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Joint Partial-time Partial-band Jamming of a Multicarrier DS-CDMA System in a Fading Environment

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Motivation

- Jamming is a commonly used method for attacking data transmissions at the physical layer

- MC-DS-CDMA allows multiple users to simultaneously transmit over the same channel, and also provides protection against jamming

- Joint partial-time, partial-band jamming provides more attacking options of MC-DS-CDMA systems compared to partial-time only and partial-band only systems

Previous work

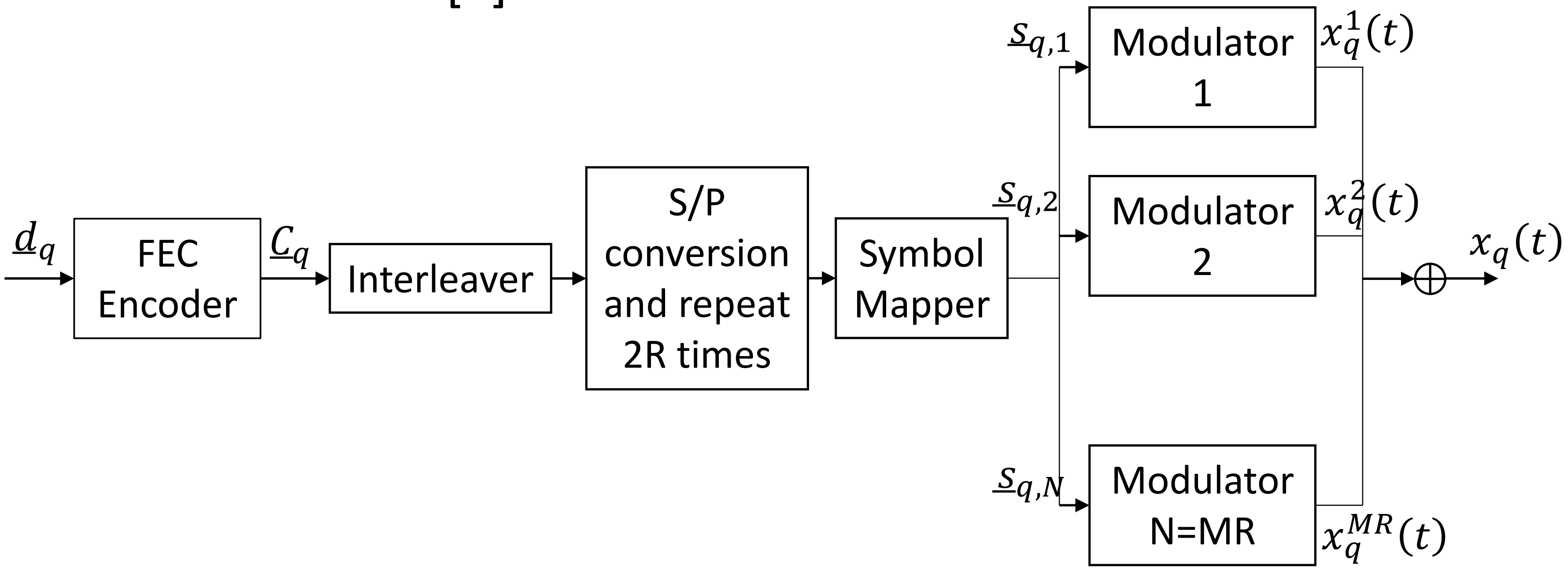
- ❖Performance of DS-CDMA system under partial-time jamming attack has been studied, can be adapted to MC-DS-CDMA

- ❖MC-DS-CDMA system using coding in both frequency and time [1,2]: analyzed performance over multipath channel under partial-band jamming

- ❖Impact of joint partial-time/partial-band jamming on an MC-DS-CDMA [3] analyzed for both AWGN and Rayleigh fading (assumed perfect channel estimation, negligible thermal noise.)

