Optimizing future wireless communication systems

"Optimization and Engineering" symposium
Louvain-la-Neuve, May 24th 2006

Jonathan Duplicy
(www.tele.ucl.ac.be/digicom/duplicy)

Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple Access
- Downlink OFDM SDMA
- Conclusions

Outline

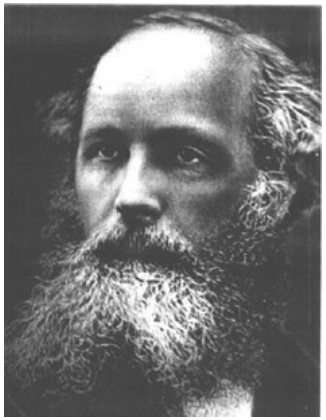
- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple Access
- Downlink OFDM SDMA
- Conclusions

The first wireless communication system

"It say sausage, chicken portion...
no,wait...it's a barbecue"

Much better

Timeline (1/2)

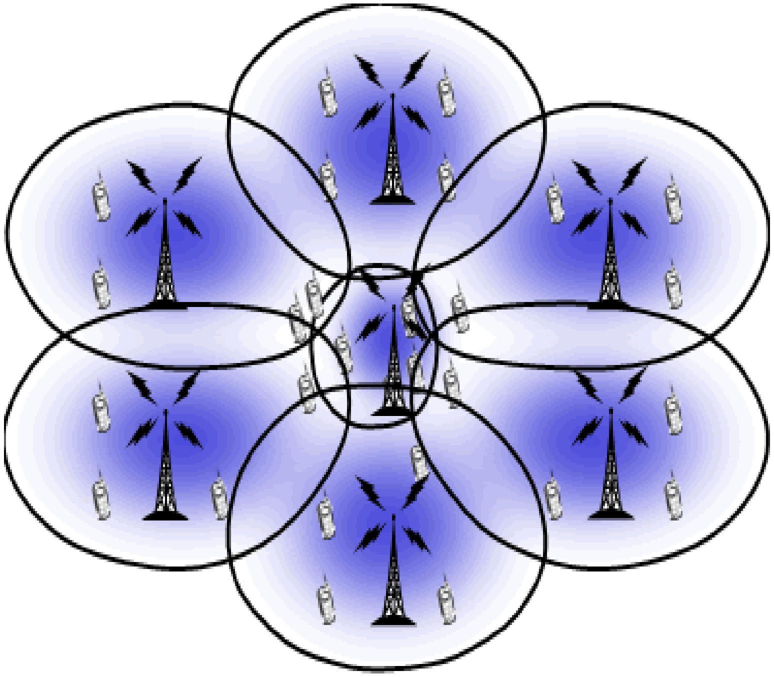


- 1864 - Maxwell predicts Electromagnetic Waves.
- 1887 - Hertz proves existence of EM waves.
- 1895 - Marconi transmits a message to his brother over 1400m.
- 1901 - Marconi successfully transmits radio signal across Atlantic Ocean.
- 1900 - First voice radio service.
- 1912 - A Marconi set was aboard the ocean liner Titanic when it went down.
- 1935 - Frequency Modulation (FM) radio invented by Armstrong.

Timeline (2/2)

- **First generation (1983) :**
  - **Cellular system**
  - **Analog transmission**
  - **Maximum 9.6kHz**

- **Second generation (1990) :**
  - **Digital transmissions to transmit data between 9.5 Kbps and 14.4 Kbps in 800 MHz and 1.9 GHz frequencies**
  - **Several advantages over analog, including :**
    - ✓ **More efficient uses of frequency spectrum**
    - ✓ **Quality of voice transmission does not degrade over distance**
    - ✓ **Better security; more difficult to decode**
    - ✓ **Requires less transmitter power**
    - ✓ **Uses smaller and less expensive individual receivers and transmitters**



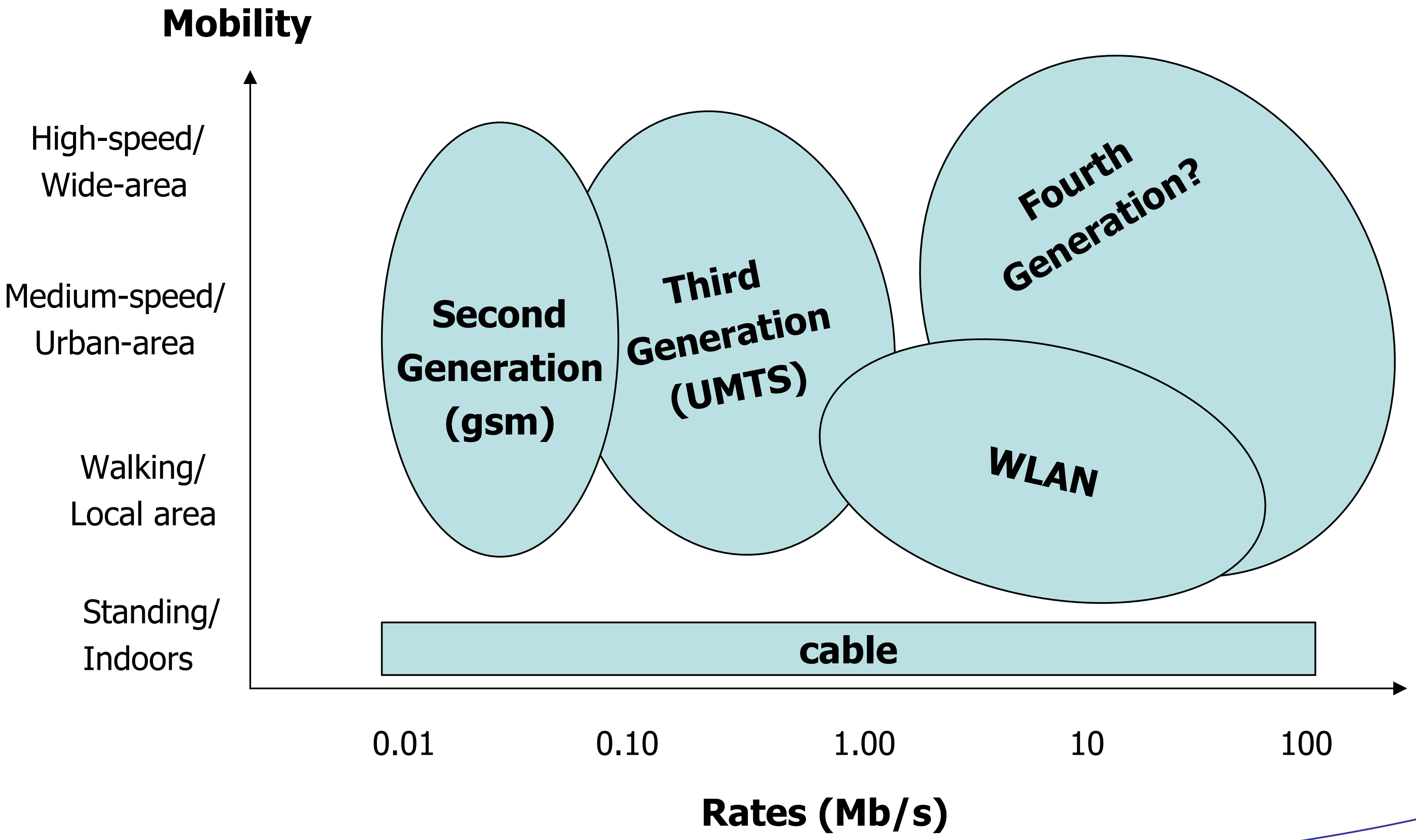
- **Third generation (recently) :**
  - **144 Kbps for a mobile user**
  - **386 Kbps for slowly moving user**
  - **2 Mbps for stationary user**

- **Fourth generation ???**

Wireless Local Area Network (WLAN)

- Provides short-range, high-speed wireless data connections between mobile data devices and nearby Wi-Fi access points.
- Short range : 30 – 100m
- High speed :
  - IEEE 802.11b : 11 Mb/s
  - IEEE 802.11g,a : 54 Mb/s
  - IEEE 802.11n : 540 Mb/s
- Low cost
- Other local protocols : Bluetooth, Wimax, Zigbee, …

Wireless systems - summary



Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple access
- Downlink OFDM SDMA
- Conclusions

Main challenges

- Increased data rates (bits/s).

- Improved quality of service :
  - Bit error rate (BER)
  - Mobility
  - Reachability
  - Latency
  - …

- Achieving a mix of both higher data rate and improved quality of service.

- Heterogeneous networks

Two major constraints

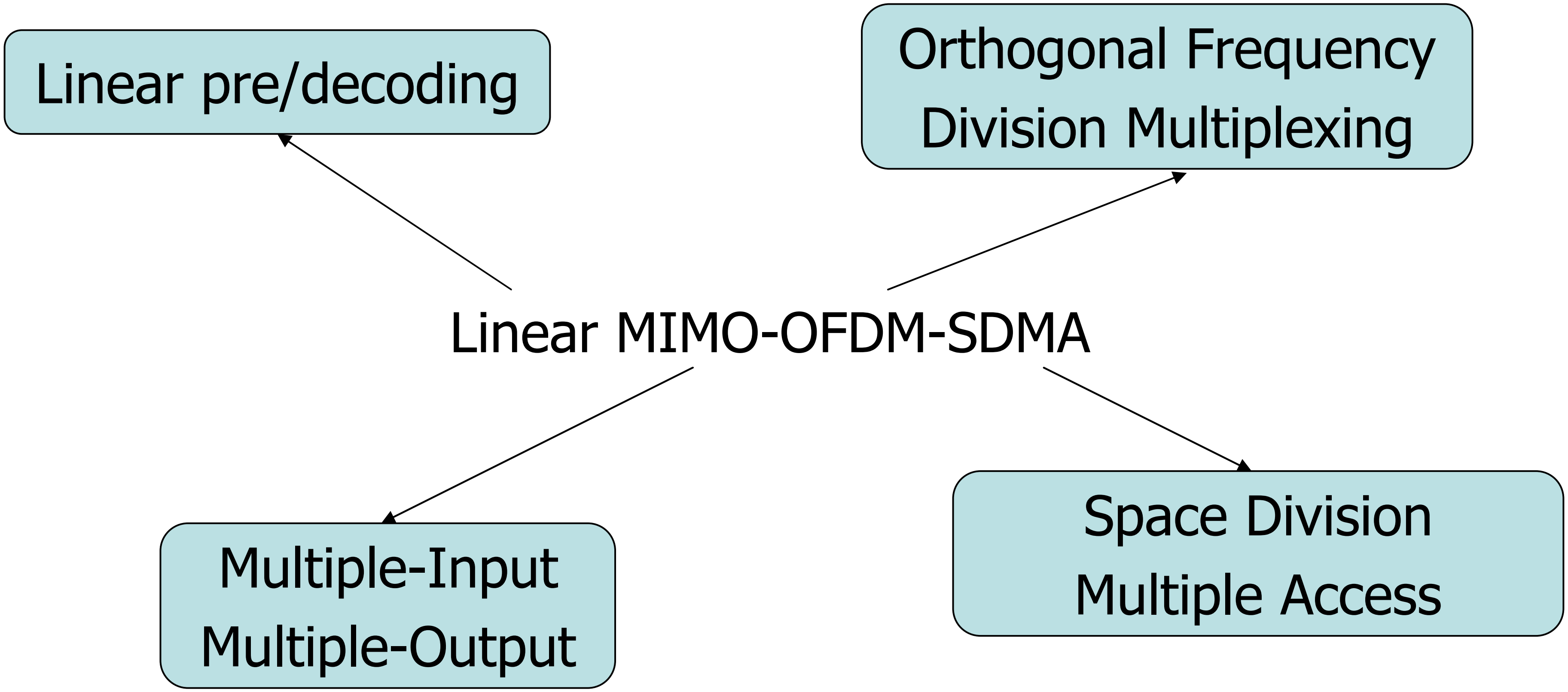
- Power
  - Environemental issues
  - Battery issues
  - Interferences

Need for power efficient schemes

- Spectrum
  - Highly occupied
  - Costly
  - Frequency selectivity

Need for highly spectrally efficient schemes

One of the many candidates



Linear MIMO-OFDM-SDMA

Linear pre/decoding

Orthogonal Frequency Division Multiplexing

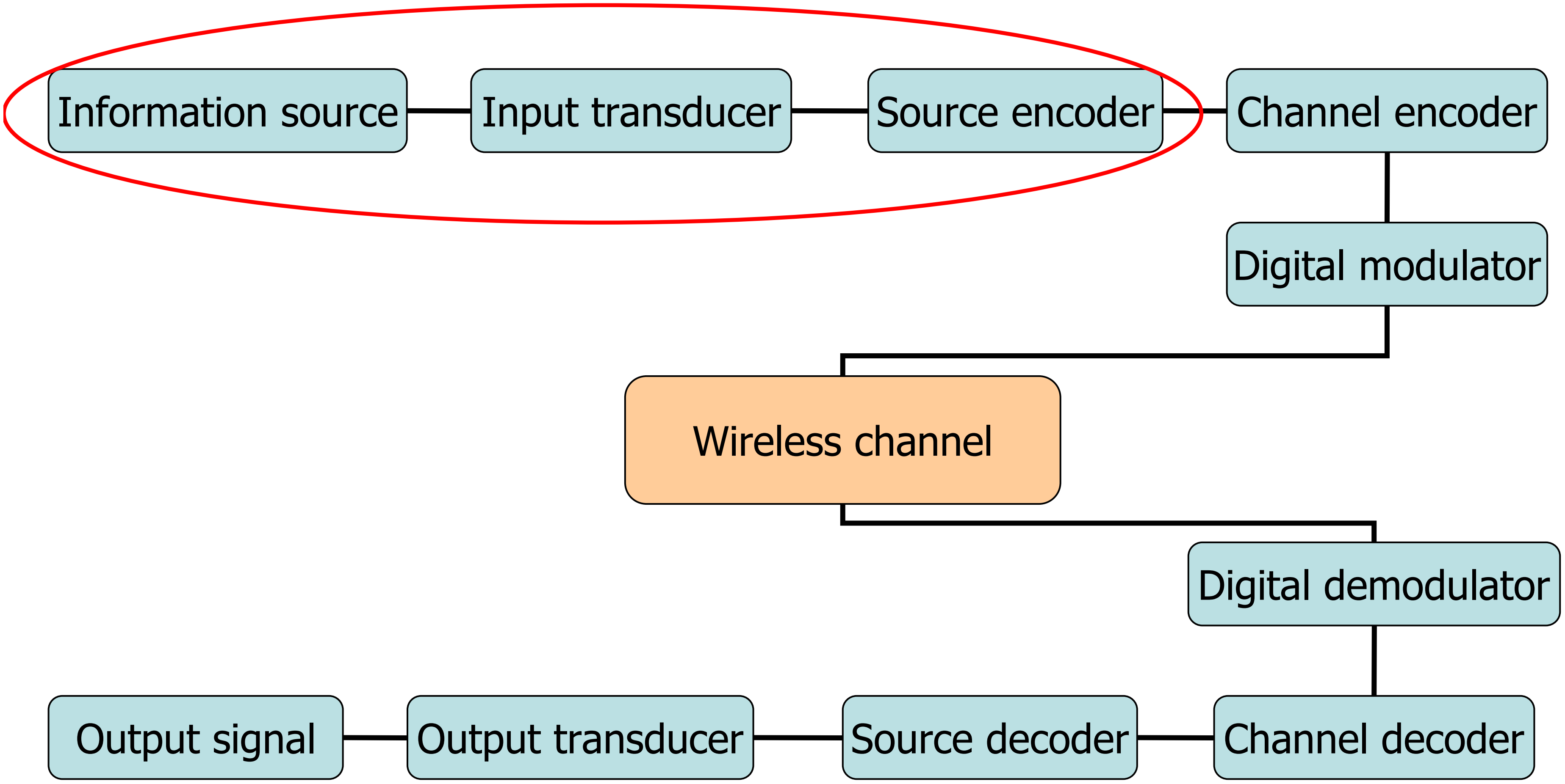
Multiple-Input Multiple-Output

Space Division Multiple Access

Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple access
- Downlink OFDM SDMA
- Conclusions

Elements of a wireless digital communication system



Information source

Input transducer

Source encoder

Channel encoder

Digital modulator

Wireless channel

Digital demodulator

Channel decoder

Source decoder

Output transducer

Output signal

Source coding

- **Mapping** from (a sequence of) symbols from an information source to a sequence of alphabet symbols (usually bits) such that the source symbols can be recovered from the binary bits.

