Cognitive Suppression of Multipath Interference In Angular Domain

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Outline

- ✓ **Heterogeneous deployment scenario**
- ✓ **Cognitive systems**
- ✓ **Uniform antenna array**
- ✓ **MuSiC & null-steering algorithms**
- ✓ **Multipath problem**
- ✓ **System model and parameters**
- ✓ **Numerical results**

Selex ES SWave™ Product Family

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30-512 MHz 5W

Swave™ Vehicular 1Ch
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50W PA V/UHF

Swave™ Vehicular 4Ch
2-2000 MHz
50W PA V/UHF

Swave™ Manpack/Vehicular 2 Ch:
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Range Extension with Mission Modules

SELEX Electronics Systems

Key facts

- 17,900 people
- Revenues in excess of 3.5 billion Euros
- Italy and UK as domestic markets
- Strong footprint in
  - US
  - Germany
  - Romania
  - Brazil
  - Saudia Arabia
  - India
  - Turkey

The Divisions

- Airborne & Space Systems
- Land & Naval Systems
- Security & Smart Systems

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Entrusted to deliver technology-enabled systems and solutions for a safer, smarter and more secure society

Heterogeneous deployment

Heterogeneous network deployment is used to maximize the network capacity

Low range cells can integrate the coverage of the macro cell (useful in hot spot or coverage integration)

Planned (open and restricted access) and Unplanned deployment

A problem arises: interference between heterogeneous systems (macrocell and femtocell)

Standard solutions exist only for Planned deployment such as ICIC (LTE)

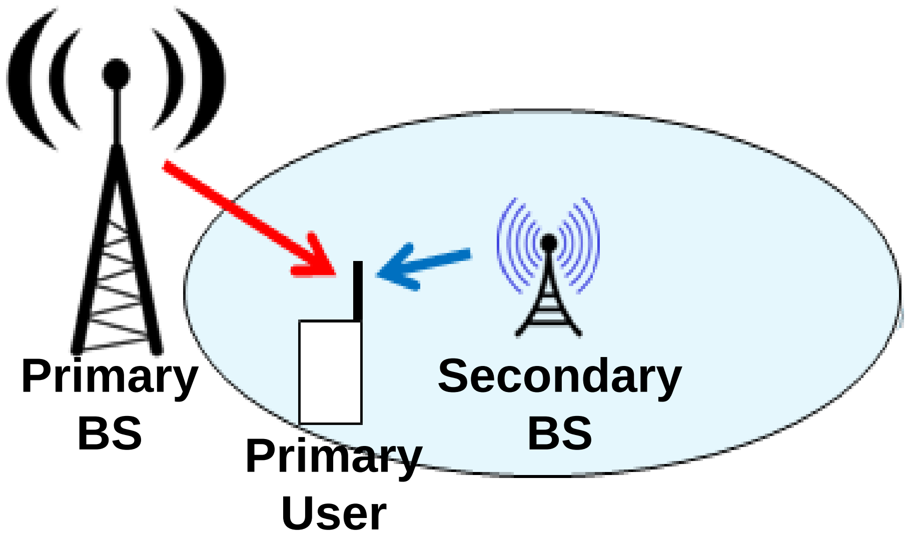
Unplanned deployment cell interference is still an open problem

Interference in Unplanned deployment

The most promising approach relies on the primary-secondary paradigm

Lack of coordination between the systems:

- Macro-cell communication must be not interfered (primary system)
- Femto-cell have to be aware of macro-cell users in its area (secondary system)



Cognitive femto-cell

Cognitive paradigm: the secondary system can use the bandwidth of the primary unless it causes interference.

- Underlay transmission: femtocell transmits on the primary system spectrum but without affecting its communications
- Overlay transmission: femtocell transmits on spectum holes

Space-time-frequency sensing → hybrid approach

Spatial dimension is exploited with a multi antenna system → Uniform Linear Antenna (ULA)

Proposed cognitive system

DoA estimation is performed using MUSIC (MUltiple SIgnal Classification) algorithm.

