Blind Goal-Oriented Detection (BGOD) for Massive Access in Future Wireless Networks

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Introduction and Motivation

- Random access (RA) is a key yet challenging component of the communication process between User Equipment (UE) and base station (BS) in 5G and beyond 5G (B5G) wireless networks.
- We consider K users consisting of K_M mobile and K_S stationary users.
- $K_a \ll K$ users aim to access the BS and send their data within time interval T.
- The channel is considered to be flat within the coherence interval T.
- BS with N-element antenna array+ single-antenna users

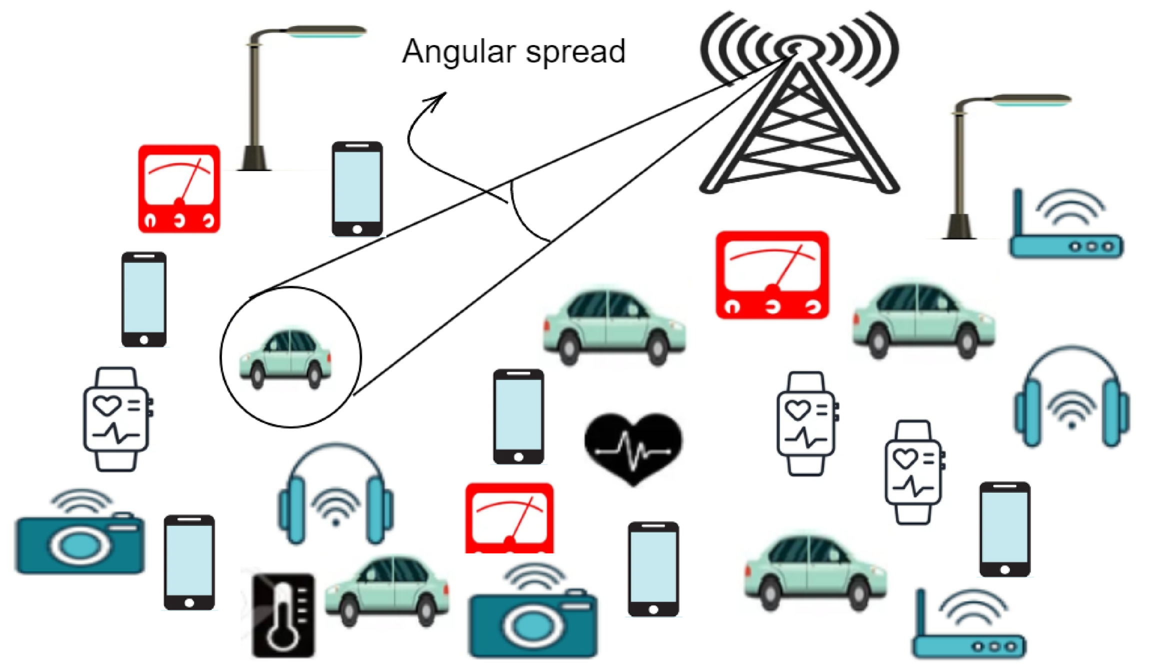

Figure 1: A typical uplink massive access scenario

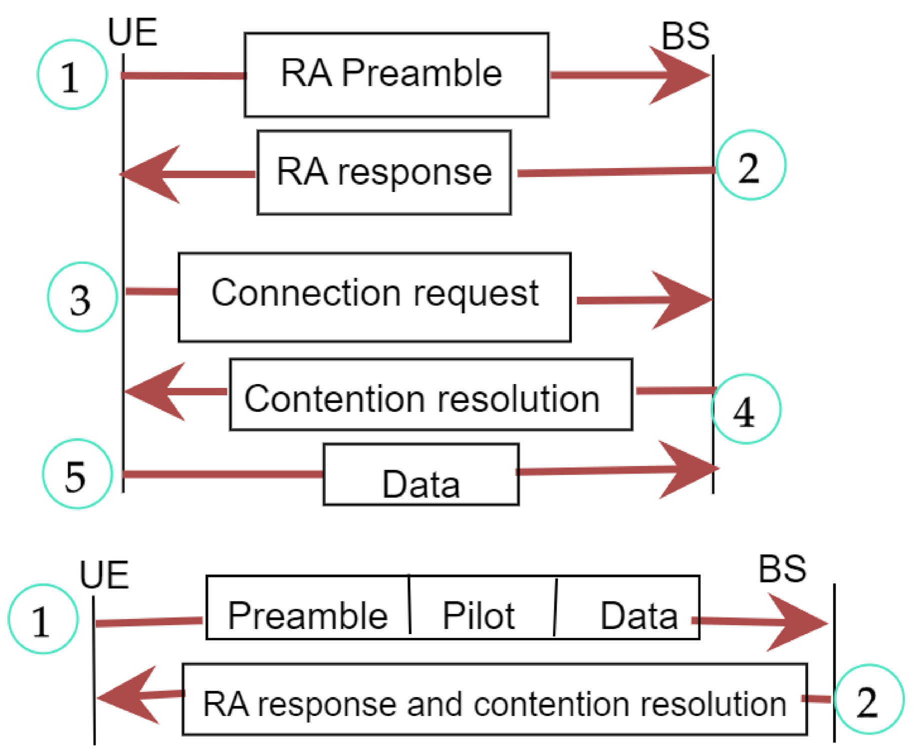

Figure 2: Prior RA schemes: Top image: Four-step RA. Bottom image: Two-step RA.

Challenges and Limitations of prior works

- ✓ **Limited** number of allowable active users.
- ✓ A huge **waste of resources** for RA.
- ✓ Not suitable for **fast** fading channels.
- ✓ Direct **dependence** on the **total** number of users.
- ✓ **Massive connectivity** is **impossible**.