Source image example

Many redundancies

Source coding

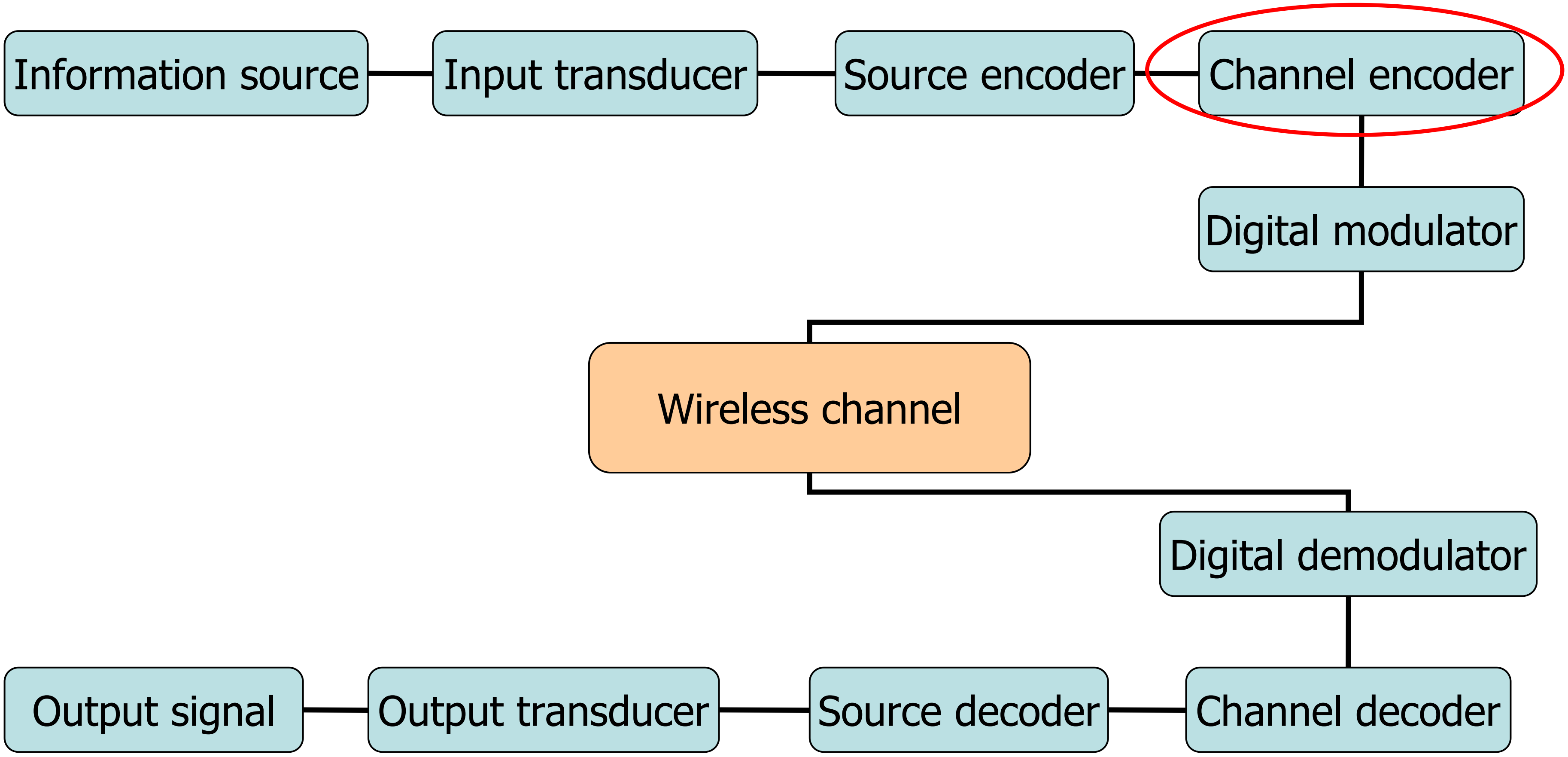
- **Mapping** from (a sequence of) symbols from an information source to a sequence of alphabet symbols (usually bits) such that the source symbols can be recovered from the binary bits.

- **Data compression** : limit the quantity of useless information transmitted by the system.

- Lossy / lossless source codes
- Fixed length / Variable length

- Ex. : JPEG, MPEG, ZIP,…

Elements of a wireless digital communication system



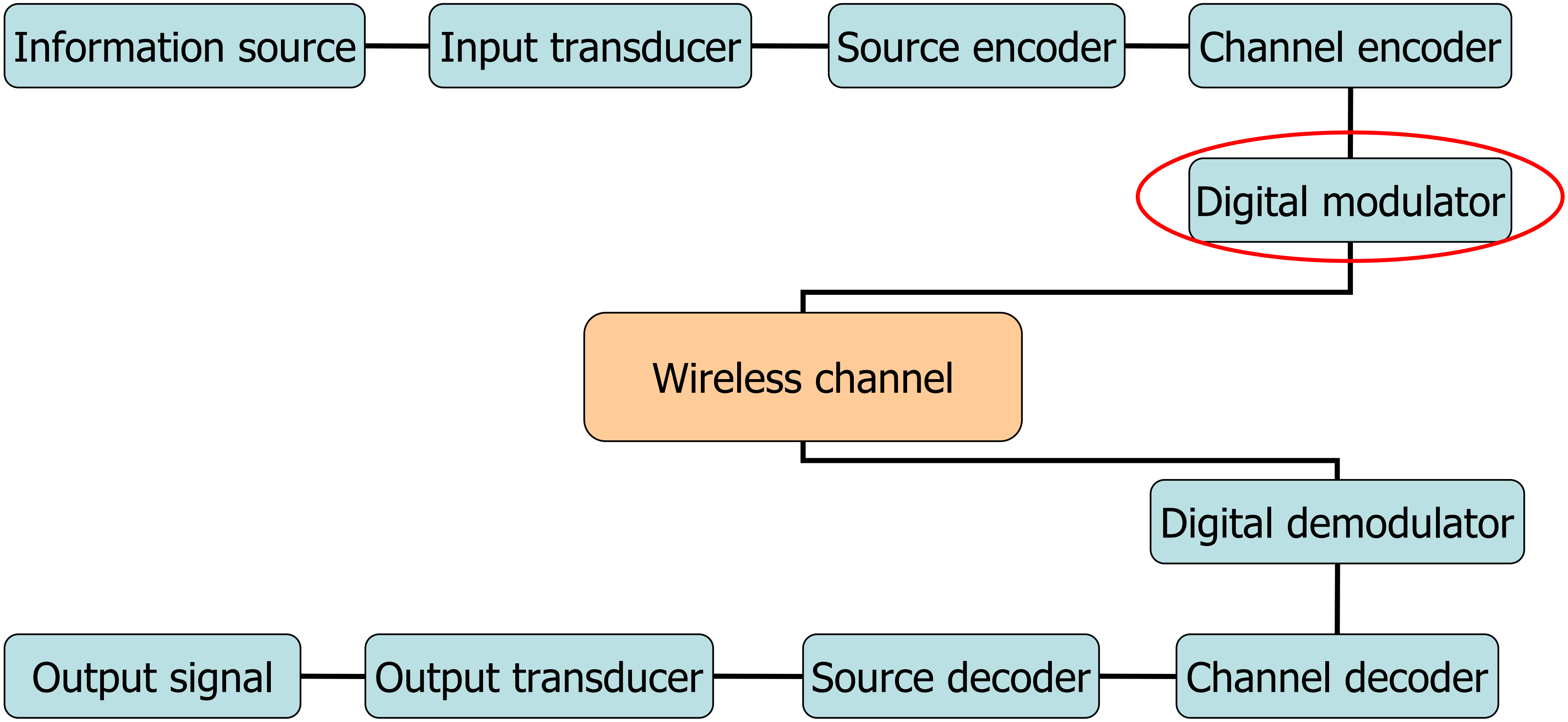
Channel coding

- Reverse of source coding :

  Introducing some *structured* redundancy among the data

- Protect data against errors from channel
- Classical codes : Linear block codes, convolutional codes,…
- "Modern codes " : LDPC codes, turbo codes.

Elements of a wireless digital communication system



Information source

Input transducer

Source encoder

Channel encoder

Digital modulator

Wireless channel

Digital demodulator

Channel decoder

Source decoder

Output transducer

Output signal

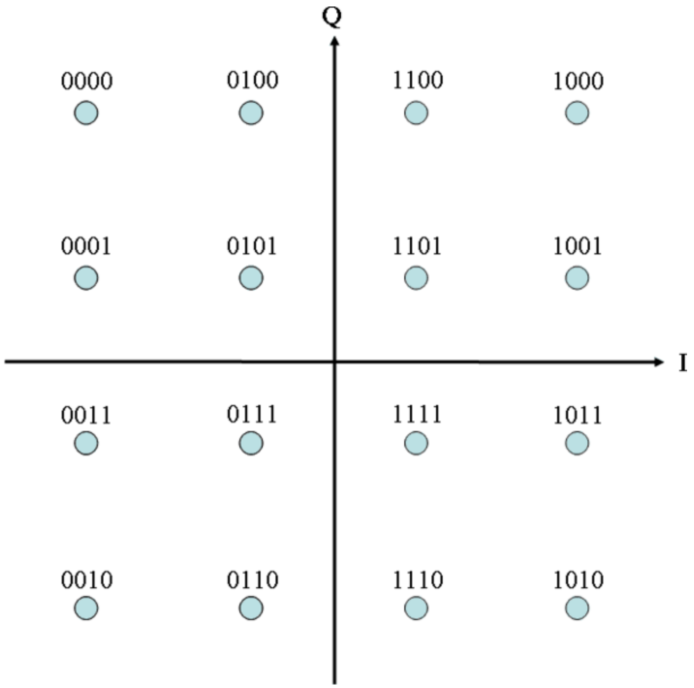
Digital modulation

- The modulator
  - maps discrete vector **x** onto analog waveform,
  - Moves it into transmission band (ex. 2.4Ghz)

- In phase and in quadrature components.

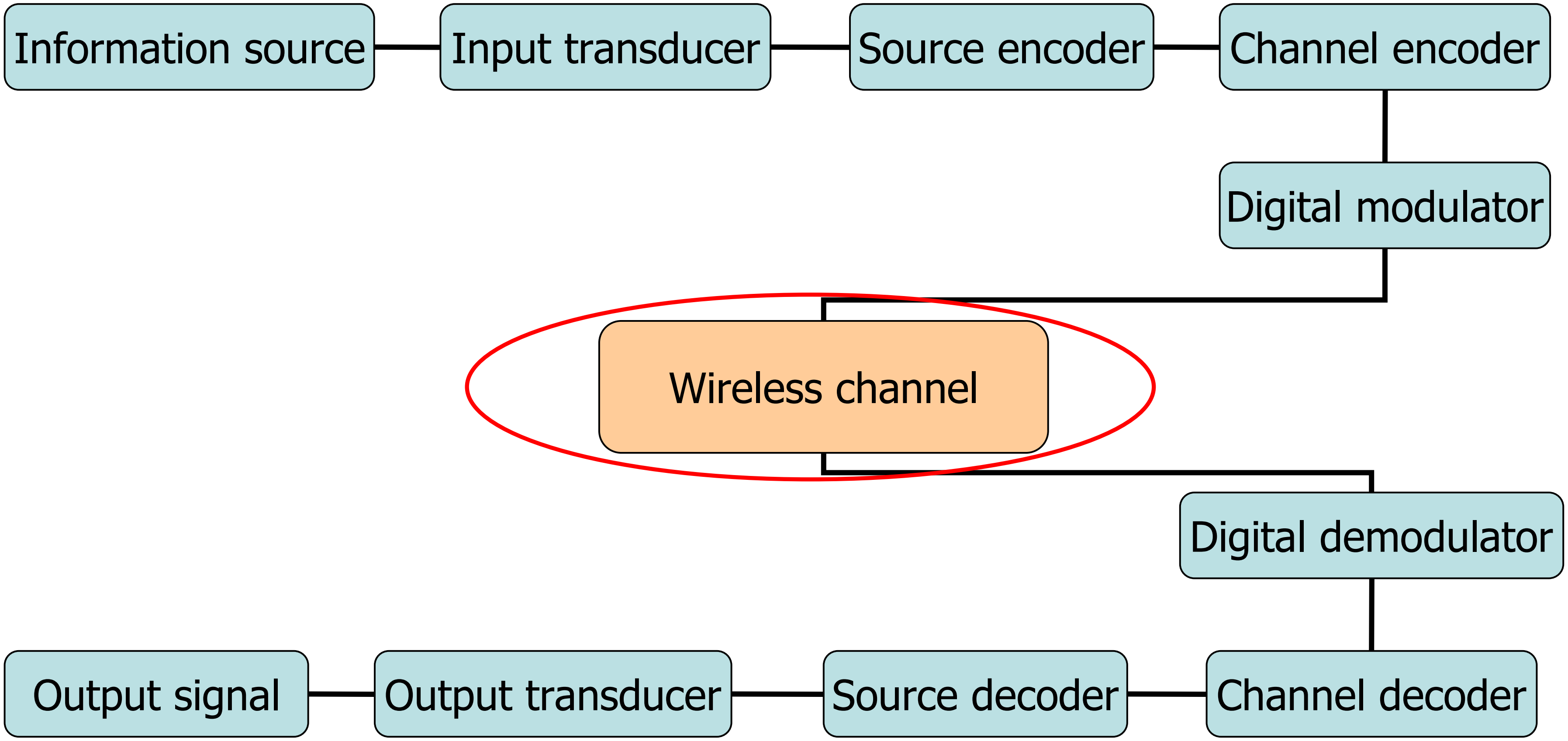
- Model :

$$\hat{s} = g\left(hfs + \nu\right)$$



s : complex symbol from constallation (e.g. 16-QAM)