The recieved signal autocorrelation is eigen decomposed in a signal space and a noise space:

$$
\begin{aligned}
R_{rr} &= E[\boldsymbol{r}\boldsymbol{r}^H] \\
&= E[\boldsymbol{S}diag(\boldsymbol{h})\boldsymbol{x}\boldsymbol{x}^H diag(\boldsymbol{h})^H \boldsymbol{S}^H] + E[\boldsymbol{v}\boldsymbol{v}^H] \\
&= \boldsymbol{S}\boldsymbol{P}\boldsymbol{S}^H + \sigma_v^2 \boldsymbol{Id}_L
\end{aligned}
$$

MUSIC looks for the steering vectors that are ortogonal with the noise subspace.

Proposed Cognitive System

After DoA estimation, Null Steering algorithm is used to achieve beamforming

The symbols to be transmitted are multiplied by a vector of weights w

$$w^H \cdot A = [1,0,0,\ldots,0]$$

Where A is the steering vectors matrix (MxL elements)

The radiation pattern is nullified in M suitable positions (one for each estimated DoA).

The femtocell coverage is not impacted.

Proposed cognitive system

MUSIC algorithm requirs that M<L (number of resolved paths < number of antenna elements)

4 antennas are used (L=4)

- f_0=2GHz brings to a ULA of 22.5 cm.
- A maximum of 3 signals are detectable.

The algorithm brings benefits to the case M>=L too, since nulls are placed in the L strongest paths directions.

Multipath channel

The number of the detected paths depends on the sampling frequency:

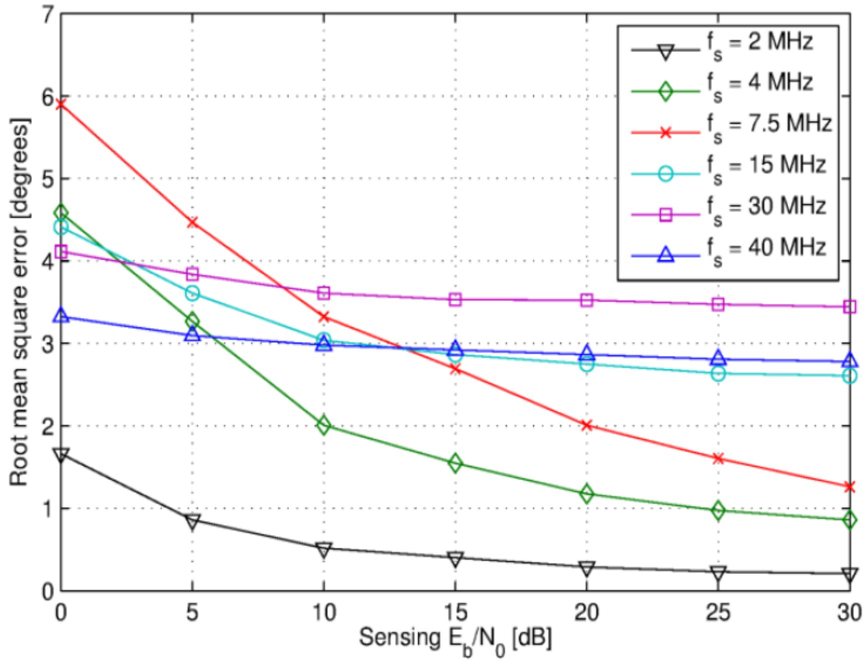
- fs=4MHz => 2 paths
- fs=30MHz => 6 paths

System assumptions:

- OFDM
- Outdoor channel
- DoAs are uniformly randomly generated in [0,π]
- Time correlation of DoAs depends on the speed of the mobile terminal
- ITU-R guidelines for IMT-2000 are applied

Performances

DoA estimation error for different sampling frequencies: weighted average on all the paths



