MASSIVE UNSOURCED RANDOM ACCESS BASED ON BILINEAR VECTOR APPROXIMATE MESSAGE PASSING

Ramzi Ayachi, Mohamed Akrout,Volodymyr Shyianov,
Faouzi Bellili, Amine Mezghani

IEEE ICASSP 2022

University of Manitoba

Outlines

Introduction

- We introduce a new algorithmic solution to the massive unsourced random access (mURA) problem.
- Relies on slotted transmissions and takes advantage of the inherent coupling provided by the users' spatial signatures in the form of channel correlations across slots to completely eliminate the need for concatenated coding.
- Bilinear vector approximate message passing (Bi-VAMP) algorithm.

University of Manitoba

System Model

- Base Station (BS) serving K_a active devices.
- The number of active devices K_a is assumed to be much smaller than the total number of devices K, i.e., $K_a \ll K$.
- Each active device aims to convey B information bits to the BS.
- Slotted transmission framework (Each active user divides its B-bit packet into L equal-sized chunks of $J = \frac{B}{L}$ bits).
- Codebook $\boldsymbol{\mathcal{A}} = \left[\mathbf{a}_1, \mathbf{a}_2, \cdots, \mathbf{a}_{2^J}\right] \in \mathbb{C}^{\frac{n}{L} \times 2^J}$.

University of Manitoba

$$\mathbf{y}_{m,l} = \sum_{k=1}^{K} \sum_{j=1}^{2^J} \sqrt{\beta_k} g_{k,m} \delta_{j,k,l} \mathbf{a}_j + \mathbf{w}_{m,l}.$$

Where :

- β_k is the large scale fading,
- $g_{k,m} \sim \mathcal{CN}(\mathbf{0}, \mathbf{I})$ is small scale fading,
- $\mathbf{w}_{m,l} \sim \mathcal{CN}\left(\mathbf{0}, \sigma_w^2 \mathbf{I}\right)$ is the white additive Gaussian noise,
- $$\delta_{j,k,l} = \begin{cases} 1 & \text{if user } k \text{ transmits codeword } \mathbf{a}_j \text{ in the } l^{th} \text{ slot} \\ 0 & \text{otherwise} \end{cases}$$

University of Manitoba

$$\mathbf{Y}_l = \boldsymbol{\mathcal{A}}\boldsymbol{\Delta}_l\mathbf{H} + \mathbf{W}_l \quad \text{for} \quad l = 1, \ldots, L.$$

- The number of codewords sent in each $\{l^{th}\}_{l=1}^{L}$ slot must be equal to K_a.
- Different users can transmit the same codeword in the same slot.
- Every user transmits exactly L codewords over the whole transmission period.

Bilinear Vector Approximate Message Passing Algorithm Bi-VAMP

- Solves the bilinear equation $\mathbf{Y}_l = \mathbf{X}_l\mathbf{H} + \mathbf{W}$.
- We set $\mathbf{X}_l \triangleq \mathbf{A}\boldsymbol{\Delta}_l$.
- Enables the use of different priors on the columns of **H** as well as on the rows of **X**.

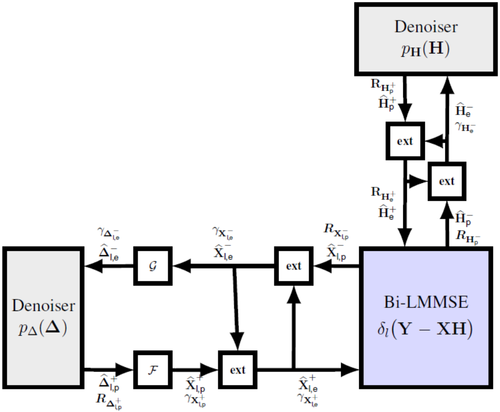


Figure – Block diagram of the adapted Bi-VAMP algorithm with its three modules : two denoising modules incorporating the prior information, $p_{\mathbf{H}}(\cdot)$ and $p_{\boldsymbol{\Delta}}(\cdot)$ and the approximate bi-LMMSE module. The three modules exchange extrinsic information/messages calculated through the **ext** blocks, $\mathcal{G}$ and $\mathcal{F}$ are used to enforce the column-wise structure of $\boldsymbol{\Delta}_l$ in mURA using its row-wise extrinsic information provided by the standard Bi-VAMP algorithm.

