Return Link Code Acquisition for 1-D and 2-D with DS-CDMA for High Capacity Multiuser Systems

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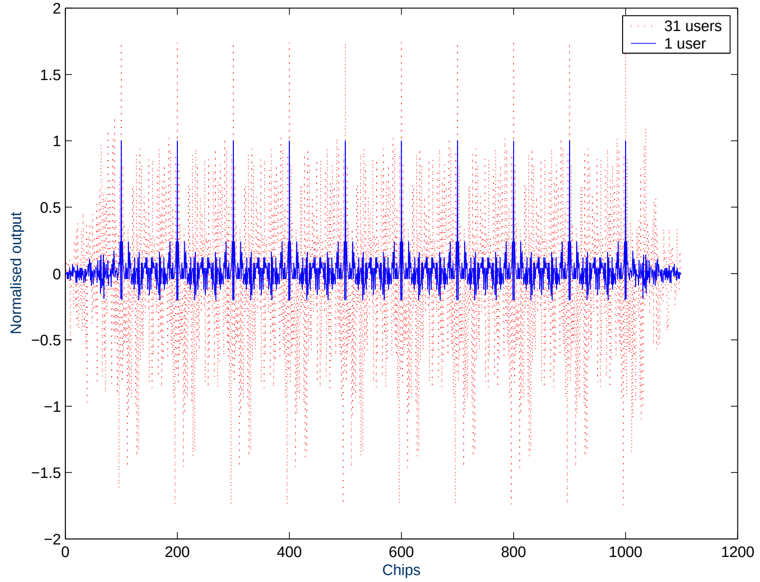
Introduction

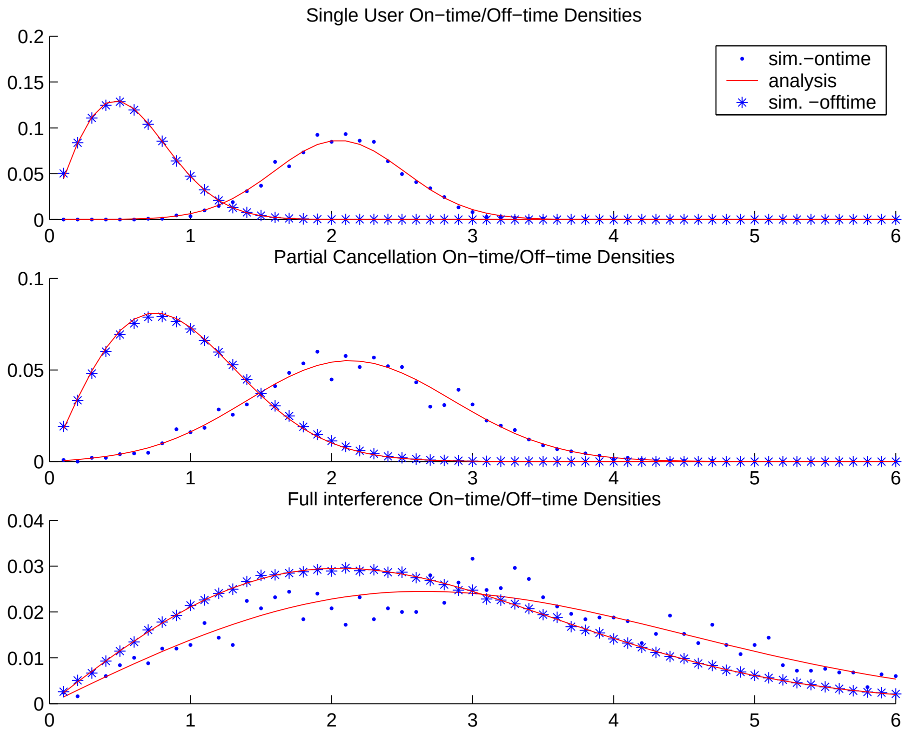
- The DS/CDMA Acquisition Problem
- System Model
- Acquisition under High MAI
- One - Dimensional Acquisition
- Two Dimensional Acquisition (ULA)
- 1-D and 2-D Performance in terms of P_{fa} and P_{md}
- 1-D and 2-D Performance in terms of E_b/N_0 (fixed P_{md})

The DS/CDMA Acquisition Problem

- Acquisition:-before signal detection/decoding, Typically using a correlator
- As the Multiple Access Interference (MAI)/Users Increases this fails as a "good" threshold point cannot be found, therefore limiting system capacity.



