Receiver-side Opportunism in Cognitive Networks

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***Abstract*— Cognitive radios may increase spectral efficiency by filling in spectral gaps, transmitting under the interference-temperature, or by exploiting transmitter-side information - all methods which rely on transmitter-side cognition. In this work we shift our focus to receiver-side cognition by extending work on *opportunistic interference cancellation (OIC)* to multi-user scenarios. We consider a single primary transmitter-receiver link which communicates simultaneously with a group of cognitive (secondary) users that form one of three classical multi-user channels: 1) a multiple access channel (MAC), 2) interference channel (IC), or 3) a broadcast channel (BC). When these cognitive users are permitted to transmit subject to peak interference at the primary receiver, we illustrate the benefit of having the primary share its transmission rate and codebook with the cognitive receivers. With these codebooks, when the channel conditions permit, the cognitive receivers decode both the primary and the intended cognitive message, which boosts the secondary rates as compared to treating the primary signal as noise. The primary users must not change their encoders/decoders and remain oblivious to the secondary operation. We obtain achievable rate regions for the secondary MAC, IC and BC in which the cognitive receivers opportunistically cancel the primary interference to achieve higher rates at the cost of codebook knowledge and, perhaps, increased decoding complexity.**

I. Introduction

Cognitive radio has the potential to improve spectral efficiency through secondary spectrum sharing / dynamic spectrum access. Much of the recent research has considered spectral gap filling [1], interference-temperature [2], [3] and transmitter-side information [4], [5] as possible secondary spectrum access techniques.

We take a different approach to cognition, focussing on intelligent processing at the *receiver* rather than at the transmitter [4], [5]. We extend the *opportunistic interference cancellation (OIC)* ideas of [6], in which a single point-to-point cognitive link employs opportunistic interference cancellation (OIC) to secondary networks in the presence of a single primary transmitter. This scheme differs from previous schemes in that the receivers, not only the transmitters, behave in a "cognitive" manner. We assume that an *interference margin* at the primary transmitter allows for the secondary users to transmit with non-trivial power simultaneously with the primary transmitter, similar to *interference temperature*-type schemes.

We will illustrate how simple receiver-side cognition may improve upon interference-temperature transmission schemes through having primary users share their *codebooks* with secondary receivers. This allows the primary and the secondary messages to be jointly decoded at the secondary receiver, which may permit higher secondary rates. This is only possible under suitable primary transmission rate and SNR at the cognitive receivers (which are beyond the cognitive link's control), and it is in this sense that we use the term *opportunistic*.

Contributions. We illustrate the potential of OIC to increase the achievable secondary rate region for three secondary multi-user channels: a multiple-access channel (MAC), an interference channel (IC) and a broadcast channel (BC). On the other hand, for given desired secondary rates, we show that the primary system will see less interference from the secondary users. The latter is particularly important for channels with multiple transmitters in which the interference towards the primary may limit the performance. We carefully explore what assumptions on the primary system are made and how these are traded off for the enlarged regions. That is, in order to perform OIC, the secondary system must know the primary's 1) codebook, 2) transmission rate and 3) interference margin. Once these are provided to the secondary system (outside the scope of this work), the primary link need not change any of its behavior, remaining oblivious to the secondary system operation, and thus implies that the primary system does **not** time-share the channel with the secondary users, unlike the spectral-gap (white-space) filling solutions. We evaluate the obtained achievable rate regions in Gaussian noise, which graphically illustrates the potential benefits. Outer bounds are the subject of ongoing work.

II. Problem definition, notation

The following assumptions will be exploited to improve spectral efficiency:

(a): Interference margin. A single primary user communicates at a rate R_p bits per channel use (bcpu) and can tolerate interference of power up to I_{max}. If the actual interference at the primary receiver is of power I_{actual} then we call $I_{margin} = I_{max} - I_{actual}$ the *interference margin* at the primary receiver, which we assume to be non-trivial.