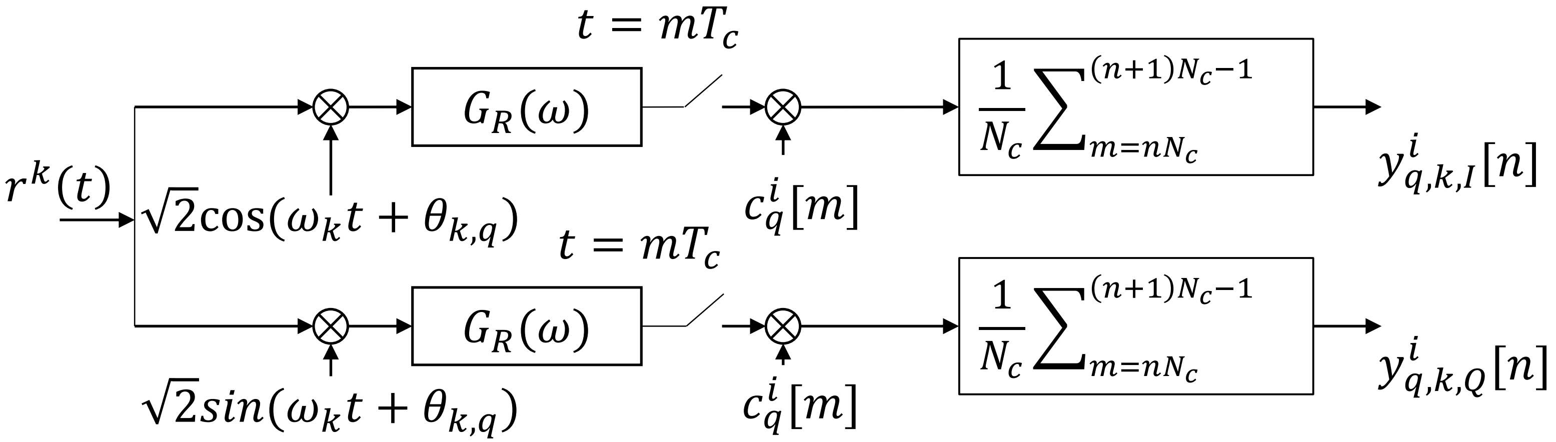
System Design

MC-DS-CDMA modified from [1].

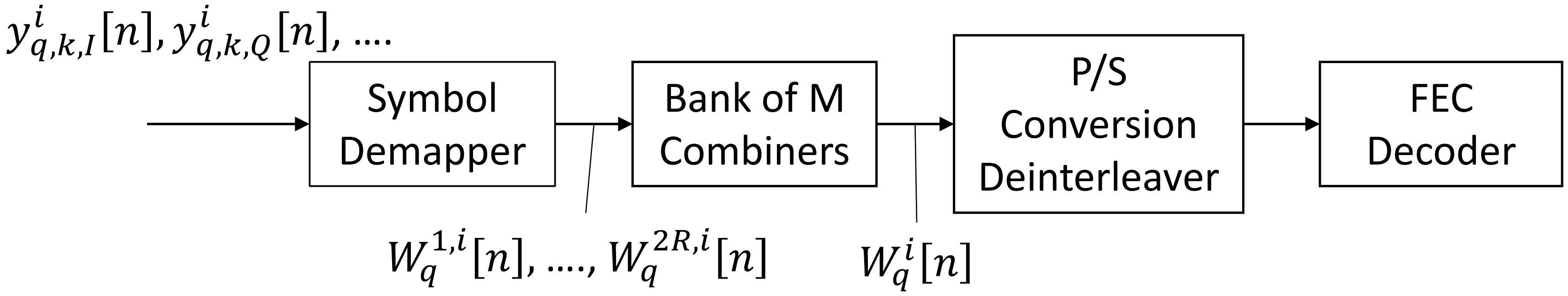


Q: number of users
1/M: rate of the FEC code
2R: number of frequency diversity branches
N=MR: number of subcarriers

System Design



a. Receiver for user q's i^{th} stream on subcarrier k. ($\theta_{k,q} = 0$)



b. Receiver for user q

Channel and Jammer Characteristics

- Narrowband Gaussian noise jammer. When on, has power spectrum density

$$S_J(f) = \begin{cases} \frac{\eta_J}{2}, & f_i - \frac{BW_0}{2} \le |f| \le f_i + \frac{BW_0}{2}, i = 1,2,\dots,N_J \\ 0, & otherwise \end{cases}$$

