The Detection Algorithms Performance in BLAST Enhanced IEEE 802.11a WLAN Standard on Measured Channels

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Outline

- Motivations
- MIMO-OFDM **HOT Topic !**
- MIMO indoor channel sounding
- BLAST-OFDM
- Numerical Results

Motivations

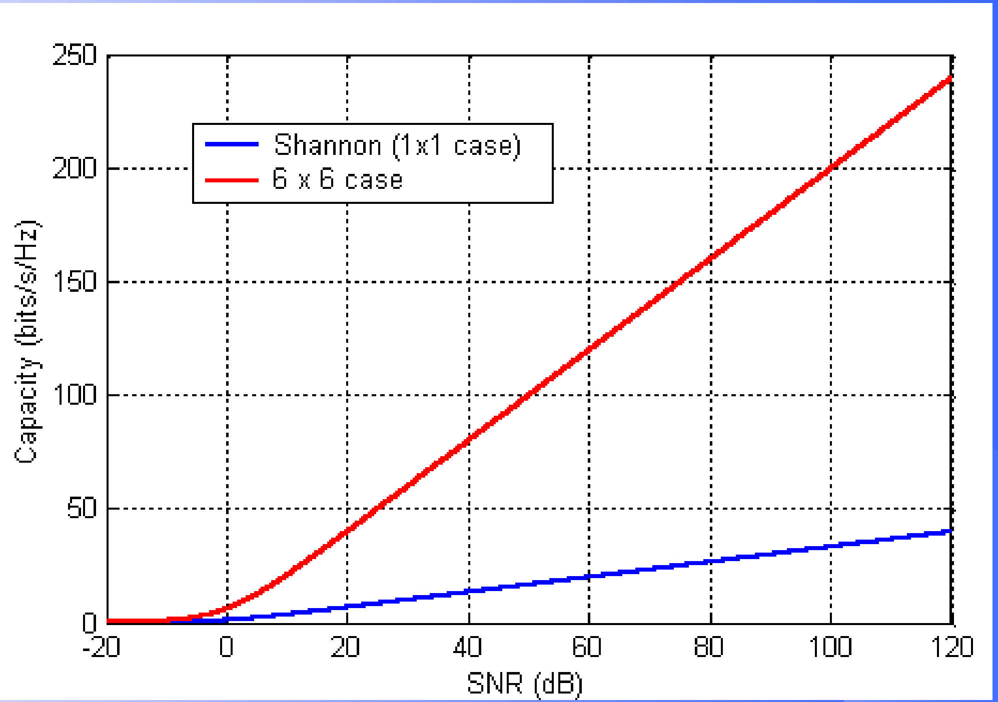
Capacity of MIMO links *(Telatar, 1995; Foschini & Gans 1998)*

Capacity of the multiplexed channels sums up:

$$C = \sum_{1}^{N} \log_2 \left(1 + \lambda_i \frac{P}{N\sigma^2}\right)$$

Hence

$$C = N \log_2 \left(1 + \frac{P}{\sigma^2}\right)$$



Capacity increases linearly with N!

e.g. 40 dB for 80 b/s/Hz !!!

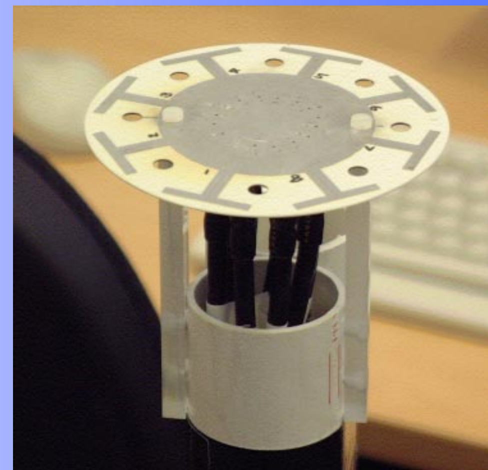
MIMO Measurements – Setup

Wideband indoor MIMO measurements

- Customised Medav RUSK BRI vector channel sounder
- 5.2 GHz operating frequency
- 120 MHz bandwidth
- up to 8 Tx elements by 8 Rx elements
- complete MIMO snapshot of the channel: 102.4 μs (well within coherence time of the channel)

