On Minimizing the Mean Squared Error In the Presence Of Channel State Information Errors

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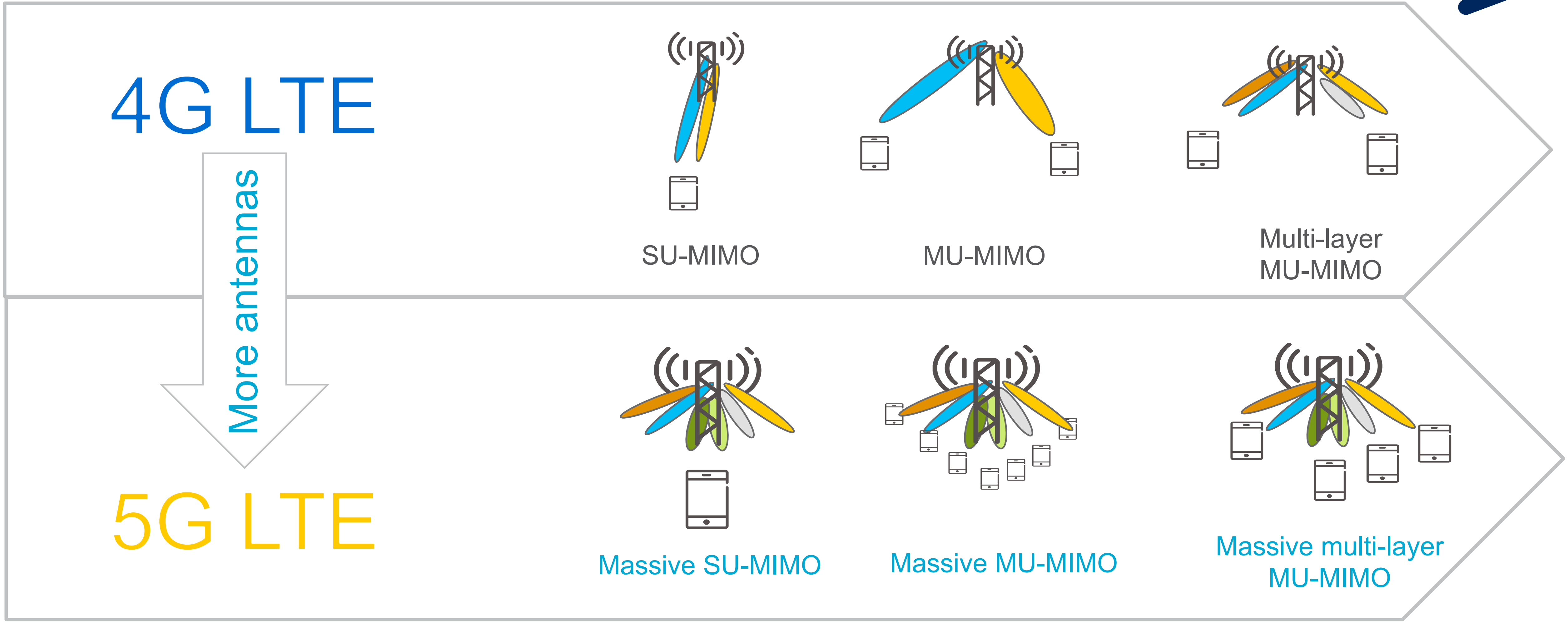
Mimo evolution



LTE: Long Term Evolution
SU MIMO: Single User Multiple Input Multiple Output
MU MIMO: Multiuser Multiple Input Multiple Output

G. Fodor, N. Rajatheva, W. Zirwas, L. Thiele, M. Kurras, K. Guo, A. Tolli, J. H. Sorensen, E. de Carvalho, "An Overview of Massive MIMO Technology Components in METIS", IEEE Communications Magazine, Vol. 55, Issue 6, pp. 155-161, June 2017.

Related Works (Pilot-to-Data Power Ratio)

- T. Kim and J. G. Andrews, “Optimal Pilot-to-Data Power Ratio for MIMO-OFDM,” IEEE Globecom, St. Louis, MO, USA, Dec. 2005, pp. 1481–1485.
- T. Marzetta, “How Much Training is Needed for Multiuser MIMO ?” IEEE Asilomar Conference on Signals, Systems and Computers (ACSSC) ,pp. 359–363, Jun. 2006.
- C. P. Sukumar and R. M. M. Eltawil, “Joint Power Loading of Data and Pilots in OFDM Using Imperfect Channel State Information at the Transmitter,” in IEEE Global Communications Conference, Nov. 2008, pp. 1–5.
- N. Jindal and A. Lozano, “A Unified Treatment of Optimum Pilot Overhead in Multipath Fading Channels,” IEEE Trans. on Communications, vol. 58, no. 10, pp. 2939–2948, October 2010.
- K. Min, M. Jung, T. Kim, Y. Kim, J. Lee, and S. Choi, “Pilot Power Ratio for Uplink Sum-Rate Maximization in Zero-Forcing Based MU-MIMO Systems with Large Number of Antennas,” in IEEE Vehicular Technology Conference (VTC-Fall), Sep. 2013, pp. 1–5.

Related Works (MMSE Receiver)

- M. Wrulich, C. Mehlfuhrer, and M. Rupp, “Managing the interference structure of MIMO HSDPA: A multi-user interference aware MMSE receiver with moderate complexity,” IEEE Transactions on Wireless Communications, vol. 9, no. 4, pp. 1536–1276, April 2010.
- J. T. Wang, “Joint MMSE equalization and power control for MIMO system under multi-user interference,” IEEE Communications Letters, vol. 16, no. 1, pp. 54–56, January 2012.
- B. Shim, J. W. Choi, and I. Kang, “Towards the performance of ML and the complexity of MMSE: A hybrid approach for multiuser detection,” IEEE Transactions on Wireless Communications, vol. 11, no. 7, pp. 2508–2519, July 2012.
- E. Eraslan, B. Daneshrad, and C.-Y. Lou, “Performance indicator for MIMO MMSE receivers in the presence of channel estimation error,” IEEE Wireless Communications Letters, vol. 2, no. 2, pp. 211–214, April 2013.
- Y. Dong and L. Qiu, “Spectral efficiency of massive MIMO systems with low-resolution ADCs and MMSE receiver,” IEEE Communications Letters, vol. 21, no. 8, pp. 1771–1774, August 2017.

Related Works (MMSE Receiver)

- M. R. McKay, I. B. Collings, and A. M. Tulino, “Achievable sum rate of MIMO MMSE receivers: A general analytic framework,” IEEE Transactions on Information Theory, vol. 56, no. 1, pp. 396 – 410, January 2010.
- Y. Wu and S. Verdu, “MMSE dimension,” IEEE Transactions on Information Theory, vol. 57, no. 8, pp. 4857 – 4879, August 2011.
- C. Artigue and P. Loubaton, “On the precoder design of flat fading MIMO systems equipped with MMSE receivers: A large-system approach,” IEEE Transactions on Information Theory, vol. 57, no. 7, pp. 4138 – 4155, July 2011.
- Y. Jiang, M. K. Varanasi, and J. Li, “Performance analysis of ZF and MMSE equalizers for MIMO systems: An in-depth study of the high SNR regime,” IEEE Transactions on Information Theory, vol. 57, no. 4, pp. 2008–2026, March 2011.
- B. Wang, Y. Chang, and D. Yang, “On the SINR in massive MIMO networks with MMSE receivers,” IEEE Communications Letters, vol. 18, no. 11, pp. 1979 – 1982, September 2014.
- G. Han and J. Song, “Extensions of the I-MMSE relationship to Gaussian channels with feedback and memory,” IEEE Transactions on Information Theory, vol. 62, no. 10, pp. 5422 – 5445, October 2016.