Elements of a wireless digital communication system



Information source

Input transducer

Source encoder

Channel encoder

Digital modulator

Wireless channel

Digital demodulator

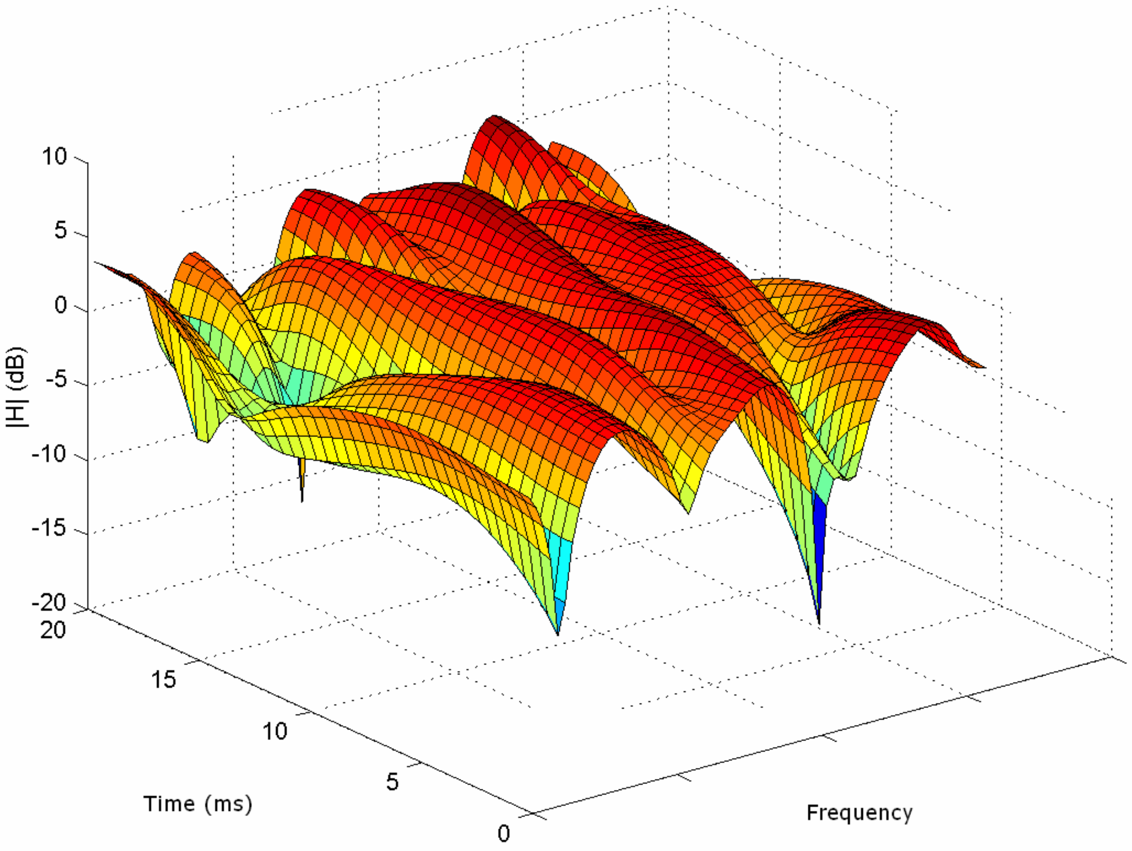
Channel decoder

Source decoder

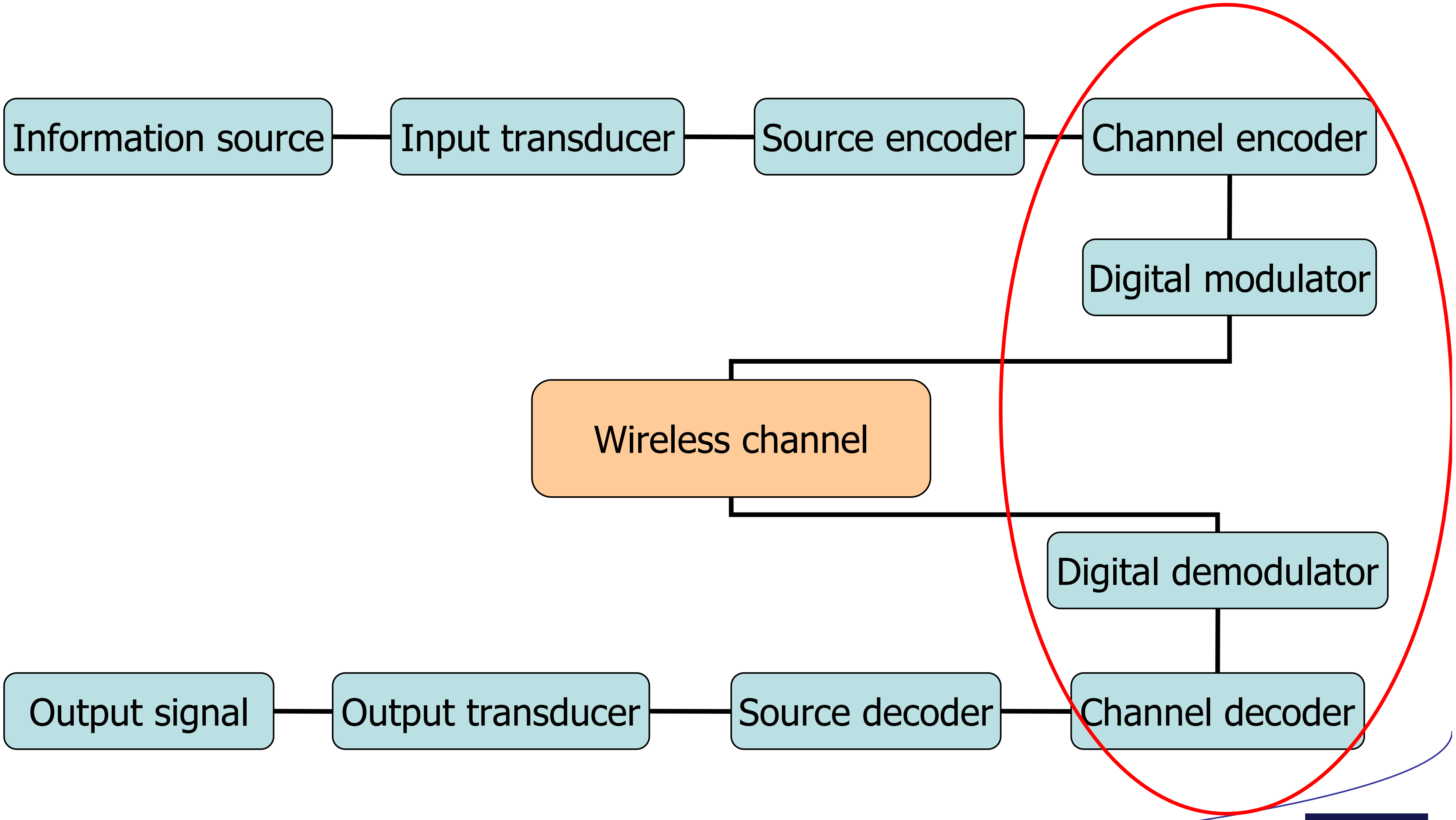
Output transducer

Output signal

Wireless channel



Elements of a wireless digital communication system



Information source

Input transducer

Source encoder

Channel encoder

Digital modulator

Wireless channel

Digital demodulator

Channel decoder

Source decoder

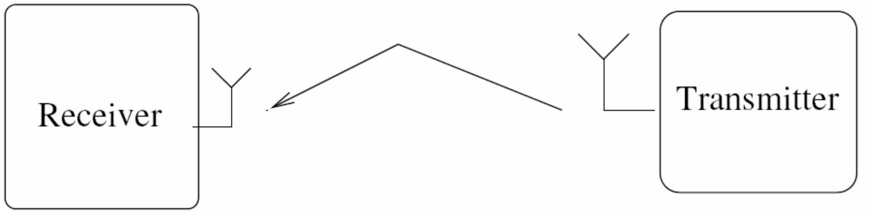
Output transducer

Output signal

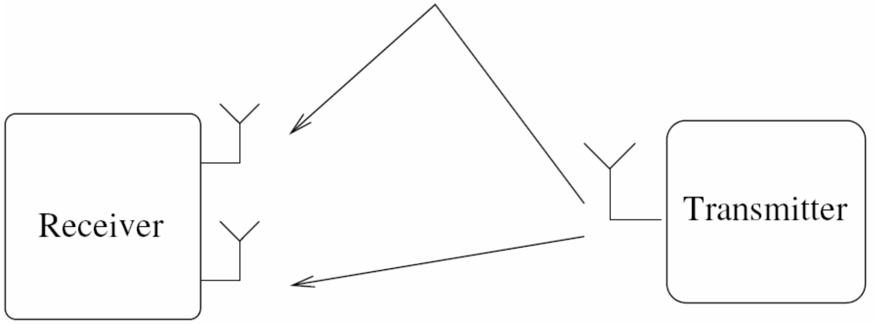
Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple Access
- Downlink OFDM SDMA
- Conclusions

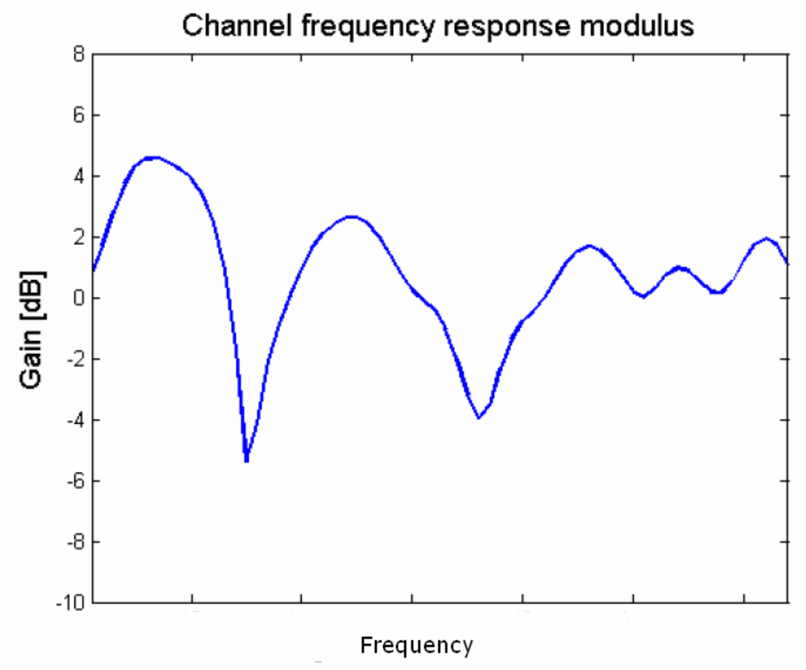
Multiple antenna concept



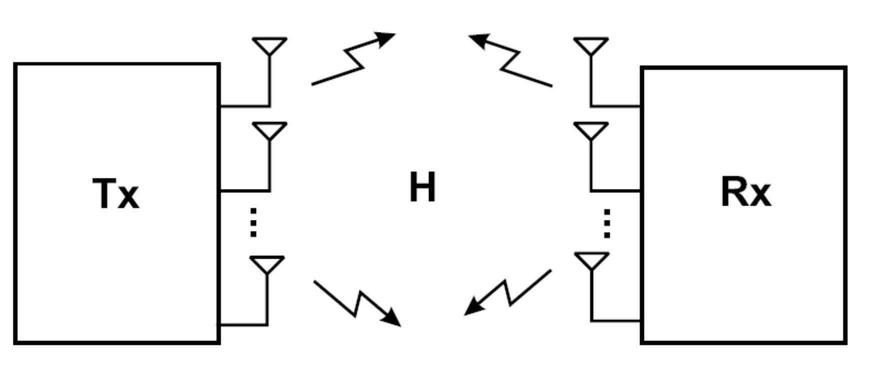
SISO : Single Input Single Output

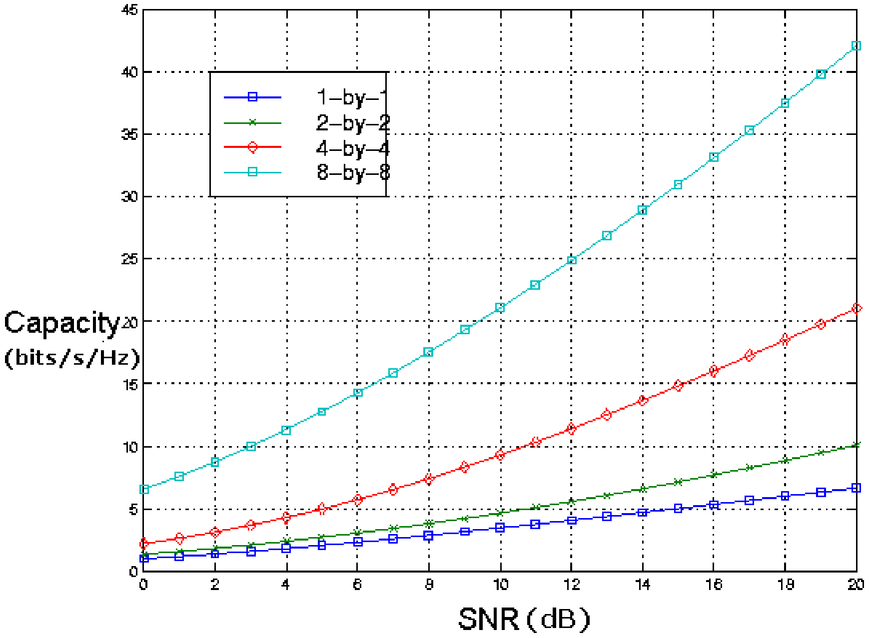


SIMO : Single Input Multiple Output



MIMO : Multiple Input Multiple Output

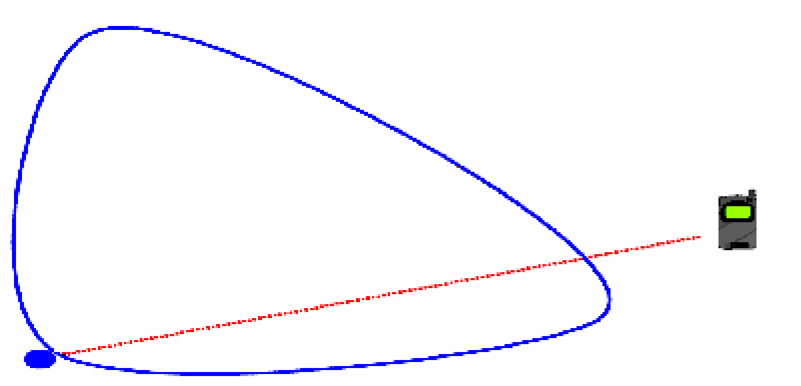




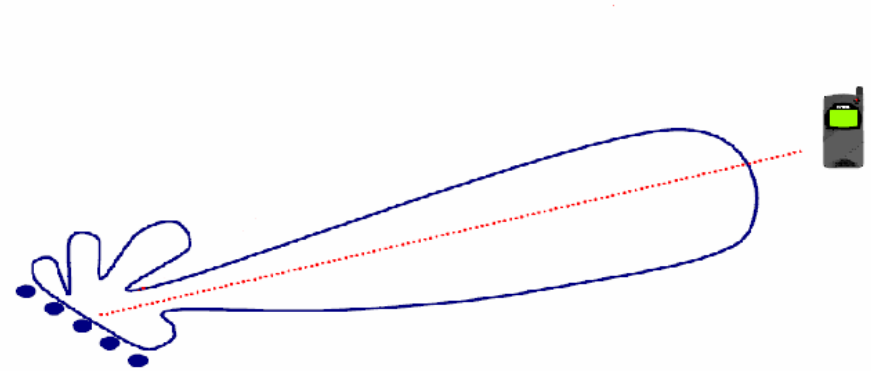
- **Increased received power** (array gain)
- **Diversity:** transmit the signal via several independent diversity branches to get independent signal replicas
- **High probability:** all signals not fade simultaneously.
- **Protection against fading.**
  - Hence, to increase the signal quality
  - Or increase data rates

