Toward Forward Link Interference Cancellation

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Toward Forward Link Interference Cancellation

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Research and Standards Group

Outline

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  - Conventional multiuser signal modeling and receiver design
  - Subspace-based signal modeling and receiver design
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- Multiuser receiver performance evaluation
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  - Implementation complexity
- Conclusions and recommendations

Introduction (1/3)

- **Through the past 20-year academic and industrial research, it shows that interference cancellation techniques have the potential to increase wireless network reliability and capacity.**
- **Narrowband interference cancellation techniques, named single-antenna interference cancellation, have been intensively investigated for GSM/EDGE network. [Cingular 03].**
  - Joint demodulation: accurate interference estimation and mitigation, high complexity; ~70% capacity gain for synchronous network.
  - Blind interference cancellation: low complexity; ~40% capacity gain for synchronous network.

- **The feasibility of Common Pilot Channel (CPICH) interference cancellation at WCDMA user equipment has been investigated [3GPP-TR25.991].**
  - For a Cancellation Set (CS) size of 6, the system level simulation results reported up to 13.6% gain for voice and 20.6% gain for 144kbps data.
  - Due to more receiver impairments/imperfections in practices, these capacity gain results will be reduced.
- **There are also reports of using interference cancellation for 1xEV-DO reverse-link.**

Introduction (2/3)

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Introduction (3/3)

- Though interference cancellation is widely regarded as an implementation-related issue, it is known to have nontrivial impacts on the whole system capacity.
- Recently it is known that many carriers are interested in the possibility of using advanced receiver techniques for enhancing system capacity.
- Therefore it should be important for us to investigate the feasibility of forward-link interference cancellation.

Forward-Link Interference Cancellation

- **Compared with access network, access terminal, AT, is known to have many limitations:**
  - limited knowledge of interfering signals,
  - limited power supply,
  - limited computation capability,
  - and limited physical form factor.
- **Different understanding of received multiuser signal can lead to different multiuser receiver design frameworks.**
  - Conventional multiuser signal modeling and receiver design.
  - Subspace-based signal modeling and receiver design
  - Blind multiuser signal modeling and receiver design
- **The incorporation of efficient and reliable blind interference cancellation techniques in the AT design is important for designing the next stage mobile systems.**

Conv. Multiuser Signal Model (1/3)