Outline

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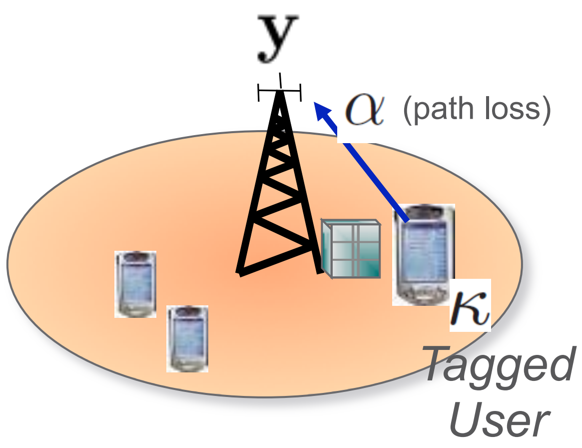
- Channel Estimation – Toy Model
- Channel Estimation and Receiver Design for Multiuser Systems

Outline

- › Channel Estimation – Toy Model
- › Channel Estimation and Receiver Design for Multiuser Systems

Channel Estimation – Toy Model



$$\mathbf{y}^p = \sqrt{P^p}\alpha \mathbf{h} x + \mathbf{n}^p$$

Channel estimation at the receiver from the received signal:

$$\hat{\mathbf{h}} = \frac{\mathbf{y}^p}{\sqrt{P^p}\alpha x}$$

$$\hat{\mathbf{h}} = \mathbf{h} + \frac{\mathbf{n}^p}{\sqrt{P^p}\alpha x}; \quad |x|^2 = 1$$

$$\mathbf{w} \sim \mathcal{CN}(\mathbf{0}, \mathbf{C_w}); \quad \mathbf{C_w} \triangleq \frac{\sigma^2}{P^p \alpha^2}\mathbf{I}$$

Channel Estimation – Toy Model

$$\hat{\mathbf{h}} = \mathbf{h} + \frac{\mathbf{n}^p}{\sqrt{P^p}\alpha x}; \quad |x|^2 = 1$$

Linear combination of Gaussian variables

$$\hat{\mathbf{h}} = \mathbf{h} + \mathbf{w} \quad \mathbf{w} \sim \mathcal{CN}(\mathbf{0}, \mathbf{C}_{\mathbf{w}}); \quad \mathbf{C}_{\mathbf{w}} \triangleq \frac{\sigma^2}{P^p\alpha^2}\mathbf{I}$$

$$\hat{\mathbf{h}} \sim \mathcal{CN}(\mathbf{0}, \mathbf{R})$$

$$\mathbf{R} \triangleq \mathcal{E}[\hat{\mathbf{h}}\hat{\mathbf{h}}^H] = \mathbf{C} + \frac{\sigma^2}{P^p\alpha^2}\mathbf{I}$$

$\mathbf{h}$ *and* $\hat{\mathbf{h}}$ *are jointly Gaussian (**multivariate** normal) !*

Three Steps to determine the Mean Squared Error of the Received Data Symbols

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- Determining the Conditional Channel Distribution $(\mathbf{h} \mid \hat{\mathbf{h}})$ ①
- Determining the Mean Squared Error (MSE) $\mathrm{MSE}(\hat{\mathbf{h}}) = \mathcal{E}_{\mathbf{h}|\hat{\mathbf{h}}}\left\{\mathrm{MSE}(\mathbf{h}, \hat{\mathbf{h}})\right\}$ ②
- Determining the average MSE as a function of the pilot and data power $\mathcal{E}\left\{MSE\right\} = \mathcal{E}_{\hat{\mathbf{h}}}\left\{\mathrm{MSE}(\hat{\mathbf{h}})\right\}$ ③

Multivariate Normal Distribution

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Theorem (Conditional PDF of Multivariate Gaussian)

If $\mathbf{x}$ *(with dimension* $k \times 1$*) and* $\mathbf{y}$ *(with dimension* $l \times 1$*) are jointly Gaussian with PDF :*

$$p(x, y) = \frac{1}{(2\pi)^{\frac{k+l}{2}} \sqrt{\det(\mathbf{C})}} \exp\left[\frac{-1}{2} \begin{bmatrix} \mathbf{x} - E(\mathbf{x}) \\ \mathbf{y} - E(\mathbf{y}) \end{bmatrix}^T \mathbf{C}^{-1} \begin{bmatrix} \mathbf{x} - E(\mathbf{x}) \\ \mathbf{y} - E(\mathbf{y}) \end{bmatrix}\right]$$

with covariance matrix : $\mathbf{C} = \begin{bmatrix} \mathbf{C}_{xx} & \mathbf{C}_{xy} \\ \mathbf{C}_{yx} & \mathbf{C}_{yy} \end{bmatrix}$

then the conditional PDF $p(\mathbf{y}|\mathbf{x})$ *is also Gaussian and :*

$$\begin{aligned} E(\mathbf{y}|\mathbf{x}) &= E(\mathbf{y}) + \mathbf{C}_{yx}\mathbf{C}_{xx}^{-1}[\mathbf{x} - E(\mathbf{x})] \\ \mathbf{C}_{y|x} &= \mathbf{C}_{yy} - \mathbf{C}_{yx}\mathbf{C}_{xx}^{-1}\mathbf{C}_{xy} \end{aligned}$$

$y \leftarrow \hat{h}$

$x \leftarrow h$

$\hat{\mathbf{h}}|\mathbf{h}$

Multivariate Normal Distribution

Theorem (Posterior PDF for the Bayesian General Linear Model)

If the observed data can be modeled as

$$\mathbf{x} = \mathbf{H}\boldsymbol{\theta} + \mathbf{w}$$

where $\boldsymbol{\theta}$ is a $p \times 1$ random vector with prior PDF $\mathcal{N}(\boldsymbol{\mu}_\theta, \mathbf{C}_\theta)$ and $\mathbf{w}$ is a noise vector with PDF $\mathcal{N}(0, \mathbf{C}_w)$, then the posterior PDF $p(\mathbf{x}|\boldsymbol{\theta})$ is Gaussian with mean :

$$E(\boldsymbol{\theta}|\mathbf{x}) = \boldsymbol{\mu}_\theta + \mathbf{C}_\theta \mathbf{H}^T (\mathbf{H}\mathbf{C}_\theta \mathbf{H}^T + \mathbf{C}_w)^{-1} (\mathbf{x} - \mathbf{H}\boldsymbol{\mu}_\theta)$$

and covariance

$$\mathbf{C}_{\theta|x} = \mathbf{C}_\theta - \mathbf{C}_\theta \mathbf{H}^T (\mathbf{H}\mathbf{C}_\theta \mathbf{H}^T + \mathbf{C}_w)^{-1} \mathbf{H}\mathbf{C}_\theta$$

$$\hat{\mathbf{h}} = \mathbf{h} + \mathbf{w}$$

$\mathbf{H} \leftarrow \mathbf{I}$

$\mathbf{h}|\hat{\mathbf{h}}$

Recall: $\hat{\mathbf{h}} = \mathbf{h} + \mathbf{w}$ $\quad \mathbf{w} \sim \mathcal{CN}(\mathbf{0}, \mathbf{C}_\mathbf{w})$; $\quad \mathbf{C}_\mathbf{w} \triangleq \dfrac{\sigma^2}{Pp\alpha^2}\mathbf{I}$

$$\theta \leftarrow h \qquad \mu_\theta = E[h] = 0 \qquad \mathbf{C}_{\hat{\mathbf{h}},\hat{\mathbf{h}}} = \mathbf{R}$$

$$x \leftarrow \hat{h} \qquad \mathbf{H}\mu_\theta = E[\hat{h}] = 0 \qquad \mathbf{C}_\theta + \mathbf{C}_\mathbf{w} = \mathbf{R}$$

$$\mathbf{C}_\theta = \mathbf{C}_{\mathbf{hh}}$$

What is the distribution of ? $(\mathbf{h} \mid \hat{\mathbf{h}})$ ①

› Applying the Theorem of MV Gaussian [see e.g. Kay '93]:

$$(\hat{\mathbf{h}} \mid \mathbf{h}) \sim \mathcal{CN}(\mathbf{h}, \mathbf{C}_{\mathbf{w}}) \quad \Leftarrow$$

$$\begin{aligned} E(\mathbf{y}|\mathbf{x}) &= E(\mathbf{y}) + \mathbf{C}_{yx}\mathbf{C}_{xx}^{-1}[\mathbf{x} - E(\mathbf{x})] \\ \mathbf{C}_{y|x} &= \mathbf{C}_{yy} - \mathbf{C}_{yx}\mathbf{C}_{xx}^{-1}\mathbf{C}_{xy} \end{aligned}$$

$$y \leftarrow \hat{h}$$
$$x \leftarrow h$$

› Applying the Bayesian Linear Model of [see e.g. Kay '93] :

$$(\mathbf{h} \mid \hat{\mathbf{h}}) \sim \mathcal{CN}\left(\mathbf{D}\hat{\mathbf{h}}, \mathbf{Q}\right) \quad \Leftarrow$$

$$E(\boldsymbol{\theta}|\mathbf{x}) = \boldsymbol{\mu}_\theta + \mathbf{C}_\theta\mathbf{H}^T(\mathbf{H}\mathbf{C}_\theta\mathbf{H}^T + \mathbf{C}_w)^{-1}(\mathbf{x} - \mathbf{H}\boldsymbol{\mu}_\theta)$$

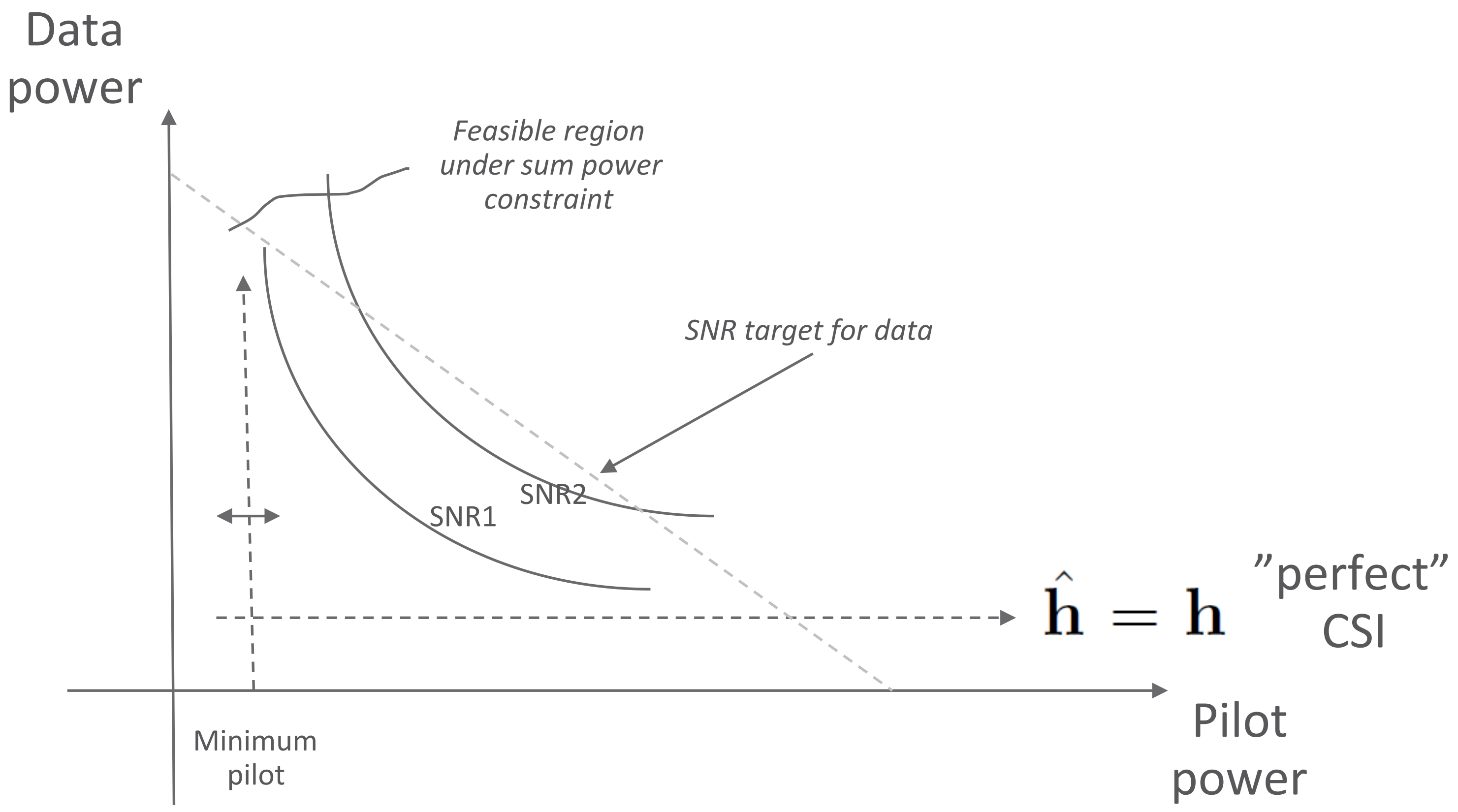
$$\mathbf{C}_{\theta|x} = \mathbf{C}_\theta - \mathbf{C}_\theta\mathbf{H}^T(\mathbf{H}\mathbf{C}_\theta\mathbf{H}^T + \mathbf{C}_w)^{-1}\mathbf{H}\mathbf{C}_\theta$$

where $\mathbf{D} = \mathbf{C}\mathbf{R}^{-1}$ and $\mathbf{Q} = \mathbf{C} - \mathbf{C}\mathbf{R}^{-1}\mathbf{C}$