Acquisition under High MAI (cross, auto-correlation distr.)



- K=200, N=100, E_s/N_0=7db, σ_n = 1, Averaged over 2500 sequences

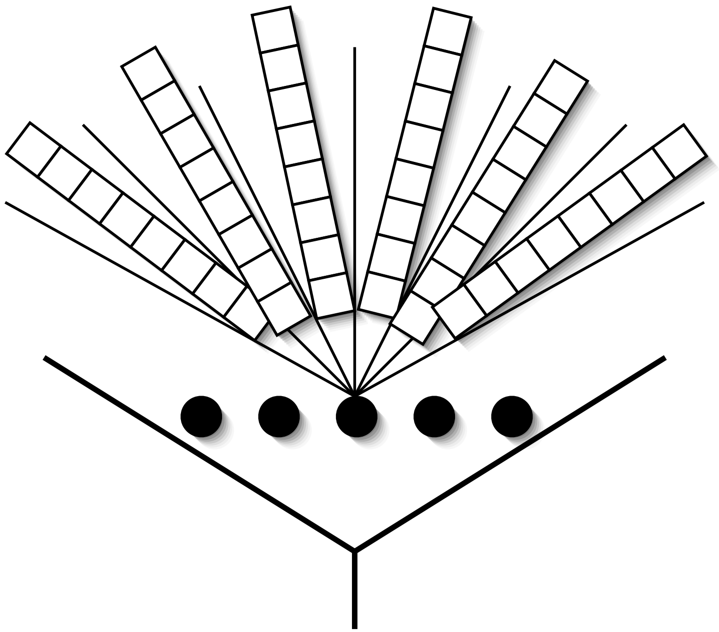
Solution

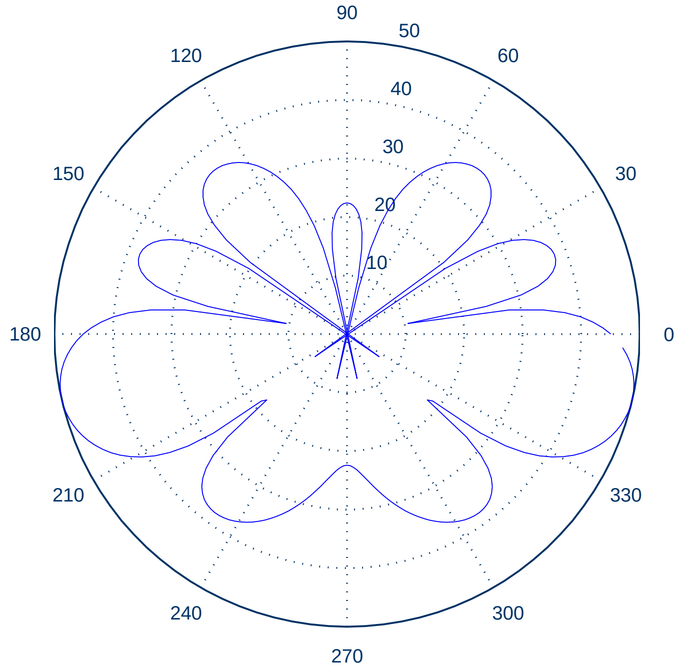
- We use a decision directed solution to this problem
- We show how this functions for 1-D and 2-D systems
- We show analysis to validate the simulation results
- We show performance/analysis with non-perfect decisions