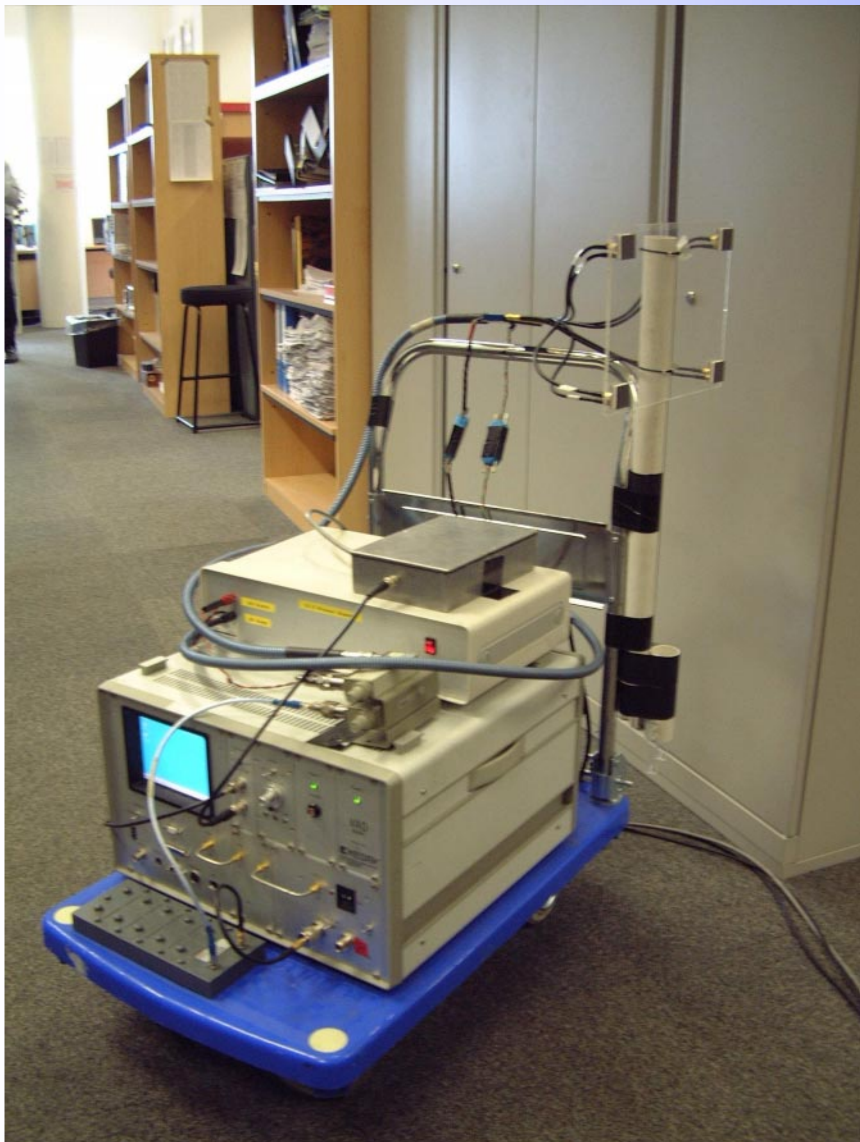
Measurements were taken in large open plan office with approximate dimensions 30L x 20W x 4H (m).

