Achievable Rate Analysis of Opportunistic Transmission in Bursty Interference Networks

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***Abstract*— In this letter, we consider the K-user *bursty* fading interference channel, where each user transmits data intermittently with a certain probability under the *local* channel state information assumption. In particular, we consider three different transmission techniques with fixed power: random transmission (RT), opportunistic transmission-based on generating interference (OT-1), and opportunistic transmission based on desired channel gain (OT-2). We mathematically analyze the *average* achievable rates of the three transmission techniques, which is the first theoretical result to the best our knowledge. The analysis is validated via extensive computer simulations. It is shown that the opportunistic transmission techniques (OT-1 and OT-2) result in better performance in terms of the achievable rate compared with the RT as well as the conventional non-bursty transmission technique.**

***Index Terms*— Interference management, K-user fading interference channel, achievable rate, bursty transmission, opportunistic communication.**

I. Introduction

INTERFERENCE has been considered as one of the most challenging issues for improving performance of modern wireless networks. Many interference management techniques have been proposed by exploiting opportunistic user scheduling, transmit/receive beamforming, etc [1]–[3]. Although most previous studies assumed that interferers are always present, some interferers may not transmit data due to bursty data traffic or medium access control mechanism in practical systems.

Recently, several studies considered the *bursty* interference characteristics. Khude *et al.* [4] characterized capacity region of *two-user* bursty interference channels by exploiting degraded message set under two possible states: either there is interference or there is not. In addition, the capacity region of the symmetric *two-user* deterministic bursty interference channel was also characterized with feedback [5]. More recently, two-user bursty interference channel with output feedback was investigated in [6]. However, the rate-splitting technique with degraded message set, proposed in [4] and [5], requires for the receivers to know the codebooks of interferers, which may not be feasible in practice. In addition, the analysis on capacity region in [4]–[6] was limited to the two-user case.

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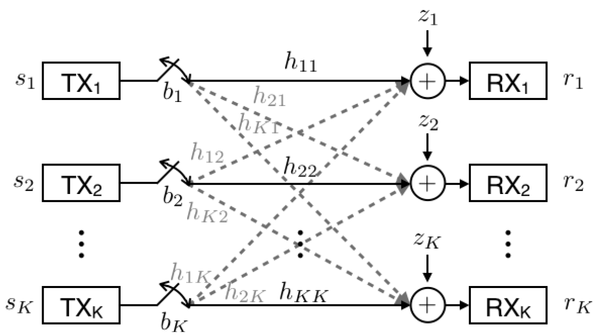

Fig. 1. System model of K-user bursty fading interference channel.

In this letter, we consider the K-user bursty fading interference channel and propose two different transmission techniques: opportunistic transmission based on the generating interference (OT-1)[1] and opportunistic transmission based on the desired channel gain (OT-2). In addition, we mathematically analyze the achievable rates of the proposed techniques. We assume a simple but practical single-user detector at receivers, which implies that the receivers treat interference as noise.

II. System Model

As described in Fig. 1, we consider the K-user bursty fading interference channel which consists of K transmitter (TX) – receivers (RX) pairs. We assume that each TX or RX is equipped with a single antenna and assume the block fading channel where channel coefficients remain constant during one transmission block (e.g., one frame) and independently changes over every transmission block. The term h_{ij} denotes the wireless channel coefficient from the j-th TX to the i-th RX and it is assumed to be an independent but non-identically distributed (i.n.d.) complex Gaussian random variable with zero mean and different variances. To be specific, $h_{ij} \sim \mathcal{CN}(0, 1)$ for $j \neq i$ and $h_{ii} \sim \mathcal{CN}(0, \sigma_i^2)$ with $\sigma_i^2 \geq 1$, where $i, j \in \mathcal{K} \triangleq \{1, \cdots K\}$. Thus, the desired channel gain is larger than the interference channel gains, which is realistic in the sense that the TX–RX pair is determined based on the distance between them in general.[2]

Therefore, the received signal at the i-th RX is given by

$$r_i = b_i\sqrt{P_i}h_{ii}s_i + \sum_{j\in\mathcal{K}\setminus i} b_j\sqrt{P_j}h_{ij}s_j + z_i, \quad (1)$$

where P_j and s_j denote the transmit power and the desired symbol of the j-th transmitter, respectively. In this letter,

[1]This technique was first proposed in [7], but Jung *et al.* [7] only considered two-user (or equivalently two-cell) interference channel.