(b): Codebook knowledge. Secondary / cognitive Txs (CTxs) have knowledge of I_{margin}, the primary rate R_p and the primary codebook. *Whether*, and not *how* this is obtained is the focus of this work. We note that this need not cause any security issues for the primary user, which could easily encrypt data at a higher layer. By making the codebooks available, the cypher text would be able to be constructed at the secondary receivers, but the plain text would still remain hidden.

(c) Primary oblivious to secondary operation. The primary transmitter (PTx) does not change its transmission strategy.

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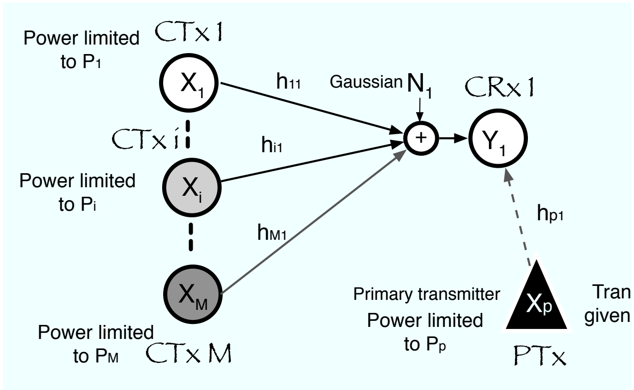


Fig. 1. The multiple access channel with OIC.

That is, besides making their codebooks public, and allowing the interference margin I_{margin} and rate R_p to be known, no other changes in the primary transmission are needed.

(d) Channel knowledge. Cognitive Tx and Rxs know all channel gains h_{ij} ($h_{ij} = h_{ji}$) between Tx i and receiver j which remain fixed over the transmission duration.

The SNR of the primary signal at CRx i is denoted by γ_{pi}, while the SNR of the cognitive transmitter i (CTx i) at the cognitive receiver j (CRx j) is denoted by γ_{ij}. All links are subject to independent real unit-variance AWGN, denoted $\mathcal{N}(0,1)$. The primary input is denoted as X_p, which is assumed to be generated iid according to $\mathcal{N}(0,P_p)$ and is of rate R_p. For notational convenience, define $C(x) = \frac{1}{2}\log_2(1+x)$, for $x \geq 0$. Definitions of a code, an achievable rate (region) and the capacity (region) all follow standard definitions for multi-user channels [7]. Furthermore, define $\mathbf{X}_T$ as the vector of X_i such that $i \in T$ for some set T with complement $\overline{T}$. Each transmission has sufficiently many n channel uses so as to justify the usage of random codebooks and vanishing error probability. A *single-user decoder* for Gaussian channels is used to mean a joint typicality decoder in which a single message is decoded at a time.

III. The Multiple Access Channel with OIC

We consider an $M \to 1$ cognitive multiple access channel (MAC) in which M independent cognitive Txs, CTx 1, $\cdots$, CTx M wish to communicate with a single cognitive Rx, CRx 1, as shown in Fig. 1. The CRx receives the primary transmission of rate R_p at an SNR of γ_{p1}, which it may be able to decode. The primary receiver (PRx) is operating at a positive interference margin I_{margin}, which is known to the CTxs. Between the transmitters and receivers there are AWGN channels. If the symbol transmitted by CTx i is given by X_i of power P_i, then the output at the CRx 1, Y_1, is given by

$$Y_1 = \sum_{i=1}^{M} h_{i1}X_i + h_{p1}X_p + N_1, \quad \text{where } N_1 \sim \mathcal{N}(0,1).$$

The admissible powers of the $M \to 1$ MAC $\mathbf{P} = (P_1, P_2, \cdots, P_M)$ lie in the region defined by the interference margin I_{margin} and channel gains to the primary Rx, h_{ip}:

$$P_{MAC} = \{(P_1, P_2, \cdots, P_M) \text{ such that } |h_{1p}|^2 P_1 + |h_{2p}|^2 P_2 + \cdots + |h_{Mp}|^2 P_M \leq I_{margin}\}.$$

The two main results of this section are Theorems 1 and 2. In Theorem 1, an achievable rate region for the $M \to 1$ MAC, $\mathcal{R}_{MAC}$ is derived as one of two regions depending on whether the cognitive Rx may decode the primary signal or not. If opportunistic decoding is possible, the region is that of an $M+1 \to 1$ MAC, reduced to an M-dimensional region by *fixing* the rate of one of the users (the primary) to R_p. We state the theorems, whose proofs may be found in the [8] online due to lack of space here.

