

**TSC**

# A MIMO-OFDM based system with backward compatibility with IEEE802.16

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**EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND  
TECHNICAL RESEARCH**

**10th MCM COST 289, 23- 24 March 2006, University of Novi Sad, Serbia  
and Montenegro**



# Outline

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- 1. Background
  - Motivation
  - MIMO-OFDM
  - IEEE 802.16d
  
- 2. Channel estimation algorithms
  - Maximum Likelihood Time Frequency (ML-TF)
  - LS
  
- 3. Frequency offset estimation algorithms
  - SISO systems
  - MIMO systems
  
- 4. Results
  
- 5. Summary and Conclusions



# TSC 1. Background-Motivation

- Nowadays the combination of Multiple-Input Multiple-Output (MIMO) systems and Orthogonal Frequency Division Multiplexing (OFDM) technologies (MIMO-OFDM) is one of the most employed techniques to provide broadband communications
- IEEE 802.16d, also known as IEEE 802.16-2004, is the standard that describes the air interface for fixed broadband wireless communications. Physical layer based on OFDM modulation.
- This standard just proposes a typical SISO system, and leaves as optional the development of a MISO 2x1 system.
- This work extends the standard to a MIMO scheme. Several scenarios (SISO, MISO, MIMO) are developed and compared.



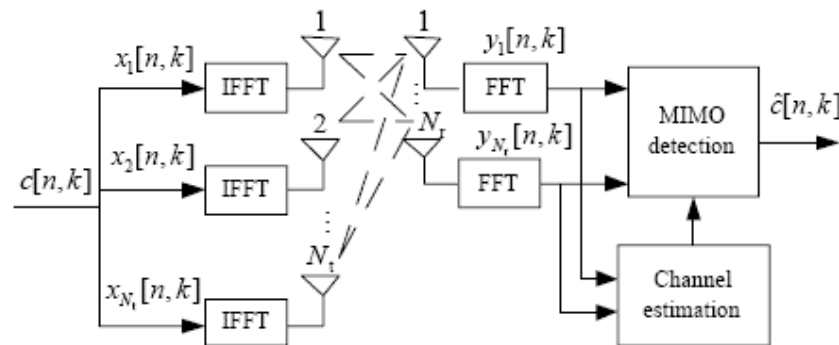
# TSC 1. Background-Motivation

- In all these schemes several algorithms are compared:
  - Channel estimation algorithms:
    - Maximum Likelihood Time Frequency (ML-TF)
    - LS estimator (Time domain)
- Another critical issue is frequency offset estimation and correction:
  - SISO systems.
  - MIMO systems.
- Space Time Coding (Alamouti configuration) is usually employed.  
Influence in:
  - Bit Error Rate (BER)
  - Data transfer rate



# 1. Background-MIMO-OFDM

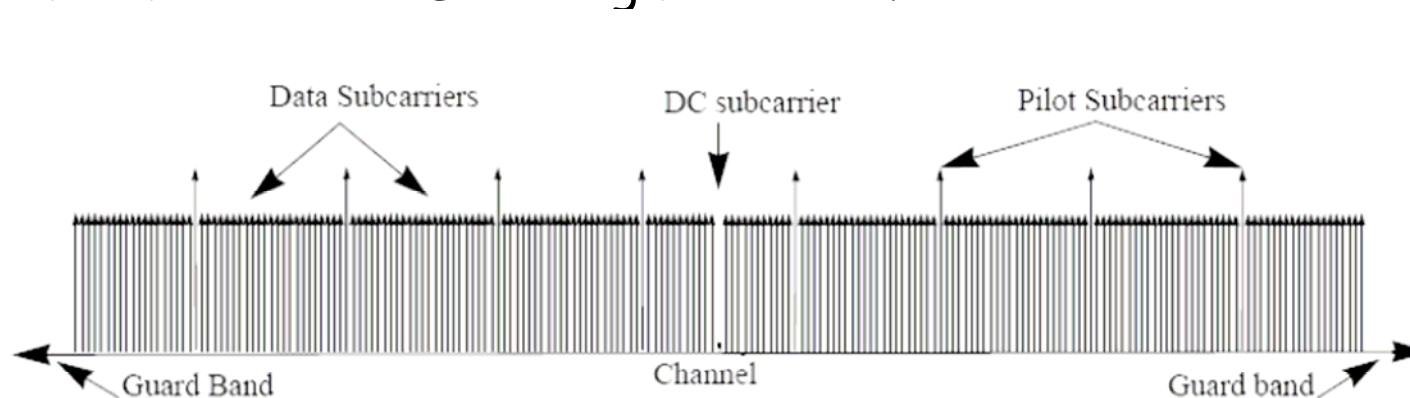
- OFDM: Modulation which divides BW in several orthogonal channels.
  - Suitable for data transmission over wideband wireless channels since it is robust to severe multipath fading.
  - Use of FFT. Easy implementation
- MIMO: Addition of antennas both in the transmitter and receiver.
  - Several channels between emitter and receiver.
  - High system capacity
  - Diversity in a fading environment
- MIMO-OFDM system:



# 1. Background-802.16

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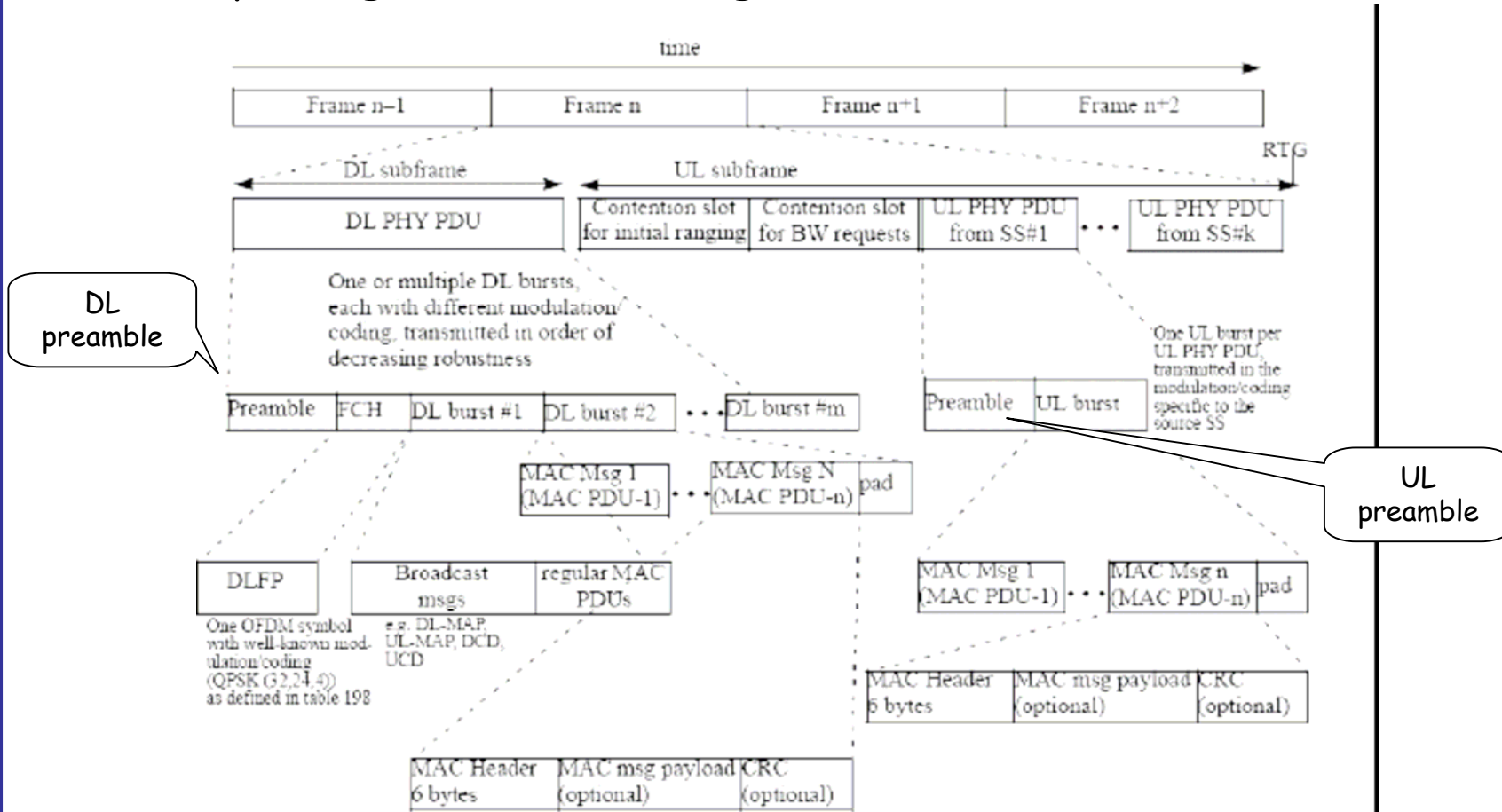
- Air interface for fixed broadband wireless communications standard
  - Revision of IEEE Std 802.16-2001.
  - IEEE802.16e. Approved December 2005. WMAN mobile.
- NLOS propagation.
- 2-11 GHz
- OFDM. FFT 256 points
  - Data subcarriers (QPSK, 16-QAM, 64-QAM-optional)
  - Pilot subcarriers: Estimation purposes (BPSK)
  - Null subcarriers: DC and guard band.