[2]Note that all channel coefficients are different from each other in reality.

we assume that $P_j = P$, and $\mathbb{E}[|s_j|^2] = 1$ for $\forall j$. z_i denotes the circular symmetric complex additive white Gaussian noise with zero mean and variance of N_0, i.e., $z_i \sim \mathcal{CN}(0, N_0)$. Let $\rho \triangleq P/N_0$. The term $b_j \in \{0, 1\}$ indicates the transmission state of the j-th TX, which is equal to 1 or 0 for an active state or a non-active state, respectively. Let α_j be the probability that the j-th TX is active. Then, α_j denotes the probability that the j-th TX sends data to the j-th RX, which is modeled by a Bernoulli random variable, $b_j \sim \mathrm{Bern}(\alpha_j)$. In this letter, we assume that all TXs have the same active probability, i.e., $\alpha_j = \alpha$ for $\forall j$. By using the channel reciprocity of time division duplexing (TDD) system, we assume the local channel state information (CSI) for all TXs and RXs as in [1]–[3]. We also assume that there is no central scheduler to control data transmission of TXs, and thus each TX determines data transmission based on its local CSI in a distributed manner.

III. Achievable Rate Analysis

In this section, we mathematically analyze the achievable rates of three different transmission techniques in a bursty fading interference channel: random transmission (RT) and two proposed opportunistic transmission techniques (OT-1 and OT-2). For a given active probability α, in the RT technique, each TX sends data with the probability α without consideration of channel states. In the OT-1 technique, each TX sends data only when all generating interference gain is lower than a certain threshold. In the OT-2 technique, each TX sends data only when its desired channel gain to its corresponding RX is larger than a certain threshold. The overall procedure of the three transmission techniques are summarized as follows: First, each TX determines whether it sends data to the corresponding RX or not based on its activation probability and local CSI. Second, active TXs send a request-to-send (RTS) packet as in IEEE 802.11 specifications, and the corresponding RX computes the received signal-to-interference ratio (SINR) value. Third, the RXs that receive the RTS packet from its corresponding TX send clear-to-send (CTS) packet, where the CTS packet includes their received SINR information. Finally, each active TX sends its data packet with a proper data-rate to the corresponding RX, based on the received SINR information.

Let $\mathcal{B} = \{j | b_j = 1, j \in \mathcal{K}\}$ denote the index set of the active TXs and $n = |\mathcal{B}|$. Without loss of generality, we focus on the achievable rate of the first TX–RX pair, i.e., $1 \in \mathcal{B}$. Then, for a given n, the average achievable rate of the first TX–RX pair is expressed as:

$$R_n\left(\frac{1}{\rho}\right) = \mathbb{E}\left[\log_2\left(1 + \frac{|h_{11}|^2}{I_n/P + 1/\rho}\right)\right], \tag{2}$$

where $I_n = \sum_{j\in\mathcal{B}, j\neq 1} |h_{1j}|^2 P$ and $I_1 = 0$.

In (2), $R_n(1/\rho)$ depends on n. Then, by averaging on n, the average achievable rate of the first TX–RX pair is obtained as:

$$R_{\mathsf{avg}}\left(\frac{1}{\rho}\right) = \sum_{n=0}^{K-1} \binom{K-1}{n} \alpha^{n+1}(1-\alpha)^{K-n-1} R_{n+1}\left(\frac{1}{\rho}\right). \tag{3}$$

In the following subsections, we analyze the achievable rate for a given n for three different transmission techniques. Then, the average achievable rate for each transmission technique is obtained by plugging it into (3).

