Anti-Jamming Partially Regular LDPC Codes for Follower Jamming with Rayleigh Block Fading in Frequency Hopping Spread Spectrum

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Outline

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Military Communication Scenario

- Jamming
  - Deliberately interferes the desired signal
  - Category
    - Full-band jamming
    - Partial band jamming: most famous
    - Follower jamming: major subject in this work
    - Smart jamming
  - Anti-jamming schemes
    - Stop-band
    - Avoiding
    - Frequency hopping spread spectrum (FHSS): considered in this work
    - Enhanced ECC (RS-concatenation, BICM-ID): major subject in this work

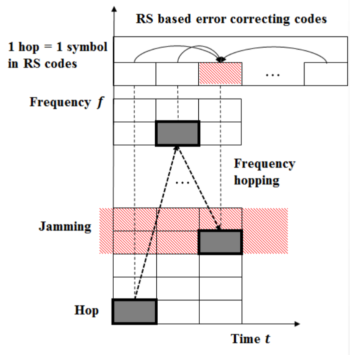

Figure: Partial band jamming and anti-jamming schemes (FHSS, ECC) in the military communication scenario

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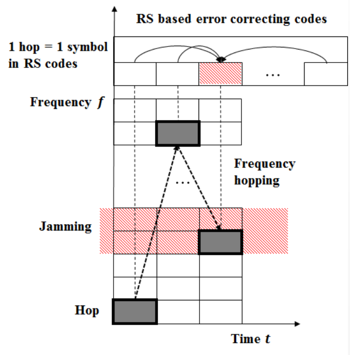

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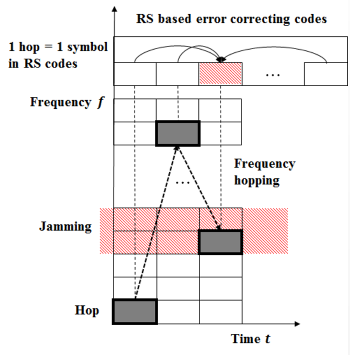

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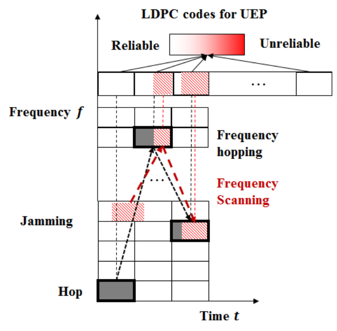
Main Research Topic

- Follower Jamming
  - Scan the occupied frequency bands
  - Send the jamming signal in the occupied bands
  - Use determinator or CESM to scan the band
- Low-density Parity Check (LDPC) Codes
  - Capacity-approaching codes
  - Can be used for special environments
    - Block fading
    - Unequal error protection (UEP)



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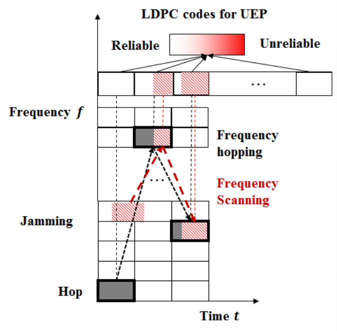

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NC-MFSK Modulation with Jamming

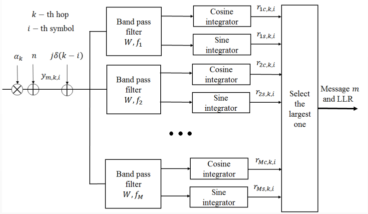

Figure: The demodulator of NC-MFSK

- $$r_{mc,k,i} = \begin{cases} \alpha_k \sqrt{\mathcal{E}_{k,i}} \cos\phi + j\delta(k,i) + n, & m = \bar{m} \\ j\delta(k,i) + n, & \text{otherwise} \end{cases} \quad (1)$$
  $$r_{ms,k,i} = \begin{cases} \alpha_k \sqrt{\mathcal{E}_{k,i}} \sin\phi + j\delta(k,i) + n, & m = \bar{m} \\ j\delta(k,i) + n, & \text{otherwise.} \end{cases} \quad (2)$$
- $$m'_{k,i} = \operatorname{argmax}_m \left(\sqrt{r^2_{mc,k,i} + r^2_{ms,k,i}}\right) \quad (3)$$