System Model

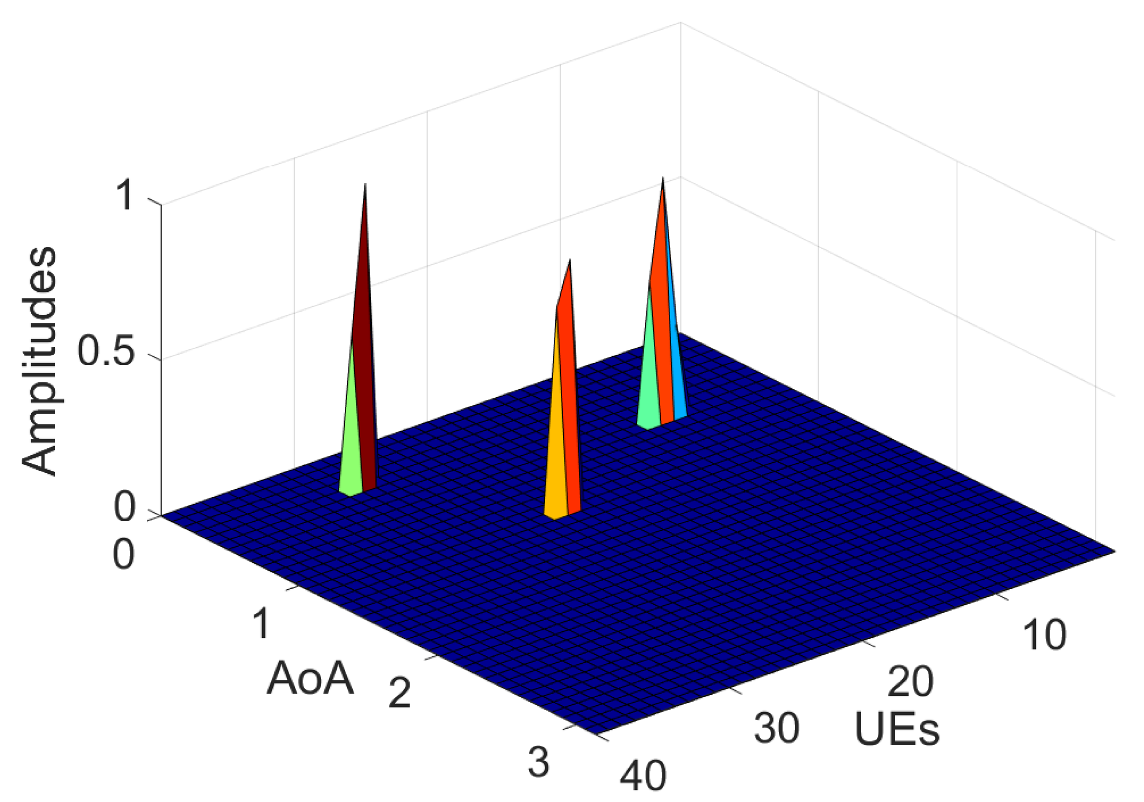

Figure 3: Angular sparse feature of channel.

Channel Model: $\boldsymbol{h}_k = \rho_k \sum_{l=1}^{L_k} \alpha_l^k \boldsymbol{a}(\theta_l^k) \in \mathbb{C}^{N\times 1}$

The observation model at BS: $\boldsymbol{Y}_\Omega = \mathcal{P}_\Omega(\boldsymbol{Y}) = \mathcal{P}_\Omega\left(\sum_{k=1}^{K} \boldsymbol{h}_k \boldsymbol{\phi}_k^H\right) + \boldsymbol{E}$

$\boldsymbol{\phi}_k$: the transmitted data of kth user.
L_k: number of multi-path components of k-th user.
Ω: the set of observed antenna elements.
ρ_k: Large scale fading coefficient

BGOD strategy

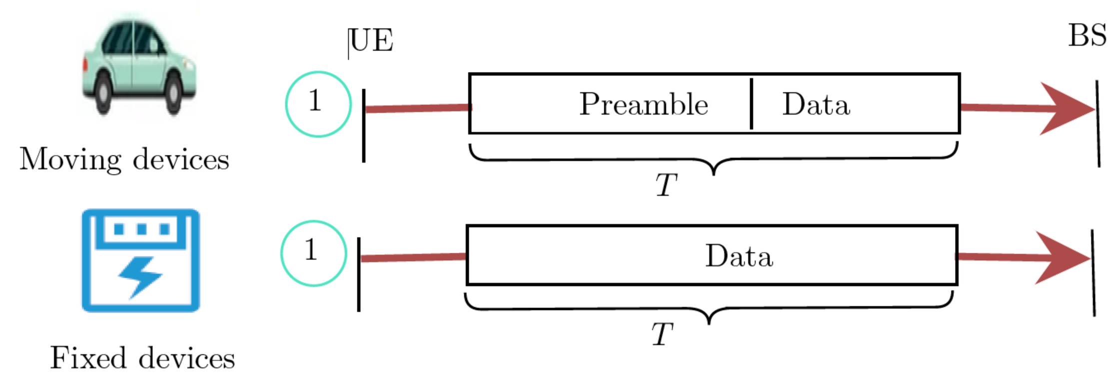

Figure 4: BGOD scheme

1. Solve the following **goal-oriented optimization** that encourages the angular sparse feature with the goal of active user detection in mind.

$$\min_{\substack{\boldsymbol{v}\in\mathbb{C}^N, \boldsymbol{Z}\in\mathbb{C}^{N\times T}\\ \boldsymbol{Y}^\star\in\mathbb{C}^{M\times T}, \boldsymbol{W}\in\mathbb{C}^{T\times T}}} \mathrm{Re}(v_1) + \mathrm{Re}(\mathrm{tr}(\boldsymbol{W})) + \frac{\gamma}{2}\|\boldsymbol{Y} - \boldsymbol{Y}^\star\|_F^2$$
$$\text{s.t.} \begin{bmatrix} \mathcal{T}(\boldsymbol{v}) & \boldsymbol{Z} \\ \boldsymbol{Z}^H & \boldsymbol{W} \end{bmatrix} \succeq \boldsymbol{0}, \quad \boldsymbol{Y}^\star = -2c_1 \mathcal{P}_\Omega(\boldsymbol{Z}). \tag{1}$$