- Need for rich scattering environnement

Beamforming

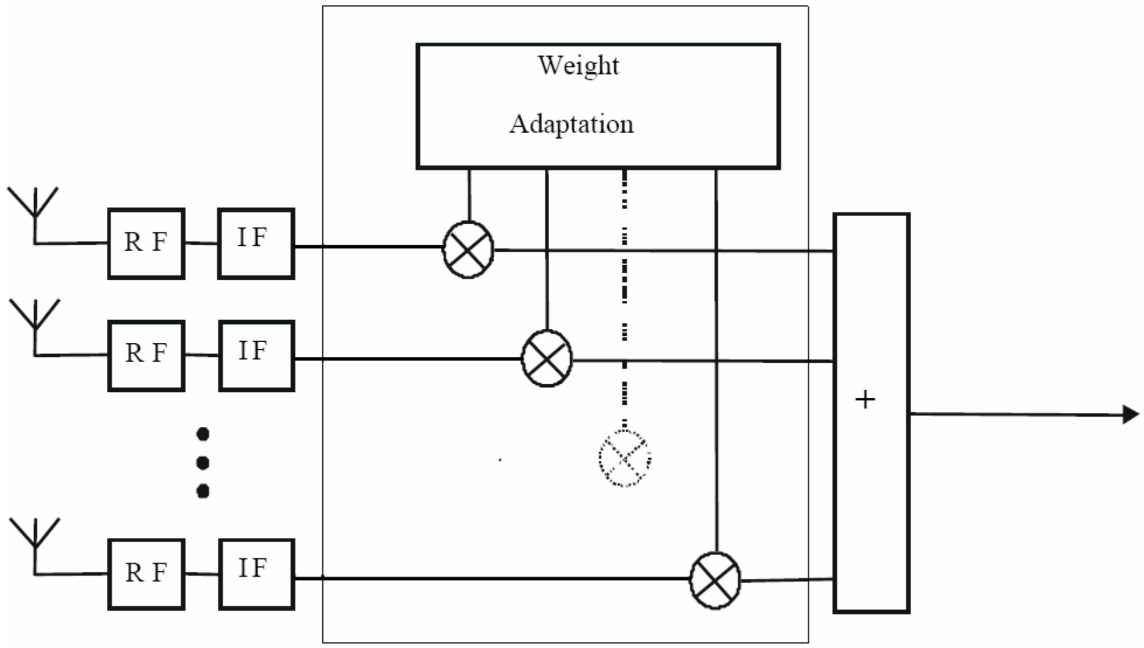


Single omni-directional antenna



Array of omni-directional antennas

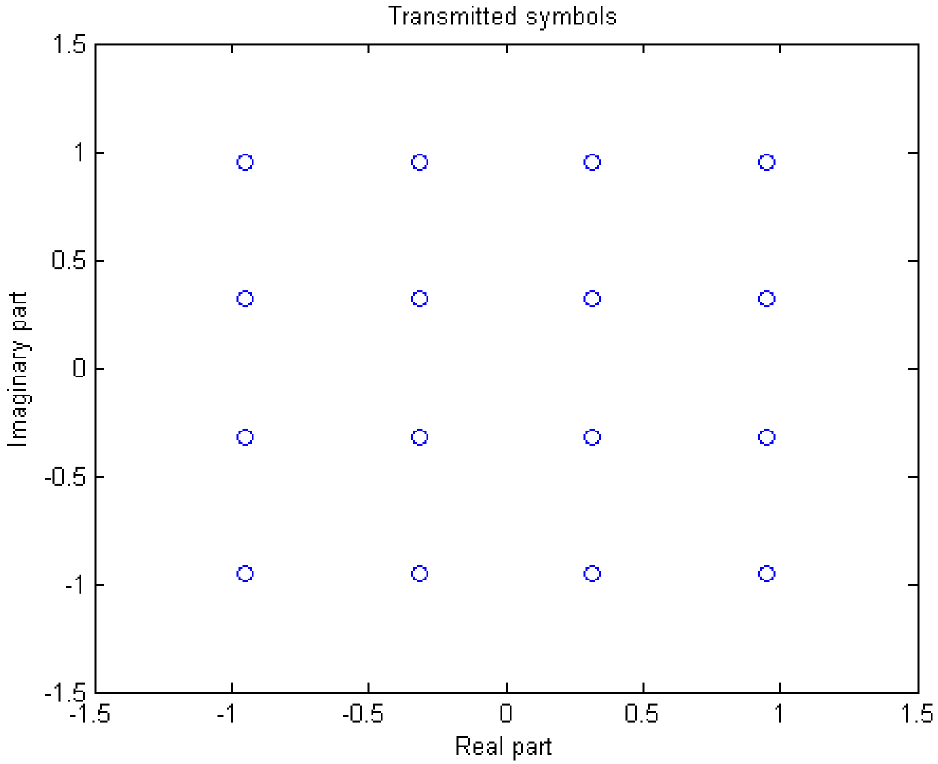
Beamforming



$$\boxed{\hat{s} = G\left[HFs + \nu\right]}$$

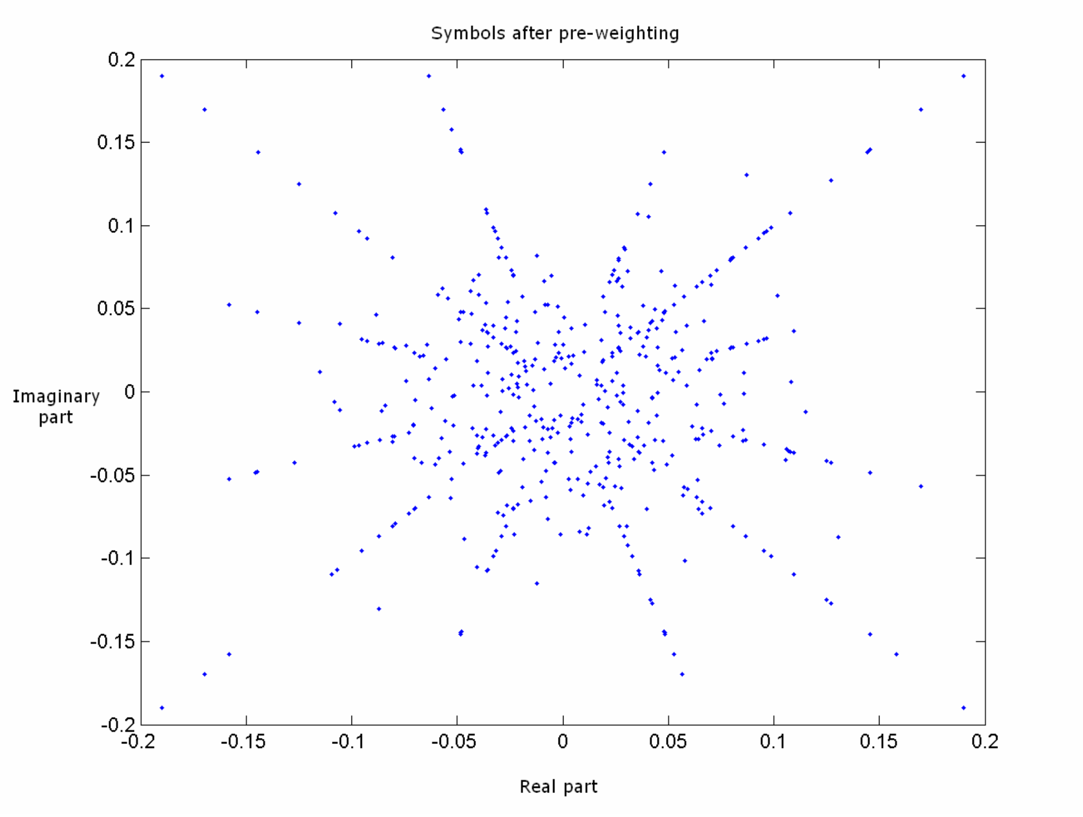
$$(L \times 1) = (L \times N_r)[(N_r \times N_t)(N_t \times L)(L \times 1) + (N_r \times 1)]$$

Beamforming illustration (1/4)



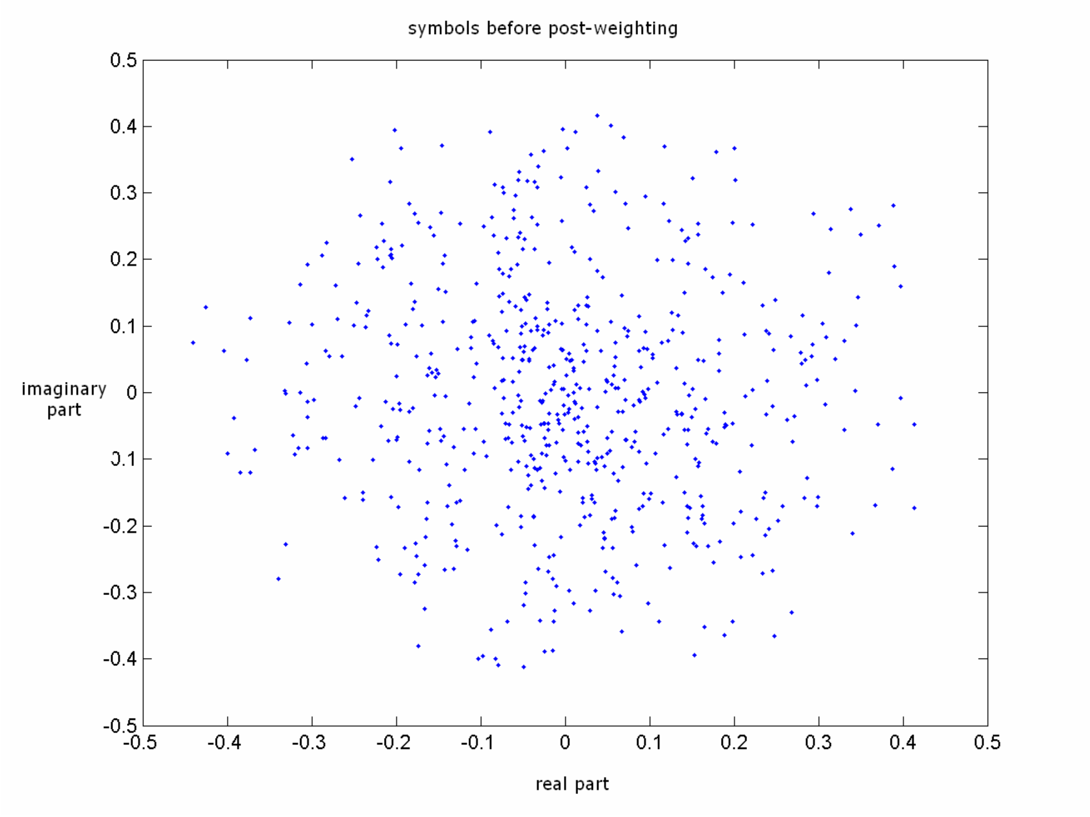
$$\hat{s} = G\left[HF\boxed{s} + \nu\right]$$

Beamforming illustration (2/4)



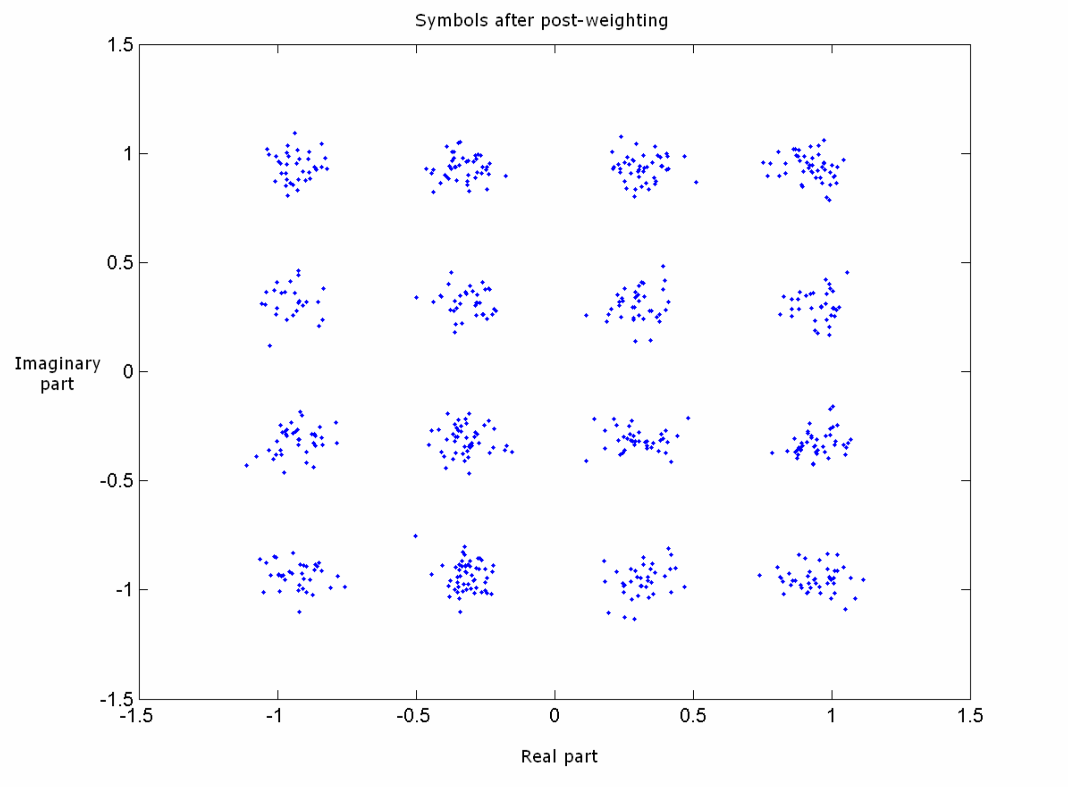
$$\hat{s} = G\left[H\boxed{F s} + \nu\right]$$

Beamforming illustration (3/4)



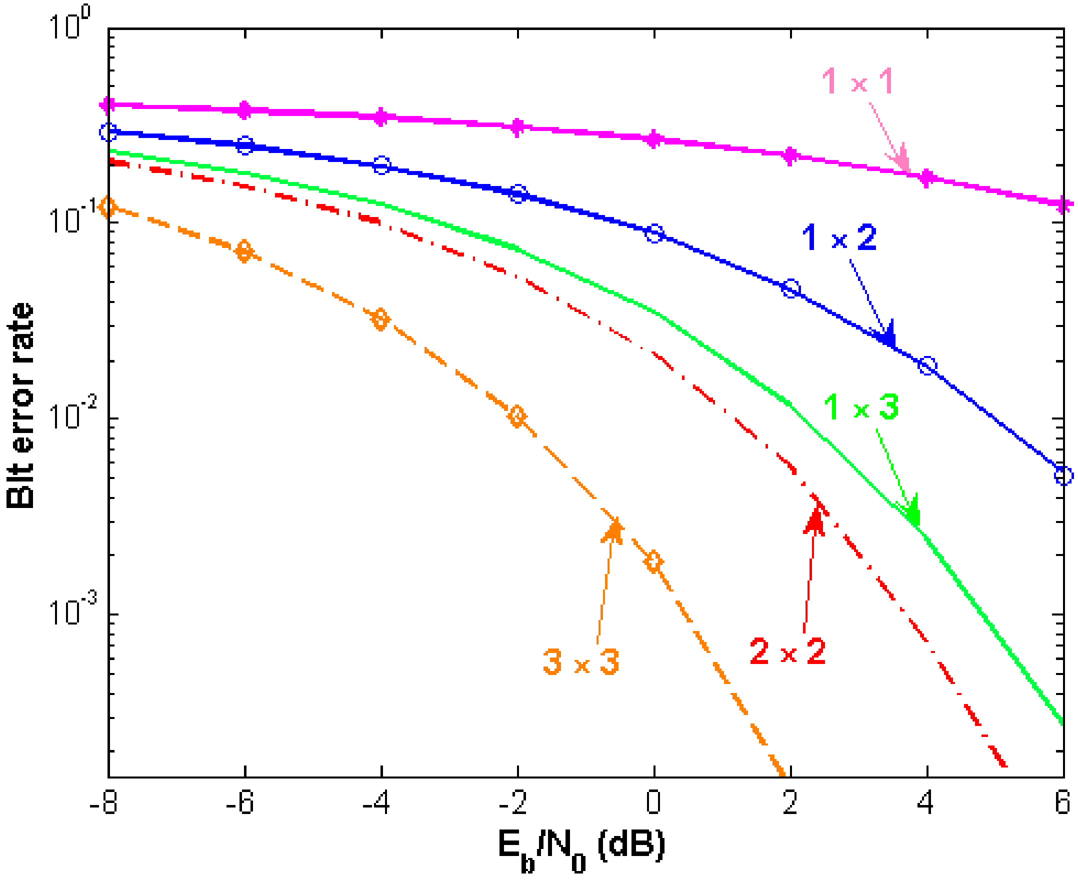
$$\hat{s} = G\boxed{[HFs + \nu]}$$

Beamforming illustration (4/4)



$$\hat{s} = G\left[HFs + \nu\right]$$

Beamforming – spatial diversity

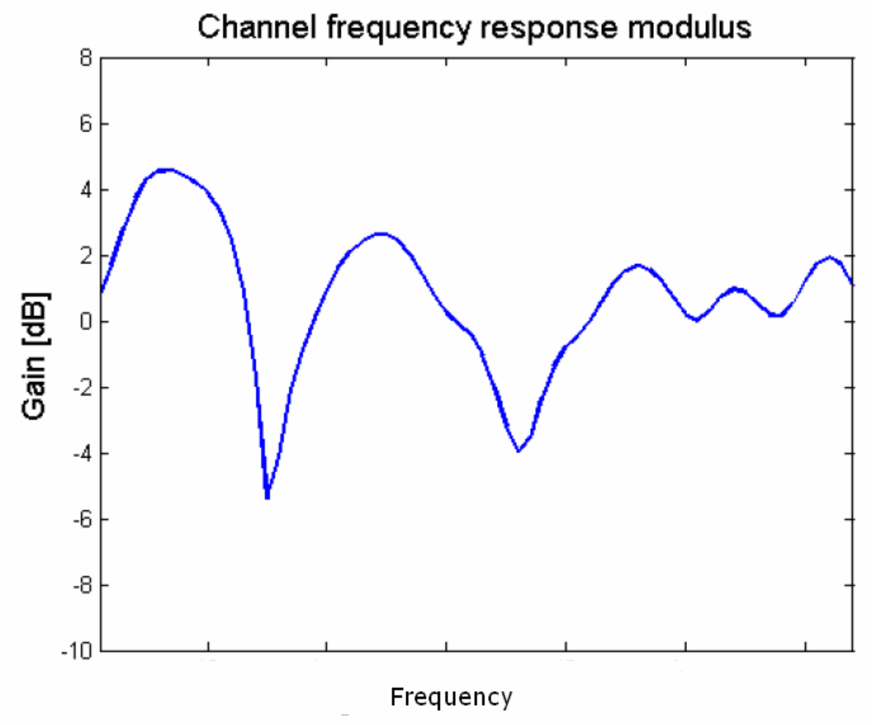


Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple Access
- Downlink OFDM SDMA
- Conclusions