MIMO Measurements – Access Point



Circular array of printed dipoles used for the Access Point

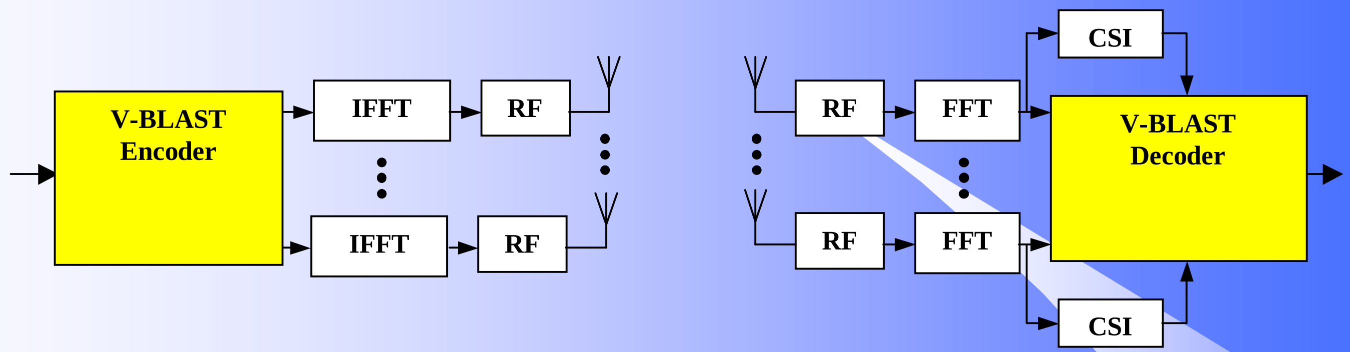
MIMO Measurements – Mobile Terminal



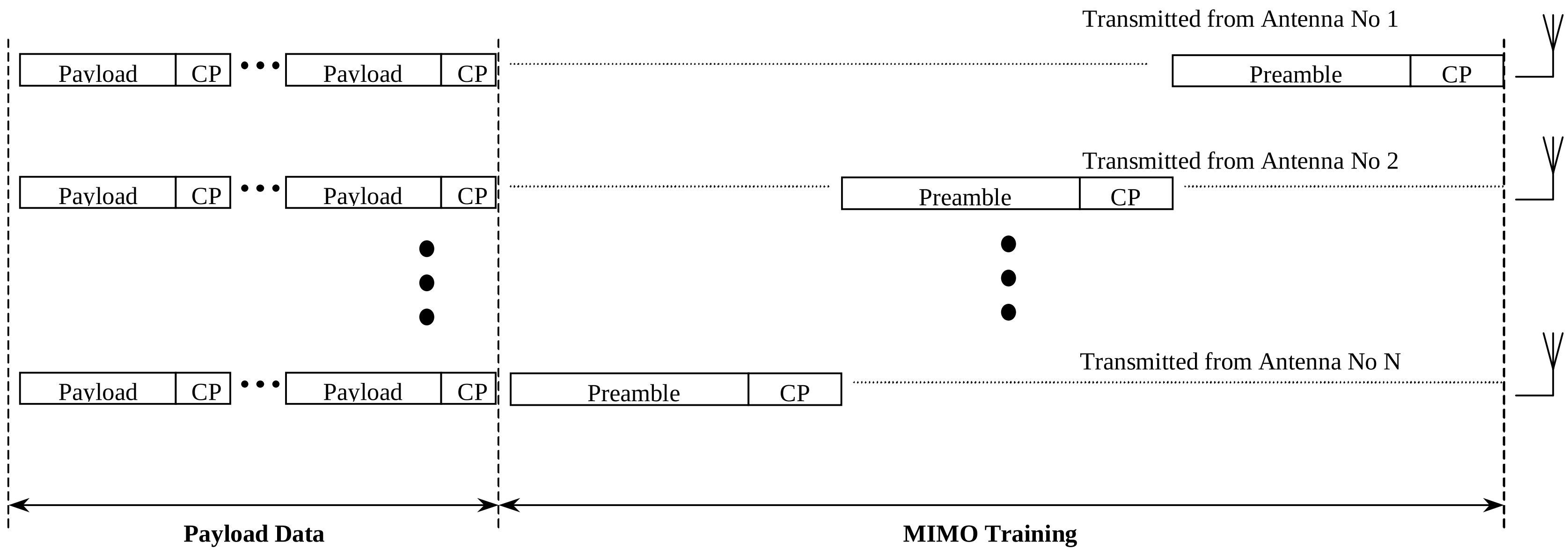
"Laptop-sized" four double polarized element antenna array used for the Mobile Terminal

MIMO – OFDM: A General Schematic

Space-time transmission in MIMO – OFDM



System with sequential MIMO training



I. Space Time Coding (Frequency-Space in OFDM)

(Tarohk, Seshadri & Calderbank 1998)

PROS

- Channel coding (error correction)
- Transmit diversity
- Modulation mapping
- Receive diversity
- All of the above optimised jointly

CONS

- No data throughput improvement
- Complexity sensitive to modulation format

Improves mainly link reliability

II. Spatial Multiplexing (BLAST)

(Foschini 1996, Paulraj & Kailath 1994)

PROS

- Directly exploits MIMO channel capacity to improve the data throughput

CONS

- poor link reliability - requires channel coding

Improves mainly data throughput

Cyclic prefix OFDM signal model (CP-OFDM)

SIMO case revisited:

i^{th} transmitted block of data

$$\bar{\mathbf{u}}_i = \mathbf{T}_{cp}\,\mathbf{F}^{-1}\mathbf{u}_i$$

$\mathbf{T}_{cp}$ - CP insertion matrix (P x K)

$\mathbf{F}$ - Fourier transform matrix (K x K)

received signal block pertaining to $\mathbf{u}_\text{i}$

$$\bar{\mathbf{x}}_i = \mathbf{H}_0\bar{\mathbf{u}}_i + \mathbf{H}_1\bar{\mathbf{u}}_{i-1} + \bar{\boldsymbol{\eta}}_i$$