System Model, 1-D and 2-D Case

- 1-D Transmited signal is $y_{c,t} = \sum_{k=2}^{K+1} s_{c,t}^{(k)} d_t^{(k)} + s_{c,t}^{(1)} + n_{c,t} = g_{c,t} + s_{c,t}^{(1)} + n_{c,t}$
- $g_{c,t}$ is the interference
- 2-D Transmitted signal is extended to include signal received by an L-element Uniform Linear Array (ULA)
- Therefore $\mathbf{y}_{c,t} = \sum_{k=2}^{K+1} \mathbf{e}^{(k)} s_{c,t}^{(k)} d_t^{(k)} + \mathbf{e}^{(1)} s_{c,t}^{(1)} + \mathbf{n}_{c,t}$
- or $\mathbf{y}_{c,t} = \sum_{k=2}^{K+1} \mathbf{e}^{(k)} g_{c,t} + \mathbf{e}^{(1)} s_{c,t}^{(1)} + \mathbf{n}_{c,t}$

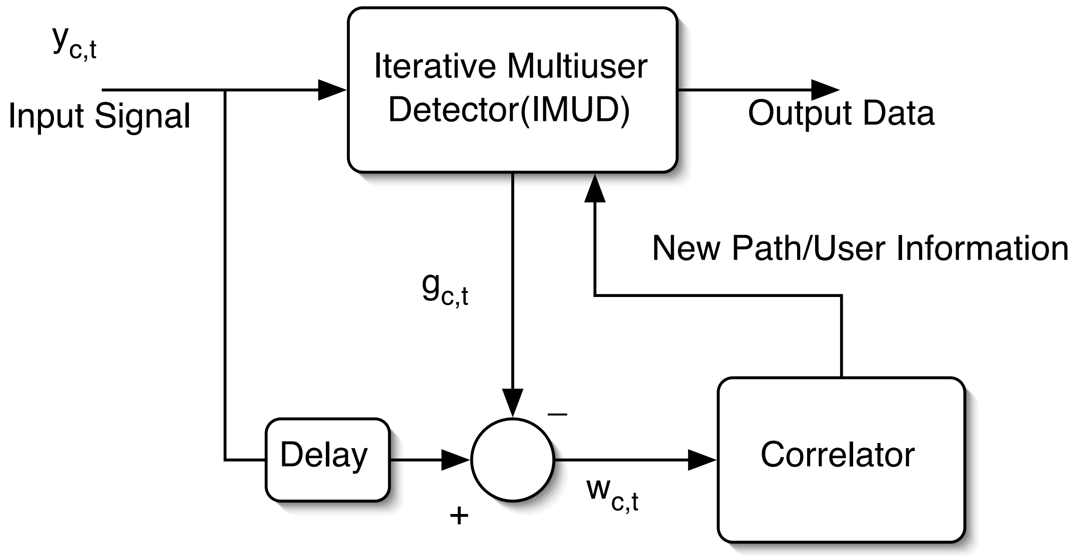
2-D System Diagram





- DOA is split into regions, each region is correlated for user of interest
- Biggest difference from 1-D: Users signal is weighted according to DOA

Acquisition Unit Block Diagram



- Receiver has "good" estimate of current users, to find new users we should subtract current users i.e. $w_{c,t} = y_{c,t} - \tilde{g}_{c,t}$,

  For 1-D case, correlator performs $r_{c,t} = \left| \sum_{c=1}^{N} w_{c,t} (s_{c,-t}^{(1)})^{T} \right|$

Acquisition for 2-D Case

Vector notation instead of scalar notation

$$\mathbf{w}_{c,t} = \mathbf{y}_{c,t} - \tilde{\mathbf{g}}_{c,t}$$

Steering vector needs to multiply with received vector

$$w_{c,t} = \left(\mathbf{e}^{(p)}\right)^T \mathbf{w}_{c,t}$$

Final correlation is the same as 1-D case

$$r_{c,t} = \left| \sum_{c=1}^{N} w_{c,t} \left(s_{c,-t}^{(1)}\right)^T \right|$$

Analysis of System Performance

- Aim is to determine densities of
  - "on-time" (auto correlation)
  - "off-time" (cross correlation)

- For a given threshold point we can then integrate these densities to find:-
  - Probability of missed detection (P_{md})
    (When auto-correlation is missed by the threshold detector)

