p_s is 0.03 and 0.67 when SNR equals to 16 and 18, respectively, therefore, p_s is increased by about 21 times when SNR is increased by just 2 units.

B. *Energy Saving Results:*

Figure 8 shows the saved energy percentage for different p_s and their corresponding SNR (dB) (which are obtained from Figure 4 results in the previous Subsection) when our proposed mechanisms 1 is employed by SUs, data rate $= 1$ Mbps, and the monitoring cycle time is 50 ms. The results show that the energy saving percentage increases when the probability of the PU to become active during the monitoring cycle, p_a, increases, for six different scenarios where the p_s (and it corresponding SNR) are different. For example, when $p_a = 0.5$ and $p_s = 0.9$ (where SNR$=$ 10 dB), the obtained energy saving is equal to 30.3%. It is worth mentioning that in CRNs the p_a is usually less than 0.8.

Figure 9 shows the energy saving percentage, with respect to monitoring cycle time (ms), when mechanism 2 is employed by SUs, data rate$=$ 6 Mbps, and p_a is fixed and set to 0.4. Results show increasing the monitoring cycle time decrease the saved energy, due to recovering the collided packets for five different scenarios which have different SNRs. For example, increasing the monitoring cycle time from 4 ms to 100 ms, when SNR is 18 dB, causes a degradation in the saved energy percentage from 27.59% to 13.47%, therefore, it is a trade-off between the monitoring cycle length and saved energy. Figure 9 also shows that when SNR value is high, e.g., 22 dB, increasing the monitoring cycle time from 4 ms to 2 sec does not degrade the saved energy, since it stays the same percentage, e.g., about 28.54%.

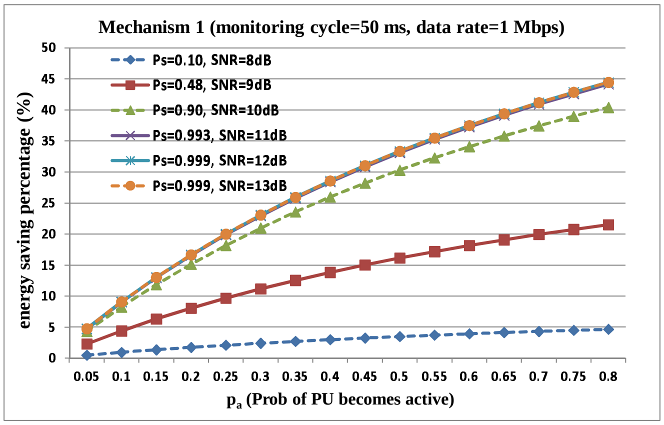

Fig. 8. Energy saving percentage, with respect to p_a for mechanism 1.

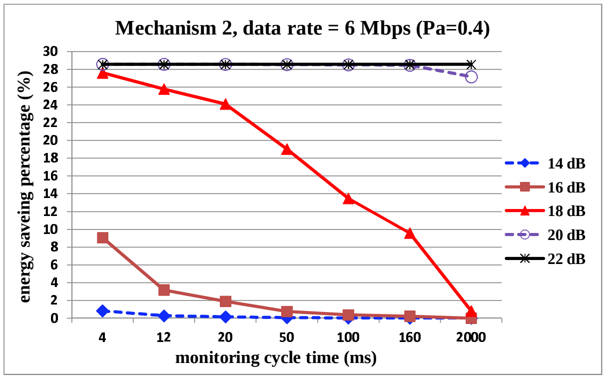

Fig. 9. Energy saving percentage, with respect to monitoring cycle time, for mechanism 2 where data rate$=$ 6 Mbps, and p_a is set to 0.4.