$\mathbf{H}_0$,$\mathbf{H}_1$ - Toeplitz channel matrices

$\boldsymbol{\eta}_i$ - the ubiquitous additive noise vector

input–output relationship

$$\mathbf{x}_i = \mathbf{F}\,\mathbf{T}_R\mathbf{H}_0\mathbf{T}_{cp}\mathbf{F}^{-1}\mathbf{u}_i + \mathbf{F}\,\boldsymbol{\eta}_i$$

$\mathbf{T}_R$ – CP remove

$\mathbf{T}_R\mathbf{H}_0\mathbf{T}_{cp}$ is circulant, and thus is diagonalised by $\mathbf{F}$

$$\mathbf{F}\,\mathbf{T}_R\mathbf{H}_0\mathbf{T}_{cp}\mathbf{F}^{-1} = \tilde{\mathbf{H}} = \begin{bmatrix} h(\omega^0) & 0 & 0 & \cdots & 0 \\ 0 & h(\omega^1) & 0 & \cdots & 0 \\ 0 & 0 & h(\omega^2) & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & h(\omega^{K-1}) \end{bmatrix}$$

Finally, the CP-OFDM SIMO case is given

$$\mathbf{x}_i = \tilde{\mathbf{H}}\,\mathbf{u}_i + \tilde{\boldsymbol{\eta}}_i$$

Spatial Multiplexing – BLAST OFDM

Extension to MIMO CP-OFDM configuration with N transmit and M received antennas

Define:

$$\boldsymbol{\mu}_i = \begin{bmatrix} \tilde{\mathbf{u}}_i^{(1)T} & \tilde{\mathbf{u}}_i^{(2)T} & \cdots & \tilde{\mathbf{u}}_i^{(N-1)T} & \tilde{\mathbf{u}}_i^{(N)T} \end{bmatrix}^T$$

N stacked $\mathbf{u}_i$ vectors (K*N x 1) – transmitted signal (Frequency - Space)

$$\boldsymbol{\chi}_i = \begin{bmatrix} \tilde{\mathbf{x}}_i^{(1)T} & \tilde{\mathbf{x}}_i^{(2)T} & \cdots & \tilde{\mathbf{x}}_i^{(M-1)T} & \tilde{\mathbf{x}}_i^{(M)T} \end{bmatrix}^T$$

stacked vector of the received data (K*M x 1)

$$H = \begin{bmatrix} \tilde{\mathbf{H}}_{1,1} & \tilde{\mathbf{H}}_{1,2} & \cdots & \tilde{\mathbf{H}}_{1,N} \\ \tilde{\mathbf{H}}_{2,1} & \tilde{\mathbf{H}}_{2,2} & \cdots & \tilde{\mathbf{H}}_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\mathbf{H}}_{M,1} & \tilde{\mathbf{H}}_{M,2} & \cdots & \tilde{\mathbf{H}}_{M,N} \end{bmatrix}$$

the overall channel matrix

Fundamental model:

$$\boldsymbol{\chi}_i = H\,\boldsymbol{\mu}_i + \boldsymbol{\eta}_i^{/}$$

The Maximum Likelihood (ML) detector of V-Blast CP-OFDM

$$\mathbf{v}_i = \arg\min_{\mathbf{v}_i}\left\{\left|\boldsymbol{\chi}_i - \boldsymbol{H}\,\mathbf{v}_i\right|^2\right\}$$

Since **H** is built up of diagonal matrices, it is possible to separate the above problem into *K* independent but lower dimensional linear problems (i.e. each subcarrier is treated separately)

Define: $\breve{\mathbf{x}}_k = \mathbf{C}_k^{(M)^T}\boldsymbol{\chi}_i$ and $\breve{\mathbf{H}}_k = \mathbf{C}_k^{(M)^T}\boldsymbol{H}\,\mathbf{C}_k^{(N)}$

$\mathbf{C}_{\boldsymbol{k}}$ – compaction matrices (subcarrier separation)

Finally ML V-BLAST:

$$\breve{\mathbf{v}}_{i,k} = \arg\min_{\breve{\mathbf{v}}_{i,k}}\left\{\left|\breve{\mathbf{x}}_{i,k} - \breve{\mathbf{H}}\breve{\mathbf{v}}_{i,k}\right|^2\right\}$$