- The $\mathcal{F}$ block finds the posterior mean/precision of the columns of $\mathbf{X}_l$ from those of the rows of $\mathbf{\Delta}_l$.

$$\widehat{\mathbf{X}}_{\mathrm{p}}^{+} = \mathbf{A}\,\widehat{\mathbf{\Delta}}_{\mathrm{p}}^{+},$$
$$\gamma_{\mathbf{X}_{\mathrm{l,p}}^{+}}^{-1} = \frac{L}{n}\mathrm{Tr}(\boldsymbol{\mathcal{A}}\,\boldsymbol{R}_{\mathbf{\Delta}_{\mathrm{l,p}}^{+}}\,\boldsymbol{\mathcal{A}}^{\mathsf{T}})$$

- The $\mathcal{G}$ block finds the extrinsic mean/precision of the columns of $\mathbf{\Delta}_l$ from those of the rows of $\mathbf{X}_l$.

$$\widehat{\mathbf{\Delta}}_{\mathrm{e}}^{-} = \beta\,\mathbf{A}^{\mathsf{T}}\widehat{\mathbf{X}}_{\mathrm{e}}^{-},$$
$$\gamma_{\mathbf{\Delta}_{\mathrm{l,e}}^{-}}^{-1} = \alpha\,\mathrm{Tr}(\boldsymbol{\mathcal{A}}^{\mathsf{T}}\,\gamma_{\mathbf{X}_{\mathrm{l,e}}^{-}}^{-1}\,\boldsymbol{\mathcal{A}})$$

University of Manitoba

Results and Benchmarking

Covariance-based

- $B = 104$
- $L = 17$ slots
- We set the parity allocation for the outer tree code to $p = [0, 8, 8, \ldots, 14]$
- Total rate of the outer code $R_{out} = 0.437$
- $J = 14$ coded bits per slot

Clustering-based

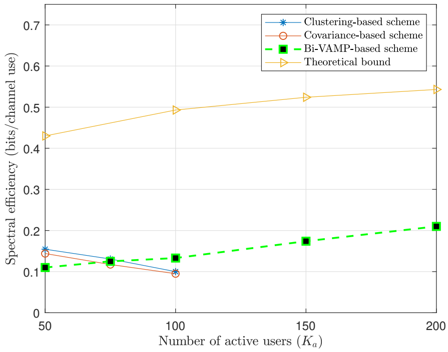
- $L = 6$ slots
- $B = 102$ information bits per packet

Bi-VAMP-based

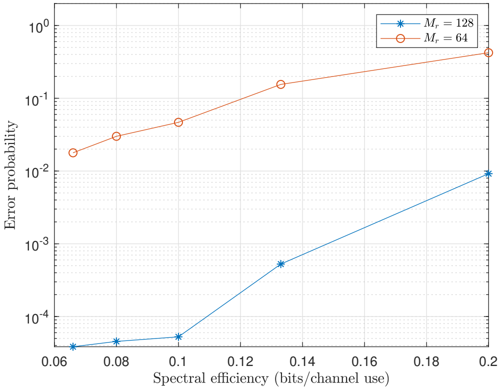
- $L = 10$ slots
- $B = 100$ information bits per packet

- 5 data points
- $M_r/K_a = 0.6$
- $K_a \in \{50, 75, 100, 150, 200\}$ and $M_r \in \{30, 45, 60, 90, 120\}$

Spectral efficiency a function of the number of active users at a target error probability of 10^{-2}.



Performance of the proposed scheme as a function of the spectral efficiency and number of receive antenna elements, M_r, with a fixed number of active users $K_a = 200$ and $\mathrm{SNR} = 30\ \mathrm{dB}$



Conclusion

- We proposed an integrated algorithmic solution to the mURA problem.
- Our method is based on slotted transmissions and the Bi-VAMP algorithm.
- It takes advantage of the inherent coupling provided by the spatial signatures in the form of channel correlations across slots and eliminates the need for concatenated coding.
- It combines the steps of activity detection, channel estimation and data decoding into a unified URA framework.

THANK YOU!