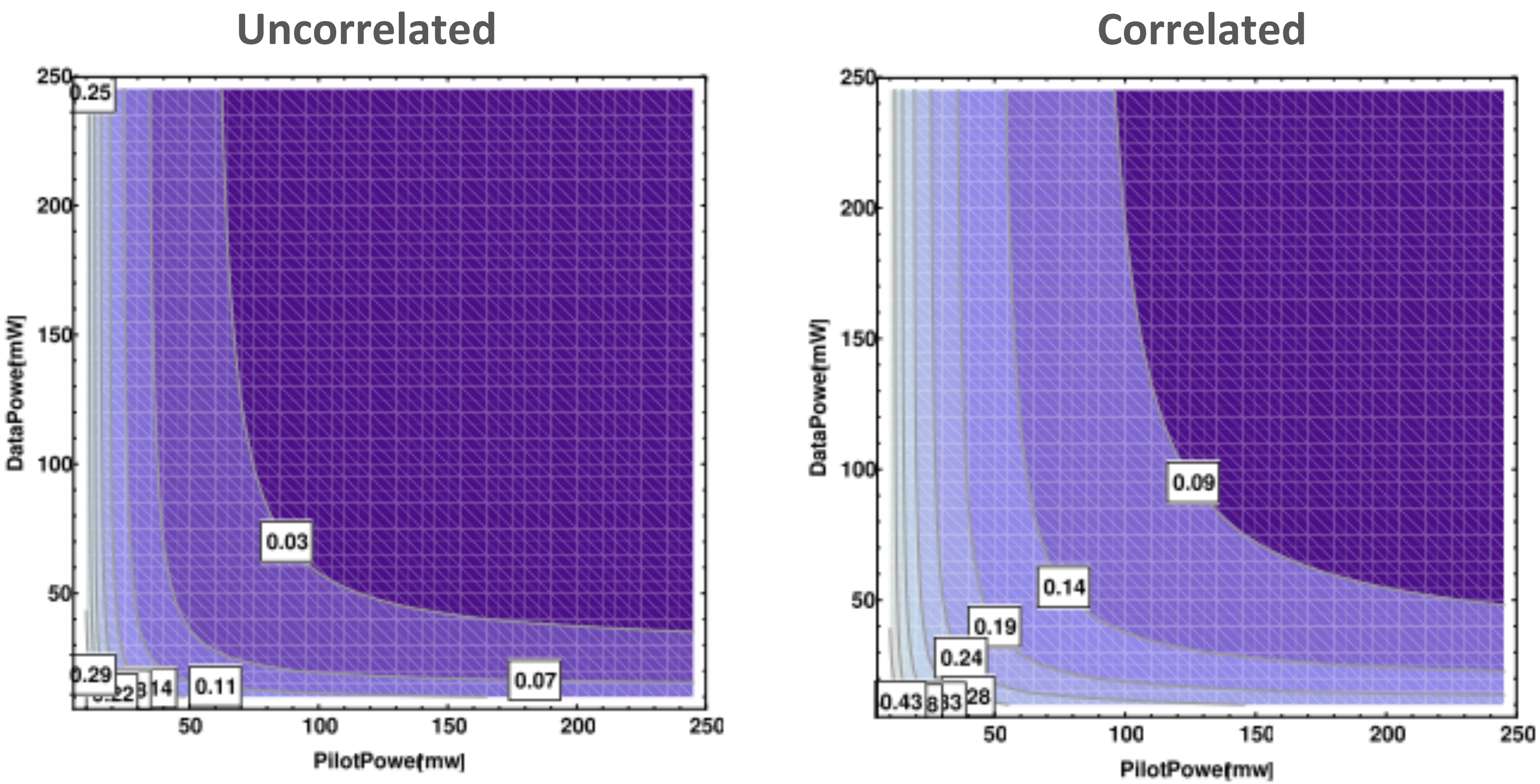
$$\theta \leftarrow h \qquad \mu_\theta = E[h] = 0 \qquad \mathbf{C}_{\hat{\mathbf{h}},\hat{\mathbf{h}}} = \mathbf{R}$$
$$x \leftarrow \hat{h} \qquad \mathbf{H}\mu_\theta = E[\hat{h}] = 0 \qquad \mathbf{C}_\theta + \mathbf{C}_{\mathbf{w}} = \mathbf{R}$$
$$\mathbf{H} \leftarrow \mathbf{I} \qquad \mathbf{C}_\theta = \mathbf{C}_{\mathbf{hh}}$$

The Pilot Power – Data Power Trade-off

- Intuitive trade off between the pilot and the data power when sustaining a given SNR (no interference !):



MSE – 20 un-correlated / correlated antennas



A given MSE of the equalized data symbols can be reached by different pilot and data power setting.

Outline

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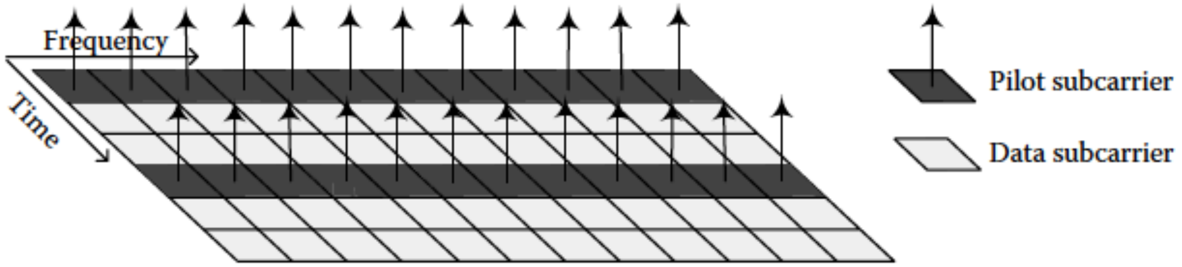
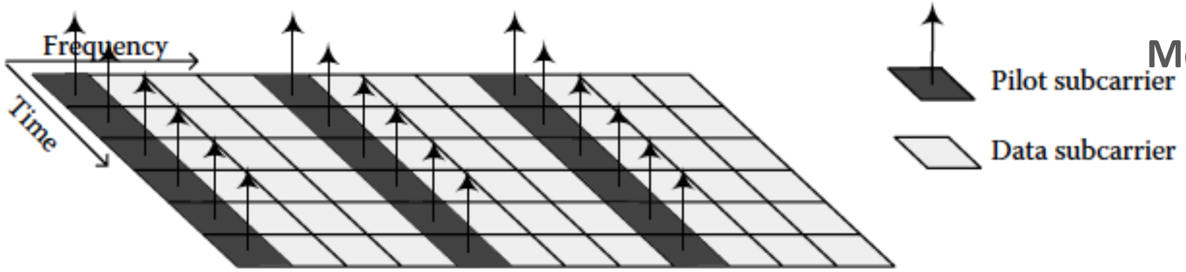
- Channel Estimation – Toy Model
- Channel Estimation and Receiver Design for Multiuser Systems

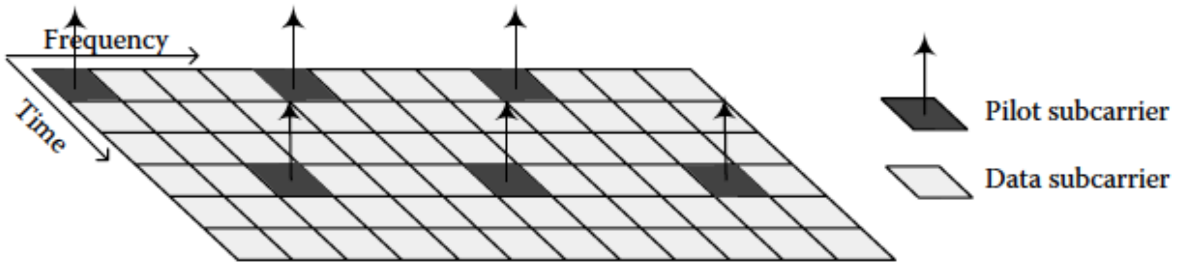
Pilot-Based Channel Estimation



(a) Frequency continuous–time spaced pilot allocation (Block type)



(b) Time continuous–frequency spaced pilot allocation (Comb type)



(c) Time spaced–frequency spaced pilot allocation

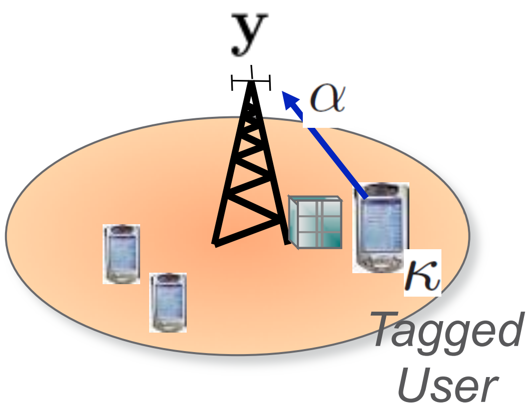
Trade-offs:

More pilot symbols
- → Better channel estimate; Less aggressive pilot reuse; More users for MU multiplexing
- → Less data symbols

Higher pilot power
- → Better channel estimate
- → SNR degradation for data + increased pilot contamination

MU: Multi user
SNR: Signal-to-Noise-Ratio

MU MIMO Signal Model



Data signal model:

$$\mathbf{y} = \underbrace{\alpha_\kappa \mathbf{h}_\kappa \sqrt{P_\kappa} x_\kappa}_{\text{User-}\kappa} + \underbrace{\sum_{k \neq \kappa}^{K} \alpha_k \mathbf{h}_k \sqrt{P_k} x_k}_{\text{Other users}} + \mathbf{n}_d$$

$$\mathbf{G}^{\text{naïve}} = \mathbf{G}^{\text{naïve}}(\hat{\mathbf{h}}) = \frac{\alpha \sqrt{P} \hat{\mathbf{h}}^H}{\alpha^2 P ||\hat{\mathbf{h}}||^2 + \sigma^2}$$

The naïve G minimizes the MSE of the received data symbols when perfect channel estimation is available at the receiver.