Linear Detection – Zero Forcing (ZF)

$$\breve{\mathbf{v}}_{i,k} = \mathbf{G}_k \, \breve{\mathbf{x}}_{i,k}$$

Where: $$\mathbf{G}_k = \left(\breve{\mathbf{H}}_k^H \breve{\mathbf{H}}_k\right)^{-1} \breve{\mathbf{H}}_k$$

Represents *Least Squares* solution

Ordered Successive Interference Cancellation (OSIC)

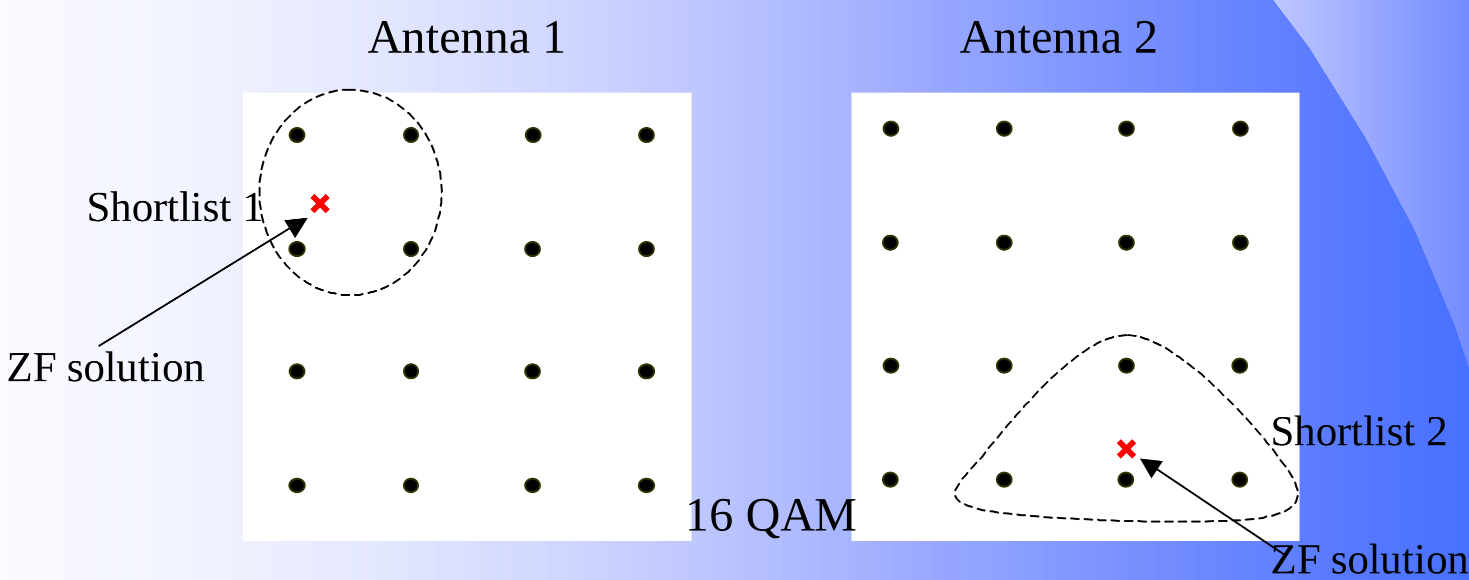
(G. Golden et al 1999)

Maximum Likelihood Zero Forcing Hybrid - ZFML

(X. Li et al, 2000)