This is the information we want to know

(K-1) unknown interfering signal amplitudes

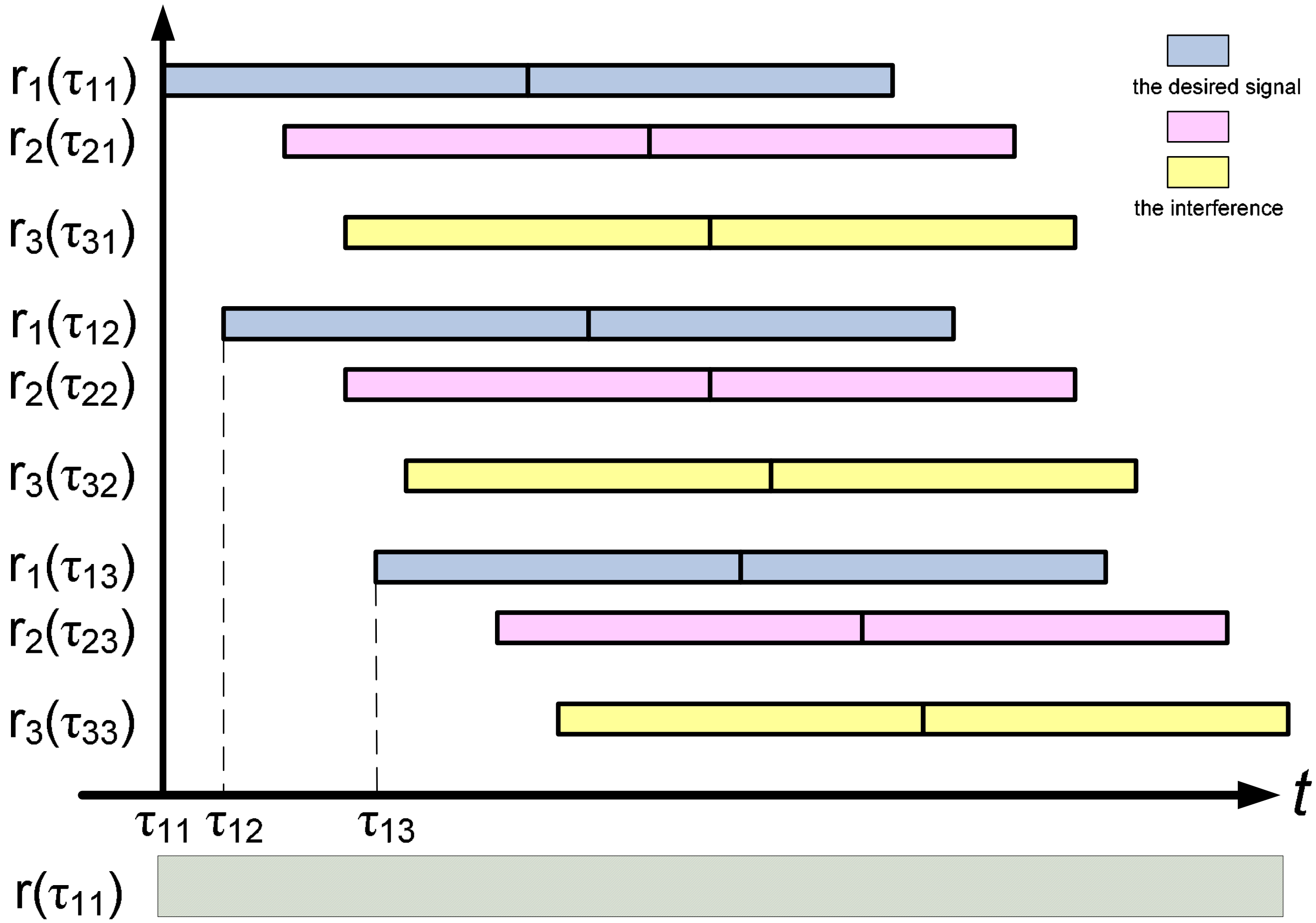
$$\mathbf{r} = \mathrm{L}^{\mathrm{C}}\left(b_1 ; A_1 , \mathbf{s}_1 ; b_2 \ldots b_K ; A_2 \ldots A_K ; \mathbf{s}_2\left(\tau_2\right) \ldots \mathbf{s}_K\left(\tau_K\right) \right) + \mathbf{n}$$

The received signal vector.

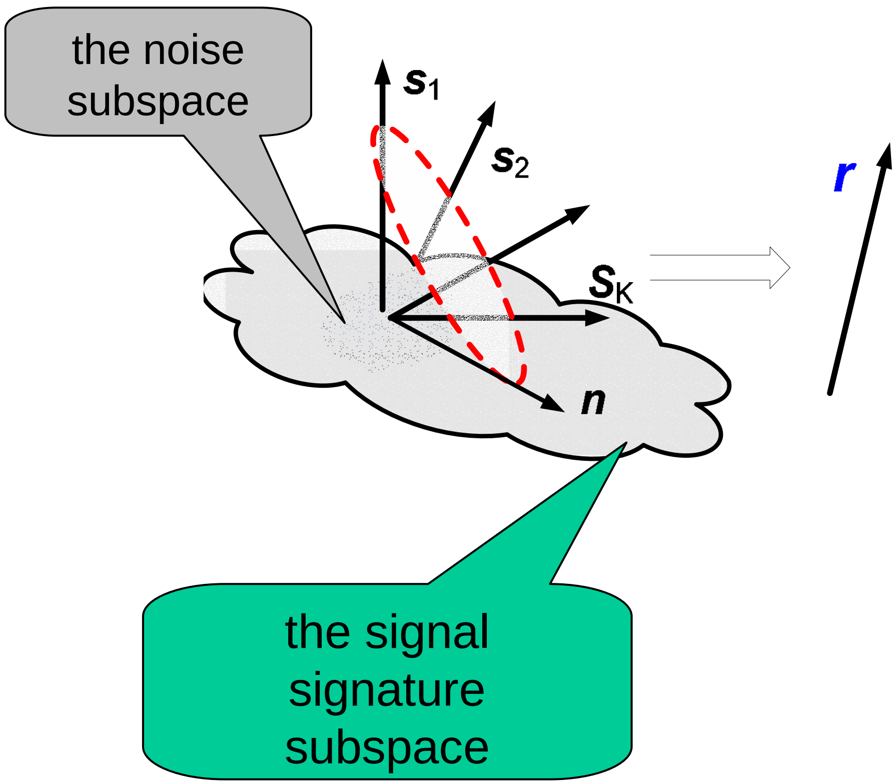
(K-1) unknown interfering signal signatures or sequences