G. Fodor, P. Di Marco, M. Telek "On Minimizing the MSE in Multiple Antenna Systems in the Presence of Channel State Information Errors",
IEEE Communications Letters, Vol. 19, No. 9, pp. 1604-1607, September 2015

Preliminaries I

Pilot signal model: $\mathbf{Y}^p = \alpha\sqrt{P_p}\mathbf{h}\mathbf{s}^T + \mathbf{N}$ $\quad \mathbf{h} \in \mathbb{C}^{N_r \times 1}$ $\quad \mathbf{h} \sim \mathcal{CN}(\mathbf{0}, \mathbf{C})$

Pilot sequence: $\mathbf{s}^* = \left[s_1^*, \ldots, s_{\tau_p}^*\right]^T \in \mathbb{C}^{\tau_p \times 1}$ $\quad (\mathbf{s}^T\mathbf{s}^*) = \tau_p$

Estimated channel: $\mathbf{R} \triangleq \mathbb{E}\{\hat{\mathbf{h}}\hat{\mathbf{h}}^H\} = \mathbf{C} + \frac{\sigma_p^2}{\alpha^2 P_p \tau_p}\mathbf{I}_{N_r}$

Preliminaries II

Data signal model:

$$\mathbf{y} = \underbrace{\alpha_\kappa \mathbf{h}_\kappa \sqrt{P_\kappa} x_\kappa}_{\text{User-}\kappa} + \underbrace{\sum_{k \neq \kappa}^{K} \alpha_k \mathbf{h}_k \sqrt{P_k} x_k}_{\text{Other users}} + \mathbf{n}_d$$

MU MIMO Receiver at the BS:

$$\mathbf{G}_\kappa \in \mathbb{C}^{1 \times N_r}$$

$$\mathbf{G}_\kappa^\star \triangleq \arg\min_{\mathbf{G}} \mathbb{E}\{\text{MSE}\} = \arg\min_{\mathbf{G}} \mathbb{E}\{|\mathbf{G}\mathbf{y} - x_\kappa|^2\}$$

N. Rajatheva, S. Suyama, W. Zirwas, L. Thiele, G. Fodor, A.Tölli, E. Carvalho, J. H. Sorensen, "Massive Multiple Input Multiple Output (MIMO) Systems", Chapter 8 in: A. Osseiran, J. F. Monserrat, P. Marsch, "5G Mobile and Wireless Communications Technology", Cambridge University Press, June 2016. ISBN: 9781107130098

How to find the (true) MMSE Receiver ?

› To find the **optimal receiver** in the presence of channel estimation errors:

$$\mathbf{G}_\kappa^\star \triangleq \arg\min_{\mathbf{G}} \mathbb{E}\{\mathrm{MSE}\} = \arg\min_{\mathbf{G}} \mathbb{E}\{|\mathbf{G}_\kappa \mathbf{y} - x_\kappa|^2\}$$

› Step 1: Determine the MSE of a tagged User κ as a function of G in the case of perfect CSI

$$\mathrm{MSE}\left(\mathbf{G}_\kappa, \mathbf{h}_1, \ldots, \mathbf{h}_K\right) = \mathbb{E}_{x,\mathbf{n}_d}\{|\mathbf{G}_\kappa \mathbf{y} - x_\kappa|^2\}$$

$$\Downarrow \quad \mathbb{E}_{\mathbf{h}_1,\ldots,\mathbf{h}_{\kappa-1},\mathbf{h}_{\kappa+1},\ldots,\mathbf{h}_K}$$

› Step 2: Determine the MSE of a tagged User κ as a function of G_κ and the estimated channel

$$\mathrm{MSE}\left(\mathbf{G}_\kappa, \mathbf{h}_\kappa\right)$$

$$\Downarrow \quad (\mathbf{h} \mid \hat{\mathbf{h}})$$

› Step 3: Determine $\mathbf{G}_\kappa^\star$ that minimizes $\mathrm{MSE}\left(\mathbf{G}_\kappa, \hat{\mathbf{h}}_\kappa\right)$

$$\mathrm{MSE}\left(\mathbf{G}_\kappa, \hat{\mathbf{h}}_\kappa\right) = \mathbb{E}_{\mathbf{h}_\kappa|\hat{\mathbf{h}}_\kappa} \mathrm{MSE}\left(\mathbf{G}_\kappa, \mathbf{h}_\kappa\right)$$

Results

› Closed form expression for the MMSE receiver in the presence of CSI errors

› Closed form expression for the MSE when using the naïve and the MMSE receiver

› Closed form expressions for the optimum pilot-to-data power ratio when using the MMSE receiver

How to find the (true) MMSE Receiver ?

Proposition The optimal $\mathbf{G}_\kappa^\star$ can be derived as:

$$\mathbf{G}_\kappa^\star = \alpha_\kappa \sqrt{P_\kappa}\hat{\mathbf{h}}_\kappa^H \mathbf{D}_\kappa^H \cdot \left(\alpha_\kappa^2 P_\kappa \left(\mathbf{D}_\kappa \hat{\mathbf{h}}_\kappa \hat{\mathbf{h}}_\kappa^H \mathbf{D}_\kappa^H + \mathbf{Q}_\kappa \right) + \sum_{k \neq \kappa}^{K} \alpha_k^2 P_k \mathbf{C}_k + \sigma_d^2 \mathbf{I} \right)^{-1}$$

Elements of proof:

$$\mathrm{MSE}\left(\mathbf{G}_\kappa, \hat{\mathbf{h}}_\kappa\right) = -\underbrace{\mathbf{G}_\kappa}_{\mathbf{x}} \underbrace{\alpha_\kappa \sqrt{P_\kappa}\mathbf{D}_\kappa \hat{\mathbf{h}}_\kappa}_{\mathbf{B}} - \alpha_\kappa \sqrt{P_\kappa}\hat{\mathbf{h}}_\kappa^H \mathbf{D}_\kappa^H \mathbf{G}_\kappa^H + 1 +$$