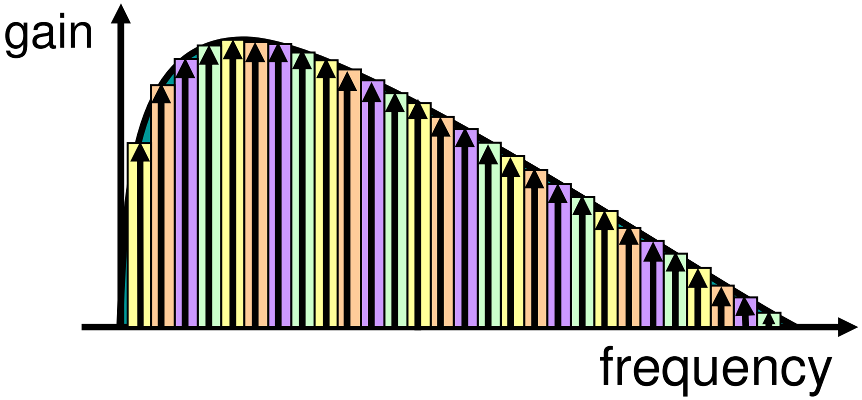
Frequency selectivity

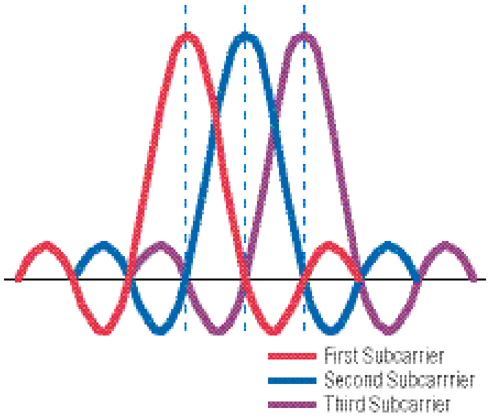
- Broadband channels are frequency selective :



Multicarrier modulation

OFDM : Orthogonal Frequency Division Multiplexing





→ $$\hat{s}_n = G_n(H_n F_n s_n + v_n) \qquad \forall n \in [1, N]$$

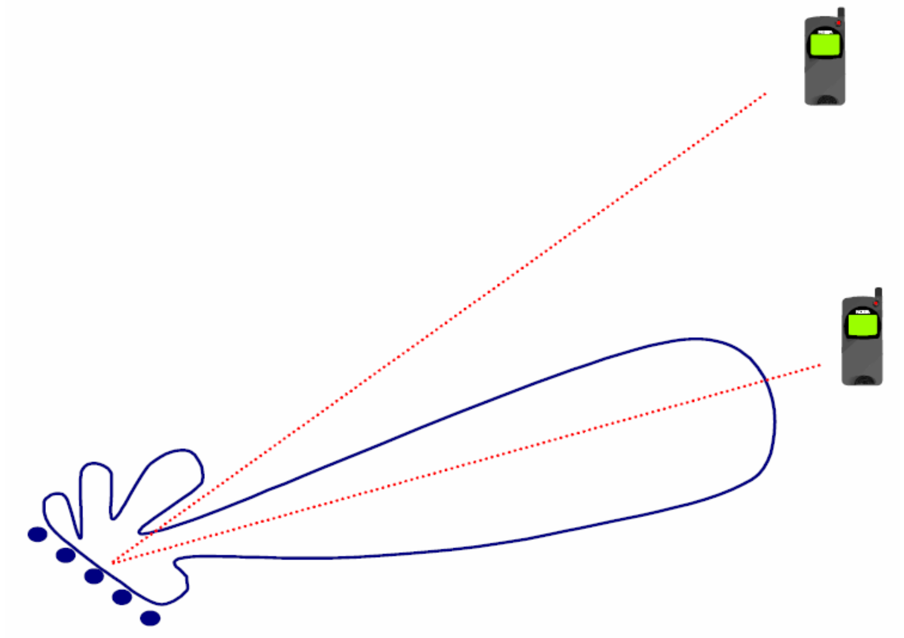
N flat fading channels

Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple Access
- Downlink OFDM SDMA
- Conclusions

Space Division Multiple Access

- Use beamforming to separate the users which transmit at :
  - The same time
  - The same frequency

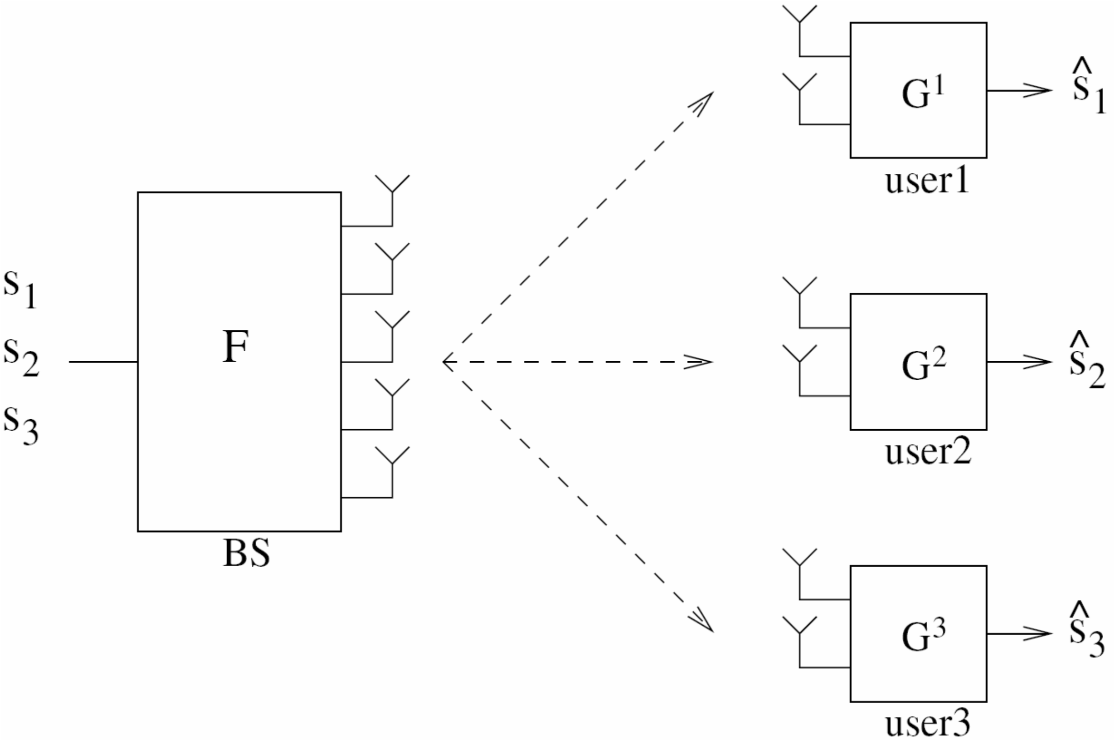


$$\hat{s}_n^u = G_n^u \left(H_n^u \sum_{j=1}^{U} F_n^j s_n^j + v_n^u \right)$$

Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple Access
- Downlink OFDM SDMA
- Conclusions

System model



$$\hat{s}_n^u = G_n^u \left(H_n^u \sum_{j=1}^{U} F_n^j s_n^j + v_n^u \right) \qquad \begin{cases} 1 \leq n \leq N \\ 1 \leq u \leq U \end{cases}$$

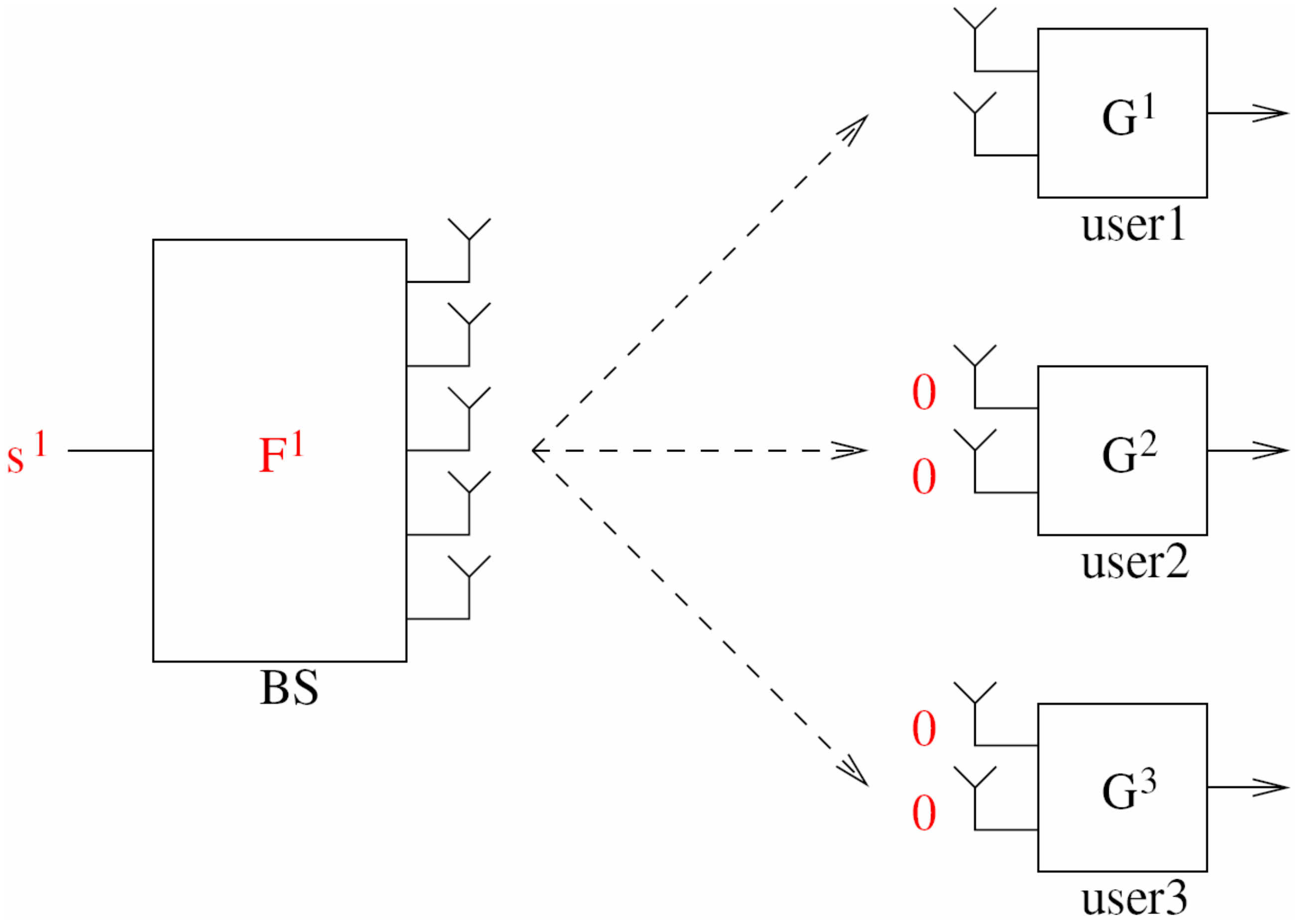
Goal / Assumptions

- Design linear pre/decoder to optimize signal quality with :
  - rate constraints
  - transmit power constraint :

$$\sum_{u=1}^{U} \sum_{n=1}^{N} \mathrm{tr}\left(F_n^u F_n^{u\dagger}\right) \leq P_t$$

- Perfect channel knowledge
- First idea : come back to single user solutions

Pre-decoder orthogonal design (Ortho1)



Ortho1 : Nulling constraints

$$\begin{pmatrix} \hat{s}^1 \\ \hat{s}^2 \\ \vdots \\ \hat{s}^U \end{pmatrix} = \begin{pmatrix} G^1 & & & 0 \\ & G^2 & & \\ & & \dots & \\ 0 & & & G^U \end{pmatrix} \begin{pmatrix} H^1 \\ H^2 \\ \vdots \\ H^U \end{pmatrix} \begin{pmatrix} F^1 & F^2 & \dots & F^U \end{pmatrix} \begin{pmatrix} s^1 \\ s^2 \\ \vdots \\ s^U \end{pmatrix}$$

$$\underline{H}^u F^u = (0) \qquad \equiv \qquad F^u \in \text{null}\{\underline{H}^u\} \qquad \forall u$$

ex. 3-user system :

$$\begin{bmatrix} H^2 \\ H^3 \end{bmatrix} F^1 = 0, \qquad \begin{bmatrix} H^1 \\ H^3 \end{bmatrix} F^2 = 0, \qquad \begin{bmatrix} H^1 \\ H^2 \end{bmatrix} F^3 = 0$$

Ortho1 : Nulling constraints

$$\begin{pmatrix} \hat{s}^1 \\ \hat{s}^2 \\ \vdots \\ \hat{s}^U \end{pmatrix} = \begin{pmatrix} G^1 & & & 0 \\ & G^2 & & \\ & & \dots & \\ 0 & & & G^U \end{pmatrix} \begin{pmatrix} H^1 \\ H^2 \\ \vdots \\ H^U \end{pmatrix} (F_A^1 \; F_A^2 \; \dots \; F_A^U) \begin{pmatrix} F_B^1 & & & 0 \\ & F_B^2 & & \\ & & \dots & \\ 0 & & & F_B^U \end{pmatrix} \begin{pmatrix} s^1 \\ s^2 \\ \vdots \\ s^U \end{pmatrix}$$

$$\underline{H}^u F_A^u = (0) \qquad \equiv \qquad F_A^u \quad \text{basis} \quad \text{of} \quad \text{null}\{\underline{H}^u\} \qquad \forall u$$

$$\boxed{H^u \longrightarrow H^u F_A^u}$$

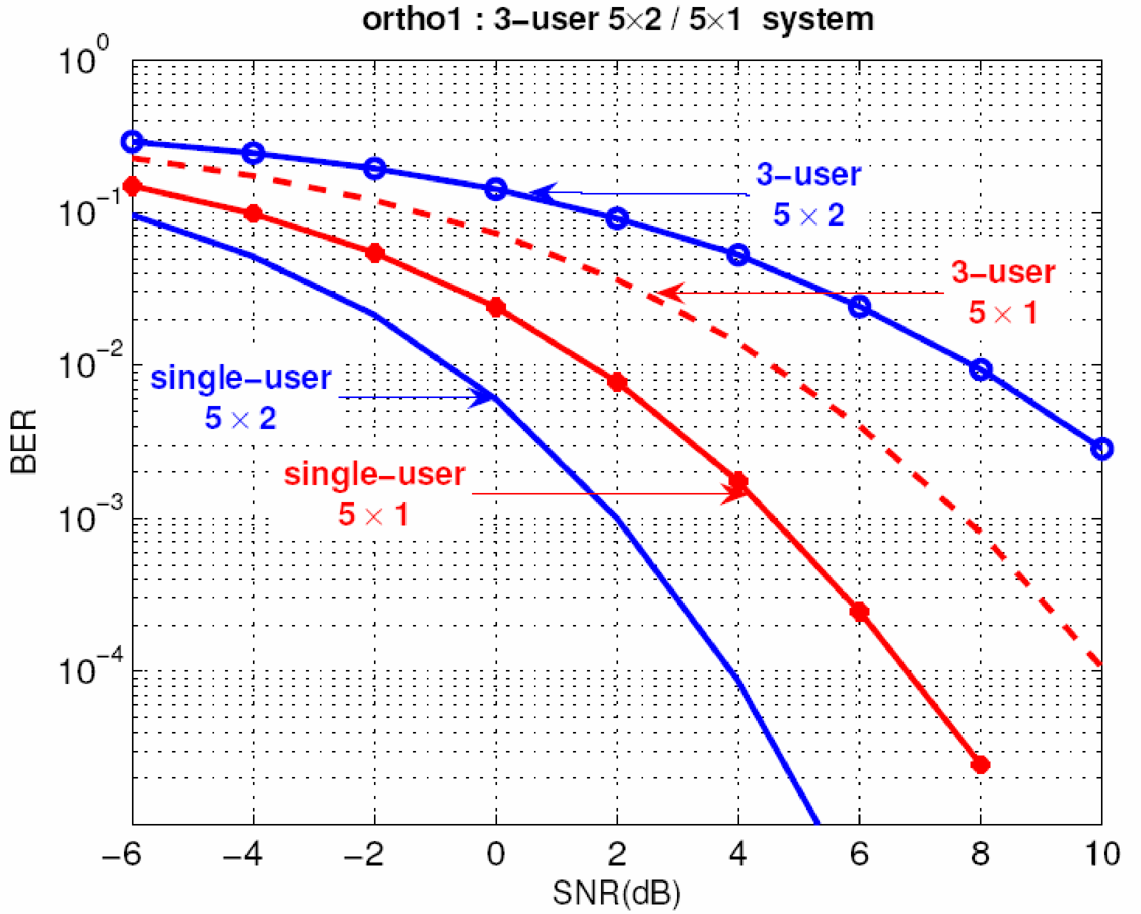
Ortho1 : Availability conditions

$$\forall n, u \quad \begin{cases} N_s^u \leq N_r^u \\ N_s^u \leq N_t - \sum_{j \neq u} N_r^j \end{cases}$$