# 1. Background-802.16



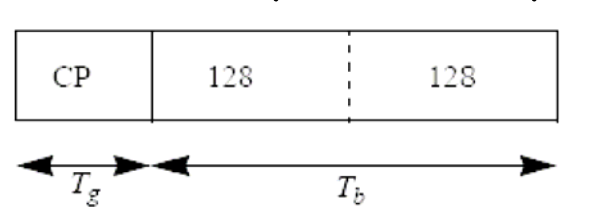
- PMP => Point to Multi-point Structure
- Duplexing: FDD / TDD. E.g TDD:



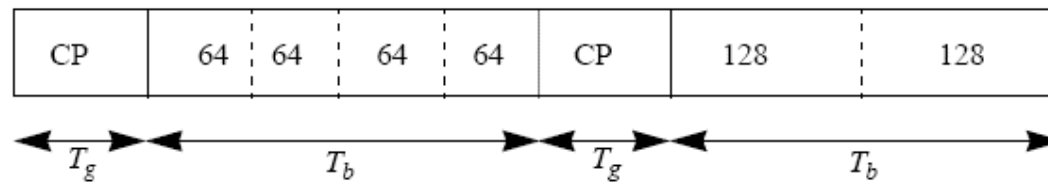
# 1. Background-802.16

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- Standard specifies preambles both for UL and DL:
  - UL: One OFDM symbol. Only even subcarriers are not null:



- DL: Two OFDM symbols. In the second one only even subcarriers are not null :



- One symbol with only even subcarriers different from zero =>  
Two equal halves in time domain.





# 1. Background-802.16

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- Implementation of MISO system is optional.
- 2x1 system employing Space-Time Coding.
- When using more than one transmitter preamble emitted in the DL is not the long preamble (2 OFDM symbols). It is a OFDM symbol where only odd subcarriers are not null.
- Preambles emitted by both antennas are orthogonal.
- Schemes studied in this work:
  - SISO
  - MISO 2X1. STC
  - MIMO 2X2. STC
  - MIMO 2X2. NO STC

\* The first one is the standard one.  
\* The second one is optional.  
\* The rest ones are new, and are not implemented in the standard yet.



# TSC 2. Channel estimation

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- When two or more transmitting antennas are used, channel estimation apart from being an essential part for decoding the received signals, becomes a challenging task.
- Signals from other transmitter become interference, disturbing the accuracy of the estimation process.
- We present two channel estimation algorithms compatible with IEEE802.16 d standard:
  - ML estimator. Frequency domain
  - LS estimator. Time domain



# TSC 2. Channel estimation

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- First algorithm employed is a ML estimator.
  - Estimation in Frequency domain
  - $L_p$  known OFDM symbols. In IEEE802.16d  $L_p=1$ .
  - Minimizes the metric:

$$\tilde{\mathbf{H}}_{ML,k}^e = \arg \min_{\tilde{\mathbf{H}}_k} \|\tilde{\mathbf{Y}}_k - \tilde{\mathbf{H}}_k \tilde{\mathbf{P}}_k\|^2$$

preamble

- Expression:

$$\tilde{\mathbf{H}}_{ML,k}^e = \tilde{\mathbf{Y}}_k \tilde{\mathbf{P}}_k^+ \quad |$$