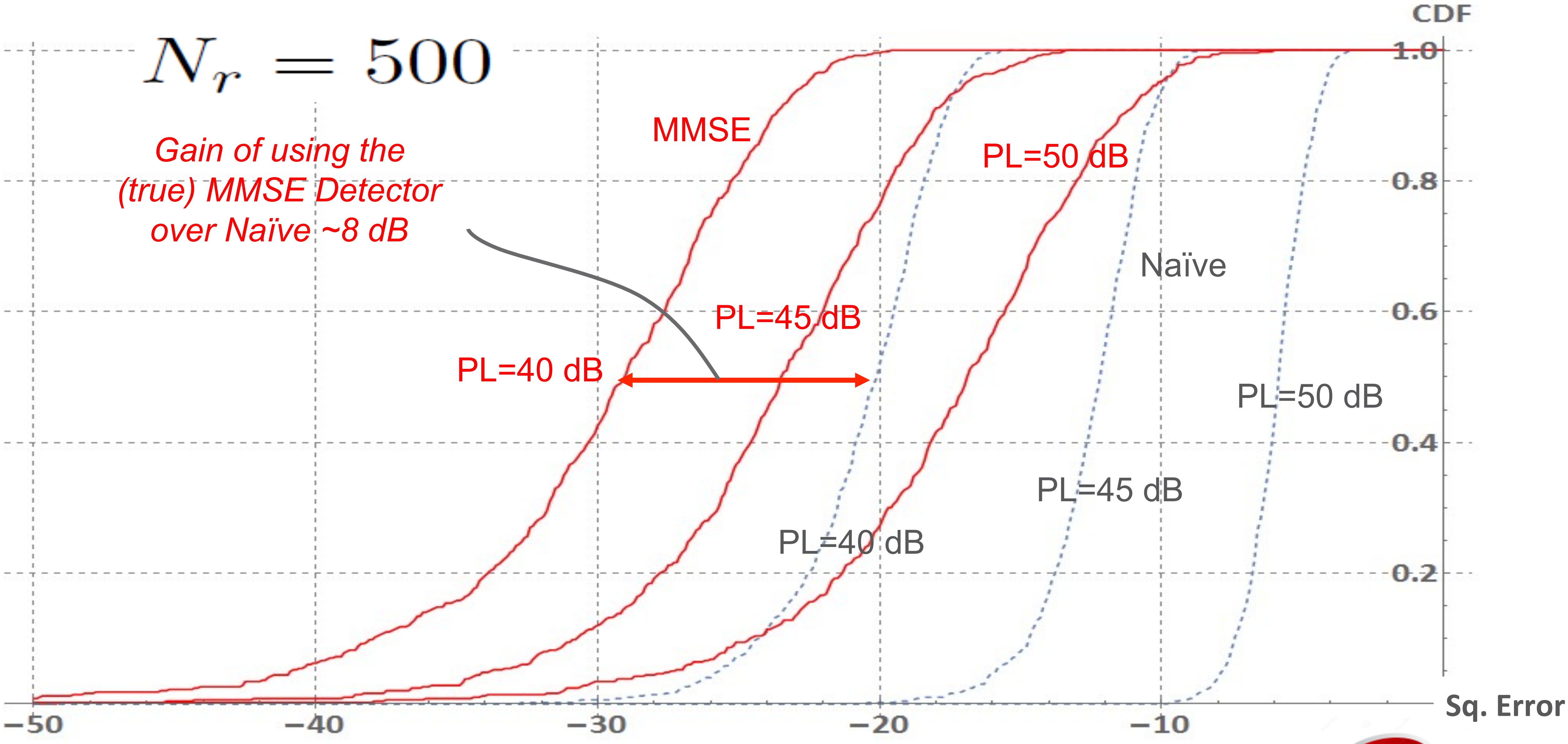
$$+\mathbf{G}_\kappa \underbrace{\left(\alpha_\kappa^2 P_\kappa \left(\mathbf{D}_\kappa \hat{\mathbf{h}}_\kappa \hat{\mathbf{h}}_\kappa^H \mathbf{D}_\kappa{}^H + \mathbf{Q}_\kappa \right) + \sum_{k \neq \kappa}^{K} \alpha_k^2 P_k \mathbf{C}_k + \sigma_d^2 \mathbf{I} \right)}_{\mathbf{A}} \mathbf{G}_\kappa^H$$

Quadratic Form:

$$\left(\mathbf{x}\mathbf{A}\mathbf{x}^H - \mathbf{x}\mathbf{B} - \mathbf{B}^H\mathbf{x}^H + 1\right)$$

$$\mathbf{x}^\star = \mathbf{B}^H \mathbf{A}^{-1}$$

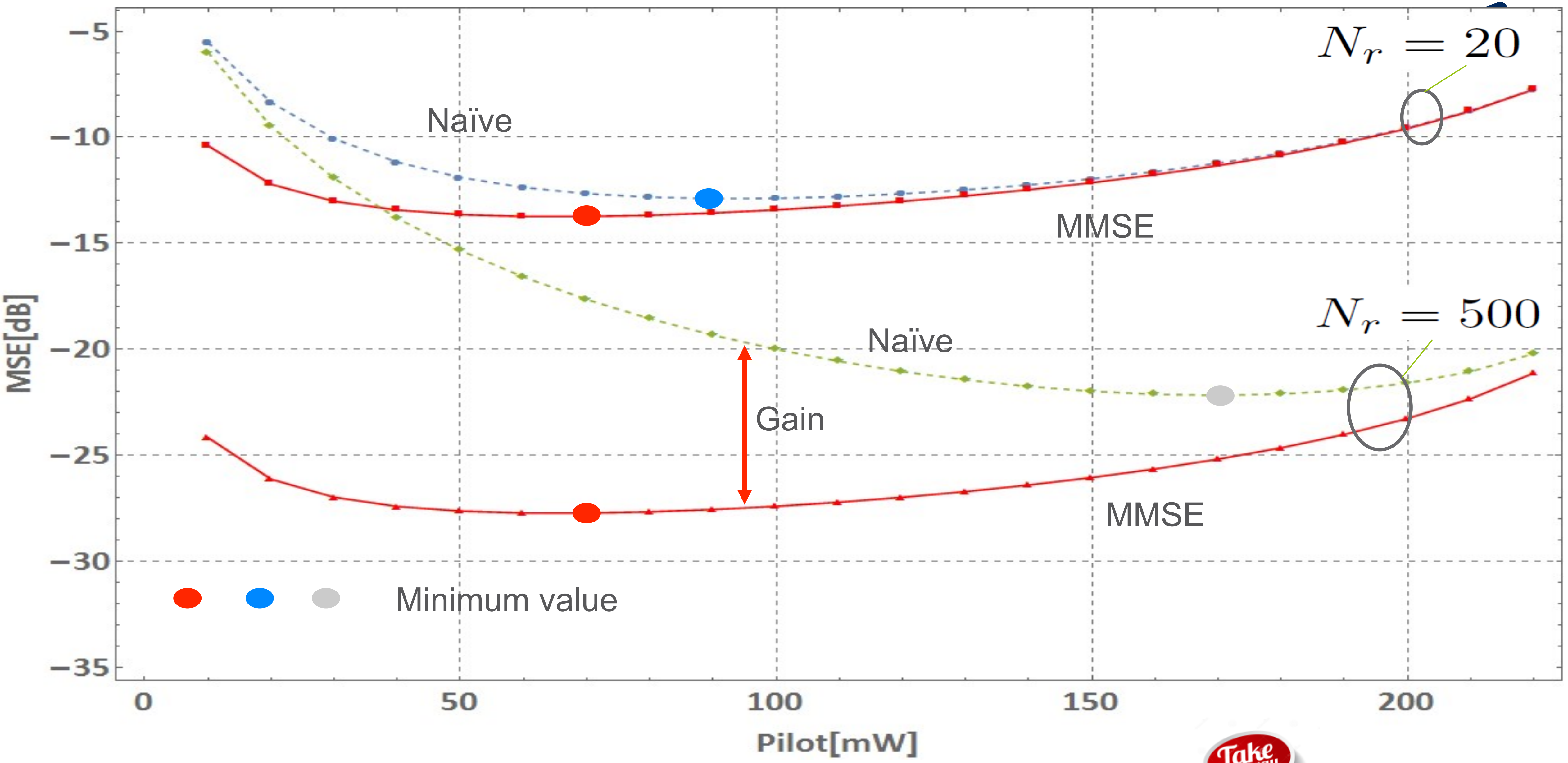
G. Fodor, P. Di Marco and M. Telek, "On the Impact of Antenna Correlation and CSI Errors on the Pilot-to-Data Power Ratio", IEEE Transactions on Communications, Volume 64, Issue 6, pp. 2622-2633, April 2016.



The optimal receiver yields significant gains over the whole CDF, including the 10 and 90 percentiles and for various levels of the path loss.