Theorem 1: For a given R_p^*, γ_{p1}, an achievable rate region $\mathcal{R}_{MAC}$ is given by the convex hull of the union over all $\mathbf{P} = (P_1, P_2, \cdots, P_M) \in \mathcal{P}_{MAC}$ of the regions $\mathcal{R}(\mathbf{P}) = (R_1, R_2, \cdots, R_p)$ such that if $R_p^* \geq C(\gamma_{p1})$, the primary signal is treated as noise, resulting in the region:

$$\bigcap_{T \subset \{1,2,\cdots M\}} \left(\sum_{t \in T} R_t\right) \leq I(Y_1; \mathbf{X_T}|\mathbf{X_{\overline{T}}}),$$

and if $R_p^* < C(\gamma_{p1})$ then the primary signal may be decoded at CRx 1, resulting in the region

$$\bigcap_{\substack{T \subset \{1,2,\cdots M,p\} \\ T \neq \{p\}}} \left(\sum_{t \in T} R_t\right) \leq I(Y_1; \mathbf{X_T}|\mathbf{X_{\overline{T}}}), \quad \text{where } R_p = R_p^*.$$

These mutual information terms may be worked out in Gaussian noise, but are left as above for simplicity.

Theorem 1 illustrates that the opportunistic decoding region depends on the interference margin I_{margin}, the primary transmission rate R_p^*, and the SNR at which the primary signal is received at CRx 1, γ_{p1}. This region is achieved by creating a "virtual" multiple-access channel between the M cognitive Txs and the primary PTx to CRx 1. We do not need the constraint for $t = \{p\}$ as the secondary receiver need not decode the primary user. It is well known that the corner points on the MAC polytope are achieved through successive interference cancellation / single-user decoding and that the faces of the polytope may then be achieved by time-sharing between these corner points. Rate tuples on surfaces which would require cognitive users time-sharing with the primary user should be excluded from consideration due to our assumed constraint that the primary user does *not* alter its protocol. In Theorem 2 we demonstrate that by carefully rate splitting the cognitive rates, all achievable $M-$ tuples may be obtained using *only* single-user decoders, based on results in [9], thereby allowing this region to be achieved with an oblivious primary Tx/Rx pair (proof in [8]).

Theorem 2: All points on the boundary of the rate region $\mathcal{R}_{MAC}$ of Theorem 1 may be achieved using single-user decoding at both primary and secondary receivers without time-sharing with the primary Tx.

IV. The Interference Channel (IC) with OIC

We now consider an IC in which two independent CTxs wish to communicate with two independent CRxs, as shown in Fig. 2. The CRxs receive the primary transmission of rate R_p at an SNR of γ_{p1} and γ_{p2} respectively, which none, one, or both may be able to decode. The primary receiver

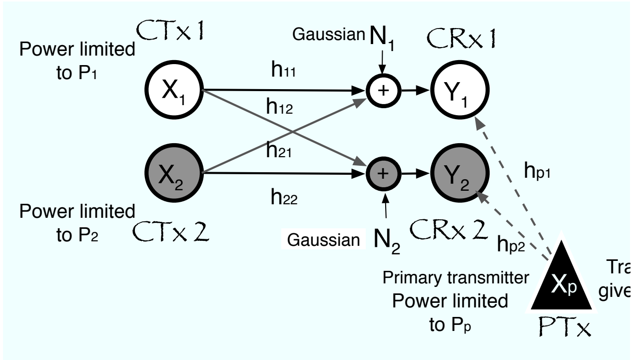


Fig. 2. The interference channel with OIC.