  - Probability of false alarm (P_{fa})
    (when threshold detector triggers at the wrong timing point)

- Analysis is determined as a function of users (K), Processing gain (N), noise variance (σ_n^2), and cancellation factor (σ_x^2)

First and Second Order Statistics of the MAI and AWGN

- The distribution of the received information

$$
\begin{aligned}
var\{w_{c,t}\} &= E\left\{(y_{c,t} - \tilde{g}_{c,t})^2\right\} \\
&= E\left\{[s_{c,t}(d_t^{(k)} - \tilde{d}_t^{(k)})]^2\right\} + \sigma_n^2 \\
&= \sigma_x^2 E\left\{\sum_{k=1}^{K+1} (s_{c,t}^{(k)})^2\right\} + \sigma_n^2 \\
&= \sigma_x^2 \frac{K+1}{N} + \sigma_n^2
\end{aligned}
$$

- The distribution of the MAI is therefore $\mathcal{N}(0, \frac{(K+1)\sigma_x^2}{N})$ and the noise is $\mathcal{N}(0, \sigma_n^2)$.

Off-time Density for 1-D Analysis

$$p_r(r) = \frac{C_1 r}{\sigma^2} \exp \frac{-r^2}{2\sigma^2}$$
$$= \frac{C_1 r}{2(\frac{(K+1)\sigma_x^2}{N} + \sigma_n^2)} \exp \left\{ \frac{-r^2}{4(\frac{(K+1)\sigma_x^2}{N} + \sigma_n^2)} \right\} \quad (1)$$

- Rayleigh distribution due to correlator output taking absolute value of complex Gaussian density

- Function in terms of the number of users K, the spreading factor N, the noise variance σ_n^2, and a given x-axis value r (used as the threshold point later)

On-time Density for 1-D Analysis

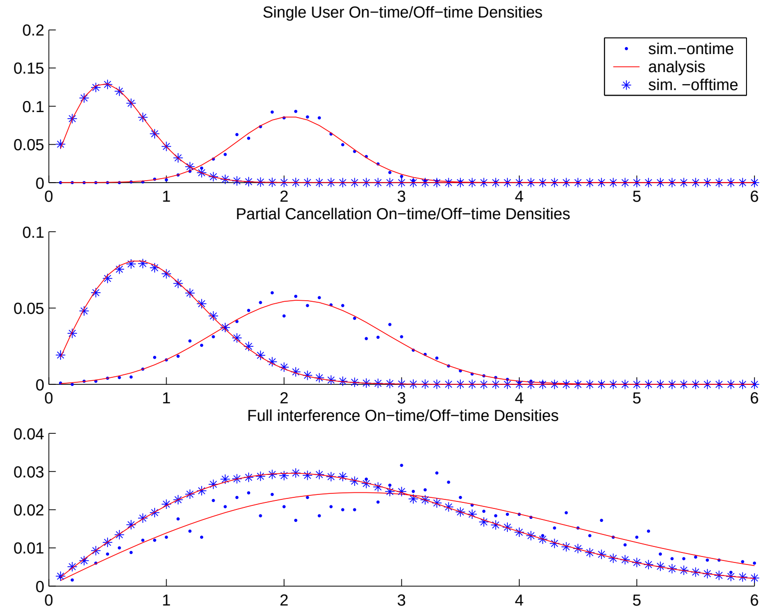
$$f_e(e) = \frac{C_2}{\sqrt{2\pi}\sigma_e} \exp \frac{-(e - m_e)^2}{2\sigma_e^2} \qquad (2)$$

- Non-zero mean due to auto-correlation peak
- Absolute value based on real/imaginary non-zero mean Gaussians
- Therefore Rician density, where $\sigma^2 = 2(\frac{K\sigma_x^2}{N} + \sigma_n^2)$, $s^2 = m_1^2 + m_2^2 = 4$, and $I_0(.)$ is the zero order modified Bessel function of the first kind

$$p_r(r) \quad = \quad \frac{C_3 r}{\sigma^2} \exp \left\{ -\frac{r^2 + s^2}{2\sigma^2} \right\} I_0 \left(\frac{rs}{\sigma^2} \right) \qquad (3)$$