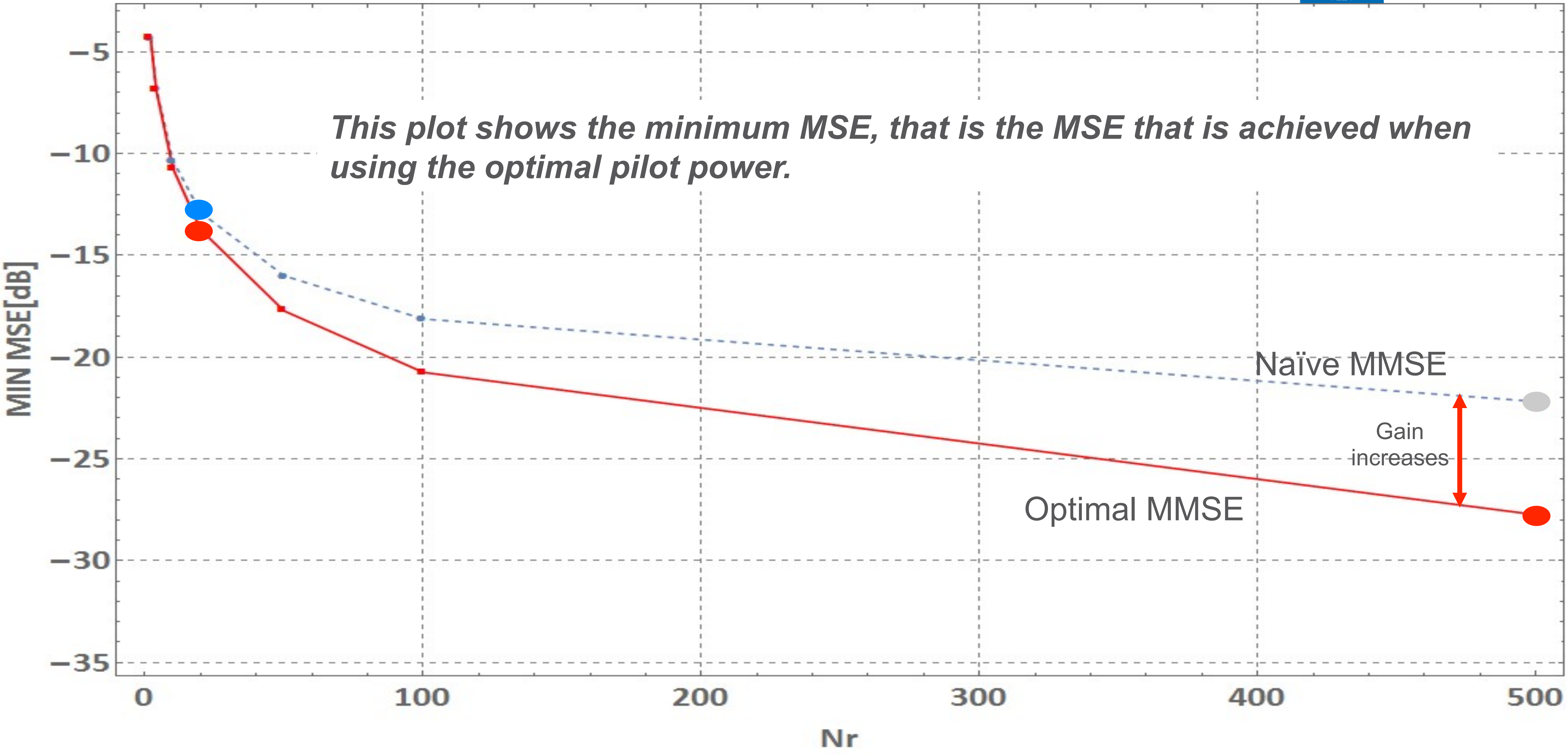
Take away

G. Fodor, P. Di Marco and M. Telek, "On the Impact of Antenna Correlation and CSI Errors on the Pilot-to-Data Power Ratio", IEEE Transactions on Communications, Volume 64, Issue 6, pp. 2622-2633, April 2016.

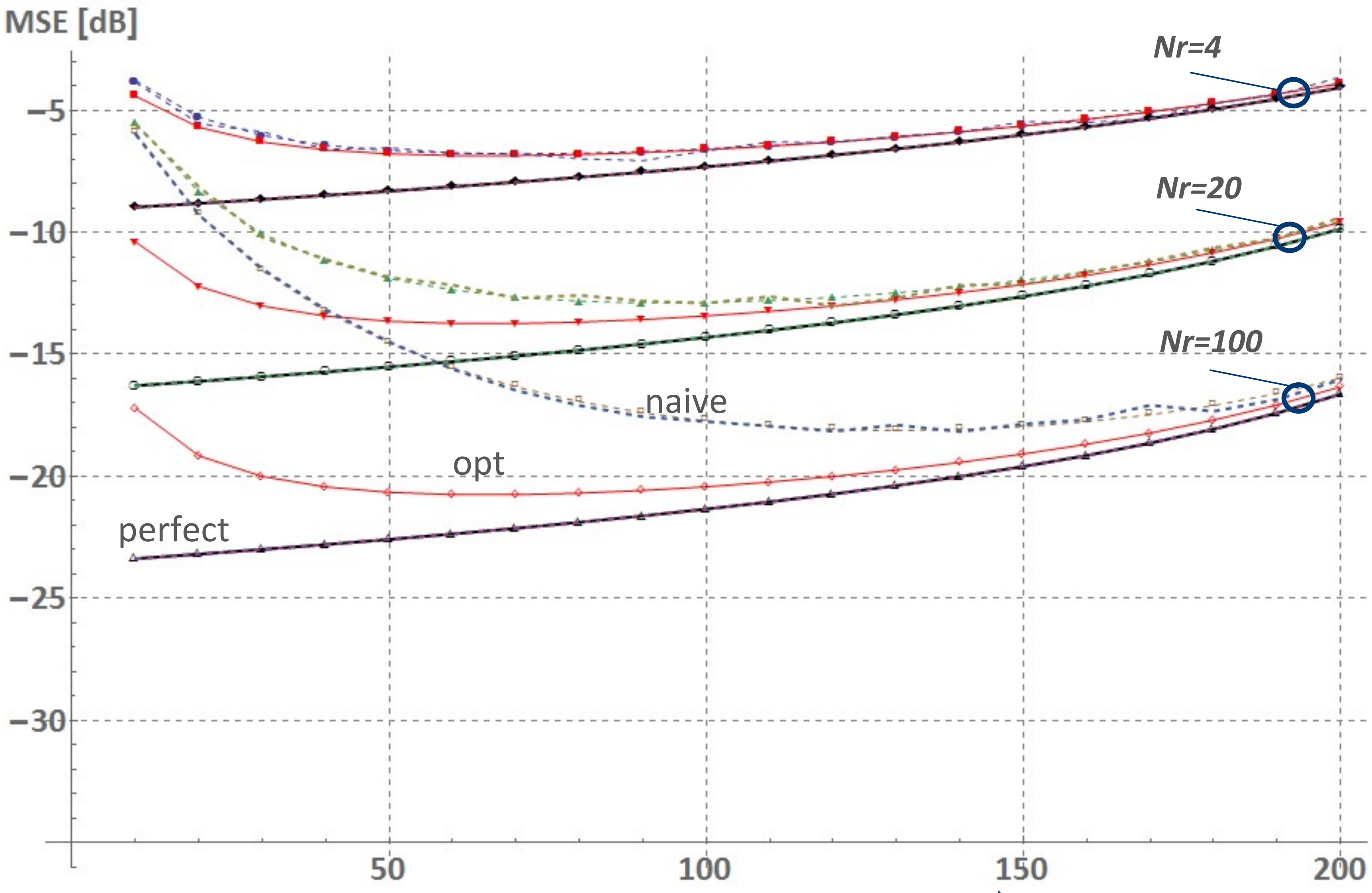


The gain increases as the number of antennas increases.

How does the Gain depend on the Number of Antennas ?