operates at a positive interference margin I_{margin} known to the CTxs. Between the transmitters and receivers there are AWGN channels. If the symbol transmitted by cognitive CTx i at a given channel use is given by X_i of power P_i, then the outputs Y_1, Y_2 at the cognitive receivers are

$$Y_1 = h_{11}X_1 + h_{21}X_2 + h_{p1}X_p + N_1, \text{ where } N_1 \sim \mathcal{N}(0,1),$$
$$Y_2 = h_{12}X_1 + h_{22}X_2 + h_{p2}X_p + N_2, \text{ where } N_2 \sim \mathcal{N}(0,1),$$

subject to the power constraints

$$P_{INT} = \left\{(P_1, P_2) \text{ such that } |h_{1p}|^2 P_1 + |h_{2p}|^2 P_2 \le I_{margin}\right\}.$$

In the IC with OIC, because there are two receivers with primary receive SNRs of γ_{p1} and γ_{p2} respectively, four decoding scenarios exist: neither, one, the other, or both of the CRxs may decode the primary's message and "subtract" it off.

To define an achievable rate region we rate split the inputs X_1 and X_2 of rates R_1 and R_2 respectively, into private and public portions, as is done in the celebrated Han and Kobayashi achievable rate region for the IC [10]. That is, let $R_1 = R_{11} + R_{12}$, $P_1 = P_{11} + P_{12}$, and $X_1 = X_{11} + X_{12}$, where X_{11} encodes a private message from CTx 1 to CRx 1 of rate R_{11} generated iid according to $\mathcal{N}(0, P_{11})$. Similarly, X_{12} encodes the public message from CTx 1 to both CRx 1 and CRx 2 at rate R_{12} and is generated iid according to $\mathcal{N}(0, P_{12})$. Similarly, X_{21}, R_{21}, P_{21} describe the public messages originating from CTx 2, while X_{22}, R_{22}, P_{22} describe the private messages of CTx 2. Let $T_1 = \{11, 12, 21\}$, $T_1^p = \{11, 12, 21, p\}$, $T_2 = \{12, 21, 22\}$ and $T_2^p = \{12, 21, 22, p\}$.

Theorem 3: For a given R_p^*, γ_{p1} and γ_{p2}, an achievable rate region $\mathcal{R}_{INT}$ is given by the convex hull of the union over all $\mathbf{P} = (P_1, P_2) \in \mathcal{P}_{INT}$ of the regions $\mathcal{R}(\mathbf{P}) = (R_1 = R_{11} + R_{12}, R_2 = R_{21} + R_{22})$ such that:

1) If $R_p^* \ge \max(C(\gamma_{p1}), C(\gamma_{p2}))$ then the primary signal is treated as noise at both CRxs, with resulting region:

$$\bigcap_{T \subset T_1} \left(\sum_{t_1 \in T} R_{t_1} \right) \le I(Y_1; \mathbf{X_T} | \mathbf{X_{\overline{T}}}),$$

$$\bigcap_{T \subset T_2} \left(\sum_{t_2 \in T} R_{t_2} \right) \le I(Y_2; \mathbf{X_T} | \mathbf{X_{\overline{T}}}).$$

2) If $C(\gamma_{p2}) < R_p^* < C(\gamma_{p1})$, then CRx 1 can decode the primary, while CRx 2 cannot, with resulting region:

$$\bigcap_{T \subset T_1^p, T \ne \{p\}} \left(\sum_{t_1 \in T} R_{t_1} \right) \le I(Y_1; \mathbf{X_T} | \mathbf{X_{\overline{T}}}), \text{ for } R_p = R_p^*$$

$$\bigcap_{T \subset T_2} \left(\sum_{t_2 \in T} R_{t_2} \right) \le I(Y_2; \mathbf{X_T} | \mathbf{X_{\overline{T}}}).$$