Calculate Probabilities

- For Analysis
  - Integrate on-time density from $0 \longrightarrow r$ to determine P_{md}
  - Integrate off-time density from $r \longrightarrow \infty$, to determine P_{fa}



- For Simulation
  - Count the number of missed detections for "on-time" position
  - Count the number of false alarms for "off-time" position

Residual Interference

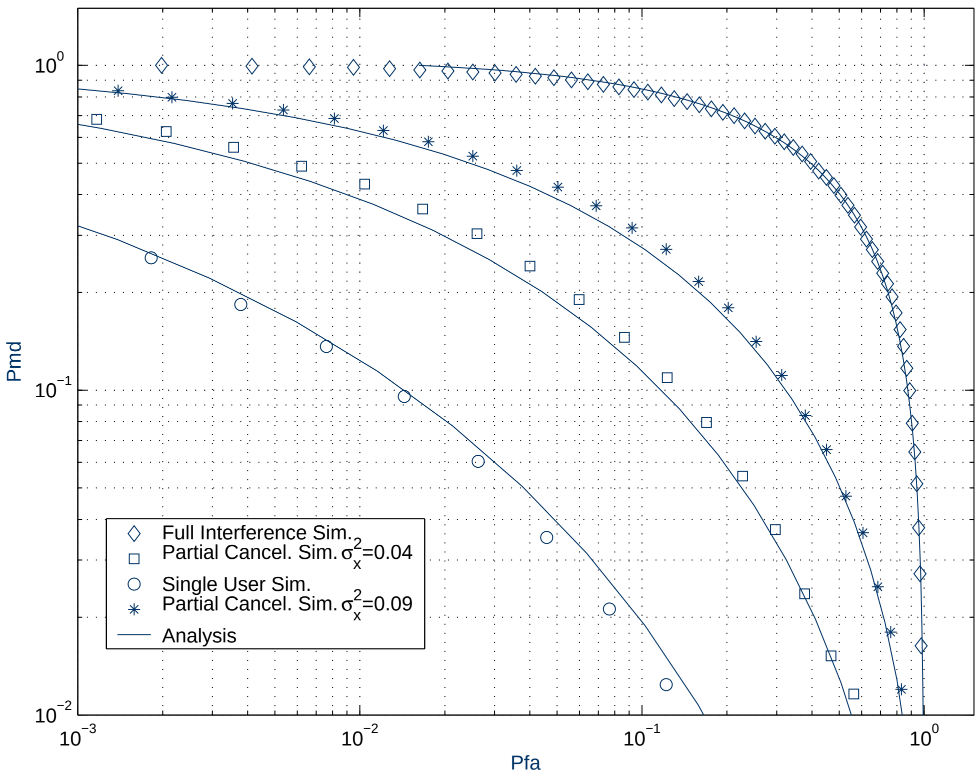
- The data results from the MUD are “soft” and not perfect - we take this into account in the analysis and simulation
- Compute variance of result based on expected Bit Error Rate Performance of receiver

$$\sigma_x^2 = \frac{N(\sigma^2 - \sigma_n^2)}{K+1}$$

- When users $K = 200$, the spreading factor $N = 100$, Bit error rate = $P_e = 10^{-2}$ and $\sigma_n^2 = 0.0998$ (for $E_s/N_0 = 1dB$), then $\sigma_x^2 = 0.0423$.