A. Random Transmission (RT)

In the RT technique, b_j of the j-th TX is determined as:

$$b_j = \begin{cases} 1 & \text{with probability } \alpha \\ 0 & \text{with probability } 1-\alpha. \end{cases} \tag{4}$$

When $n = 1$, there is no interference and the achievable rate of the RT technique is given by

$$R_1^{\mathsf{RT}}\left(\frac{1}{\rho}\right) = \int_0^\infty \log_2(1 + x\rho) f_X^{\mathsf{RT}}(x)dx = \frac{e^{\frac{\lambda}{\rho}} \mathrm{E}_1\left(\frac{\lambda}{\rho}\right)}{\ln 2}, \tag{5}$$

where X represents the random variable (RV) denoting the desired channel gain and its probability density function (PDF) is given as $f_X^{\mathsf{RT}}(x) = \lambda e^{-\lambda x}$, where $\lambda = 1/\sigma_i^2$. For the first TX–RX, $\lambda = 1/\sigma_1^2$. In (5), $\mathrm{E}_1(x)$ denotes the exponential integral function which is defined as $\int_x^\infty e^{-t}t^{-1}dt$ [8].

When $n = 2$, there are two active users in the network and one interferer exists. The achievable rate of the RT scheme for $n = 2$ is expressed as follows:

$$\begin{aligned} R_2^{\mathsf{RT}}\left(\frac{1}{\rho}\right) &= \int_0^\infty \int_0^\infty \log_2\left(1 + \frac{x}{y + 1/\rho}\right) f_{XY}^{\mathsf{RT}}(x, y)dxdy \\ &= \int_0^\infty R_1^{\mathsf{RT}}(1/\rho + y) f_Y^{\mathsf{RT}}(y)dy \\ &= \frac{\mathrm{E}_1(1/\rho)\exp(1/\rho) - \mathrm{E}_1(\lambda/\rho)\exp(\lambda/\rho)}{(\lambda - 1)\ln 2} \\ &= \frac{\mathrm{E}_1(1/\rho)\exp(1/\rho)}{(\lambda-1)\ln 2} - \frac{1}{(\lambda-1)} R_1^{\mathsf{RT}}\left(\frac{1}{\rho}\right), \end{aligned}$$

where Y indicates the RV denoting the interference channel gain, i.e., $f_Y^{\mathsf{RT}}(y) = e^{-y}$ for $y \geq 0$, and $f_{XY}^{\mathsf{RT}}(x, y)$ denotes a joint PDF with X and Y. Since all channel coefficients are independent, $f_{XY}^{\mathsf{RT}}(x, y) = f_X^{\mathsf{RT}}(x) f_Y^{\mathsf{RT}}(y)$.

Interestingly, for $n \geq 3$, $R_n^{\mathsf{RT}}(\rho)$ can be rewritten as:

$$\begin{aligned} R_n^{\mathsf{RT}}\left(\frac{1}{\rho}\right) &= \int_0^\infty R_{n-1}^{\mathsf{RT}}(1/\rho + y)e^{-y}dy \\ &= \frac{1}{(\lambda-1)\ln 2} B_n\left(\frac{1}{\rho}\right) - \frac{1}{(\lambda-1)} R_{n-1}^{\mathsf{RT}}(\rho), \end{aligned} \tag{6}$$

where $B_n(1/\rho)$ represents integral of $\mathrm{E}_1(y)$. By using [8, eq. (5.231)], $B_n(1/\rho)$ can be obtained as:

$$\begin{aligned} \frac{B_n(1/\rho)}{\exp(1/\rho)} &= \underbrace{\int_0^\infty \cdots \int_0^\infty}_{n-1} \mathrm{E}_1\left(\frac{1}{\rho} + \sum_{m=1}^{n-1} y_m\right) dy_1 \cdots dy_{n-1} \\ &= \frac{1}{\exp(1/\rho)} \left(\frac{\mathrm{E}_1\left(\frac{1}{\rho}\right)\exp\left(\frac{1}{\rho}\right)}{(-\rho)^{n-1}} + \sum_{m=0}^{n-2} \frac{m!}{(-\rho)^{n-2-m}}\right). \end{aligned} \tag{7}$$