Unknown information carried by interfering signals

Conv. Multiuser Signal Model (2 / 3)



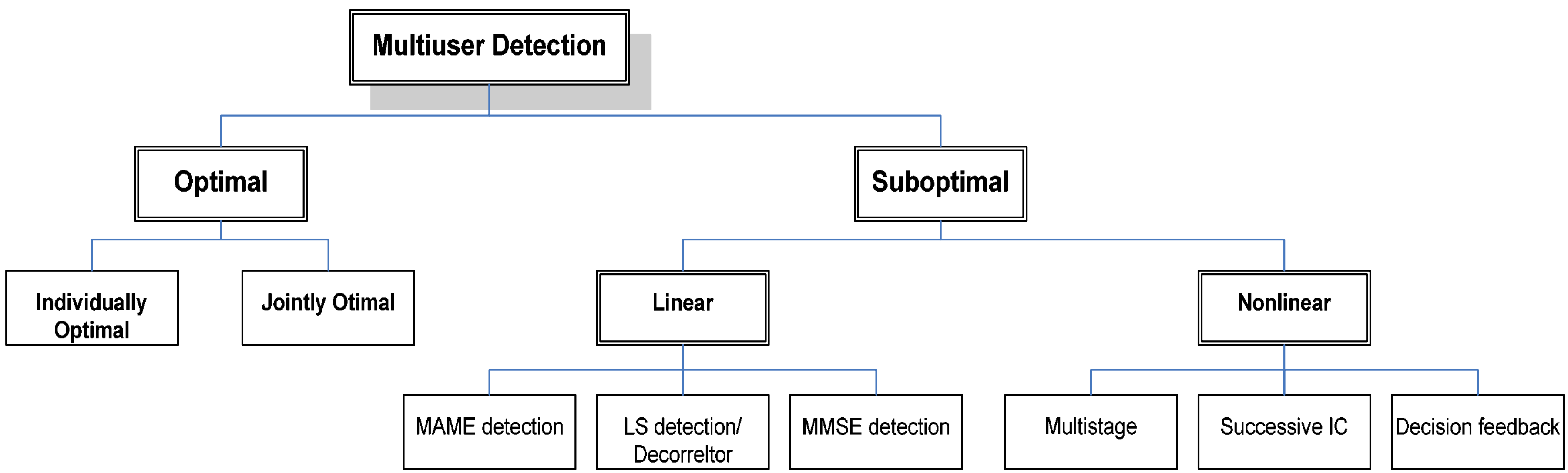
Conv. Multiuser Signal Model (2/3)



- The conventional model is a nature and straightforward description of received signals.
- It is known to be critical in understanding multiuser communication and designing conventional interference cancellation receiver.
- The problem in developing blind MUD: many parameters in this model are unknown beforehand by AT.

Popular Multiuser Detection Schemes

- With different optimization criteria in signal processing, there are lots of conventional multiuser receiver design schemes available.
- One of the critical problems of directly applying them in AT is most of these schemes require the channel and signal sequence/signature knowledge of each interference.



Multiuser Receiver Comparison

MUD type	Complexity order	Latency	ECCs?	$K > N$ allowed?
Optimal max. likelihood	2^K	1	Separate	Yes
Linear	K to K^3	1	Separate[1]	No (ZF), Yes (MMSE)
Turbo	PK to 2^K	$2P$	Integrated	Yes
Parallel IC	PK	P	Integrated	Yes
Successive IC	K	K	Integrated	Yes
Nonorth. matched filter	K	1	Separate	Yes[2]
Orth. matched filter	K	1	Separate	No

[1] With some exceptions (e.g., [39]), generally linear receivers cannot seamlessly integrate ECCs.
[2] Although allowed in principle, $K > N$ is not likely to be achievable in practice for the MF receiver.

Source: IEEE Communication Magazine, April 2005

Example: Successive Interference Cancellation

❑ A simple and nature idea:

- Estimation or detection is made firstly about interfering user(s) if possible
- Recreate and substrate interfering signal
- So a supposedly better version of desired signals.