2. Obtain the dual matrix variable $\boldsymbol{V}$ corresponding to $\boldsymbol{Y}^\star$.
3. Find the angles that maximize the ℓ_2 norm of the goal-oriented dual polynomial function $\boldsymbol{q}_G(\theta) = (\mathcal{P}_\Omega^{\mathrm{Adj}}(\boldsymbol{V}))^H \boldsymbol{a}(\theta)$.
4. Place the angles into several clusters.
5. Use alternative minimization to jointly recover the data and channel gains of active users.

BGOD unique features

1. Arbitrary **channel** distribution
2. Arbitrary **noise** distribution
3. Not dependent on the **total number of users**.
4. **The allowable number of active users is directly related to the computational complexity that BS can bear.**
5. **Communication costs at the user side are somehow transferred into the computational complexity at the receiver side.**
6. BGOD finds the information of active users without **searching**.
7. BGOD performs **active user detection, channel estimation and data recovery**.

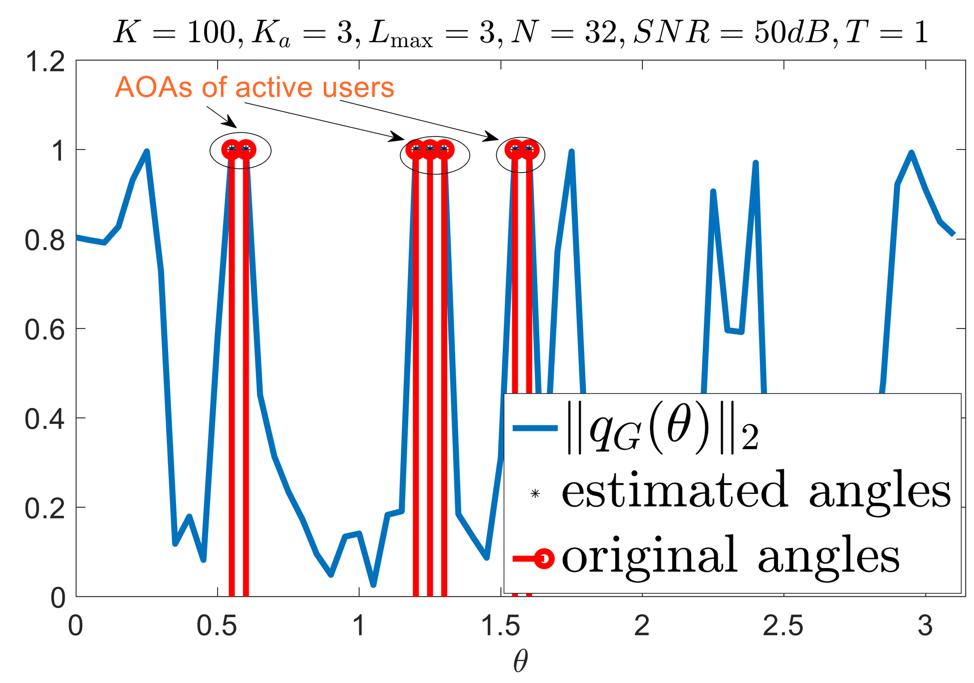

Figure 5: ℓ_2 norm of the goal-oriented dual polynomial function

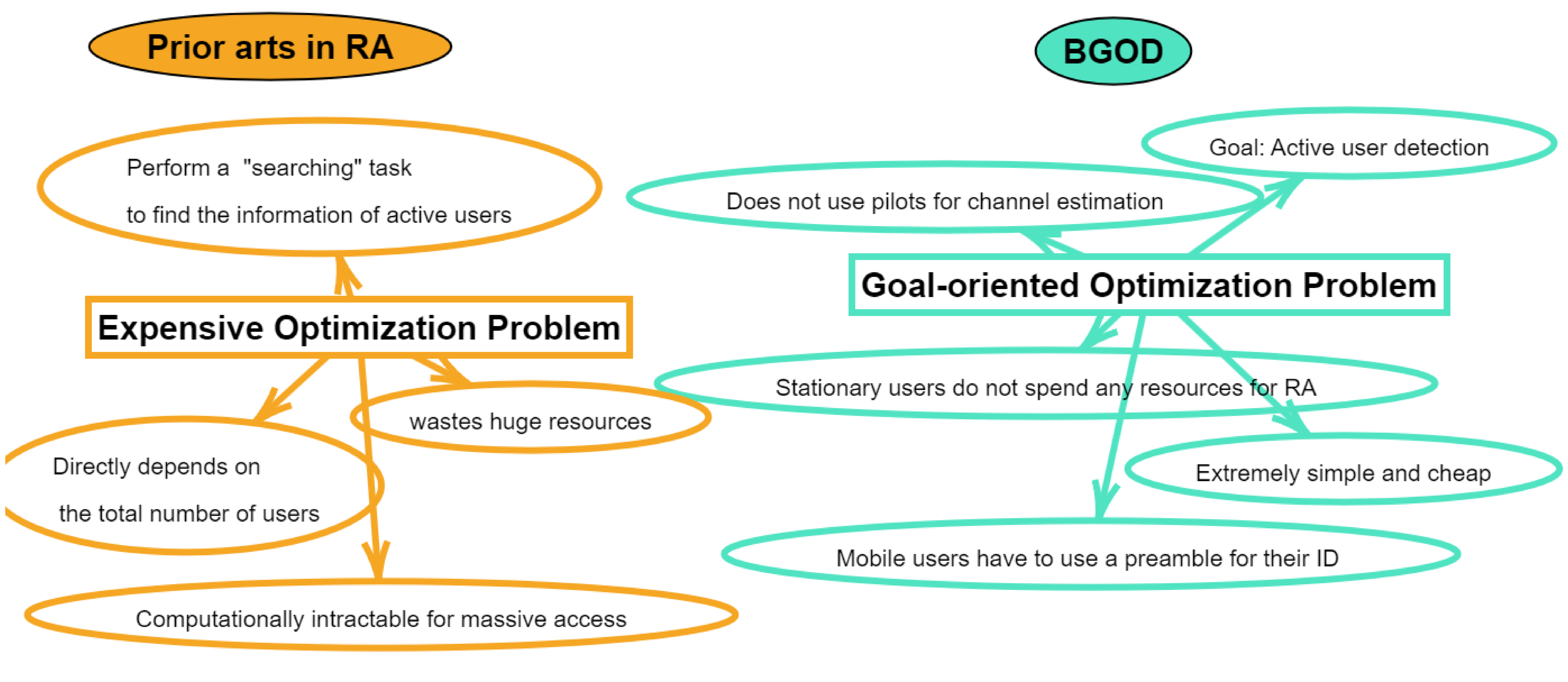

Figure 6: Our contributions in connection with prior RA works.