Then, (6) is rewritten as:

$$R_{n+1}^{\mathsf{RT}}\left(\frac{1}{\rho}\right) + \frac{R_n^{\mathsf{RT}}(1/\rho)}{\lambda - 1} = \frac{1}{n!(\lambda-1)\ln 2} B_n\left(\frac{1}{\rho}\right). \tag{8}$$

Therefore, $R_{\mathsf{avg}}^{\mathsf{RT}}(1/\rho)$ can be obtained by plugging (8) into (3) for a given α.

B. Opportunistic Transmission Based on Generating Interference (OT-1)

As noted before, in the OT-1 technique, b_j of the j-th TX is determined as:

$$b_j = \begin{cases} 1 & \text{if } y_{ij} < \eta, \quad \forall i \neq j \\ 0 & \text{otherwise,} \end{cases} \tag{9}$$

where $y_{ij} \triangleq |h_{ij}|^2$ denotes the generating interference gain from the j-th TX to the i-th RX and η denotes a certain threshold. The activation probability at the TX is given as $\alpha = (1-e^{-\eta})^{K-1}$. For a given activation probability, the threshold is given as $\eta = -\ln\left(1-\alpha^{\frac{1}{K-1}}\right)$.

For $n = 1$, since there is no interference, the achievable rate of the OT-1 technique is the same as that of the RT technique, i.e., $R_1^{\text{OT-1}} = R_1^{\text{RT}} \triangleq \beta(1)F_1(1/\rho)$ where $\beta(n)$ is represented as constant term. For $n = 2$, as in (6), the achievable rate of the OT-1 technique is given by:

$$\begin{aligned} &R_2^{\text{OT-1}}\left(\frac{1}{\rho}\right) \\ &= \int_0^{\eta} R_1^{\text{OT-1}}\left(\frac{1}{\rho}+y\right) f_Y(y)dy \\ &= \frac{\exp(1/\rho)}{(1-e^{-\eta})(\lambda-1)}\Big[\mathrm{E}_1(\lambda(1/\rho+\eta))\exp((\lambda-1)(1/\rho+\eta)) \\ &- \mathrm{E}_1(\lambda/\rho)\exp((\lambda-1)/\rho) - \mathrm{E}_1(1/\rho+\eta) + \mathrm{E}_1(1/\rho)\Big]/\ln 2 \\ &\triangleq \frac{\beta(2)}{(\lambda-1)}\left(H_2(1/\rho+\eta) - H_2(1/\rho)\right), \end{aligned} \tag{10}$$

where $f_Y(y)$ denotes the PDF of Y which is given as:

$$f_Y^{\text{OT-1}}(y) = \begin{cases} e^{-y}/(1-e^{-\eta}) & \text{if } 0 \le y < \eta \\ 0 & \text{otherwise,} \end{cases} \tag{11}$$

where $R_n^{\text{OT-1}}(1/\rho) \triangleq \beta(n)F_n(1/\rho)$, $H(y)$ is function of integral $F(y)$, i.e., $H_{n+1}(1/\rho) \triangleq \int_0^{\eta} H_n(1/\rho+y)dy = \int_0^{\eta} F_n(1/\rho+y) - G_n(1/\rho+y)dy$. $G_1(1/\rho)$ is represented as $\mathrm{E}_1(1/\rho)$, and $\beta(2) \triangleq \frac{\exp(1/\rho)}{(1-e^{-\eta})\ln 2}$. For a general $n \ge 3$, the function of $F_n(1/\rho)$ of the OT-1 technique is obtained recursively as:

$$\begin{aligned} F_{n+1}\left(\frac{1}{\rho}\right) = \frac{1}{\lambda-1}\Bigg(&F_n\left(\frac{1}{\rho}+\eta\right) - F_n\left(\frac{1}{\rho}\right) \\ &- G_n\left(\frac{1}{\rho}+\eta\right) + G_n\left(\frac{1}{\rho}\right)\Bigg), \end{aligned} \tag{12}$$

by using [8, eq. (5.231)]. $G_n(1/\rho)$ is defined as:

$$\begin{aligned} &G_n\left(\frac{1}{\rho}\right) \\ &= \underbrace{\int_0^{\eta}\cdots\int_0^{\eta}}_{n-1} \mathrm{E}_1\left(\frac{1}{\rho}+\sum_{m=1}^{n-1} y_m\right) dy_1\cdots dy_{n-1} \\ &= \sum_{m=0}^{n-1} \frac{(-1)^{n-1-m}}{(n-1-m)!m!} \\ &\times\Bigg(\mathrm{E}_1(\frac{1}{\rho}+m\eta)(\frac{1}{\rho}+m\eta)^{n-1} - \exp(-(\frac{1}{\rho}+m\eta)) \\ &\times \sum_{l=0}^{n-2}(n-2-l)!(1/\rho+n\eta)^l(-1)^{n-2-l}\Bigg) \end{aligned} \tag{13}$$

Finally, $R_{\text{avg}}^{\text{OT-1}}(1/\rho)$ is obtained by plugging (13) into (12), and then plugging $R_n^{\text{OT-1}}(1/\rho)$ into (3) for a given η and α.

C. Opportunistic Transmission Based on Desired Channel Gain (OT-2)

In the OT-2 technique, b_j of the j-th TX is determined as:

$$b_j = \begin{cases} 1 & \text{if } x_j > \zeta \\ 0 & \text{otherwise,} \end{cases} \tag{14}$$

where $x_j \triangleq |h_{jj}|^2$ denotes the instantaneous channel gain from the j-th TX to the j-th RX and ζ is a threshold which is determined as a system parameter. Then, the activation probability at each transmitter in the OT-1 technique becomes a function of ζ, i.e., $\alpha = e^{-\lambda\zeta}$. For a given activation probability, hence, the threshold is given by $\zeta = -\frac{1}{\lambda}\ln\alpha$.

Different from the OT-1 technique, the OT-2 technique only considers its own desired channel gain. For $n = 1$, the achievable rate of the OT-2 technique is given by

$$\begin{aligned} &R_1^{\text{OT-2}}\left(\frac{1}{\rho}\right) \\ &= \int_{\zeta}^{\infty} \log_2(1+\rho x) f_X^{\text{OT-2}}(x)dx \\ &= \log_2(1+\zeta\rho) + \frac{\exp\left(\lambda(\zeta+1/\rho)\right)\mathrm{E}_1\left(\lambda(\zeta+1/\rho)\right)}{\ln 2} \\ &= \log_2(1+\zeta\rho) + R_1^{\text{RT}}(\zeta+1/\rho), \end{aligned} \tag{15}$$

where $R_1^{\text{RT}}(\zeta+1/\rho)$ has defined at RT technique, and $f_X^{\text{OT-2}}(x)$ denotes the PDF of X, which is give by

$$f_X^{\text{OT-2}}(x) = \begin{cases} e^{-\lambda x}/e^{-\lambda\zeta} & \text{if } x > \zeta \\ 0 & \text{otherwise.} \end{cases} \tag{16}$$