❑ Known shortcomings

- Asymmetric performance: equal-power users are demodulated with disparate reliability.
- It requires knowledge of absolute amplitudes/power estimation in addition to the phases and signal sequences estimation of interfering signals.

Subspace-Based Multiuser Signal Model (1/2)

This is the data we want to know

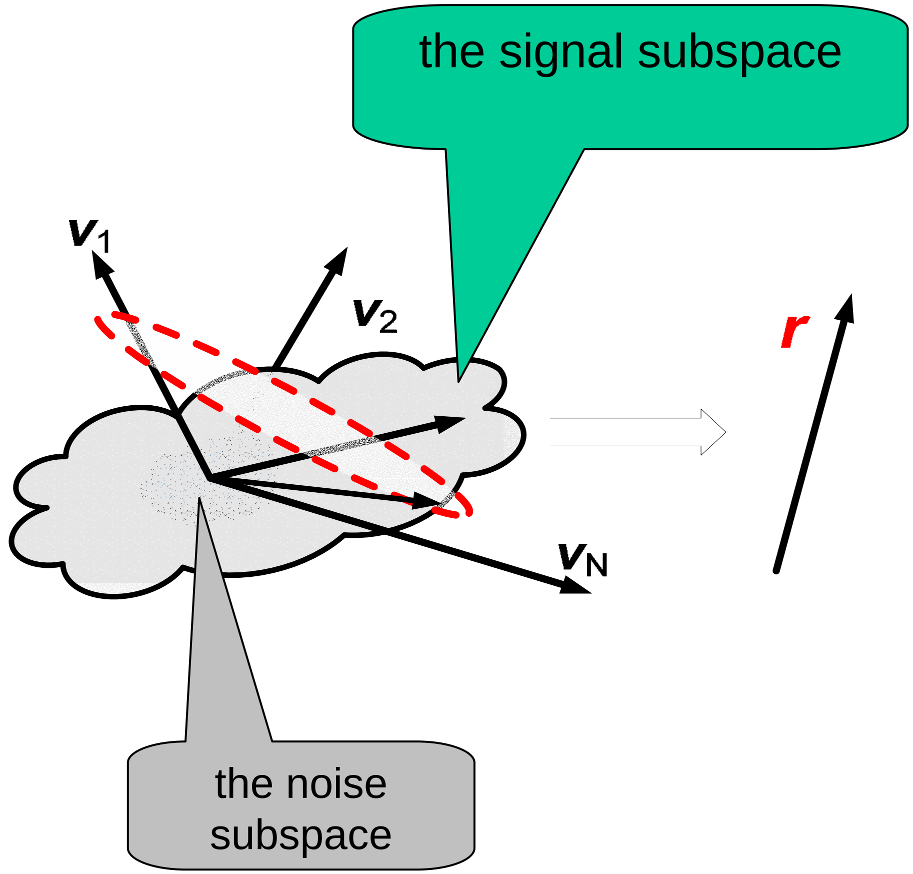
$$\mathbf{r} = \mathrm{L}^{S}\left(b_1 ; A_1 , \mathbf{s}_1 ; \boldsymbol{\upsilon}_1 , \boldsymbol{\upsilon}_2 \,\mathrm{K}\; \boldsymbol{\upsilon}_N ; \lambda_1 , \lambda_2 \,\mathrm{K}\; \lambda_N \right) + \mathbf{n}$$

The current received signal vector

K bases of the signal subspace

Subspace-Based Multiuser Signal Model (2/2)

- The subspace-based model gives us in-deep presentation of the received signal structure.
- The performance of subspace-based detectors can be the exactly the same to conventional detectors.
- The bad thing is the signal subspace separation or matrix inverse is non-trivial.



Example: Subspace-Based Decorrelator

❑ The basic detection scheme

- Estimate the phases/delays and spreading sequences of interfering signals.
- Calculate a set of orthonormal bases from the signal signatures/sequences of interfering signals. For example, Gram-Schmidt procedure or Gauss elimination.
- Reconstruct the conventional decorrelating detector

❑ The problems with the decorrelators

- The channel estimation cannot be avoided.
- The computation complexity still is more than $O(N^2)$ with Gaussian elimination.
- Possible singularity problem and noise enhancement.
- There is performance degradation when $\alpha=K/N$ is close or greater than 1.