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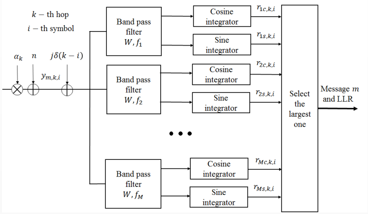

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Follower Noise Jamming with Fixed Scan Speed

- Geometrical Limitation of the Follower Jamming
  - Transmission and processing time can limit the possibility of the follower jamming
  - T_p (transmission) $+ T_j$ (processing) $\leq T_h$ (hop duration)
  - $T_p = \frac{D_{tj}+D_{jr}-D_{tr}}{c}$, T_j can be determined by fixed speed assumption
  - $\mu = \frac{\text{(Duration of jamming exists)}}{\text{(Hop duration)}}$, Jamming eclipse: $[0, (1-\mu)T_h]$

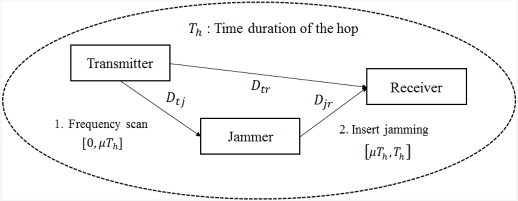

Figure: Follower jamming environment

Follower Noise Jamming with Fixed Scan Speed (Cont')

- New Assumption: Fixed Scan Speed v
  - T_j (processing) $= T^*$ (inherent) $+ T_{scan}$ (scanning time)
  - $\mu \sim u[\mu_a, \min(\mu_b, 1)]$, μ_a(initial) $= \frac{T_p+T^*}{T_h}$, μ_b(end) $= \mu_a + \frac{N_{fr}}{vT_h}$.
  - ρ (prob. that jamming exists in a hop) $= \min\{\frac{1-\min(1,\mu_a)}{\mu_b-\mu_a}, 1\}$

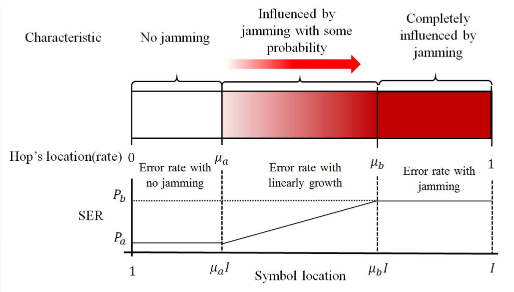

Figure: Average symbol error rate of the hop in the presence of the follower jamming

Outline

$(\boldsymbol{\lambda}, d_c, \boldsymbol{d}_v)$ AJ-PR-LDPC codes

- Parameters $(\boldsymbol{\lambda}, d_c, \boldsymbol{d}_v)$
  - Location vector $\boldsymbol{\lambda} = [\lambda_1, ..., \lambda_{|\lambda|}]$, $\sum \lambda_i = 1$
  - Variable node degree $\boldsymbol{d}_v = [d_{v,1}, ..., d_{v,|\lambda|}]$ with $r(\boldsymbol{\lambda} \cdot \boldsymbol{d}_v) = d_c$
- AJ-PR-LDPC codes
  - Constant check node degree d_c on the each row
  - Each v_j, j-th column of each hop whose size is B, has to satisfy

$$wt(v_j) = d_{v,k}, j \in \left[B \sum_{i=1}^{k-1} \lambda_i, B \sum_{i=1}^{k} \lambda_i \right] \quad (4)$$

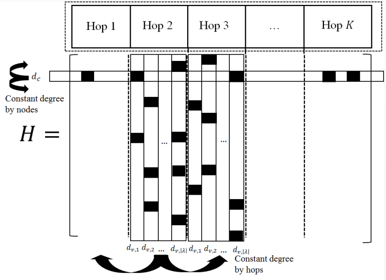

Figure: Parity check matrix of AJ-PR-LDPC codes

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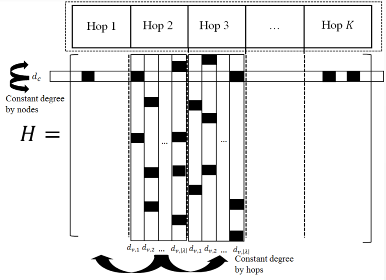