N_J: number of subcarriers being jammed
ρ_T: percentage of time the jammer is on

- Block, flat, fading channel: Flat within each frequency bin

Fast-Fading, Soft-decision, Independent jammer

- Denote SNR at output of maximal-ratio combiner as γ, where γ is a function of the channel gains

- Assume rate-1/M convolutional code, soft Viterbi decoding

- Assume the all-zero sequence (r=0) is transmitted and some competing path (r=1) is selected at the decoder

$$P\left(U^{(1)} - U^{(0)} \geq 0\right) = P\left(\sum_{l=1}^{B}\sum_{i=1}^{M} Y_{i,l}\left[b_{i,l}^{(1)} - b_{i,l}^{(0)}\right] \geq 0\right)$$

- Given a partial-time jamming ratio ρ_T, and an independent jammer, we can calculate conditional average probability of error

$$\overline{P(U^{(1)} - U^{(0)} \geq 0|d_i)} = \sum_{j=0}^{d_i}\binom{d_i}{j}\rho_T^j(1-\rho_T)^{d_i-j}P\left(U^{(1)} - U^{(0)} \geq 0|d_i, j\right)$$

Fast-Fading, Soft-decision, Independent jammer

❖ $P(U^{(1)} - U^{(2)} \geq 0|d_i, j)$ can be upper bounded using the Chernoff bound

$$\gamma_i^{(l)} = \frac{\alpha_{i,l}^2}{\sigma_{i,l}^2}$$

$$P\left(U^{(1)} - U^{(1)} \geq 0\middle|d_i, j\right) = E[\mathrm{P}(\textstyle\sum_{(i,l)\in\mathcal{E}} Y_{i,l} \leq 0|d_i, j, \gamma)]$$

$$\leq\ E_\gamma\left\{\min_{\rho>0} E_{Y_{i,l|\gamma}}\left[e^{-\rho\left(\sum_{(i,l)\in\mathcal{E}} Y_{i,l}\right)}\middle|d_i, j\right]\right\} =\ E_\gamma\left\{\prod_{(i,l)\in\mathcal{E}} e^{-\frac{P^s\gamma_i^{(l)}}{2}}\right\}$$

$$= \prod_{(i,l)\in\mathcal{E}} E_{\gamma_i^{(l)}}\left\{e^{-\frac{P^s\gamma_i^{(l)}}{2}}\right\}$$

$$= \prod\nolimits_{(i,l)\in\mathcal{J}}\left(\mathbb{E}\left\{\prod\nolimits_{k=1}^{2R}\frac{1}{1+\bar{\gamma}_{i,k}^{(l)}}\right\}\right)\prod\nolimits_{(i,l)\in(\mathcal{E}-\mathcal{J})}\left(\prod\nolimits_{k=1}^{2R}\frac{1}{1+\bar{\gamma}_{i,k}^{(l)}}\right)$$

$$=\ \prod\nolimits_{(i,l)\in\mathcal{J}}\left\{\sum\nolimits_{k=N_{min}}^{N_{max}}\frac{\binom{N_J}{k}\binom{N-N_J}{2R-k}}{\binom{N}{2R}}\left(\frac{1}{1+\bar{\gamma}_J}\right)^k\left(\frac{1}{1+\bar{\gamma}_o}\right)^{2R-k}\right\}\prod\nolimits_{(i,l)\in(\mathcal{E}-\mathcal{J})}\left\{\prod\nolimits_{k=1}^{2R}\frac{1}{1+\bar{\gamma}_{i,k}^{(l)}}\right\}$$