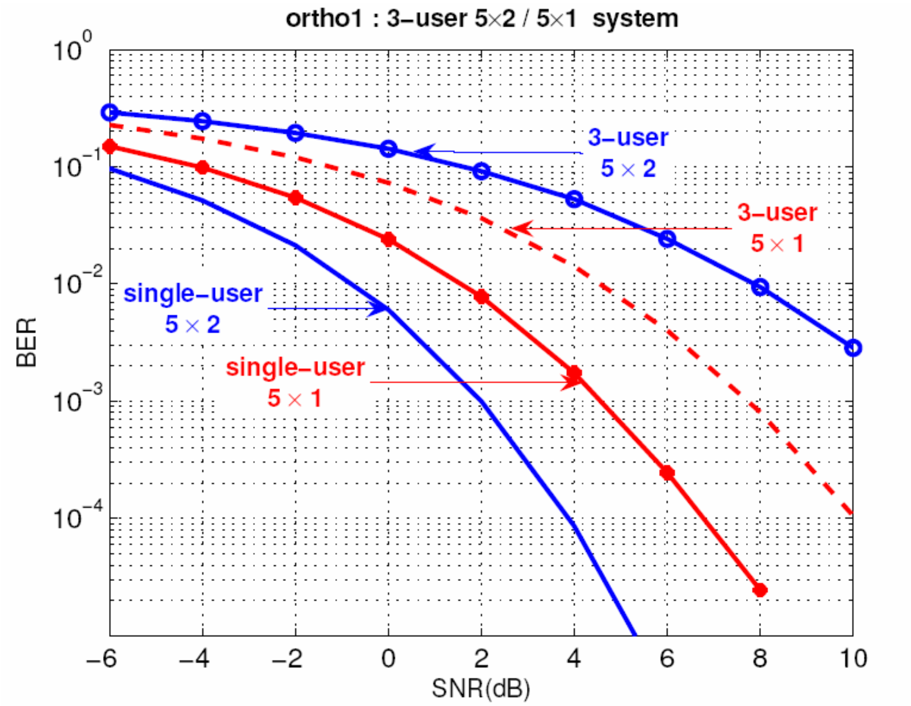
Ex. for single beamforming (N_s=1) :

	N_r=1	N_r=2	N_r=3
N_t=3	3 users	2 users	1 user
N_t=4	4 users	2 users	2 users
N_t=5	5 users	3 users	2 users

Ortho1 : Simulations

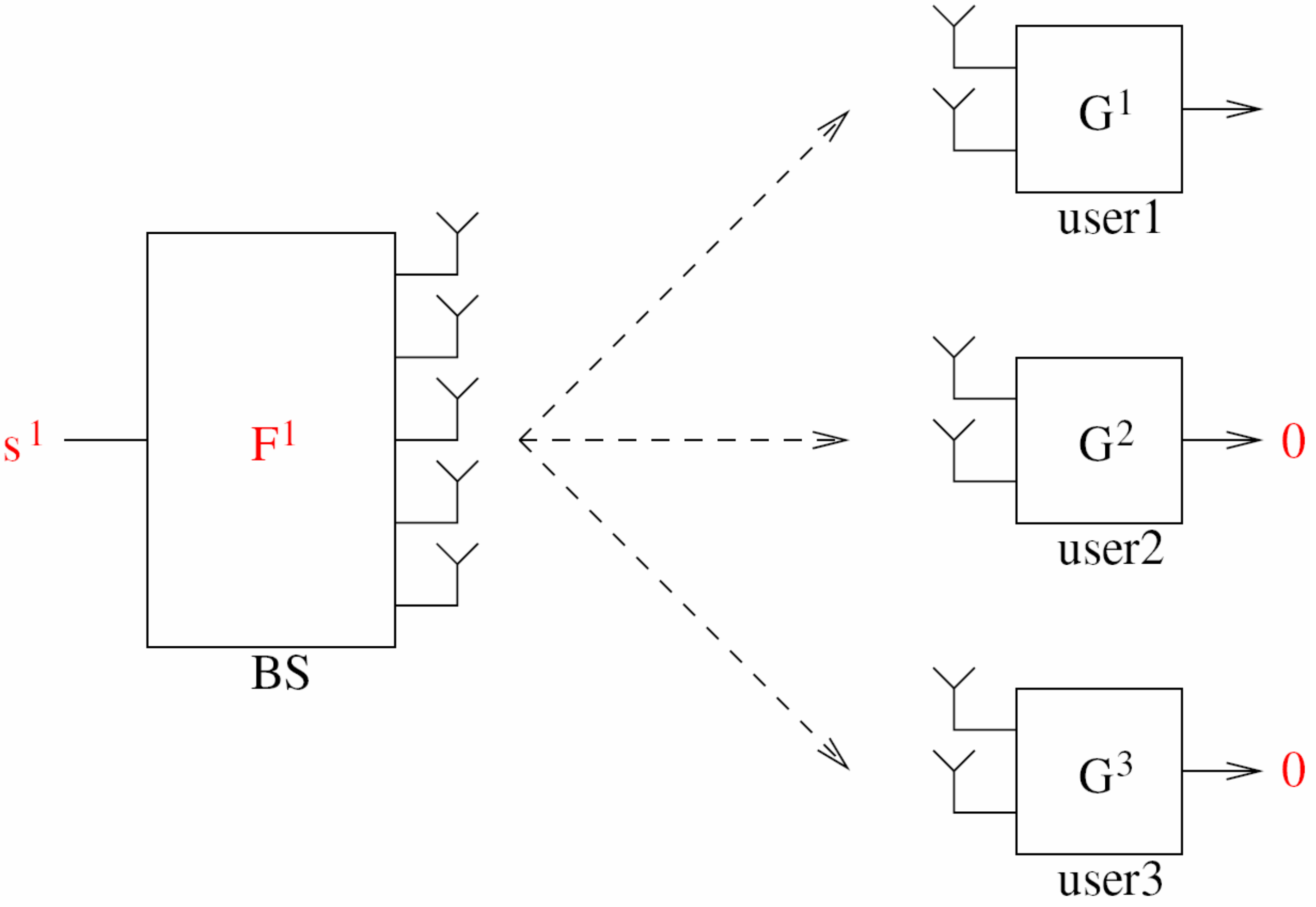


Ortho1 : Simulations



Pre-ortho	Post-ortho
(5x2)	(1x2)
(5x1)	(3x1)

Post-decoder orthogonal design (Ortho2)



Ortho2 : nulling constraints

- Idea : same as *Ortho1* with enhanced channel :

$$\Theta_n^u = G_n^u H_n^u$$

- However, optima receivers *G* :

$$G_n^u = F_n^{u\dagger} H_n^{u\dagger} \left[\sigma_n^{u2} I + \sum_{j=1}^{U} H_n^u F_n^j F_n^{j\dagger} H_n^{u\dagger} \right]^{-1}$$

Ortho2 : iterative algorithm

√ 1. choose random $G's$

√ 2. compute F'_As given $G's$

√ 3. compute $G's$ (MU-MMSE) and F'_Bs given F'_As

√ 4. go to step 2 until convergence

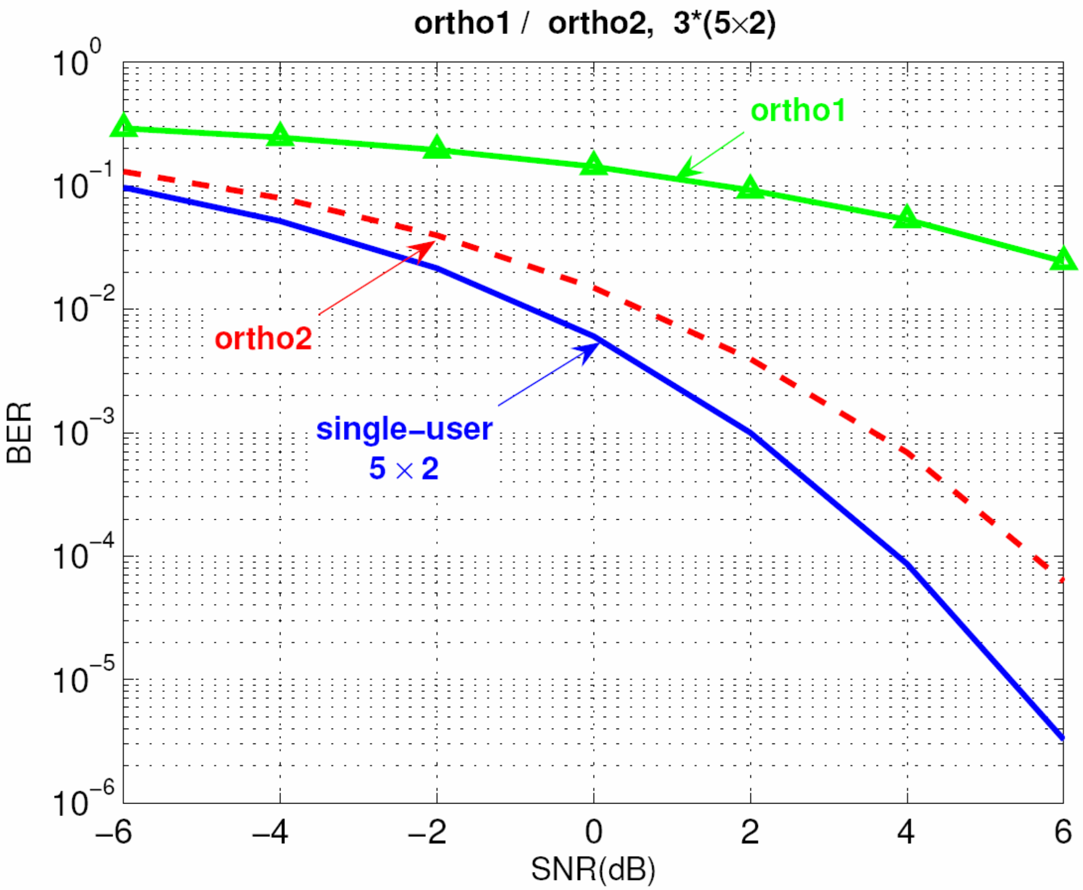
Ortho2 : Availability conditions

$$\begin{cases} N_s^u \leq N_r^u \\ N_s^u \leq N_t - \sum_{j \neq u} N_s^j \end{cases} \qquad \forall u, n$$

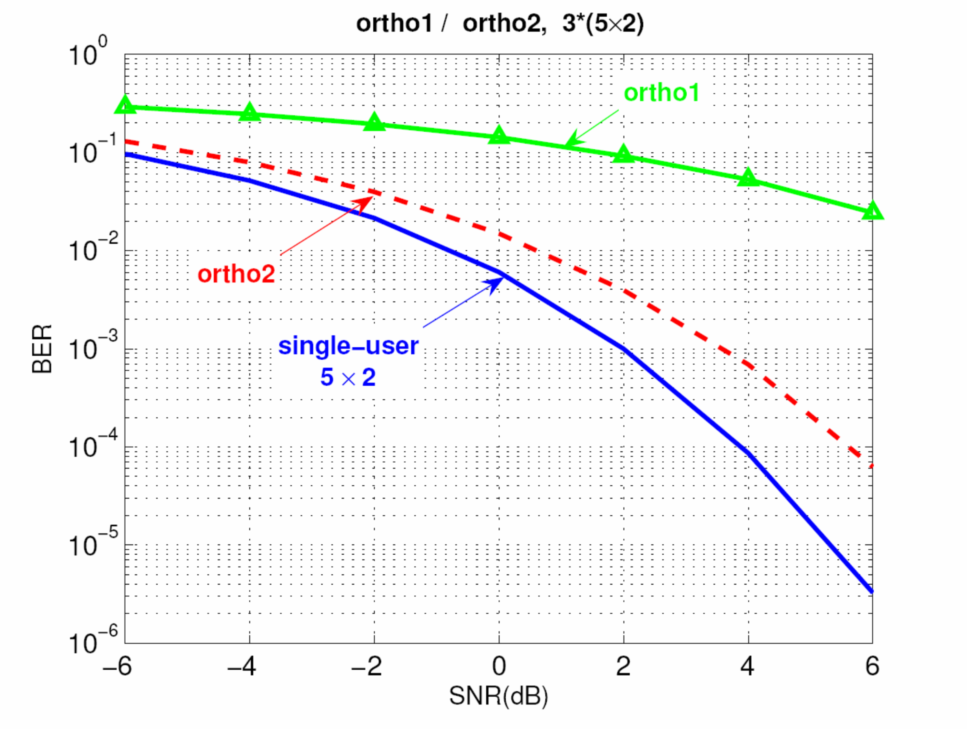
Ex. for single beamforming (N_s=1) :

	N_r=1,2,3,4,. . .
N_t=3	3 users
N_t=4	4 users
N_t=5	5 users

Ortho2 : simulations



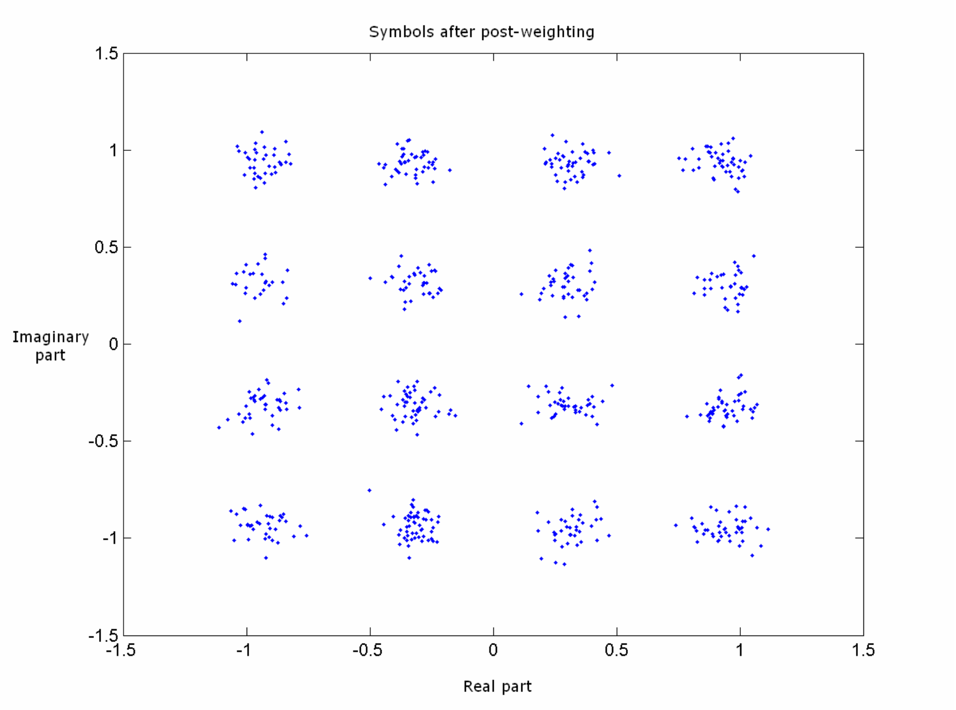
Ortho2 : simulations



	Pre-ortho	Post-ortho
Ortho1	(5x2)	(1x2)
Ortho2	(5x2)	(3x2)

Min-MSE design

MSE : Mean Square Error



$$E_n^u = G_n^u \left(H_n^u \sum_{j=1}^{U} F_n^j s_n^j + v_n^u \right) - s_n^u$$

$$MSE_n^u = E\left\{ \mathrm{tr}\left\{ E_n^u E_n^{u\dagger} \right\} \right\}$$

Min-MSE design

$$\min_{F,G} \quad MSE = \sum_{u=1}^{U} \sum_{n=1}^{N} MSE_n^u$$

$$\text{s.t.} \quad \sum_{u=1}^{U} \sum_{n=1}^{N} \operatorname{tr}\left(F_n^u F_n^{u\dagger}\right) \leq P_t$$