Blind Multiuser Signal Model (1/3)

This is the information we want to know

M previously received signal vectors

$$\mathbf{r}[n] = \mathrm{L}^{B}\left(b_1[n];\mathbf{s}_1;b_1[n-M]\ldots b_1[n-1];A_1;\mathbf{r}[n-M],\ldots\mathbf{r}[n-1]\right)+\mathbf{n}$$

the trick here is to find the function $L^B(\cdots)$

The signal amplitude of desired users

M previously detected correct information

The current received signal vector

Blind Multiuser Signal Model (2/3)

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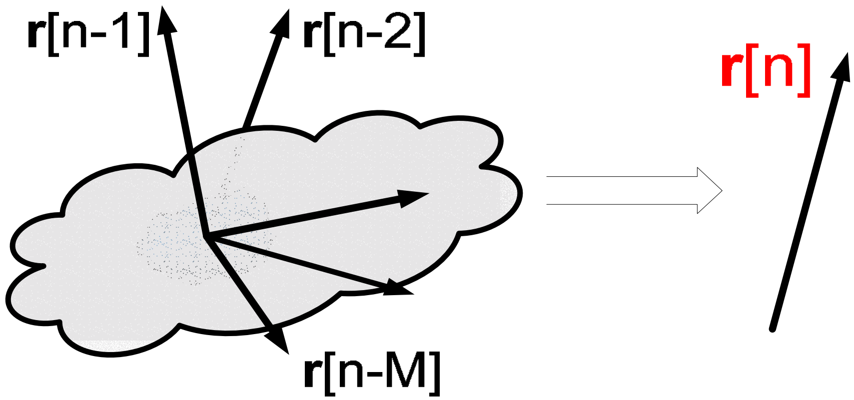


Blind Multiuser Signal Model (3/3)