3) If $C(\gamma_{p1}) < R_p^* < C(\gamma_{p2})$, then CRx 2 can decode the primary, while CRx 1 cannot, with resulting region:

$$\bigcap_{T \subset T_1} \left(\sum_{t_1 \in T} R_{t_1} \right) \le I(Y_1; \mathbf{X_T} | \mathbf{X_{\overline{T}}})$$

$$\bigcap_{T \subset T_2^p, T \ne \{p\}} \left(\sum_{t_2 \in T} R_{t_2} \right) \le I(Y_2; \mathbf{X_T} | \mathbf{X_{\overline{T}}}), \text{ for } R_p = R_p^*.$$

4) If $R_p^* < C(\gamma_{p1})$ and $R_p^* < C(\gamma_{p2})$ then both CRxs can decode the primary message, resulting in the region:

$$\bigcap_{T \subset T_1^p, T \ne \{p\}} \left(\sum_{t_1 \in T} R_{t_1} \right) \le I(Y_1; \mathbf{X_T} | \mathbf{X_{\overline{T}}}), \text{ for } R_p = R_p^*$$

$$\bigcap_{T \subset T_2^p, T \ne \{p\}} \left(\sum_{t_2 \in T} R_{t_2} \right) \le I(Y_2; \mathbf{X_T} | \mathbf{X_{\overline{T}}}), \text{ for } R_p = R_p^*.$$

Whether this region is achievable solely through the use of single-user decoders and without time-sharing with the PTx (as in the MAC with OIC) is the subject of ongoing research. The capacity region of the IC with OIC is an open problem, at least as difficult as the IC capacity region.

V. The Broadcast Channel with OIC

We lastly consider a channel in which a primary transmitter-receiver (PTx-PRx) pair and a single secondary transmitter (CTx) wishing to communicate independent messages to two secondary receivers (CRx 1, CRx 2) co-exist. All links are subject to independent real AWGN with $\mathcal{N}(0,1)$, and the channel model from Fig. 3 is described by:

$$Y_1 = h_1 X + h_{p1} X_p + N_1, \; N_1 \sim \mathcal{N}(0,1)$$
$$Y_2 = h_2 X + h_{p2} X_p + N_2, \; N_2 \sim \mathcal{N}(0,1).$$
$$Y_p = h_{1p} X_1 + h_{pp} X_p + N_p, \; N_P \sim \mathcal{N}(0,1).$$

An achievable rate region may be constructed as an extension of Marton-like schemes as follows. Although we are ultimately interested in the BC with OIC in a memoryless AWGN channel, we present an achievable rate region for the discrete memoryless BC with OIC in this section (more intuitive and general), and evaluate the bounds under certain assumed Gaussian inputs. The CTx has two messages: w_1 and w_2, encoded using codewords U and V, generated iid according to $p(u,v)$. CTx sends the signal X which is generated iid according to $p(x|u,v)$. The received signals at CRx 1 and CRx 2 are Y_1 and Y_2, obtained from the inputs X and X_p according to $p(y_1, y_2|x, x_p) = p(y_1|x, x_p)p(y_2|x, x_p)$. An achievable rate region for the BC with OIC may be obtained

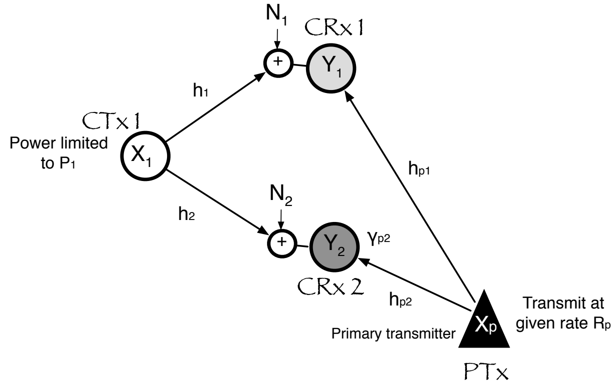


Fig. 3. The broadcast channel with OIC.

by considering four separate cases, depending on whether CRx 1 and/or CRx 2 may decode the primary message.