- $\surd$ for given G, F optimization is convex
- $\surd$ for given F, G optimization is convex

- $\surd$ joint F, G optimization is *non convex*

Min-MSE design

$$L = \sum_{u=1}^{U} \sum_{n=1}^{N} MSE_n^u + \mu \left(\sum_{u=1}^{U} \sum_{n=1}^{N} \mathrm{tr} \left\{ F_n^u F_n^{u\dagger} \right\} - P_t \right)$$

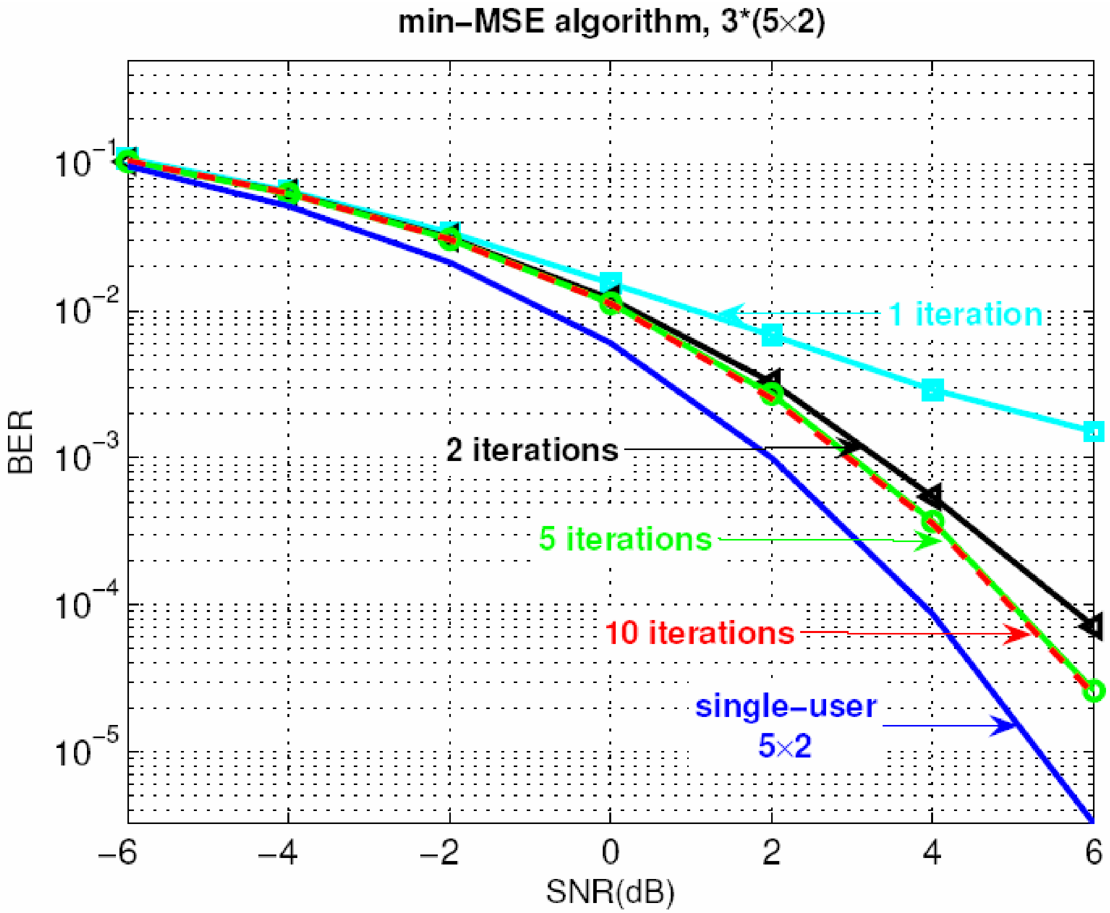
$$G_n^u = F_n^{u\dagger} H_n^{u\dagger} \left[\sigma_n^{u2} I + \sum_{j=1}^{U} H_n^u F_n^j F_n^{j\dagger} H_n^{u\dagger} \right]^{-1}$$

$$F_n^u = \left(\mu I + \sum_{j=1}^{U} H_n^{j\dagger} G_n^{j\dagger} G_n^j H_n^j \right)^{-1} H_n^{u\dagger} G_n^{u\dagger}$$

Min-MSE design : iterative algorithm

- ✓ 1. init all G_n^u with single-user solution
- ✓ 2. compute all F_u^n with μ satisfying power constraint
- ✓ 3. compute all G_n^u
- ✓ 4. go to step 2 until convergence

Min-MSE design : simulations



Max-min-SINR design - preliminaries

- Assume flat fading channels (*N=1*)
- Split beamforming design and power allocation :

$$\hat{\boldsymbol{s}}_u = \boldsymbol{G}_u \left[\boldsymbol{H}_u \boldsymbol{F}_u \sqrt{\boldsymbol{P}_u} \boldsymbol{s}_u + \boldsymbol{H}_u \sum_{j \neq u} \boldsymbol{F}_j \sqrt{\boldsymbol{P}_j} \boldsymbol{s}_j + \boldsymbol{\nu}_u \right]$$

$$\begin{cases} \operatorname{trace}\left\{ \boldsymbol{f}_{ul} \boldsymbol{f}_{ul}{}^{\dagger} \right\} = 1 \\ \sqrt{P_u} = diag\left\{ \sqrt{p_{u1}}, \sqrt{p_{u1}}, \ldots, \sqrt{p_{uL_u}} \right\} \end{cases}$$

Max-min-SINR design

SINR : Signal to Interference and Noise Ratio

$$\hat{\boldsymbol{s}}_u = \boldsymbol{G}_u \left[\boldsymbol{H}_u \boldsymbol{F}_u \sqrt{\boldsymbol{P}_u} \boldsymbol{s}_u + \boldsymbol{H}_u \sum_{j \neq u} \boldsymbol{F}_j \sqrt{\boldsymbol{P}_j} \boldsymbol{s}_j + \boldsymbol{\nu}_u \right]$$

$$SINR_{ul}^{DL} = \frac{\boldsymbol{g}_{ul} \boldsymbol{H}_u p_{ul} \boldsymbol{f}_{ul} \boldsymbol{f}_{ul}^{\dagger} \boldsymbol{H}_u^{\dagger} \boldsymbol{g}_{ul}^{\dagger}}{\boldsymbol{g}_{ul} \boldsymbol{R}_{\underline{ul}}^{DL} \boldsymbol{g}_{ul}^{\dagger}}$$

$$\boldsymbol{R}_{\underline{ul}}^{DL} = \sigma_u^2 \boldsymbol{I} + \boldsymbol{H}_u \left[\sum_{j=1}^{U} \sum_{\substack{m=1 \\ (j,m) \neq (u,l)}}^{L(j)} p_{jm} \boldsymbol{f}_{jm} \boldsymbol{f}_{jm}^{\dagger} \right] \boldsymbol{H}_u^{\dagger}$$

Max-min-SINR design

$$\max_{F,G} \min_{u,l} \quad SINR_{ul}$$

$$\text{s.t.} \quad \sum_{u=1}^{U} trace\left\{P^u\right\} \leq P_t$$

$$\boxed{\rightarrow SINR_{ul} = C \quad \forall u, l}$$

Max-min-SINR design

- *Optimal receive beamformers for given p,F :*

$$SINR_{ul}^{DL} = \frac{\boldsymbol{g}_{ul}\boldsymbol{H}_u p_{ul}\boldsymbol{f}_{ul}\boldsymbol{f}_{ul}^{\dagger}\boldsymbol{H}_u^{\dagger}\boldsymbol{g}_{ul}^{\dagger}}{\boldsymbol{g}_{ul}\boldsymbol{R}_{\underline{ul}}^{DL}\boldsymbol{g}_{ul}^{\dagger}}$$

$$\boldsymbol{R}_{\underline{ul}}^{DL} = \sigma_u^2\boldsymbol{I} + \boldsymbol{H}_u\left[\sum_{\substack{j=1 \\ (j,m)\neq(u,l)}}^{U}\sum_{m=1}^{L(j)} p_{jm}\boldsymbol{f}_{jm}\boldsymbol{f}_{jm}^{\dagger}\right]\boldsymbol{H}_u^{\dagger}$$

$$\boxed{\forall u,l,\quad \boldsymbol{g}_{ul} := \left(\text{max eigvect. of }\left(\boldsymbol{H}_u p_{ul}\boldsymbol{f}_{ul}\boldsymbol{f}_{ul}^{\dagger}\boldsymbol{H}_u^{\dagger}\,,\ \boldsymbol{R}_{\underline{ul}}^{DL}\right)\right)^{\dagger}}$$

Max-min-SINR design

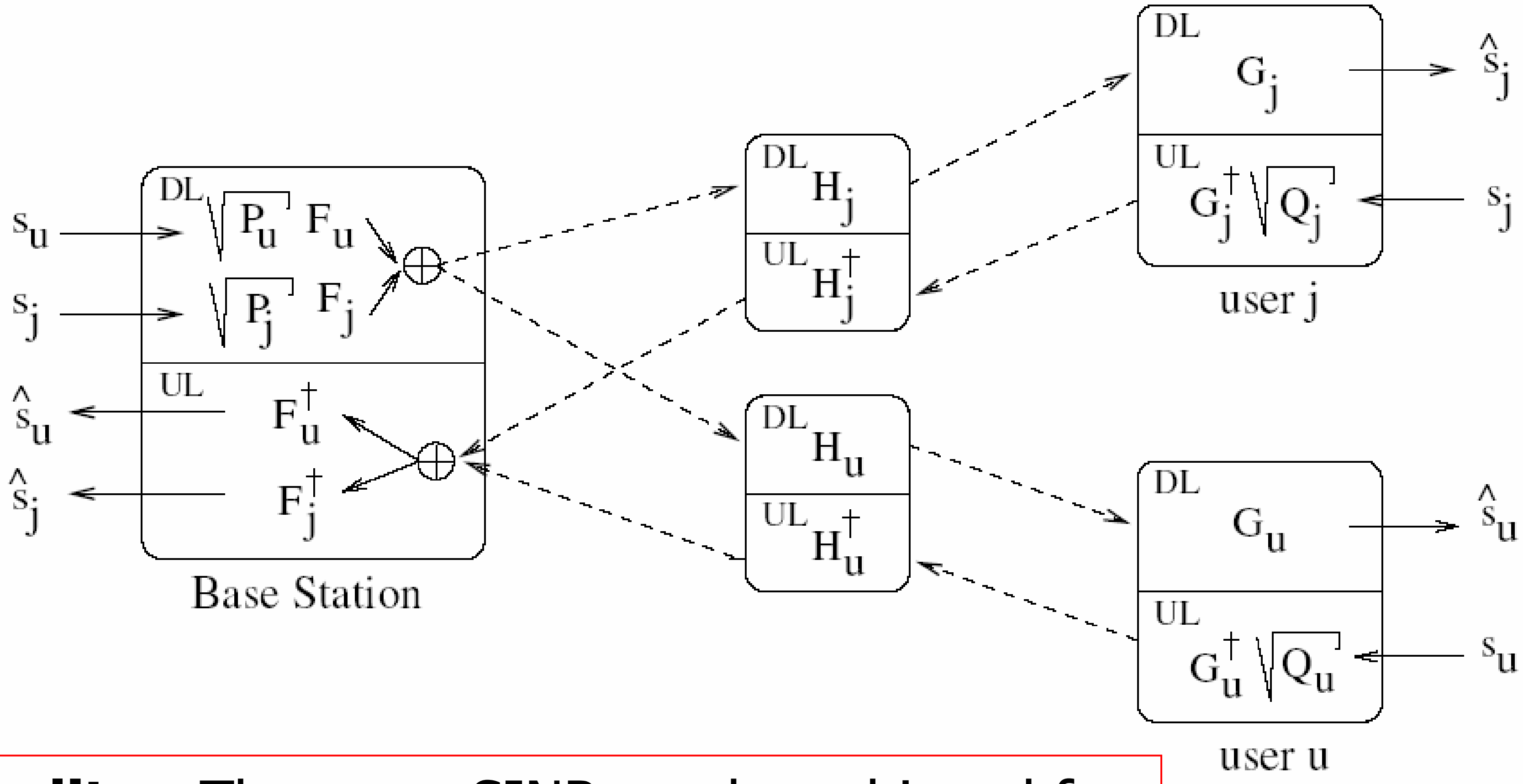
- *Optimal transmit beamformers for given p,G :*

$$SINR_{ul}^{DL} = \frac{\boldsymbol{g}_{ul}\boldsymbol{H}_u p_{ul}\boldsymbol{f}_{ul}\boldsymbol{f}_{ul}^{\dagger}\boldsymbol{H}_u^{\dagger}\boldsymbol{g}_{ul}^{\dagger}}{\boldsymbol{g}_{ul}\boldsymbol{R}_{\underline{ul}}^{DL}\boldsymbol{g}_{ul}^{\dagger}}$$

$$\boldsymbol{R}_{\underline{ul}}^{DL} = \sigma_u^2\boldsymbol{I} + \boldsymbol{H}_u\left[\sum_{\substack{j=1\\(j,m)\neq(u,l)}}^{U}\sum_{m=1}^{L(j)} p_{jm}\boldsymbol{f}_{jm}\boldsymbol{f}_{jm}^{\dagger}\right]\boldsymbol{H}_u^{\dagger}$$

Coupled problem !!

SINR duality



Duality : The same SINR can be achieved for both the downlink and uplink scenarios.

Uplink dual system

$$\hat{\boldsymbol{s}}_u = \boldsymbol{F}_u^\dagger \left[\boldsymbol{H}_u^\dagger \boldsymbol{G}_u^\dagger \sqrt{\boldsymbol{Q}_u} s_u + \sum_{j \neq u} \boldsymbol{H}_j^\dagger \boldsymbol{G}_j^\dagger \sqrt{\boldsymbol{Q}_j} \boldsymbol{s}_j + \boldsymbol{\nu}_u \right]$$

$$SINR_{ul}^{UL} = \frac{\boldsymbol{f}_{ul}^\dagger \boldsymbol{H}_u^\dagger q_{ul} \boldsymbol{g}_{ul}^\dagger \boldsymbol{g}_{ul} \boldsymbol{H}_u \boldsymbol{f}_{ul}}{\boldsymbol{f}_{ul}^\dagger \boldsymbol{R}_{\underline{ul}}^{UL} \boldsymbol{f}_{ul}}$$

$$\boldsymbol{R}_{\underline{ul}}^{UL} = \sigma_u^2 \boldsymbol{I} + \sum_{j=1}^{U} \sum_{\substack{m=1 \\ (j,m) \neq (u,l)}}^{L(j)} \boldsymbol{H}_j^\dagger q_{jm} \boldsymbol{g}_{jm}^\dagger \boldsymbol{g}_{jm} \boldsymbol{H}_j$$

Max-min-SINR design

- *Optimal transmit beamformers for given p,G :*
  - **Duality** => F designed as the optimal receiver of the dual system

$$SINR^{UL}_{ul} = \frac{\boldsymbol{f}^{\dagger}_{ul}\boldsymbol{H}^{\dagger}_{u} q_{ul} \boldsymbol{g}^{\dagger}_{ul} \boldsymbol{g}_{ul} \boldsymbol{H}_{u} \boldsymbol{f}_{ul}}{\boldsymbol{f}^{\dagger}_{ul} \boldsymbol{R}^{UL}_{\underline{ul}} \boldsymbol{f}_{ul}}$$

$$\boldsymbol{R}^{UL}_{\underline{ul}} = \sigma^2_u \boldsymbol{I} + \sum_{\substack{j=1 \\ (j,m)\neq(u,l)}}^{U} \sum_{m=1}^{L(j)} \boldsymbol{H}^{\dagger}_{j} q_{jm} \boldsymbol{g}^{\dagger}_{jm} \boldsymbol{g}_{jm} \boldsymbol{H}_{j}$$

$$\boxed{\forall u, l, \;\; \boldsymbol{f}_{ul} := \text{max eigvect. of } \left(\boldsymbol{H}^{\dagger}_{u} q_{ul} \boldsymbol{g}^{\dagger}_{ul} \boldsymbol{g}_{ul} \boldsymbol{H}_{u} \;,\;\; \boldsymbol{R}^{UL}_{\underline{ul}} \right)}$$