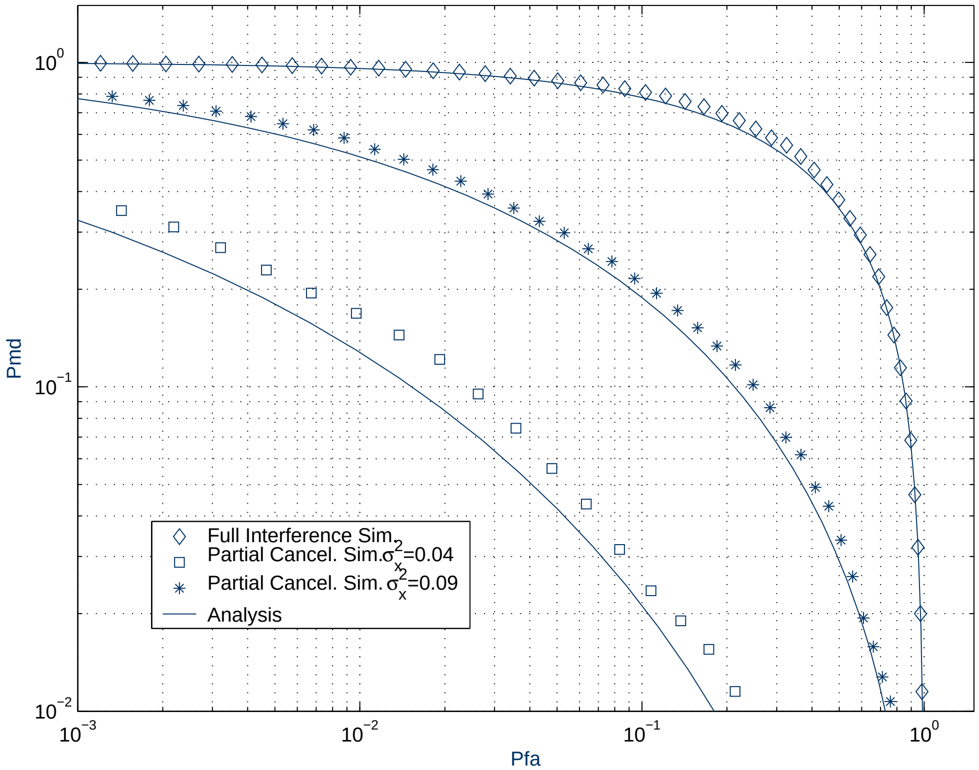
Performance of 1-D System in terms of P_{md} and P_{fa}

- K=200 users,
- $\tilde{d} = 0.7d \rightarrow \sigma_x^2 = 0.09$,
- Processing Gain (N=100)
- Conventional Acquisition fails
- Partial cancellation performance result is acceptable



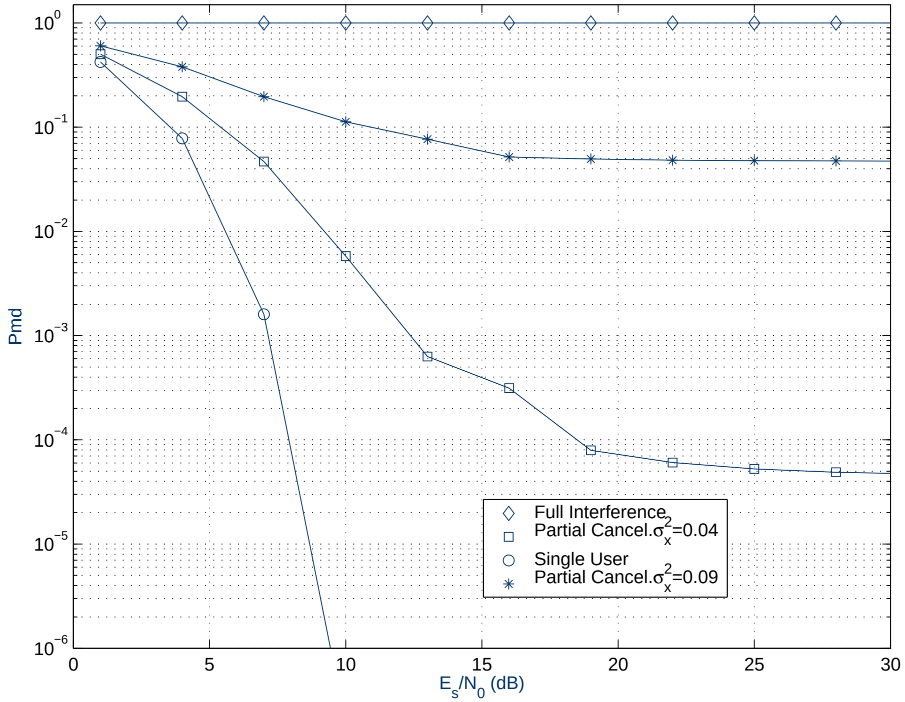
Performance of 2-D System in terms of P_{md} and P_{fa}