IX. CONCLUSIONS

We propose two mechanisms, together with protocols, to be used to recover the collided sub-packets for a PU and an SU in Cognitive Radio Networks (CRNs), when the PU becomes active while the SU is transmitting over the PU's channel. To recover these collided sub-packets, we propose to use Physical layer Network Coding (PNC) by the SU and the PU. In mechanism 1, we assume PUs and SUs employ the standard Binary Phase-Shift keying (BPSK) and a 90 degree phase shifted version, i.e., orthogonal to BPSK, respectively, as their modulation techniques. In mechanism 2, we assume PUs and SUs employ BPSK and QPSK as their modulation techniques, respectively, or vice versa. Our numerical results show the efficiency of our proposed protocols for both mechanisms, since a high fraction of the collided packets can be recovered. The results also show that p_s increases by decreasing the BER (increasing SNR) or decreasing the monitoring cycle time for different data rates. **Also, results show a high percentage of energy is saved when our either one of our proposed mechanisms is employed by SUs, and It depends on the probability for a PU to become active, and the monitoring cycle time of SUs**.

REFERENCES

[1] I. Akyildiz et al., "Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey". Comput. Netw., vol.50, no.13, 2006.
[2] I. Mitola, J., "Cognitive radio for flexible mobile multimedia communications". In IEEE MoMuC 1999 International Workshop, pp.3-10.
[3] A. Ghasemi and E. Sousa, "Collaborative spectrum sensing for opportunistic access in fading environments". In IEEE DySPAN 2005.
[4] X. Chen, et al., "Detection efficiency of cooperative spectrum sensing in cognitive radio network". The Journal of China Universities of Posts and Telecommunications, vol. 15, pp. 1–7, 2008.
[5] IEEE Standard 802.16: A Technical Overview of the WirelessMAN Air Interface for Broadband Wireless Access.
[6] Minh-Viet Nguyen, et al., "Scheduling in cellular cognitive radio network," In IEEE WCNC 2011.
[7] Yao Ma, Dong In Kim, Zhiqiang Wu, "Optimization of OFDMA-Based Cellular Cognitive Radio Networks," IEEE Transactions on Communications, vol.58, no.8, pp.2265–2276, August 2010.
[8] Hsiao-Hwa Chen; Chang-Xin Fan; Lu, W.W., "China's perspectives on 3G mobile communications and beyond: TD-SCDMA technology," IEEE Wireless Communications, vol.9, no.2, pp. 48–59, April 2002.
[9] Stevenson, C.; et al.; "IEEE 802.22: The first cognitive radio wireless regional area network standard," Communications Magazine, IEEE , vol.47, no.1, pp.130–138, January 2009.
[10] S. Zhang, et al., "Hot Topic: Physical-Layer Network Coding". In MobiCom 2006.
[11] S. Katti, S. Gollakota, and D. Katabi, "Embracing Wireless Interference: Analog Network Coding". In SIGCOMM'07, August 27–31, 2007.
[12] Hang Su, and Xi Zhang, "Cross-Layer Based Opportunistic MAC Protocols for QoS Provisionings Over Cognitive Radio Wireless Networks," In IEEE JSAC, vol.26, no.1, pp.118–129, 2008.
[13] Tu Y. and Pottie G., "Coherent cooperative transmission from multiple adjacent antennas to a distant stationary antenna through AWGN channels". In the 55th IEEE VTC 2002.
[14] R. Mudumbai, et al., "On the Feasibility of Distributed Beamforming in Wireless Networks". IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 6, NO. 4, APRIL 2007.
[15] M. Simon, et al., "Information Reduced Carrier Synchronization of BPSK and QPSK Using Soft Decision Feedback". 44th Annual Allerton Conference Allerton House, 2006.
[16] Dobre, O.A.; et al.; "Survey of automatic modulation classification techniques: classical approaches and new trends". Institution of Engineering and Technology (IET Commun), vol. 1, no. 2, 2007.
[17] "IEEE Standard for Information Technology—Telecommunications and information exchange between systems WRAN-Specific requirements Part 22: Cognitive WRAN MAC and PHY Layer Specifications: Policies and Procedures for Operation in the TV Bands," IEEE Std 802.22-2011, pp.1–680, Active, July 2011.