The current received signal vector

$$\mathbf{r}[n] = \boldsymbol{S}[n]\mathbf{f} + \boldsymbol{n}$$

A new noise component

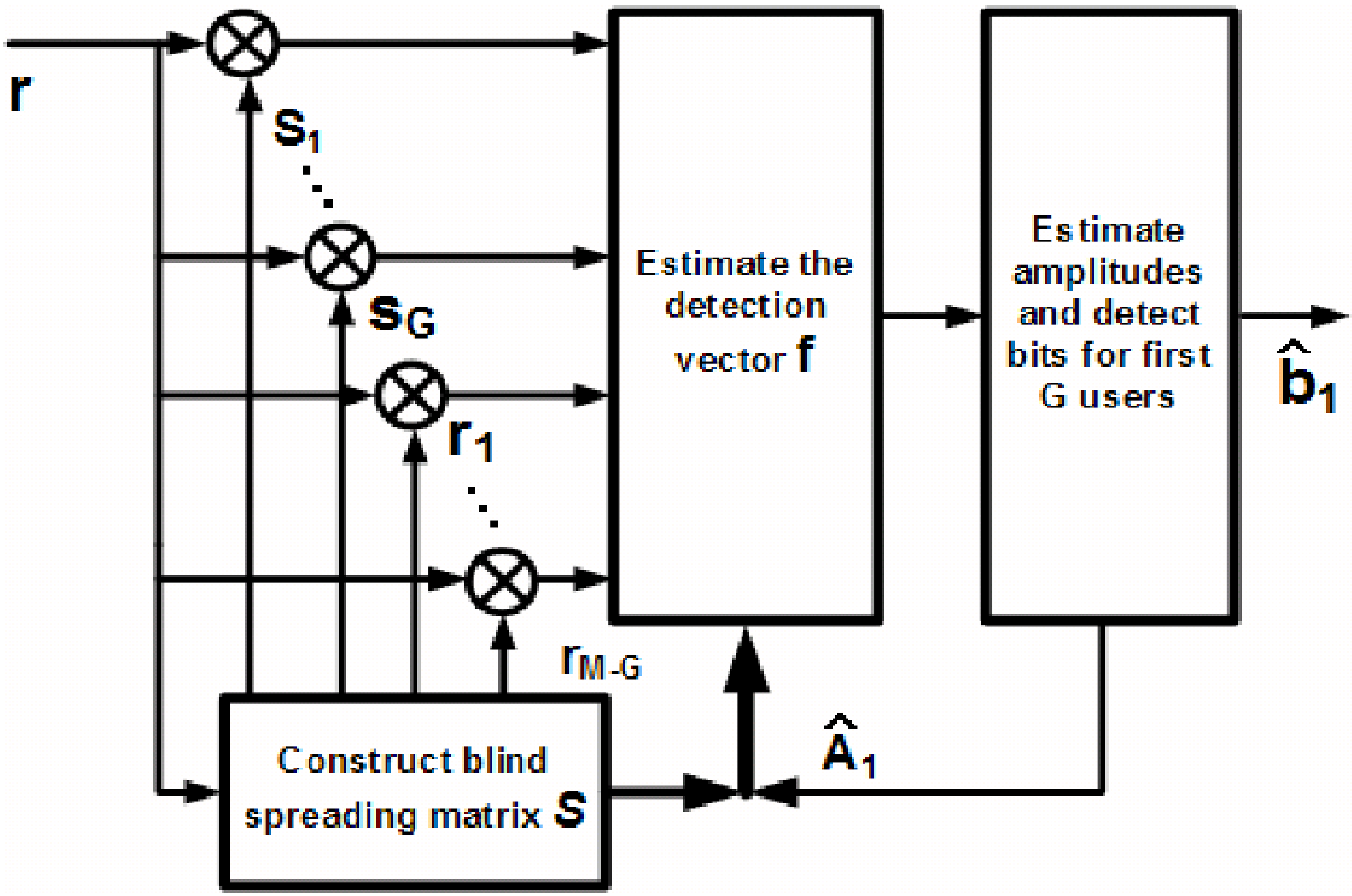
It is termed ***detection vector.***

S[n] = [**s**$_1$ **r**[n-1] **r**[n-1] ⋯ **r**[n-M]] is termed a blind signal signature matrix

$$\hat{A}_1[n]\hat{b}_1[n] = \mathbf{f}^{\mathrm{H}} \begin{bmatrix} 1 \\ \hat{A}_1[n-1]\hat{b}_1[n-1] \\ \vdots \\ \hat{A}_1[n-M]\hat{b}_1[n-M] \end{bmatrix}$$

The interference cancellation can be realized in a simple adaptive filtering format.

Example: An Blind Interference Cancellation Structure



Multiuser Receiver Design Strategies

- **With different signal processing criteria, different blind receiver design scheme can be devised.**
  - least squares based approaches
  - minimum mean-squared errors based approaches
  - maximum likelihood based approaches
  - etc.
- **The good thing is that there is no channel estimation necessary.**

Performance Evaluation

- Different interference cancellation receivers usually have different trade-offs between performance and complexity.
- For the evaluation purpose, we need consider
  - Radio network simulations to evaluate capacity gains.
  - Link level simulations to evaluate feasible accuracy of cancellation.
  - Implementation complexity

Network Level Simulation Considerations

- **Many network level simulation assumptions should be made:**
  - the cell network architecture, e.g. single cell or multiple-cells, etc.
  - the definition of Cancellation Set. The Cancellation Set size can be between the number of total received signals and the Active Set size.
  - the modeling of IC-enabled/disabled power control and handover.
  - the distribution of IC-enabled ATs and IC-disable ATs.

Link Level Simulation Considerations

- **In link level simulation of interference cancellation receiver, we may consider**
  - the spreading sequence allocation for interfering signals
  - in a multi-cell link level simulation, the power spectral densities of other cells will be modeled, whether or not they are in the Cancellation Set.
  - Sensitivity performance with estimation imperfection and/or DSP errors.
  - The delays of different multipath and interfering signals.

Implementation Complexity

- **The evaluation of major receiver DSP components should include**
  - the calculation of the cross-correlation terms between different spreading codes,
  - the tracking of timing,
  - the channel estimation,
  - the regeneration of interference terms,
  - the cancellation of interference terms,
  - etc.

Conclusions and Recommendations

- With the investigation of existing interference cancellation applications, it is suggested that the employment of interference cancellation techniques at AT is important for enhancing the capacity of future mobile systems.
- With different understandings of received signal, three interference cancellation frameworks are discussed.
- For the evaluation purpose, several considerations for network level, link level and complexity evaluations are recommended.