

# Application of Multiuser Detection to Third Generation Wireless Systems

*by*

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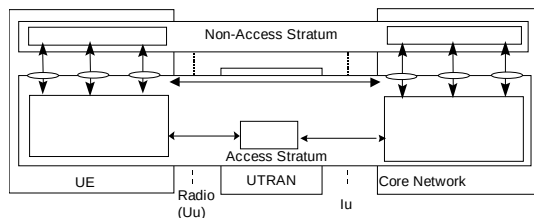
## Research Summary

- ❖ For the uplink, use
  - ✓ Linear MMSE or
  - ✓ PIC
- ❖ For the downlink, use Blind Detection with Linear MMSE
- ❖ Further studies required to confirm performance

## Outline

- ❖ 3G Physical Layer Parameters
- ❖ Introduction to Multiuser Detection
- ❖ Applying Multiuser Detection to 3G Systems
- ❖ Conclusion and Further Research

## 3G Architecture



### Useful Acronyms

|       |                                            |
|-------|--------------------------------------------|
| 3GPP  | Third Generation Partnership Project       |
| UMTS  | Universal Mobile Telecommunications System |
| UTRAN | UMTS Terrestrial Radio Access Network      |
| UE    | User Equipment                             |
| CE    | Core Network                               |

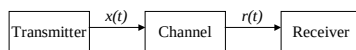
## 3G Physical Layer

| Description          | Parameter                                                      |
|----------------------|----------------------------------------------------------------|
| Multiple Access      | Wideband DS-CDMA                                               |
| Duplex modes         | FDD, TDD                                                       |
| Channel Bandwidth    | 5 MHz or multiples of.                                         |
| Chip rate            | 3.84 Mcps                                                      |
| Multi-rate concept   | Orthogonal Variable Spreading Factor (OVSF) and Multiple Codes |
| Frame Length         | 10 ms or multiples of.                                         |
| Coherent detection   | Pilot symbols transmitted                                      |
| Spreading Modulation | QPSK                                                           |
| Data Modulation      | QPSK                                                           |
| Channel coding       | Block coding concatenated with Convolution or Turbo Coding     |

## What is Multiuser Detection?

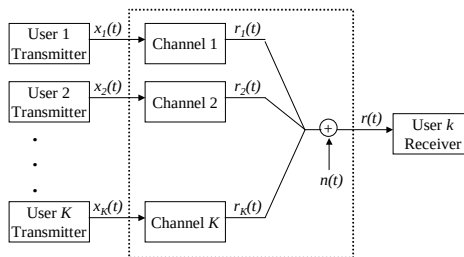
Usually, the use of every piece of information available in the communication channel to detect desired user's signal

Single user communication system:



$$r(t) = x(t) + n(t)$$

Multiple user communication system:



$$r(t) = \sum_{j=1}^K r_j(t) + n(t)$$

$A = [A_1, A_2, \dots, A_K]$   
 $A$  = received amplitude

$b = \{-1, 1\}$

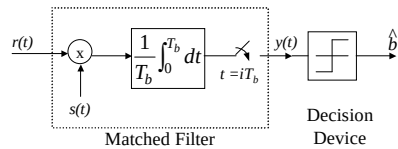
$s(t) = \text{PN code}$   
 $\int_0^{T_b} s_j(t) s_k(t) dt = \begin{cases} 1 & j = k \\ 0 & j \neq k \end{cases}$

$$r(t) = \sum_{j=1}^K A_j b_j s_j(t) + n(t)$$

## Conventional Detector

- ❖ Matched Filter.
- ❖ Uses RAKE receiver to combat multipath propagation.
- ❖ Interference treated as Gaussian noise.

Single user :

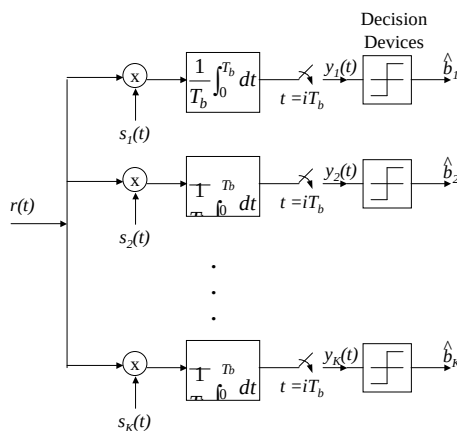


$$y(t) = \frac{1}{T_b} \int_0^{T_b} r(t)s(t)dt$$

$$y(t) = Ab + n_s(t)$$

## Conventional Detector

Multiple user communication system:



$$y_k(t) = \frac{1}{T_b} \int_0^{T_b} r(t)s_k(t)dt$$

$$y_k(t) = A_k b_k + \sum_{j=1, j \neq k}^K A_j b_j \rho_{j,k} + n_k(t)$$

$$\rho_{j,k} = \frac{1}{T_b} \int_0^{T_b} s_j(t)s_k(t)dt = 1 \quad \text{for } j = k$$