Theorem 4: For a given primary rate $R_p = R_p^*$, and given γ_{p1} and γ_{p2}, an achievable rate region $\mathcal{R}_{BC}$ is given by the convex hull of the union over all distributions $p(u,v,x) = p(u,v)p(x|u,v)$ of the regions $\mathcal{R}(\mathbf{P}) = \{(R_1, R_2)\}$ such that:

1) If $R_p^* \geq I(X_p;Y_1|X)$ and $R_p^* \geq I(X_p;Y_2|X)$ then the primary signal is treated as noise at both Rxs:

$$R_1 \leq I(U;Y_1) \qquad R_2 \leq I(V;Y_2)$$
$$R_1 + R_2 \leq I(U;Y_1) + I(V;Y_2) - I(U;V)$$

2) If $I(X_p;Y_2|X) < R_p^* < I(X_p;Y_1|X)$, then CRx 1 can decode the primary, while CRx 2 cannot:

$$\begin{aligned} R_1 &\leq \min(I(U;Y_1|X_p), I(U,X_p;Y_1) - R_p^*) \\ R_2 &\leq I(V;Y_2) \\ R_1 + R_2 &\leq \min(I(U;Y_1|X_p), I(U,X_p;Y_1) - R_p^*) \\ &\quad + I(V;Y_2) - I(U;V) \end{aligned}$$

3) If $I(X_p;Y_1|X) < R_p^* < I(X_p;Y_2|X)$, then CRx 2 can decode the primary, while CRx 1 cannot:

$$\begin{aligned} R_1 &\leq I(U;Y_1) \\ R_2 &\leq \min(I(V;Y_2|X_p), I(V,X_p;Y_2) - R_p^*) \\ R_1 + R_2 &\leq \min(I(V;Y_2|X_p), I(V,X_p;Y_2) - R_p^*) \\ &\quad + I(U;Y_1) - I(U;V) \end{aligned}$$

4) If $R_p^* < I(X_p;Y_1|X)$ and $R_p^* < I(X_p;Y_2|X)$ then both Rxs can decode the primary message:

$$\begin{aligned} R_1 &\leq \min(I(U;Y_1|X_p), I(U,X_p;Y_1) - R_p^*) \\ R_2 &\leq \min(I(V;Y_2|X_p), I(V,X_p;Y_2) - R_p^*) \\ R_1 + R_2 &\leq \min(I(U;Y_1|X_p), I(U,X_p;Y_1) - R_p^*) \\ &\quad + \min(I(V;Y_2|X_p), I(V,X_p;Y_2) - R_p^*) - I(U;V) \end{aligned}$$

An outline of the proof is found in [8] online.

VI. Graphical comparison of opportunistic and non-opportunistic rate regions

In this section we illustrate the impact of opportunistic interference cancellation (or opportunistic cognitive decoding) graphically. We consider a $2 \rightarrow 1$ MAC, a $2 \rightarrow 2$ IC, and a $1 \rightarrow 2$ BC in which the cognitive Rx(s) wish to opportunistically decode the messages of a single primary Tx-Rx pair. As in [11], [10], Theorems 1, 3 and 4 can readily be extended to memoryless channels with discrete time and continuous alphabets by finely quantizing the input, output, and interference variables (Gaussian in this case). We now evaluate the mutual information terms of Theorems 1, 3, and 4 under specific Gaussian input distributions and plot the obtained regions in Fig. 4 and 5.