- Parameters
  - Users (K=500),
  - $E_s/N_0 = 7$dB,
  - $\tilde{d} = 0.7d \rightarrow \sigma_x^2 = 0.09$,
  - Processing Gain (N=100),
  - 120^0 sector
- Single User performance has $P_{fa} = 0$, therefore not plotted
- Partial Cancellation provides acceptable performance

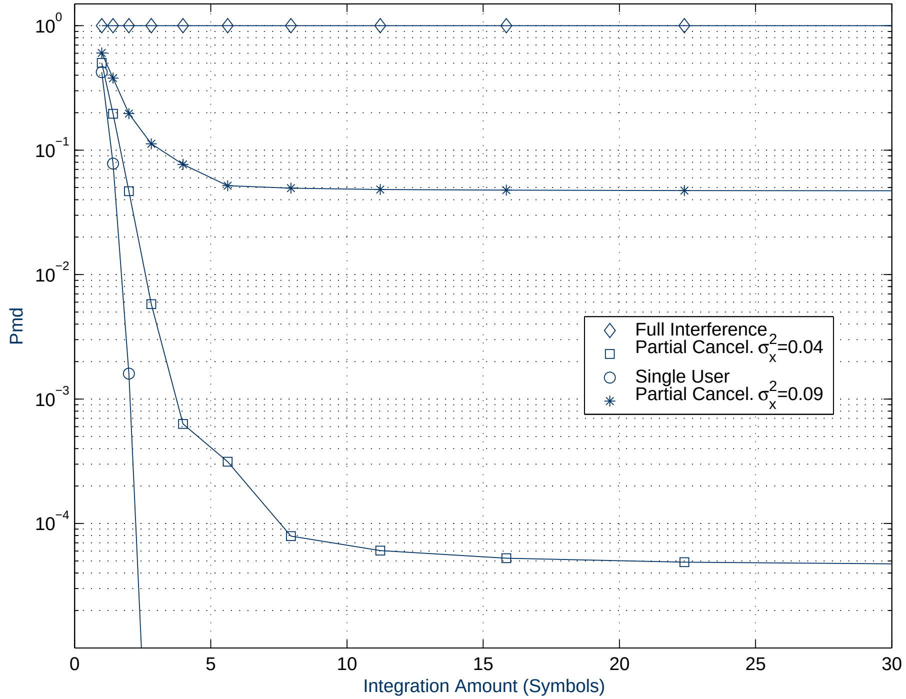


1-D Analytical Performance in terms of P_{md}, (P_{fa} fixed)

- Check Performance for fixed P_{fa}
  - Fixed $P_{fa} = 10^{-2}$ (sets receiver availability)
  - Increase E_b/N_0
- Partial Cancellation Schemes provide adequate performance at low E_b/N_0
- No amount of signal power will improve Full interference case (conventional correlator)



1-D Analytical Performance in terms of P_{md}, (E_b/N_0 fixed)



- Fixed $E_b/N_0 = 1$dB, Integration amounts show improvement only for Partial Cancellation Schemes

Conclusions

- Investigated Decision Directed Acquisition Technique under severe MAI
- Derived densities for cross and auto-correlations of complex transmitted data
- Integrated densities to determine analytical results
- Showed Analytical and Simulation results for 1-D and 2-D systems
- Illustrated that increasing the E_s/N_0, or integration amount beyond certain points bring no benefit with cancellation
- showed single user and conventional approaches, whereby the conventional approach is not practical

Take home Message

- High performance MUD designs are capacity limited by conventional acquisition techniques
- Sharing of information between acquisition unit and receiver are essential to maximise capacity
- Based on known receiver performance (BER), our proposed technique significantly improves performance