fs>7.5 MHz leads to the case M>=L

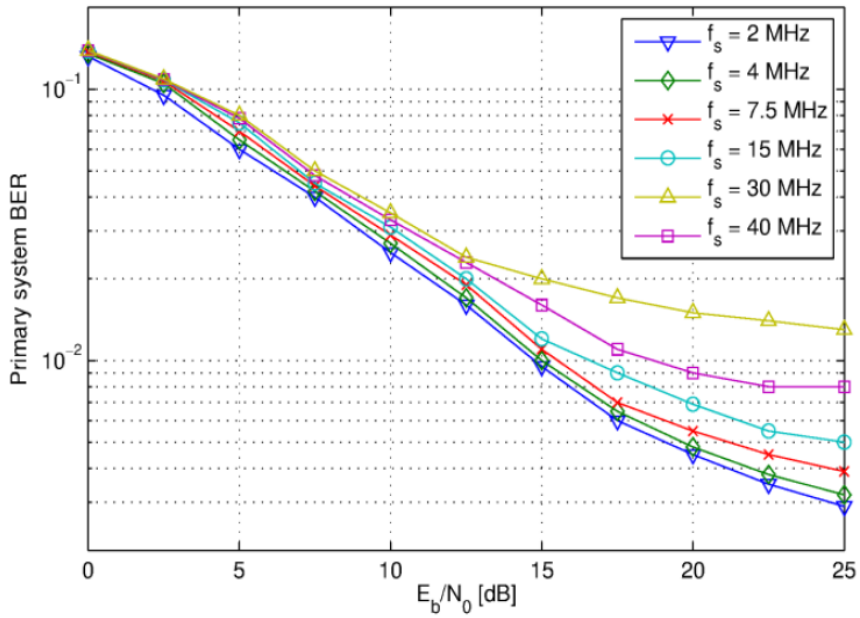
Errors decrease as Eb/N0 increases

Errors increases with the number of paths

With a very low Eb/N0, a higher sampling rate means more samples => a better AWGN noise filtering

Performances

BER of the Primary System at the User side for different sampling frequencies



Mobile speed 5 km/h

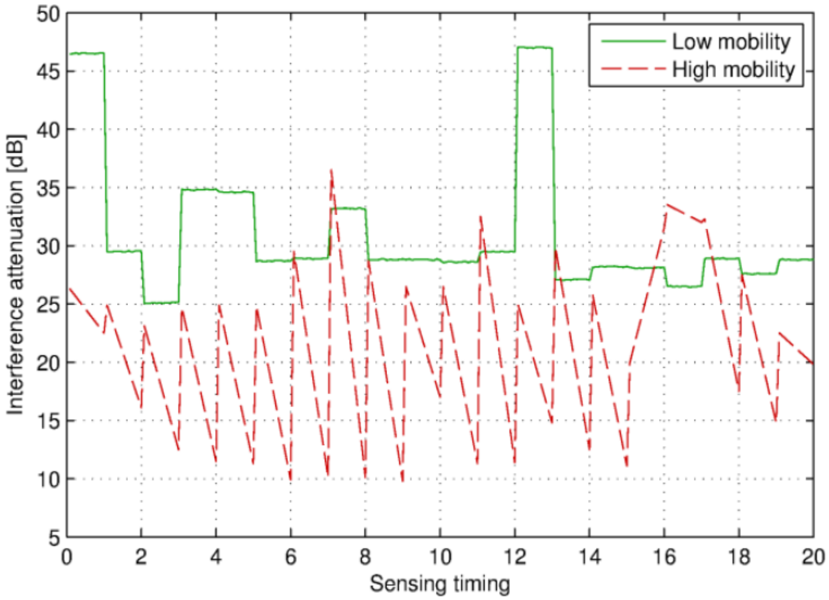
fs>7.5 leads to the case M>=L

For high Eb/N0 all the curves show floors due to the remaining iterference noise

The proposed solution leads to a more accurate reception of primary service downlink for all the considered bandwidth

Impact of speed on performance

Interference Attenuation on the Primary System at the user side



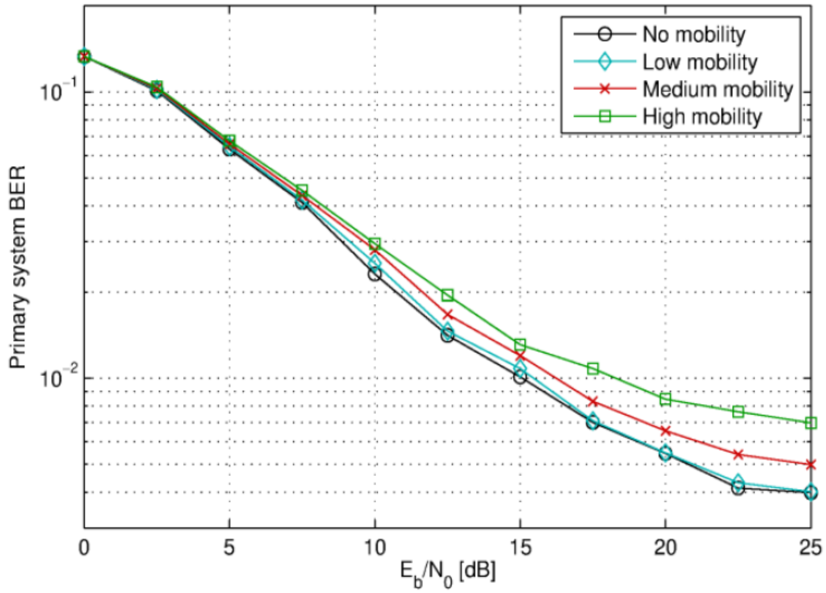
fs = 7.5 MHz
Speeds = 5 km/h, 25 km/h

Each peak corresponds to a single estimation.