$$\rho_{j,k} = 0 \quad \text{for } j \neq k$$

## Causes of Multiple Access Interference

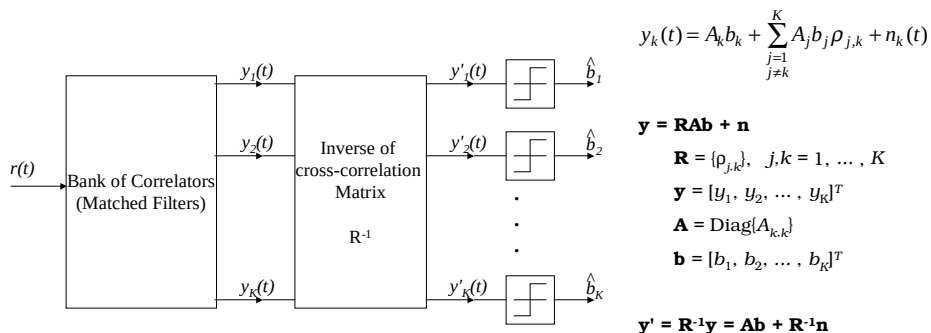
- ❖ Non-orthogonal signature codes
- ❖ Asynchronous transmission
- ❖ Near-far effect
- ❖ Multipath propagation and fading
- ❖ Time varying channel characteristics

## Mitigation of Multiple Access Interference

- ❖ Approach 1: Eliminate causes of MAI individually
- ❖ Approach 2: Employ Multiuser Detection schemes:
  - ✓ Optimum Detector
  - ✓ Decorrelating Detector
  - ✓ Linear MMSE
  - ✓ Successive Interference Cancellation
  - ✓ Parallel Interference Cancellation
  - ✓ Group-wise Successive Interference Cancellation
  - ✓ Blind Detection
  - etc.

## Decorrelating Detector

De-correlates output of the Conventional Detector



## Decorrelating Detector

### ❖ Advantage:

- ✓ Best performance in the absence of AWGN

### ❖ Disadvantages:

- ✓ Requires knowledge of signature codes and channel delays of all users
- ✓ Enhances noise (AWGN)
- ✓ Matrix inversion involves lots of calculations
- ✓ As channel characteristics change, recalculating  $\mathbf{R}^{-1}$  becomes demanding

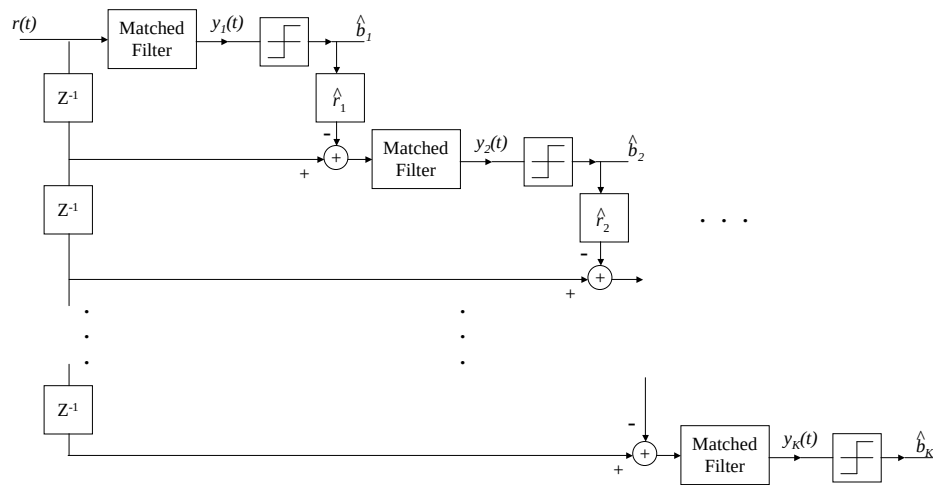
## Linear Minimum Mean Squared Error

- ❖ De-correlates output of the Conventional Detector (similar to Decorrelating Detector)
- ❖ Before inverting correlation matrix  $\mathbf{R}$ , modify it to:

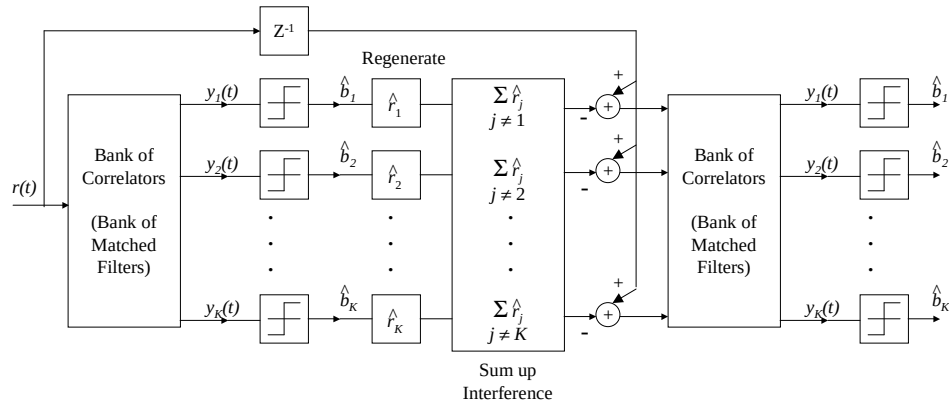
$$\mathbf{R}_{\text{MMSE}} = \mathbf{R} + \mathbf{A}^{-2} (N_0/2)$$