Simulation Results

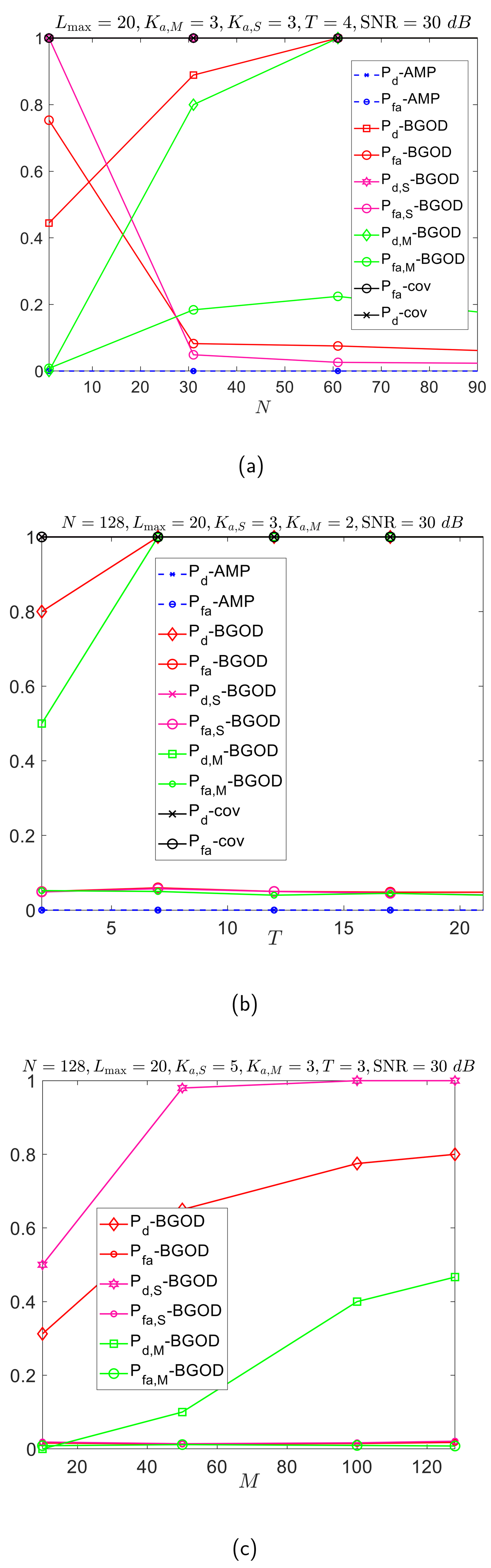

Figure 7: $K_S = 1500, K_M = 500$. Detection accuracy.

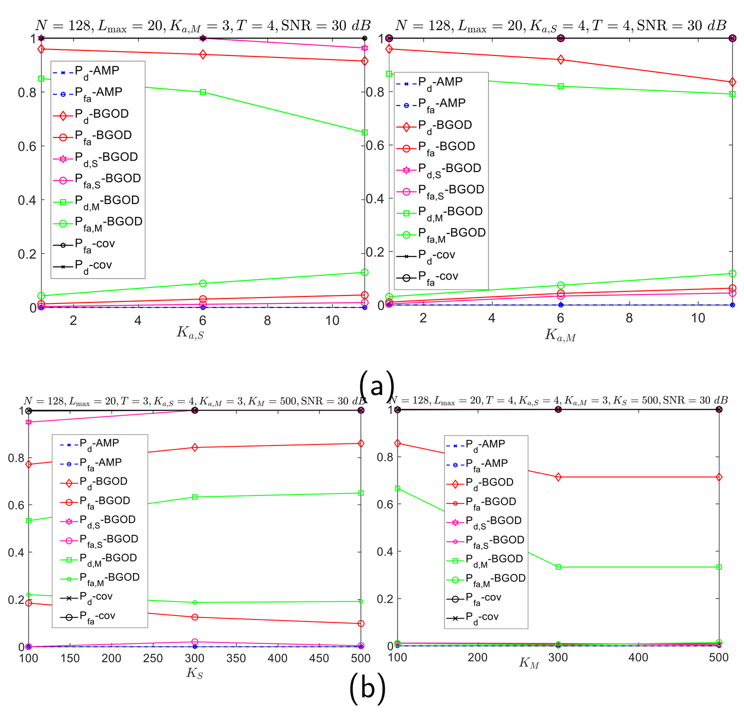

Figure 8: $K_S = 1500, K_M = 500$. Detection accuracy.