Step 1: Perform ZF and identify shortlists for each antenna

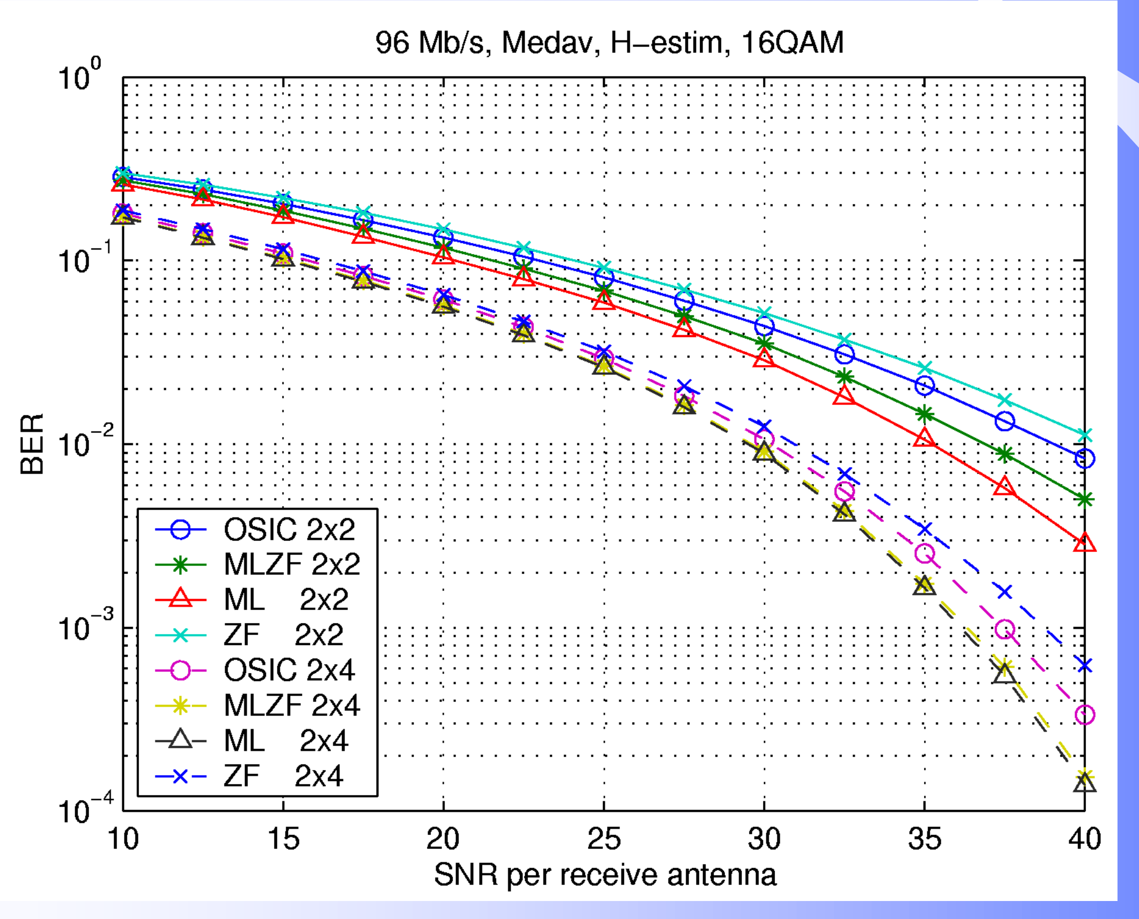
Step 2: Perform ML search on shortlists



Numerical Results (1/4)