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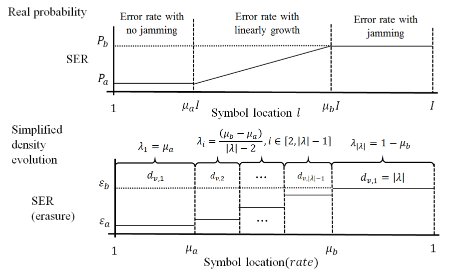
Simplified Channel Model for Density Evolution

- Density Evolution and Simplifed Channel Model
  - Mathematical tools for analyzing asymptotic performance of the LDPC codes
  - Difficult to apply the error channel with linearly growth and general LDPC codes.
  - Alternative solution: simplified channel model with stair-case erasure and partially regular structure.



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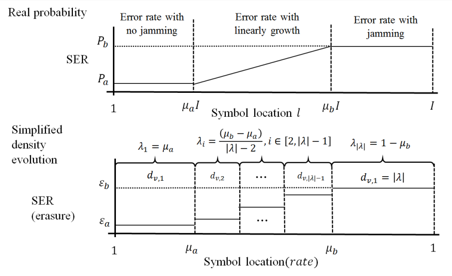

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Corresponding Density Evolution and Construction Algorithm

- Corresponding Density Evolution of Erasure Channel
  - $$\epsilon_i = (\epsilon_b - \epsilon_a)\frac{i-1}{|\boldsymbol{\lambda}|-1} + \epsilon_a, i \in [1, |\lambda|] \tag{5}$$
    $$q_{l+1} = 1 - \left(1 - \sum_{i=1}^{|\boldsymbol{\lambda}|} \lambda_i p_{l,i}\right)^{d_c-1} \tag{6}$$
    $$p_{l+1,i} = \epsilon_i q_{l+1}^{d_{v,i}-1} \tag{7}$$
- Construction Algorithm of the Parity Check Matrix
  - Search for the all degree values less than $\boldsymbol{d}_{v,max}$ and $d_{c,max}$
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Simulation Criteria

- System Parameters
  - SFH and NC-MFSK with Rayleigh block fading
  - $M = 2, 4, 8$, and 16
  - Hop size: 192[bits]
- Jamming Parameters
  - Slow scan: $\mu_a = \frac{3}{8}$, $\mu_b = \frac{11}{8}$, $\rho = \frac{5}{8}$, $\frac{E_b}{N_j} = -50$[dB]
  - Fast scan: $\mu_a = \frac{3}{8}$, $\mu_b = \frac{7}{8}$, $\rho = 1$, $\frac{E_b}{N_j} = -50$[dB]
- Codes in the Simulation
  - $(2304, 1152)$ LDPC codes in IEEE 802.16e standard
  - $(2304, 1152)$ AJ-PR-LDPC (proposed) codes with $\boldsymbol{\lambda} = (\frac{5}{8}, \frac{2}{8}, \frac{1}{8})$, $\boldsymbol{d}_v = (2, 3, 4)$, and $d_c = 5$

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Simulation results

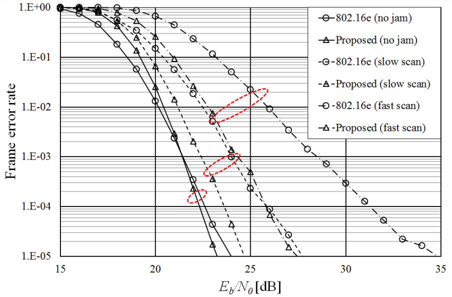

Figure: Decoding performance when $M = 2$

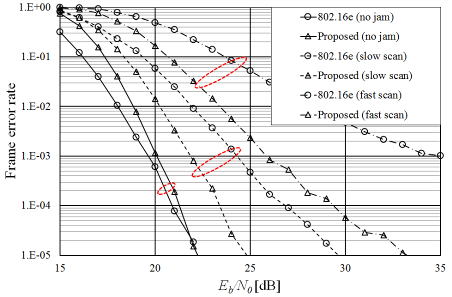

Figure: Decoding performance when $M = 4$

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Summary

- Explain geometrical characteristic of the follower jamming and propose new model of follower jamming with fixed speed.
- Propose AJ-PR-LDPC codes for the proposed follower jamming model. Simplified channel model and the corresponding density evolutions are used to construct the parity check matrix of AJ-PR-LDPC codes.
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