Fast-Fading, Soft-decision, Independent jammer

$$P\left(U^{(1)} - U^{(1)} \geq 0 \middle| d_i, j\right) \leq$$

$$\prod_{(i,l)\in\mathcal{J}} \left\{ \sum_{k=N_{min}}^{N_{max}} \frac{\binom{N_J}{k}\binom{N-N_J}{2R-k}}{\binom{N}{2R}} \left(\frac{1}{1+\bar{\gamma}_J}\right)^k \left(\frac{1}{1+\bar{\gamma}_o}\right)^{2R-k} \right\} \prod_{(i,l)\in(\mathcal{E}-\mathcal{J})} \left\{ \prod_{k=1}^{2R} \frac{1}{1+\bar{\gamma}_{i,k}^{(l)}} \right\}$$

$$= \left\{ \sum_{k=N_{min}}^{N_{max}} \frac{\binom{N_J}{k}\binom{N-N_J}{2R-k}}{\binom{N}{2R}} \left(\frac{1}{1+\bar{\gamma}_J}\right)^k \left(\frac{1}{1+\bar{\gamma}_o}\right)^{2R-k} \right\}^j \left\{ \left(\frac{1}{1+\bar{\gamma}_o}\right)^{2R} \right\}^{d_i-j}$$

$$N_{min} = \max\{2R - (N - N_J), 0\}, N_{max} = \min\{N_J, 2R\}$$

$$\bar{\gamma}_o \triangleq \frac{\bar{\alpha}_q P^s}{Var\left[I_q^{\nu(i,k)}[l]\right] + \sigma_0^2} \qquad \bar{\gamma}_J \triangleq \frac{\bar{\alpha}_q P^s}{Var\left[J_q^{\nu(i,k)}[l]\right] + Var\left[I_q^{\nu(i,k)}[l]\right] + \sigma_0^2}$$

$$P_b \leq \sum_{d_i=d_{free}}^{\infty} A(d_i)\overline{P(U^{(1)} - U^{(0)} \geq 0 | d_i)}$$

Fast-Fading, Soft-decision, Burst jammer

- The previous result is also applicable to estimate average performance under burst jamming with interleaving

- Consider a randomly chosen interleaver, with a burst jammer
- Then symbols are jammed equally likely with probability ρ_T

$$\overline{P(U^{(1)} - U^{(0)} \geq 0|d_i)} = \sum_{j=0}^{d_i} \binom{d_i}{j} \rho_T^j (1-\rho_T)^{d_i - j} P\left(U^{(1)} - U^{(0)} \geq 0|d_i, j\right)$$

Fast-Fading, Soft-decision, Burst jammer

❖ $[x_1, x_2, \dots, x_L]$: codeword bits before interleaving.
$[z_1, z_2, \dots, z_L]$: codeword bits after interleaving.

❖ For any index $i \epsilon [1, L]$, the probability that randomly picked interleaver will map x_1 to z_i is

$$\frac{1!\,(L-1)!}{L!} = \frac{1}{L}$$

❖ For a jammer that picks random starting points in each codeword and jams for duration $\rho_T L$, the probability z_i is jammed is

$$P(z_i) = \begin{cases} \dfrac{N_{b,J}}{L - N_{b,J} + 1}, & N_{b,J} \le i \le L - N_{b,J} + 1 \\ \dfrac{k}{L - N_{b,J} + 1}, & k = 1, if\ i < N_{b,J}; k = L - i + 1, if\ i > L - N_{b,J} + 1 \end{cases}$$