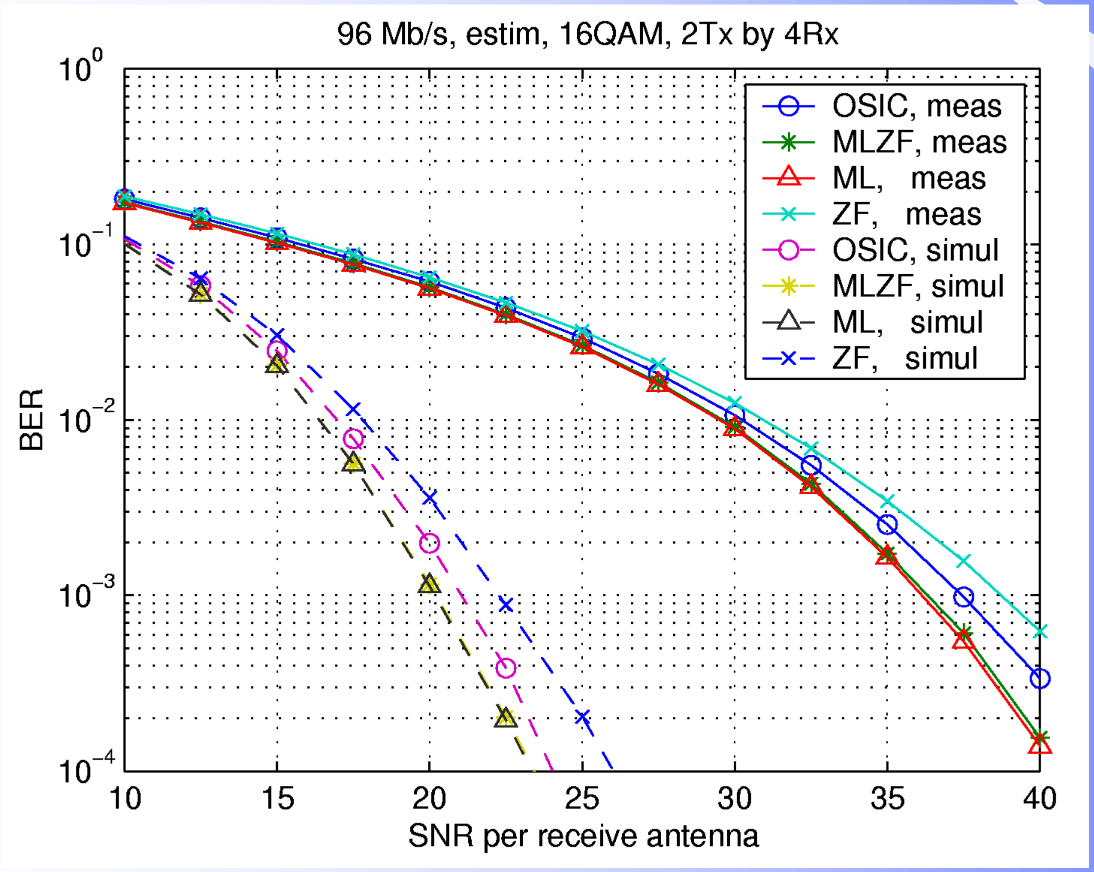
96 Mb/s, 2 Tx by 2 & 4 Rx, 16 QAM,

MIMO channel estimated via sequential preamble



Numerical Results (2/4)

96 Mb/s, 2 Tx by 4 Rx, 16 QAM,

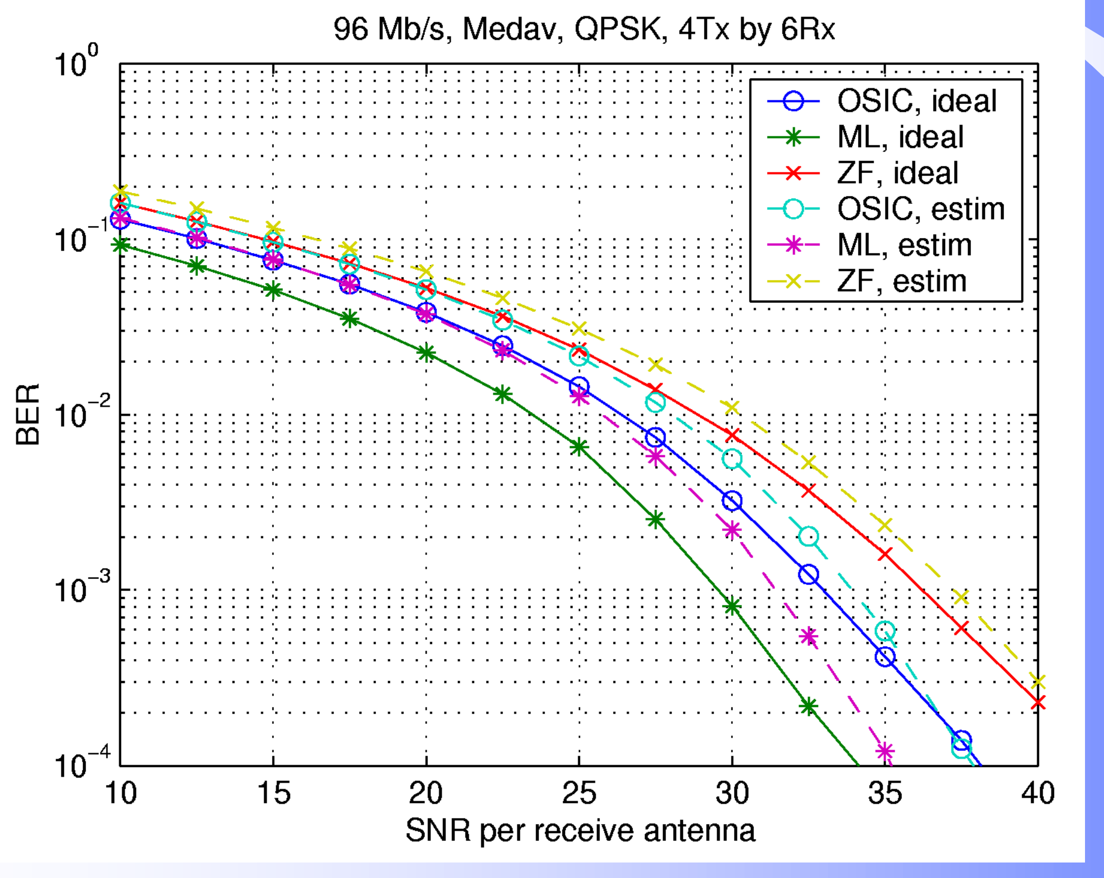


"meas" – measured channel

"simul" – ETSI, H/2 Channel A, (energy normalised)