Comparison With Perfect CSI



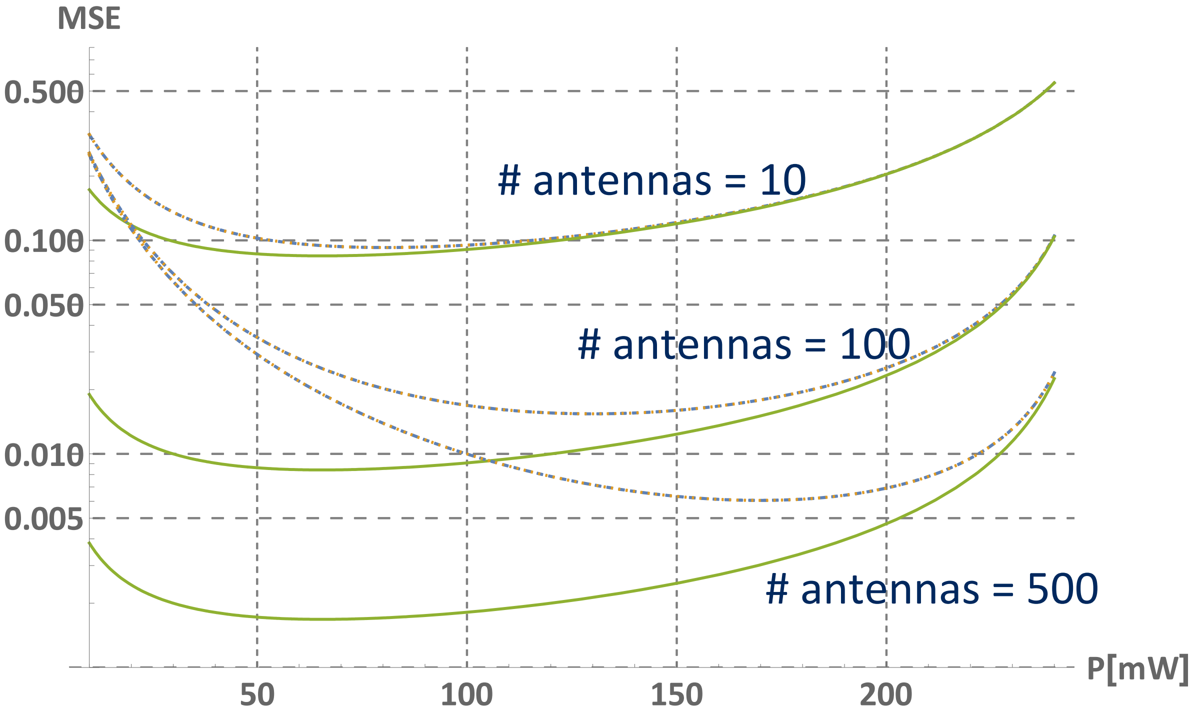
Pilot power [mW]

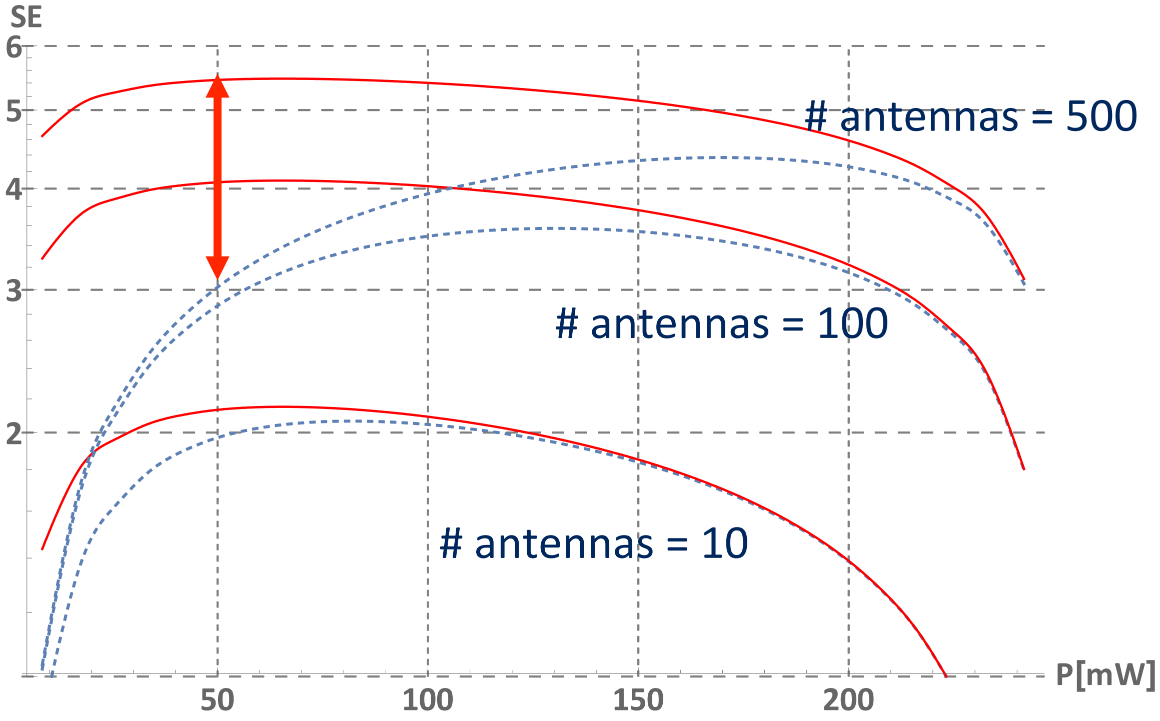
With large number of antennas, the MSE performance of the optimal receiver remains close to the perfect CSI performance, whereas the performance of the naïve receiver is far from the perfect CSI case.

Therefore, with larger number of antennas, the importance of applying the optimal receiver increases.

Data transmit power decreases

MSE And SE With Comb Pilot Pattern





↕ Gain due to optimal MMSE receiver (over naïve MMSE)

Take Away

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- The gain of the optimal receiver increases with increasing number of antennas. In the massive MIMO domain, this gain can be up to 8-10 dB in terms of MSE;
- The true MMSE receiver well approximates the perfect channel estimation case, independently of the number of antennas (as opposed to the naïve receiver);
- With the true MMSE, the transmit power that minimizes the MSE, does not depend on the number of receive antennas (as opposed to the naïve receiver);
- Impact of antenna spacing and angular spread on MSE decreases with increasing number of antennas.

Full Dimension in 3GPP

- Full Dimension MIMO (FD-MIMO)
  - Greater number of antenna ports
  - Efficient MU MIMO Spatial Multiplexing
  - Robustness against CSI Impairments (e.g. intercell interference)

- 3GPP Technical Report: Study on Elevation Beamforming and FD-MIMO for LTE
  - See also:
    - 36.873 Study on 3D Channel Model for LTE
    - 37.105 Active Antenna System BS Radio Transmission and Reception

3GPP TSG RAN Meeting #71 **RP-160623**
Göteborg, Sweden, March 7 - 10, 2016

Source: Samsung
Title: New WID Proposal: Enhancements on Full-Dimension (FD) MIMO for LTE
Document for: Approval
Agenda Item: 10.1.1

3GPP™ Work Item Description

For guidance, see 3GPP Working Procedures, article 39; and 3GPP TR 21.900.
Comprehensive instructions can be found at http://www.3gpp.org/Work-Items

Title: Enhancements on Full-Dimension (FD) MIMO for LTE

Acronym: LTE_eFDMIMO

Unique identifier:

NOTE: If this is a RAN WID including Core and Perf. Part, then Title, Acronym and Unique identifier refer to the feature WI. Please tick (X) the applicable box(es) in the table below:

This WID includes a Core part	X
This WID includes a Performance part	X

1 3GPP Work Area

X	Radio Access
	Core Network
	Services

3GPP TR 36.897 V13.0.0 (2015-06)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Study on elevation beamforming / Full-Dimension (FD) Multiple Input Multiple Output (MIMO) for LTE
(Release 13)

3GPP TS 37.105 V1.0.0 (2016-03)

Technical Specification

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Active Antenna System (AAS) Base Station (BS) radio transmission and reception
(Release 13)