With High mobility the interference attenuation deteriorates in the interval between sensing events

Impact of speed on performance

BER of the Primary System at the user side for different user speeds

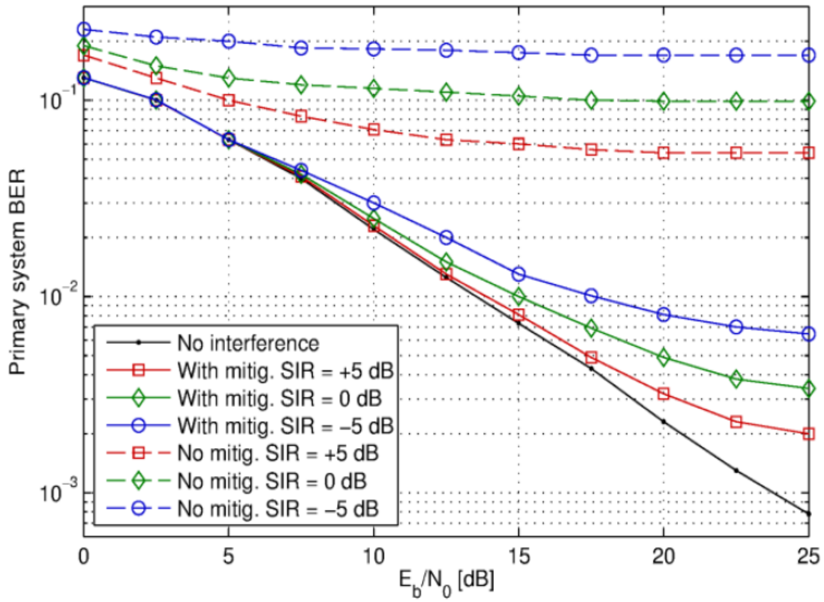


fs = 7.5 MHz
Speeds = 5 km/h, 10 km/h, 25 km/h

Increasing the speed there is a growth of residual interference between two sensing intervals. The estimation is less accurate and the BER is higher

Performance for different SIR

BER of the Primary System at the User side for different SIR, with and without mitigation



fs = 7.5 MHz

The benefits of the algorithm are evident.

For high Eb/N0 all the curves (but the No Interference one) show floors due to the remaining iterference noise

Conclusions

Heterogeneous deployment requires efficient interference management algorithms.

In Unplanned deployment we proposed a Cognitive Approach:

- The Secondary system identifies the DoAs of the signal from the Primary User terminal.
- Null Steering algorithm is used to reduce interference through beamforming.
- Outdoor propagation conditions are considered, with a variable number of detected/nulled DoAs and a variable mobile speed.
- The proposed method achieves good performance even in the worst conditions.

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Backup Slides

Proposed cognitive system

MUSIC looks for the steering vectors that are ortogonal with the noise subspace via searching the local maximums of the following function:

$$P'_{SM}(\theta) = \frac{d^2\left(\log_{10}\left(\frac{1}{\left\|\underline{s}^H(\theta)\cdot\underline{\underline{U}}_N\right\|}\right)\right)}{d\theta^2}$$

Limits of the algorithm

The weight vector $\underline{w}$ is obtained as:

$$\underline{w}^H = \underline{c}^H \cdot \underline{\underline{A}}^H \cdot (\underline{\underline{A}} \cdot \underline{\underline{A}}^H)^{-1}$$

where:

- $\underline{c}$ = [1, 0, .. 0], with L elements
- $\underline{A}$ = [$\underline{s}(\theta_0)$, $\underline{s}(\theta_1)$, .. $\underline{s}(\theta_{L-1})$], with M x L elements
- $\underline{s}(\theta_i)$ = exp(jπ(i-1)sin(θ))

The number of nulls introduced by the weights is equal to the number of estimated DoAs