Channel parameters for MAC and IC with OIC: We assume all noise powers are equal to 1, while $h_{11} = 1, h_{21} = 0.5, h_{12} = 0.5, h_{22} = 1, h_{p1} = 0.3, h_{p2} = 0.5, h_{1p} = h_{2p} = 0.2$ and $P_p = 10$. These are the same for both the MAC and interference channels with OIC. Notice that all parameters are specified except the primary transmission rate R_p, the PTx to PRx channel, h_{pp}, and the cognitive transmit powers P_1 and P_2. When all other parameters are fixed, by adjusting h_{pp} and R_p, different subsets of the cognitive Rxs will be able to decode the primary message. We fix the interference margin at $I_{margin} = 1$,[1] so that the primary rate R_p and h_{pp} are related as $R_p = \log_2\left(1 + \frac{|h_{pp}|^2 P_p}{1+I_{margin}}\right)$. We summarize the remaining parameters and cases in Table I. The transmit powers of the cognitive transmitters may be anything such that the interference margin is met, i.e. $(P_1, P_2) \in \mathcal{P}_{MAC}$ and $(P_1, P_2) \in \mathcal{P}_{INT}$ respectively, which, with the given parameters, are $\mathcal{P}_{MAC} = \mathcal{P}_{INT} = \{(P_1, P_2) | P_1 + P_2 \leq 25\}$. This is more general than fixing the transmit powers.

Channel parameters for BC with OIC: For the BC with OIC, we vary the channel to visit the four different OIC scenarios described in Theorem 4. Specifically, let $\gamma_{pi} = |h_{pi}|^2 P_p$ then the parameters used in the four cases of Theorem 4 are: $P = 6$, noise power 1, $R_p = 0.5$, $h_1 = 1, h_2 = 0.7$. Case 1: $\gamma_{p1} = \gamma_{p2} = 0.3$. Case 2: $\gamma_{p1} = 1, \gamma_{p2} = 0.3$. Case 3: $\gamma_{p1} = 0.3, \gamma_{p2} = 1$. Case 4: $\gamma_{p1} = \gamma_{p2} = 1$.

To evaluate the mutual information terms of Theorems 1, 3 and 4, the following *Gaussian input distributions* are assumed:

In Theorem 1: For power split $0 \leq \lambda \leq 1$, et $\bar{\lambda} := 1 - \lambda$,

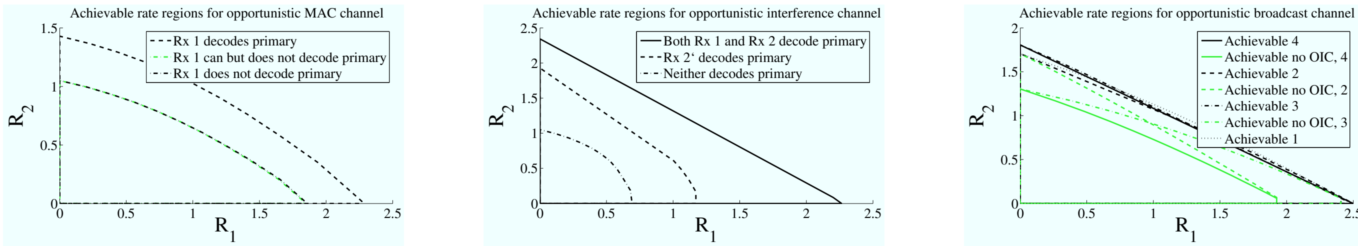
$$X_p \sim \mathcal{N}(0, P_p),\ X_1 \sim \mathcal{N}(0, \lambda 25),\ X_2 \sim \mathcal{N}(0, \bar{\lambda} 25).$$

In Theorem 3: For power splits $0 \leq \lambda, \alpha, \beta \leq 1$, let $\bar{\alpha} :=$

[1]This margin was chosen to equal the noise power as it seems plausible that systems are likely to be able to withstand double the background noise.

TABLE I
Parameters used for Gaussian MAC and IC with OIC.