Numerical Results (3/4)

96 Mb/s, 4 Tx by 6 Rx, QPSK , Measured channel

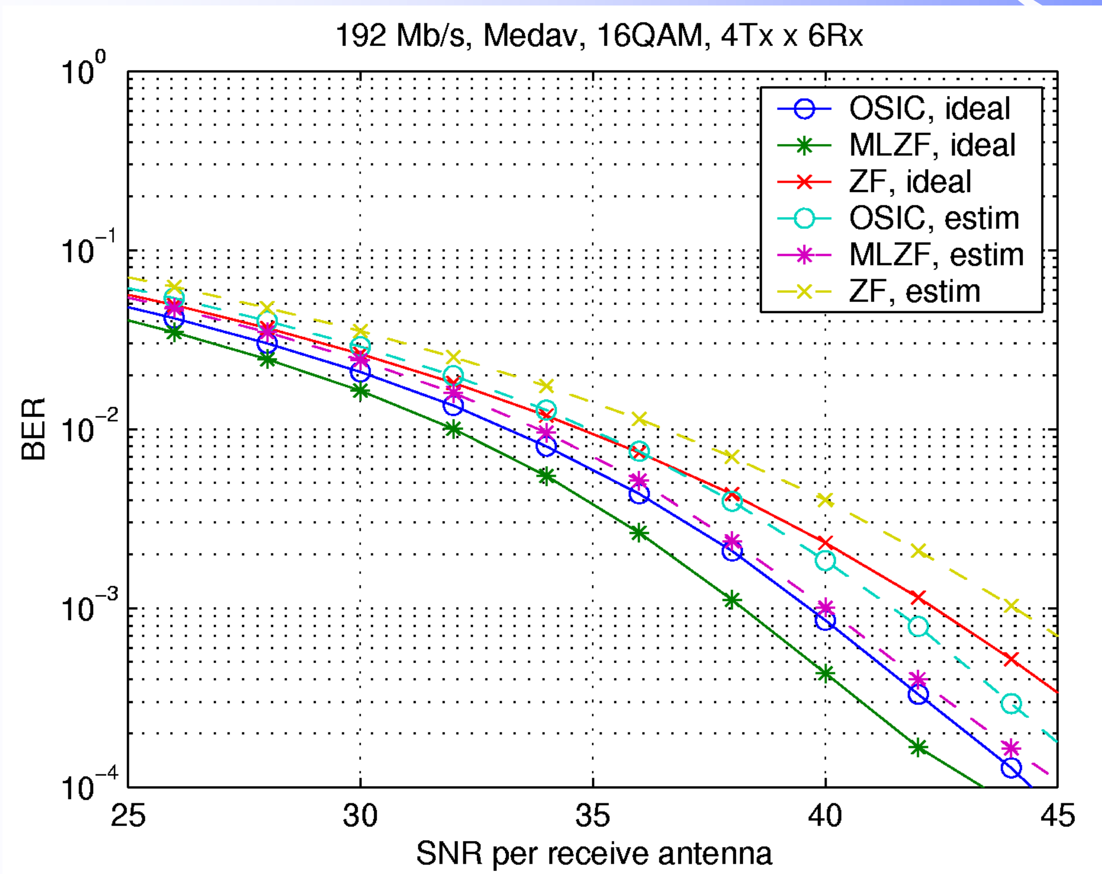


"ideal" – ideal MIMO CSI avaiable

"estim" – MIMO CSI estimated via sequential preamble

Numerical Results (4/4)

192 Mb/s, 4 Tx by 6 Rx, 16-QAM, Measured channel



"ideal" – ideal MIMO CSI avaiable

"estim" – MIMO CSI estimated via sequential preamble

Conclusions

- Possibility of 192 Mb/s (uncoded in IEEE 802.11A band) in a real setting has been demonstrated

- Difference between an ideal setting and our measured channel is 12 dB (@ BER 10^{-2}, 2x4, 16-QAM)

- Difference in the performance between the detection algorithms tightens as the number of receive antennas increases

- Future research into MIMO-OFDM:
  - Flexible blend of spatial multiplexing/frequency space coding
  - Advanced detection algorithms (Reduced complexity)
  - Antenna configurations/strategies studies

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