Fast-Fading, Soft-decision, Burst jammer

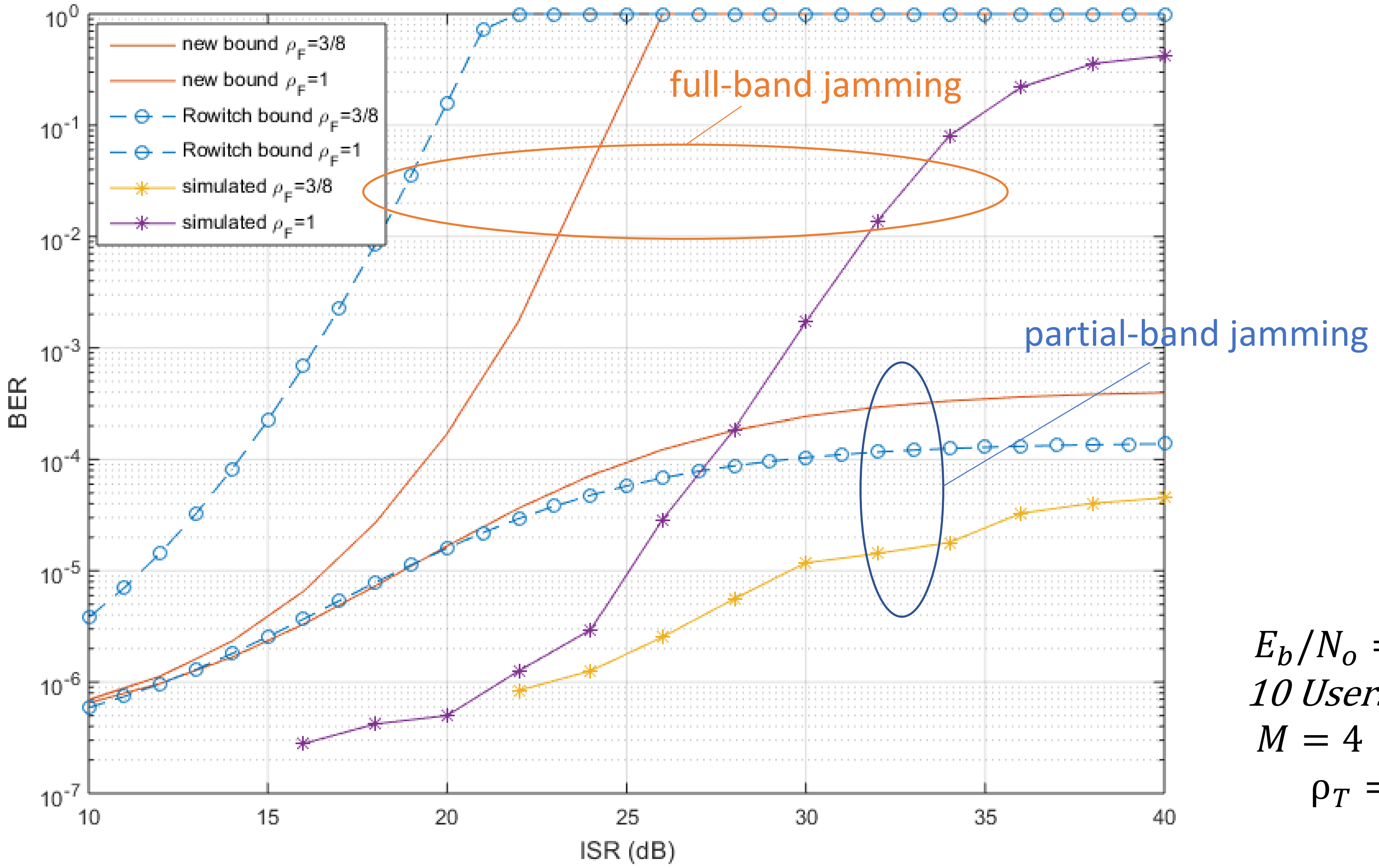
- Average probability that x_1 is jammed can then be calculated as

$$P(x_1) = \frac{1}{L}\left\{\frac{2}{L - N_{b,J} + 1} + \frac{2 \times 2}{L - N_{b,J} + 1} + \cdots + \frac{2(N_{b,J}-1)}{L - N_{b,J} + 1} + \left[L - 2\,(N_{b,J}-1)\right]\frac{N_{b,J}}{L - N_{b,J} + 1}\right\}$$

$$= \frac{N_{b,J}}{L} \approx \rho_T$$

$$P(z_i) = \begin{cases} \dfrac{N_{b,J}}{L - N_{b,J} + 1}, & N_{b,J} \le i \le L - N_{b,J} + 1 \\ \dfrac{k}{L - N_{b,J} + 1}, & k = 1, if\ i < N_{b,J}; k = L - i + 1, if\ i > L - N_{b,J} + 1 \end{cases}$$