MAC with OIC	Interference channel with OIC
CRx 1 cannot decode $h_{pp} = 1$ $R_p = 1.2925$	CRx 1 and CRx 2 cannot decode $h_{pp} = 1$ $R_p = 1.2925$
	Only CRx 2 can decode $h_{pp} = 0.4$ $R_p = 0.424$
CRx 1 can decode $h_{pp} = 0.1$ $R_p = 0.0352$	CRx 1 and CRx 2 can both decode $h_{pp} = 0.1$ $R_p = 0.0352$



(a) Rate regions for opportunistic MAC channel with $(P_1, P_2) \in \mathcal{P}_{MAC}$

(b) Rate regions for opportunistic interference channel with $(P_1, P_2) \in \mathcal{P}_{INT}$

(c) Rate regions for opportunistic BC with P = 6, numbered cases in "Channel parameters for BC with OIC"

Fig. 4. Impact of opportunistic interference cancellation.

$1-\alpha, \bar{\beta} = 1-\beta,$

$$X_p \sim \mathcal{N}(0,P_p), X_{11} \sim \mathcal{N}(0,\lambda\alpha 25),\ X_{12} \sim \mathcal{N}(0,\lambda\bar{\alpha}25),$$
$$X_{21} \sim \mathcal{N}(0,\bar{\lambda}\beta 25),\, X_{22} \sim \mathcal{N}(0,\bar{\lambda}\bar{\beta}25),$$
$$X_1 = X_{11}+X_{12},\, X_2 = X_{21}+X_{22}$$

In Theorem 4: For some power split $0 \le \lambda \le 1$, select the input distributions

$$X_p \sim \mathcal{N}(0,P_p), X_1 \sim \mathcal{N}(0,\lambda P),\ X_2 \sim \mathcal{N}(0,\bar{\lambda}P),$$
$$X = X_1 + X_2,\ U = X_1 + \alpha X_2,\ V = \beta X_1 + X_2,$$

where α, β are arbitrary real coefficients such that the right hand sides of the bounds of Theorem 4 remain positive. Such an approach is motivated by [11].

Plots. Fig. 4(a),(b) and (c) illustrates the improvement in the rate region when using opportunistic decoding at the cognitive receiver of a MAC, IC and BC respectively. The use of OIC is seen to increase achievable rates at the expense of increased decoding complexity - acceptable as our computing abilities continue to advance - and codebook knowledge - an assumption whose validity will depend on the scenario of interest. Outer bounds are the subject of ongoing work [12].

Effect on the primary user. The benefits of OIC are not only relevant to the secondary links. Primary receivers see a significant reduction in the amount of interference they undergo from the secondary transmitters if OIC is enabled. Fig. 5 illustrates that if the secondary system is determined to send at a particular sum-rate, the interference to the primary will be notably reduced if the primary users make their codebooks, transmission rate and interference margins public. This is because the cognitive transmitters are able to reduce their transmission powers if the cognitive receivers experience less interference from the primary system.

VII. Conclusion

We have extended work on *opportunistic interference cancellation (OIC)* to three multi-user scenarios in which a single primary Tx-Rx link communicates simultaneously with a group of cognitive (secondary) users that form one of three classical multi-user channels: 1) a multiple access channel (MAC), 2) interference channel (IC), or 3) a broadcast channel (BC). Assuming the cognitive users are permitted to transmit subject to peak interference at the primary receiver, we derived achievable rate regions which, when evaluated in Gaussian noise, demonstrated the benefits of exploiting this codebook knowledge at the secondary Rxs through opportunistically canceling the interference seen from the primary Tx. Interestingly, these gains are possible simply through codebook sharing and do not require the primary link to change its encoders/decoders.

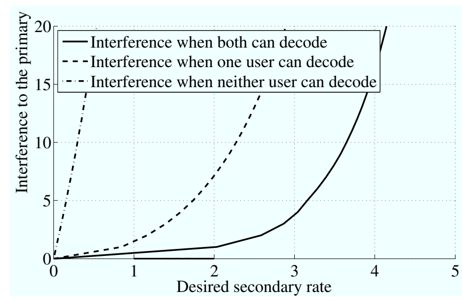


Fig. 5. The interference to the primary for given desired secondary rates in the interference channel under the different decoding scenarios.

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