Max-min-SINR design

- *Optimal power assignment for fixed pre/decoders*

$$\boldsymbol{D} = \operatorname{diag}\{d_{11}, d_{12}, \ldots, d_{UL_U}\}$$

$$d_{ul} = \frac{\gamma_{ul}}{\boldsymbol{g}_{ul}\boldsymbol{H}_u\boldsymbol{f}_{ul}\boldsymbol{f}_{ul}^{\dagger}\boldsymbol{H}_u^{\dagger}\boldsymbol{g}_{ul}^{\dagger}}$$

$$\boldsymbol{\Psi} = \begin{bmatrix} 0 & \psi_{11,12} & \cdots & \psi_{11,UL_U} \\ \psi_{12,11} & 0 & \cdots & \psi_{12,UL_U} \\ \vdots & & \ddots & \vdots \\ \psi_{UL_U,11} & \psi_{UL_U,12} & & 0 \end{bmatrix}$$

$$\psi_{ul,jm} = \boldsymbol{g}_{ul}\boldsymbol{H}_u\boldsymbol{f}_{jm}\boldsymbol{f}_{jm}^{\dagger}\boldsymbol{H}_u^{\dagger}\boldsymbol{g}_{ul}^{\dagger}$$

Max-min-SINR design

- *Optimal power assignment for fixed pre/decoders*

$$\boldsymbol{\Upsilon}(\boldsymbol{F},\boldsymbol{G},\boldsymbol{P_t}) = \begin{bmatrix} \boldsymbol{D\Psi} & \boldsymbol{D\sigma} \\ \frac{1}{\boldsymbol{P_t}}\mathbf{1}^T\boldsymbol{D\Psi} & \frac{1}{\boldsymbol{P_t}}\mathbf{1}^T\boldsymbol{D\sigma} \end{bmatrix}$$

$$\boldsymbol{\Upsilon}(\boldsymbol{F},\boldsymbol{G},\boldsymbol{P_t})\boldsymbol{p}_{ext} = \frac{1}{C^{DL}(\boldsymbol{F},\boldsymbol{G},\boldsymbol{P_t})}\boldsymbol{p}_{ext}$$

$$\boxed{\boldsymbol{p} := \text{solution of} \quad \boldsymbol{\Upsilon}\begin{pmatrix} \boldsymbol{p} \\ 1 \end{pmatrix} = \frac{1}{C^{DL}}\begin{pmatrix} \boldsymbol{p} \\ 1 \end{pmatrix}}$$

Max-min-SINR design

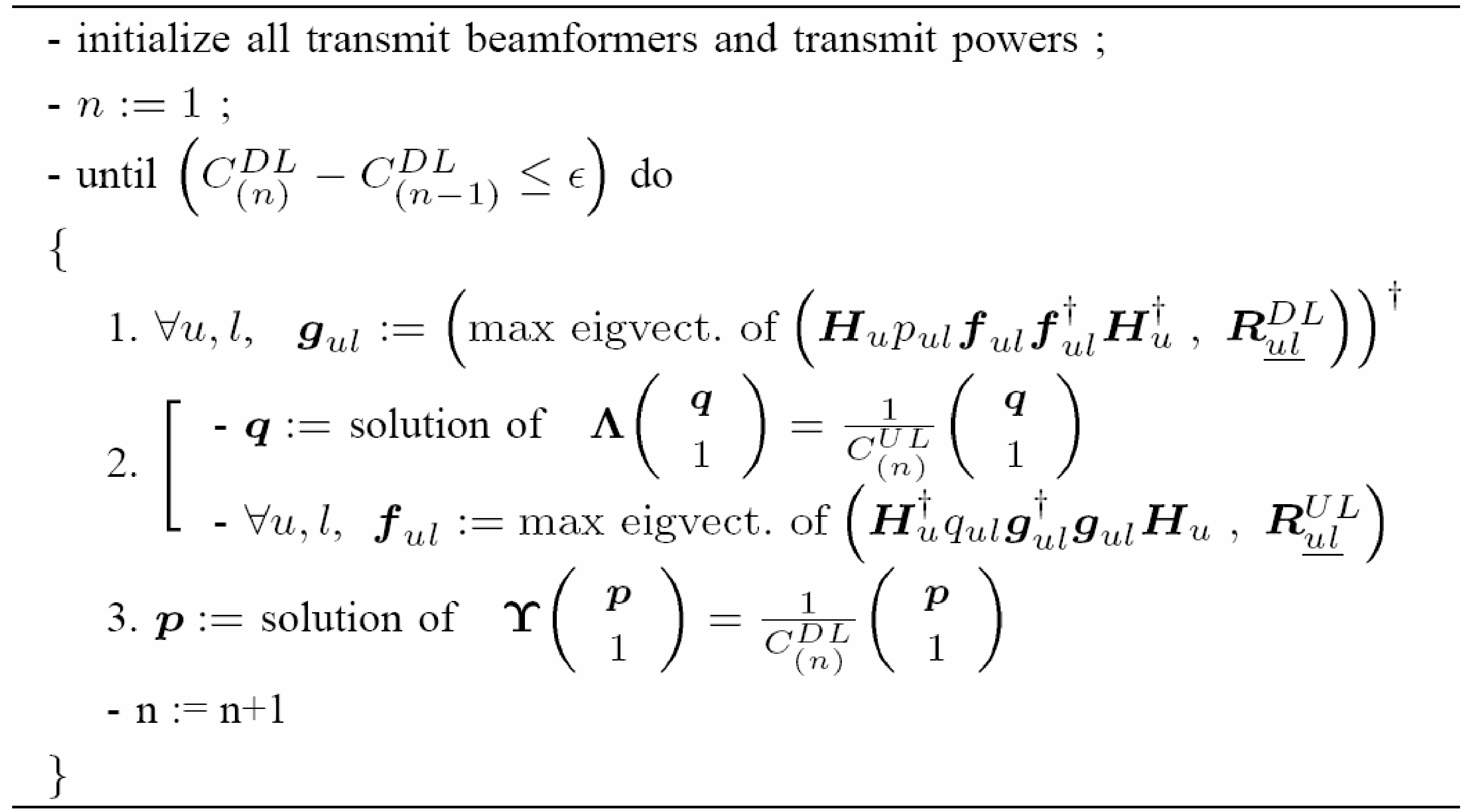
- *Optimal power assignment for fixed pre/decoders*
  - *Uplink case :*

$$\Lambda(F,G,P_t) = \begin{bmatrix} D\Psi^T & D\sigma \\ \frac{1}{P_t}1^T D\Psi^T & \frac{1}{P_t}1^T D\sigma \end{bmatrix}$$

$$\Lambda(F,G,P_t)q_{ext} = \frac{1}{C^{UL}(F,G,P_t)}q_{ext}$$

$$\boxed{\boldsymbol{q} := \text{solution of} \quad \boldsymbol{\Lambda}\begin{pmatrix} \boldsymbol{q} \\ 1 \end{pmatrix} = \frac{1}{C^{UL}}\begin{pmatrix} \boldsymbol{q} \\ 1 \end{pmatrix}}$$

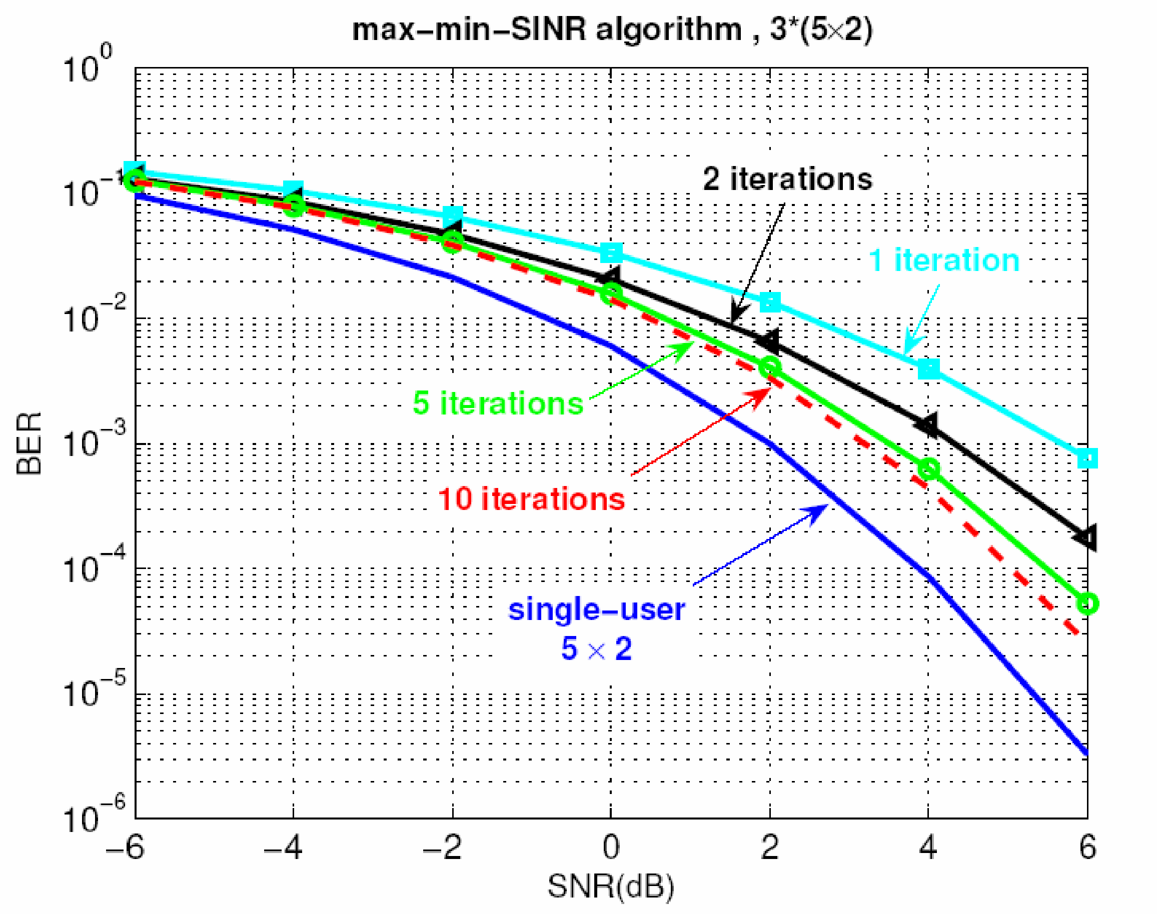
Max-min-SINR design : iterative algorithm



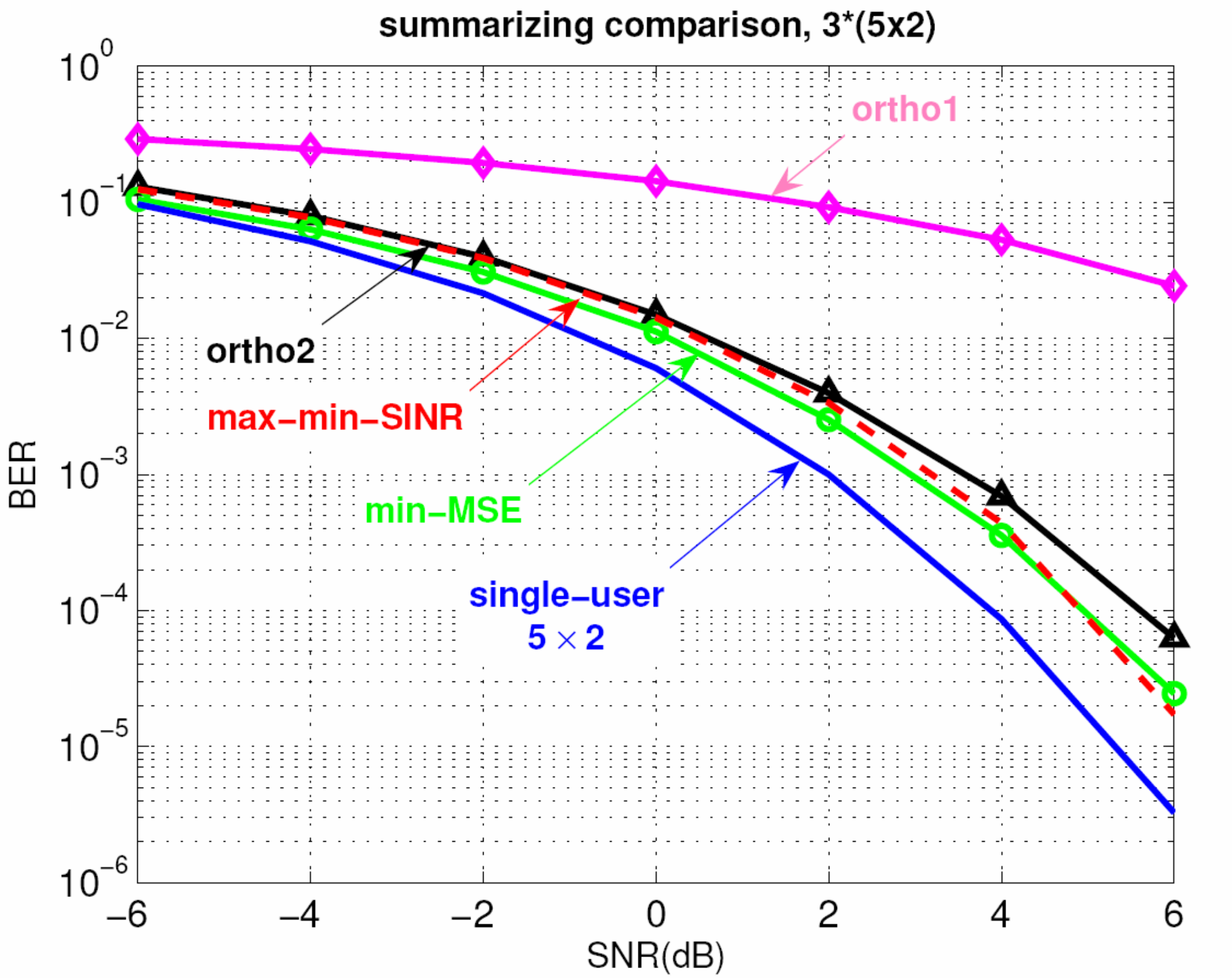
```
- initialize all transmit beamformers and transmit powers ;
- $n := 1$ ;
- until $\left(C^{DL}_{(n)} - C^{DL}_{(n-1)} \leq \epsilon\right)$ do
{
    1. $\forall u, l, \quad \boldsymbol{g}_{ul} := \left(\text{max eigvect. of } \left(\boldsymbol{H}_u p_{ul} \boldsymbol{f}_{ul} \boldsymbol{f}^{\dagger}_{ul} \boldsymbol{H}^{\dagger}_u \,,\; \boldsymbol{R}^{DL}_{\underline{ul}}\right)\right)^{\dagger}$
    2. [ - $\boldsymbol{q} :=$ solution of $\quad \boldsymbol{\Lambda}\begin{pmatrix} \boldsymbol{q} \\ 1 \end{pmatrix} = \frac{1}{C^{UL}_{(n)}}\begin{pmatrix} \boldsymbol{q} \\ 1 \end{pmatrix}$
       [ - $\forall u, l, \quad \boldsymbol{f}_{ul} :=$ max eigvect. of $\left(\boldsymbol{H}^{\dagger}_u q_{ul} \boldsymbol{g}^{\dagger}_{ul} \boldsymbol{g}_{ul} \boldsymbol{H}_u \,,\; \boldsymbol{R}^{UL}_{\underline{ul}}\right)$
    3. $\boldsymbol{p} :=$ solution of $\quad \boldsymbol{\Upsilon}\begin{pmatrix} \boldsymbol{p} \\ 1 \end{pmatrix} = \frac{1}{C^{DL}_{(n)}}\begin{pmatrix} \boldsymbol{p} \\ 1 \end{pmatrix}$
    - n := n+1
}
```

Concave for *Nr=1*

Max-min-SINR : simulations



Summarizing comparison



Outline

- History
- Challenges and constraints
- Fundamentals
- Multiple antenna concept
- Multicarrier Modulation
- Space Division Multiple access
- Downlink OFDM SDMA
- Conclusions

Conclusions

- You are very welcome to the digital communications community !
- Hot topics include :
  - MIMO Multiuser schemes
  - Imperferct CSI based designs
  - Relay networks
  - Ad Hoc networks
  - Sensor networks
  - Ultrawide band systems
  - Turbo coding
  - …

www.tele.ucl.ac.be/digicom/

Thanks for your attention

Questions ?