Simulation Result, Independent jammer



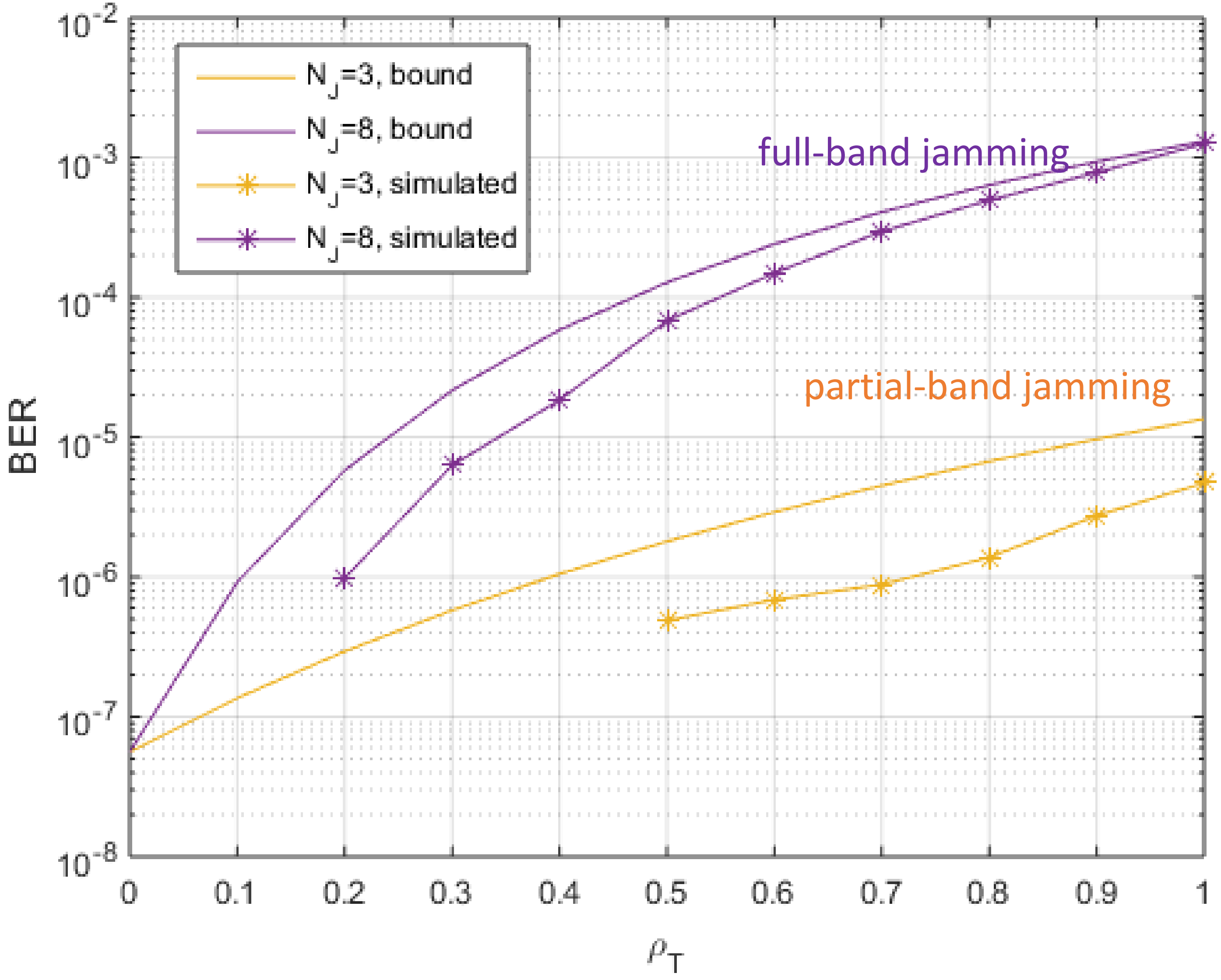
$E_b/N_o = 7dB$

10 Users

$M = 4 \;\; R = 2$

$\rho_T = 1$

Simulation Result, Independent jammer



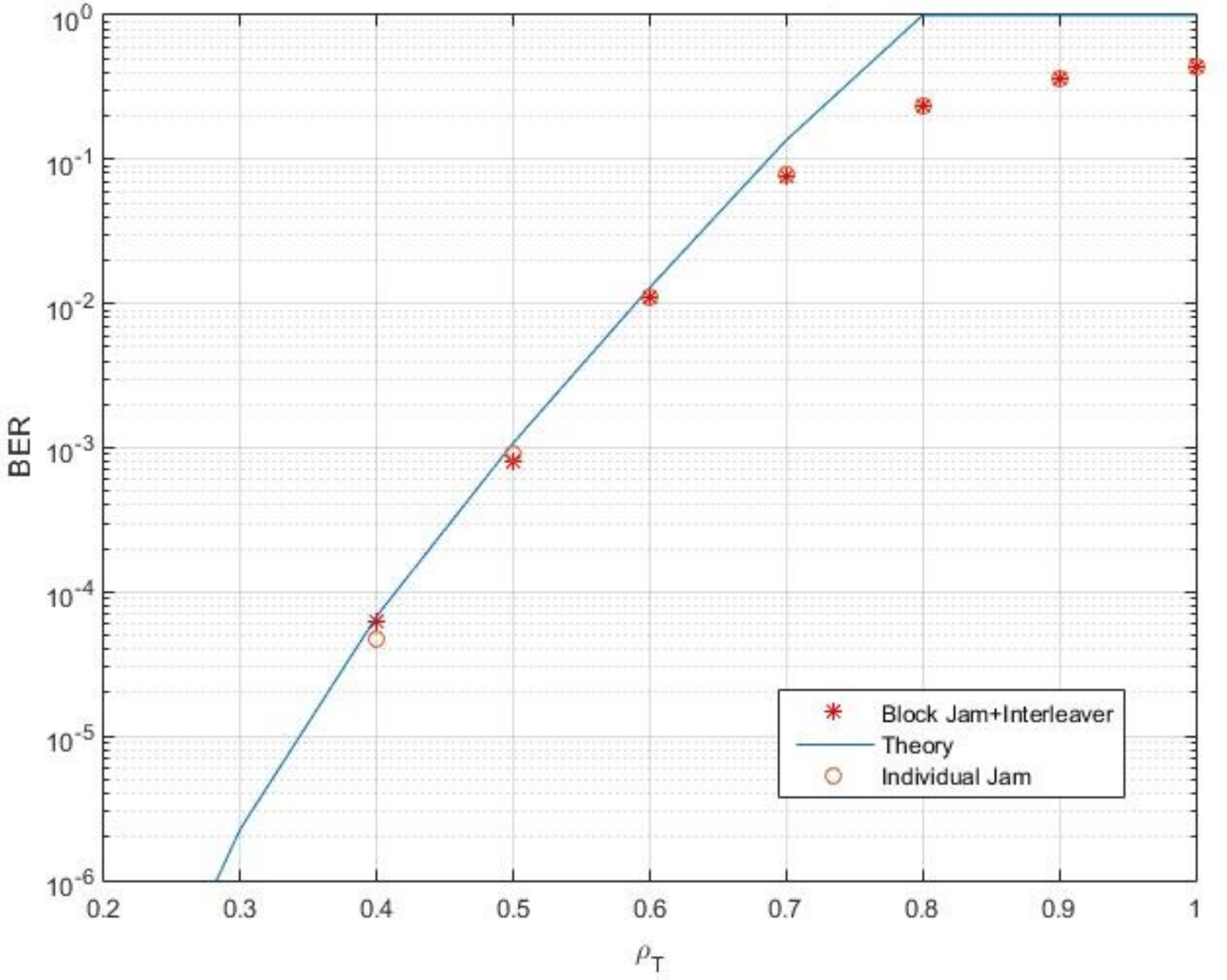
$E_b/N_o = 10dB$

$ISR = 30dB$

10 Users

$M = 4 \;\; R = 2$

Simulation Result, Soft-decision, Burst jammer



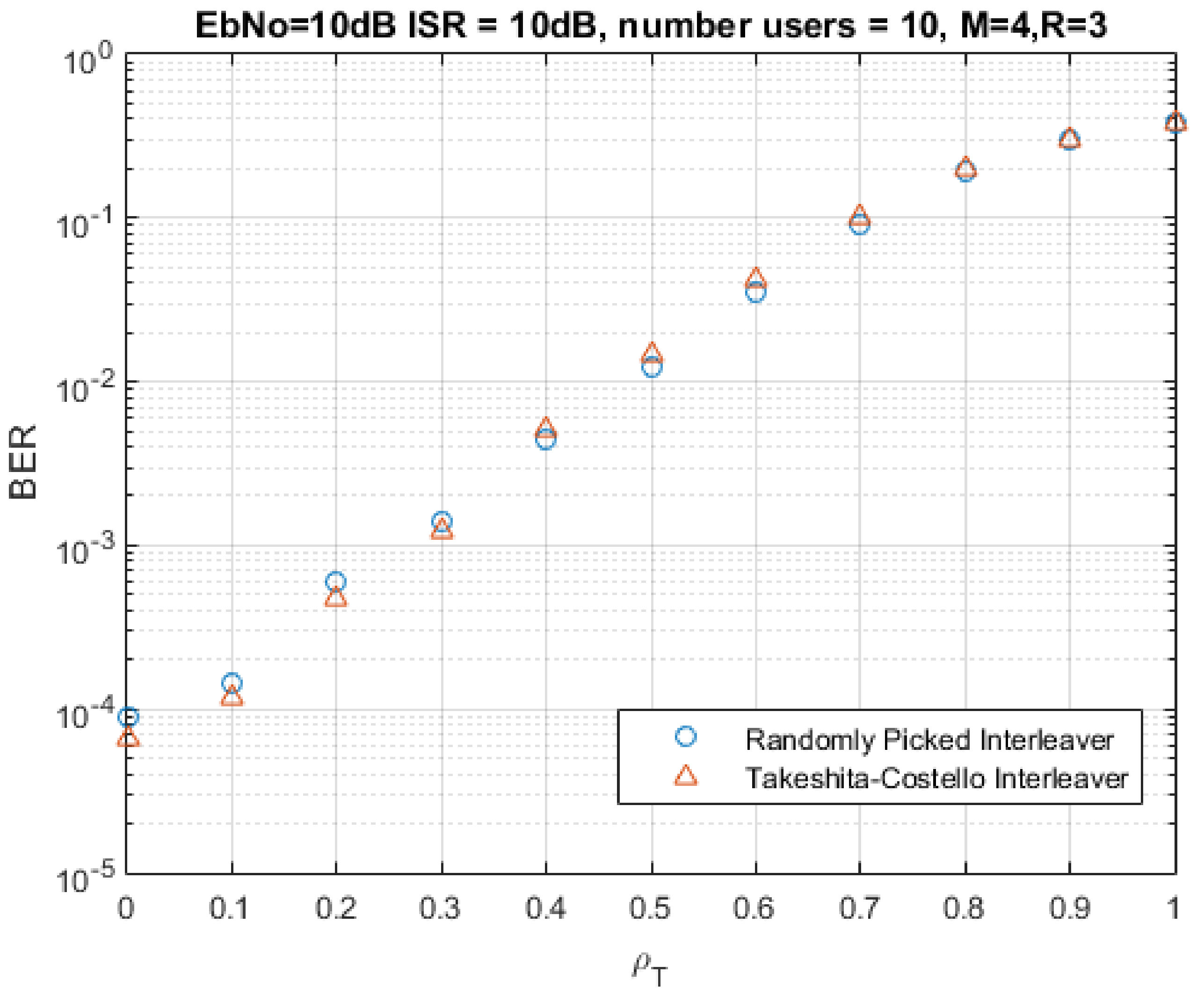
$E_b/N_o = 20dB$

$ISR = 10dB$

10 Users

$M = 3 \;\; R = 3$

Simulation Result, Soft-decision, Burst jammer



References

[1]D.N. Rowitch, and L. B. Milstein, “Convolutionally coded multicarrier DS-CDMA systems in a multipath fading channel. I. Performance analysis”. Communications, IEEE Transactions on 47.10 (1999): 1570-1582

[2] D.N. Rowitch, and L. B. Milstein, “Convolutionally coded multicarrier DS-CDMA systems in a multipath fading channel. II. Narrow-band Interference suppression”. Communications, IEEE Transactions on 47.1 (1999): 1729-1736.

[3]K. Cheun, K. Choi, H. Lim, and K. Lee, “Antijamming performance of a multicarrier direct sequence spread-spectrum system”. IEEE Transactions of Communications 47.12 (1990): 1781-1784.