- where

$$\tilde{\mathbf{P}}_k^+ = \tilde{\mathbf{P}}_k^\dagger (\tilde{\mathbf{P}}_k \tilde{\mathbf{P}}_k^\dagger)^{-1}$$



# TSC 2. Channel estimation

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- Second algorithm employed is a LS estimator.
  - Estimation in Time domain
  - Minimizes the metric:

$$\|\mathbf{Qy} - \Delta_p \mathbf{Qh}\|^2$$

preamble

- Expression:

$$\mathbf{h}_{LS}^e = (\tilde{\mathbf{Q}}^H \Delta_p^H \tilde{\Delta}_p \tilde{\mathbf{Q}})^{-1} \tilde{\mathbf{Q}}^H \Delta_p^H \mathbf{Q}_d \mathbf{y}$$



- Synchronization of the carrier frequency at the receiver must be performed or there will be a loss of orthogonality between the subsymbols.
- As preamble is composed of two equal halves in time domain, algorithms are based on finding these two equal parts. The offset is measured in number of intercarrier spacings (Hertz).
- Extensible to MIMO systems, with few adaptations.



- Expression to estimate fractional part of the frequency offset:

$$\hat{\epsilon}_{frac} = \frac{1}{\pi} \arg\left( \sum_{m=0}^{N/2-1} \mathbf{r}_{m+N/2} \mathbf{r}_m^* \right)$$

Received signal in time domain

- Correction:

$$\mathbf{y}_n = \mathbf{r}_n e^{-j2\pi\hat{\epsilon}_{frac}n/N} \quad n = 0, \dots, N-1$$

- ii Frequency offset  $\Leftrightarrow$  Phase change in received signal (time domain) !!



- Using this fractional part estimation and LS channel estimation a joint channel estimation and frequency estimation can be derived. It takes into account the estimation of the integer part of the frequency offset:
- 1) Estimation and correction of the fractional part of the frequency offset
- 2) Consider the integer frequency offset hypothesis from  $(-M, -M+2, \dots, -2, 0, 2, \dots, M)$  where  $M$  is the maximum possible even integer offset and obtain the corresponding LS channel estimates by circularly shifting the FFT outputs accordingly.
- 3) Calculate the corresponding LS error for the channel estimates obtained in the previous step
- 4) Iterate over steps 2 and 3 till all frequency offset hypotheses are considered and choose the one that minimizes the LS error.