- ❖ Minimizes the error between the detected bits,  $\mathbf{b}$  and the output of the conventional detector

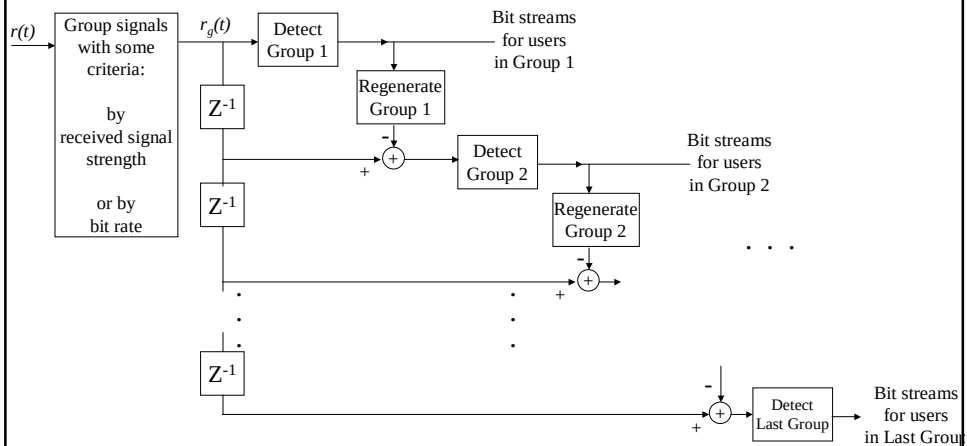
## Successive Interference Cancellation



## Parallel Interference Cancellation



## Group-wise Successive Interference Cancellation



| Comparison                 |                            |                            |                                        |                                    |                             |                                |
|----------------------------|----------------------------|----------------------------|----------------------------------------|------------------------------------|-----------------------------|--------------------------------|
|                            | Decorrelating              | Linear MMSE                | SIC                                    | PIC                                | GSIC                        | Blind Detection                |
| Detection Delay            | Single bit detection delay | Single bit detection delay | $K-1$ bits detection delay for weakest | Two bits detection delay per stage | Hybrid between SIC and PIC  | Single bit detection delay     |
| Closed loop power control  | No effect                  | No effect                  | Worse compared with Conv. detector     | Enhances performance               | Mid-way between SIC and PIC | No effect                      |
| Knowledge of Signal energy | Not required               | Required                   | Required                               | Required                           | Required                    | Not required                   |
| Knowledge of Signal delay  | Required                   | Required                   | Required                               | Required                           | Required                    | Required for desired user only |
| Complexity                 | Complex: matrix inversion  | Complex: matrix inversion  | Simpler: hardware re-use               | Complex: parallel processing       | Medium complexity           | Complex adaptation             |
| Others                     | Enhances Noise             |                            |                                        |                                    |                             | Requires training bits         |

### 3G without Multiuser Detection

- ❖ If there is no Multiple Access Interference, Multiuser Detection is not required
- ❖ 3G anticipates Multiple Access Interference and combats it with:
  - ✓ Orthogonal codes
  - ✓ Synchronization channels
  - ✓ Fixed frame length
  - ✓ Coherent detection
  - ✓ Channel coding

## Other Issues

- ❖ 3G uses standardized receiver structure
- ❖ Long spreading codes
- ❖ Adaptive detection
- ❖ Complexity

## Further Research

- ❖ For the uplink, use
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  - ✓ PIC
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## References

- ❖ Tutorial on Wideband-CDMA
  - ✓ E. Dahlman, P. Beming, J. Knutsson, F. Ovesjo, M. Persson and C. Roobol, "WCDMA-The Radio Interface for Future Mobile Multimedia Communications", IEEE Transactions on Vehicular Technology, vol. 47, no 4, Nov. 1998, pp1105 to 1118.
- ❖ 3GPP web site and ftp server
  - ✓ [www.3gpp.org](http://www.3gpp.org)
  - ✓ [ftp.3gpp.org/specs](ftp://ftp.3gpp.org/specs) *(for Physical layer, check 25.000 series of latest release)*
- ❖ Tutorial on Multiuser Detection
  - ✓ S. Moshavi, "Multi-User Detection for DS-CDMA Communications", IEEE Communications Magazine, October 1996, pp 124 - 136
  - ✓ S. Verdu, "Multiuser Detection", Cambridge University Press, 1998