For $n = 2$, as in (6), the achievable rate of the OT-2 technique is given by:

$$\begin{aligned} &R_2^{\text{OT-2}}\left(\frac{1}{\rho}\right) \\ &= \int_0^{\infty} R_1^{\text{OT-2}}\left(\frac{1}{\rho}+y\right)e^{-y}dy \\ &= \int_0^{\infty} \log_2\left(1+\frac{\zeta}{y+1/\rho}\right)e^{-y} + R_2^{\text{RT}}\left(\zeta+\frac{1}{\rho}\right) \\ &= \log_2(1+\zeta\rho) - \mathrm{E}_1\left(\zeta+\frac{1}{\rho}\right)\exp\left(\zeta+\frac{1}{\rho}\right) \\ &\quad + \mathrm{E}_1\left(\frac{1}{\rho}\right)\exp\left(\frac{1}{\rho}\right) + R_2^{\text{RT}}\left(\zeta+\frac{1}{\rho}\right) \\ &= R_1^{\text{OT-2}}\left(\frac{1}{\rho}\right) - R_1^{\text{RT}}\left(\zeta+\frac{1}{\rho}\right) + R_2^{\text{RT}}\left(\zeta+\frac{1}{\rho}\right) \\ &\quad - B_1\left(\zeta+\frac{1}{\rho}\right) + B_1\left(\frac{1}{\rho}\right), \end{aligned} \tag{17}$$

where $B_1(\zeta+1/\rho)$ and $B_1(1/\rho)$ are come from (7).

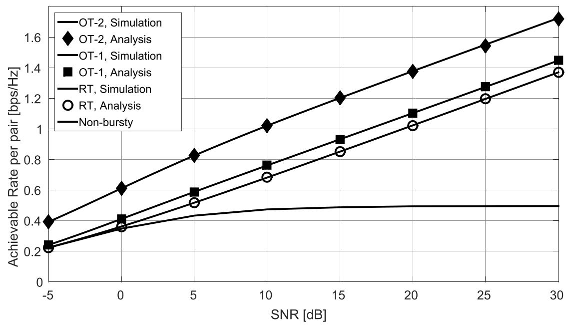

Fig. 2. Achievable rate of the proposed opportunistic transmission techniques for varying SNR with $K = 4$.

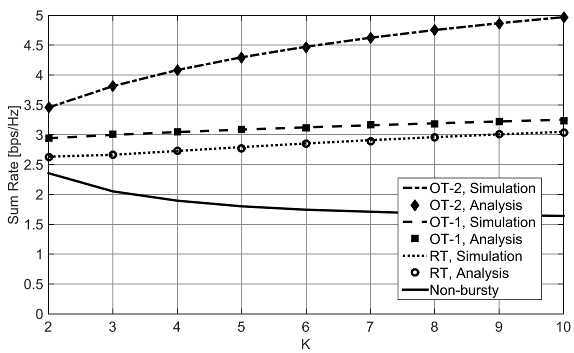

Fig. 3. Achievable rate of the proposed opportunistic transmission techniques for varying K with SNR = 10 dB.

For a general $n \geq 3$, the achievable rate of the OT-2 technique is obtained recursively as:

$$R_{n+1}^{\text{OT-2}}\left(\frac{1}{\rho}\right) = R_n^{\text{OT-2}}\left(\frac{1}{\rho}\right) - R_n^{\text{RT}}\left(\zeta + \frac{1}{\rho}\right) + R_{n+1}^{\text{RT}}\left(\zeta + \frac{1}{\rho}\right) - B_{n-1}\left(\zeta + \frac{1}{\rho}\right) + B_{n-1}\left(\frac{1}{\rho}\right) \quad (18)$$

Therefore, $R_{\text{agv}}^{\text{OT-2}}\left(\frac{1}{\rho}\right)$ is obtained by plugging (18) into (3) for a given ζ and α.