# TSC Simulations Parameters

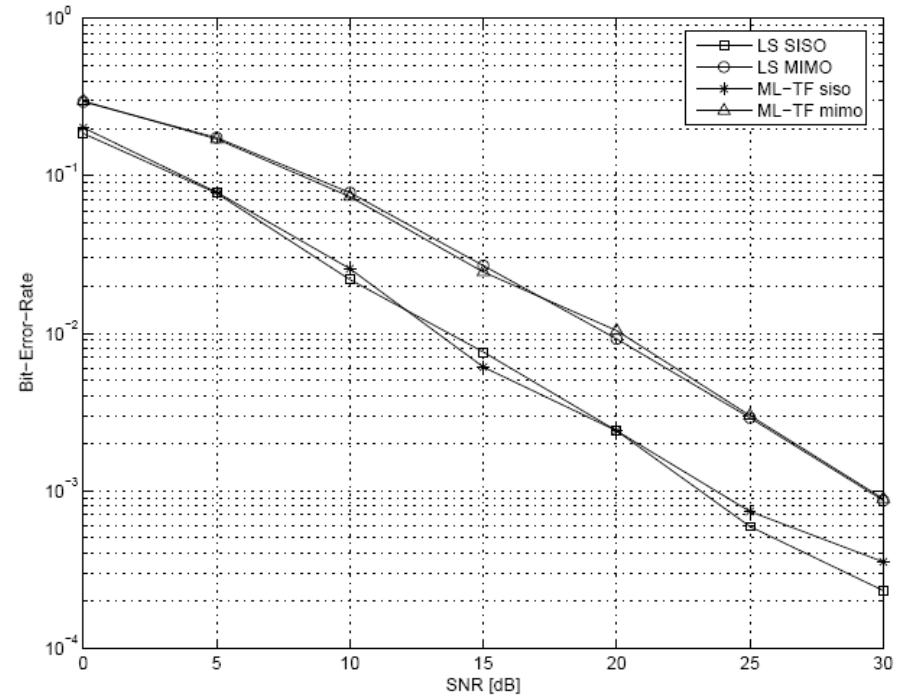
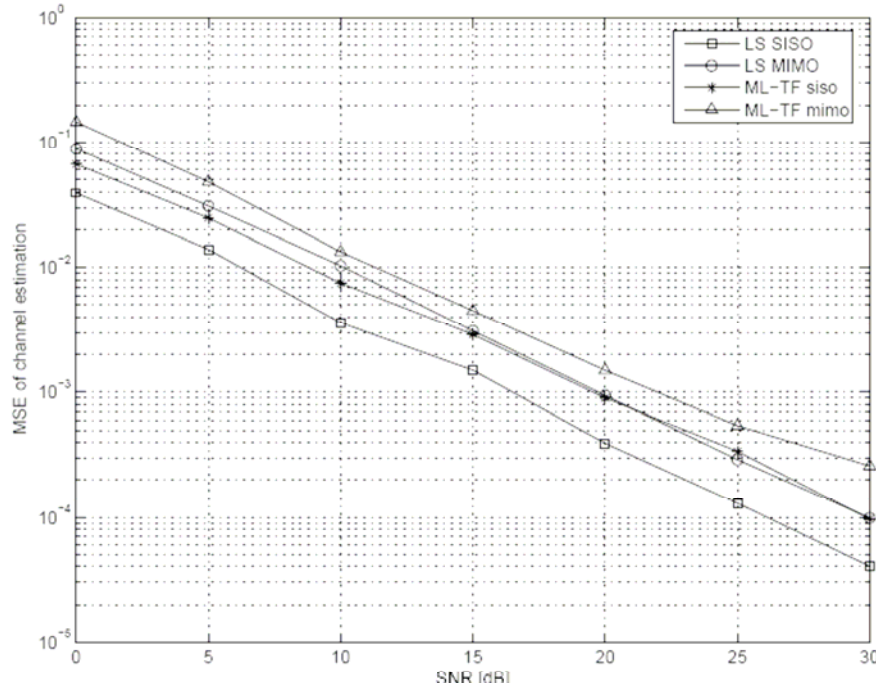
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- Simulations parameters:
  - Modified Stanford University Interim (SUI) 3 Channel
    - $L = 3$  taps
    - Maximum delay spread of  $1 \mu\text{s}$
    - Maximum Doppler frequency  $0.4 \text{ Hz}$
    - Round Shapped Doppler Spectrum
  - QPSK modulation
  - $N = 256$  subcarriers
  - 192 useful subcarriers
  - 1 and 2 transmitted antennas
  - 1 and 2 received antennas





➤ CHANNEL ESTIMATION ALGORITHMS:



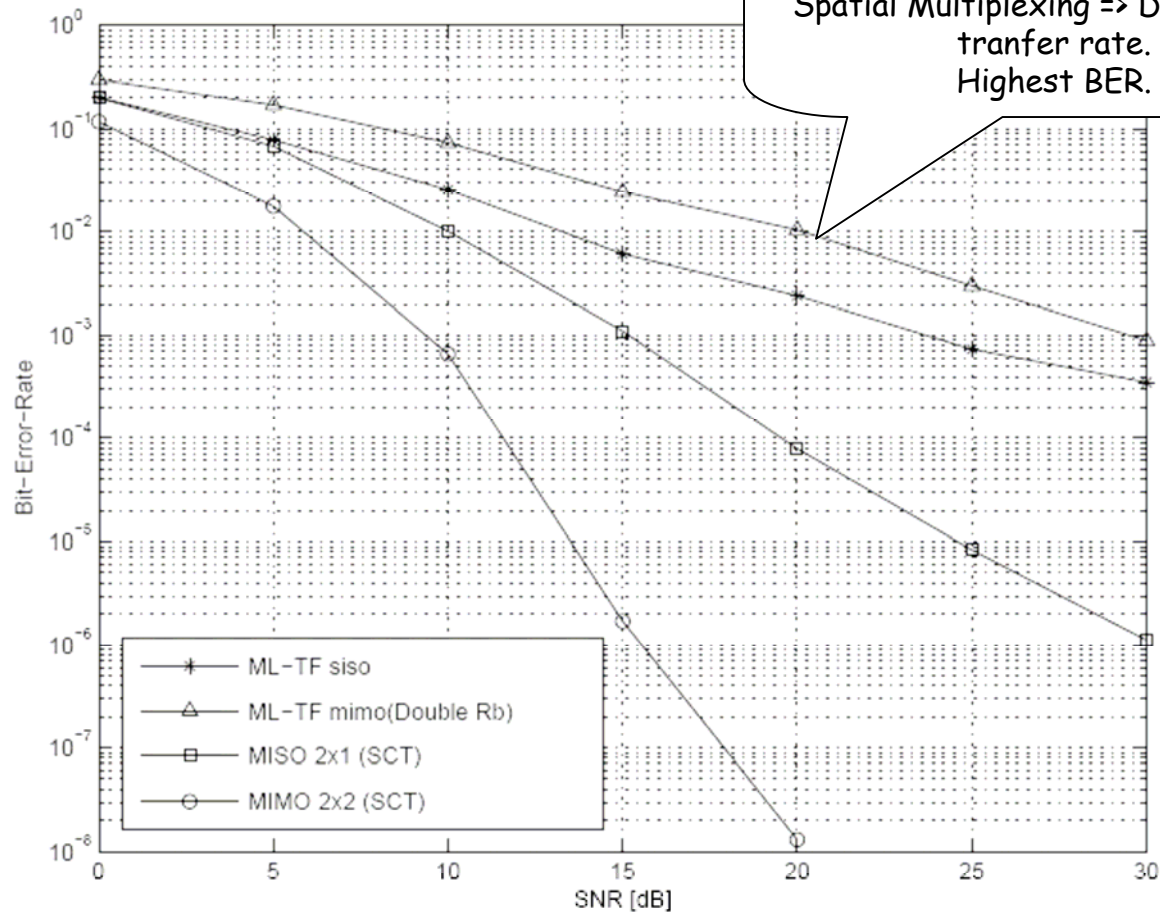
➤ Very similar performance



- CHANNEL ESTIMATION ALGORITHMS:
- The LS estimator presents less Mean Square Error, but BER is not seriously affected. Both algorithms can be used indistinctly.
- BER is higher in MIMO systems. More interference is present.



➤ BER OF DIFFERENT SCHEMES:

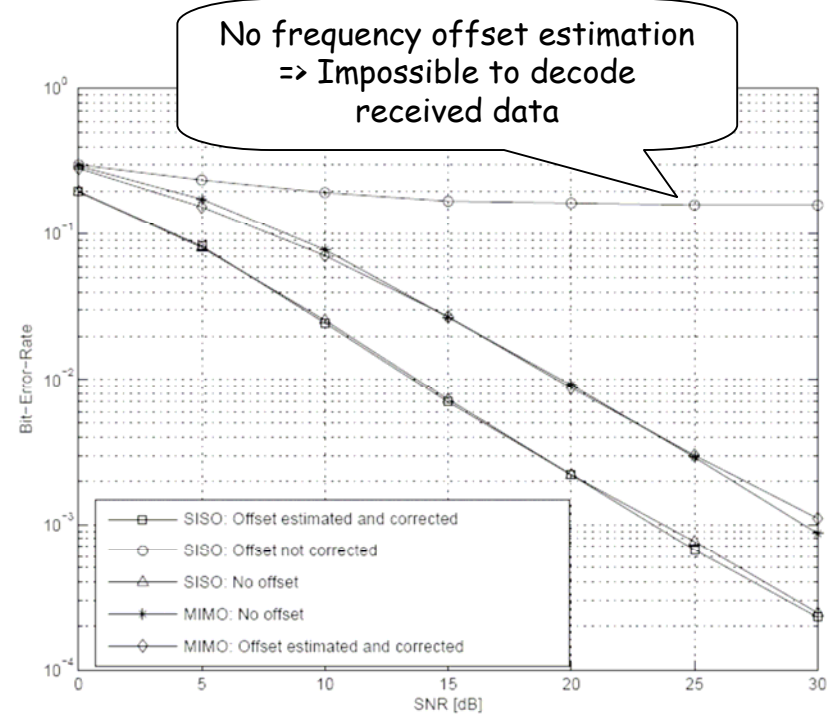
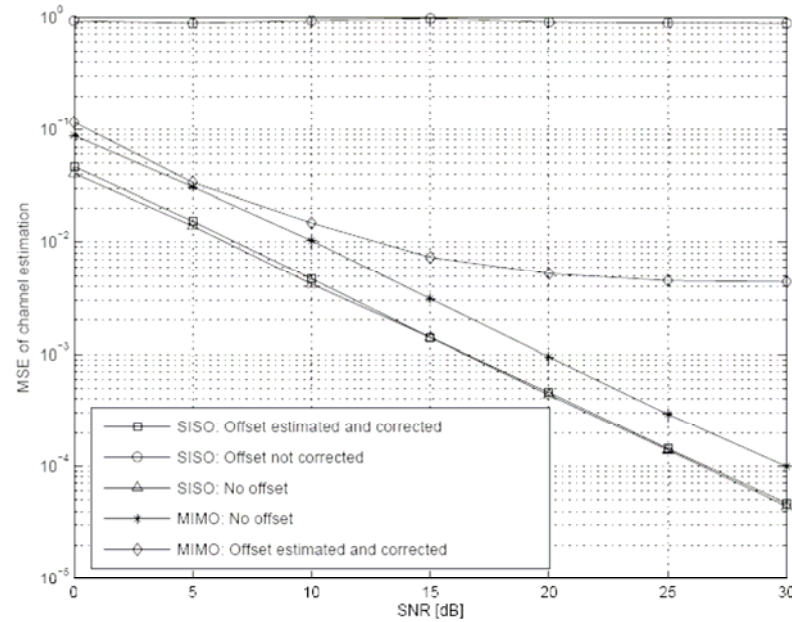


## ➤ BER OF DIFFERENT SCHEMES:

- In all of them ML-TF channel estimator has been employed.
- Using a 2X2 scheme data transfer rate is doubled, in case no space time coding is applied. It could be very useful for situations where a big amount of data must be transferred, although BER is higher than in the typical SISO scenario.
- Last two curves in Figure show the benefits of employing Space Time Coding (Alamouti configuration). When using ST Coding data transfer rate is not doubled, keeping the data rate of the SISO case, although a second antenna has been added in transmission.
- On the other hand BER of the system decreases significantly. The 2X1 system is leaved as optional in the standard. If a second antenna is added in reception, it can be clearly appreciated how much BER decreases, reaching  $10^{-8}$  values just with a signal to noise ratio of 20 dB



## ➤ FREQUENCY OFFSET ESTIMATION ALGORITHMS:



- FREQUENCY OFFSET ESTIMATION ALGORITHMS:
  - Only fractional part of the offset has been considered (0.3 inter carrier spacing for the simulation).
  - LS channel estimator has been jointly implemented.
  - Offset is estimated and corrected resulting in a small residual error that do not affect the final system performance in terms of BER.
  - Employing these algorithms frequency offset can be considered as completely eliminated.
  - Nevertheless, it can be seen that in MIMO systems, where more interference is present, the residual error is perceptible in terms of MSE of the estimation.



# 5. Summary and Conclusions

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- Extension to the IEEE802.16 d standard.
- Addition of a second antenna in the receiver.
- Several scenarios, combining SISO, MISO and MIMO configurations. Use/ Not use of Space Time Coding.
- Two channel estimation in frequency and time domain with similar performance
- Frequency offset must be taken into account. With presented algorithms residual error is almost null.
- Depending on the requirements of the systems in terms of BER, data transfer rate, physical space to add more antennas to the system and cost, one of the schemes studied in this paper may be chosen to implement a next generation fixed broadband wireless access downlink system based on IEEE 802.16 standard.