IV. Numerical Results

In this section, we evaluate the performance of the proposed OT techniques with the i.i.d. channel models. We assume that all bursty transmission techniques adopt the optimal transmission probability resulting in the best achievable rate. Fig. 2 shows the (average) achievable rates of the proposed opportunistic transmission techniques for varying SNR values. First of all, our mathematical analysis is exactly the same as the simulation results. Both OT-1 and OT-2 outperforms non-bursty transmission technique and RT technique. In addition, OT-2 technique outperforms OT-1 technique since OT-2 technique more directly increases the received SINR than OT-1 technique. Fig. 3 shows the average achievable rate of the proposed techniques for varying K when $\rho = 10$dB.

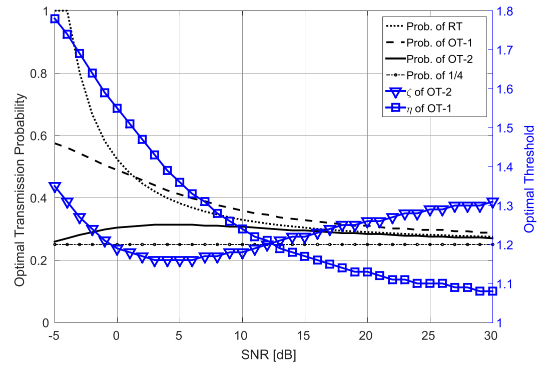

Fig. 4. Optimal transmission probability and corresponding threshold of the bursty transmission techniques for varying SNR values when $K = 4$.

The sum rate of OT-2 technique increases as K increases, while the sum-rate of the OT-1 and the RT slightly increases. Note that the sum-rate of the non-bursty transmission technique even decreases.

Fig. 4 shows the optimal transmission probability and the corresponding threshold for varying SNR values when $K = 4$. In the low SNR regime, the optimal transmission probability of the RT technique approaches to 1, while the optimal transmission probability of the OT-2 is much smaller than that of both RT and OT-1. In addition, the optimal transmission probabilities of techniques intuitively approach $1/K$ as the SNR increases, which implies that it is optimal for a single TX to send data with bursty transmission techniques.

V. Conclusion

We considered three different bursty transmission techniques in K-user bursty fading interference channel. We mathematically analyzed the achievable rate of the three techniques for a given transmission probability. It was shown that OT-2 outperforms RT, OT-1, and the non-bursty transmission technique via computer simulations.

References

[1] B. C. Jung and W.-Y. Shin, "Opportunistic interference alignment for interference-limited cellular TDD uplink," *IEEE Commun. Lett.*, vol. 15, no. 2, pp. 148–150, Feb. 2011.
[2] H. J. Yang, W. Shin, B. C. Jung, and A. Paulraj, "Opportunistic interference alignment for MIMO interfering multiple-access channels," *IEEE Trans. Wireless Commun.*, vol. 12, no. 5, pp. 2180–2192, May 2013.
[3] H. J. Yang, W.-Y. Shin, B. C. Jung, C. Suh, and A. Paulraj, "Opportunistic downlink interference alignment for multi-cell MIMO networks," *IEEE Trans. Wireless Commun.*, vol. 16, no. 3, pp. 1533–1548, Mar. 2017.
[4] N. Khude, V. Prabhakaran, and P. Viswanath, "Opportunistic interference management," in *Proc. IEEE ISIT*, Jun./Jul. 2009, pp. 2076–2080.
[5] I.-H. Wang, C. Suh, S. Diggavi, and P. Viswanath, "Bursty interference channel with feedback," in *Proc. IEEE ISIT*, Jul. 2013, pp. 21–25.
[6] S. Mishra, I.-H. Wang, and S. N. Diggavi, "Harnessing bursty interference in multicarrier systems with output feedback," *IEEE Trans. Inf. Theory*, vol. 63, no. 7, pp. 4430–4452, Jul. 2017.
[7] B. C. Jung, Y. J. Hong, D. K. Sung, and S. Y. Chung, "Fixed power allocation with nulling for TDD-based cellular uplink," *IEEE Commun. Lett.*, vol. 12, no. 4, pp. 253–255, Apr. 2008.
[8] I. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Seris, and Products*. Cambridge, MA, USA: Academic, 2003.