INSTITUT D'ÉLECTRONIQUE ET DE TÉLÉCOMMUNICATIONS DE RENNES

Antenna selection in a SIMO architecture for HF radio links

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Contents

- **Introduction**
- **Channel impulse response**
- **Selection criterion : outage capacity**
- **Set of antennas under test**
- **Results**
- **Conclusion**

Introduction (1/2)

Radio communication through the ionospheric channel :

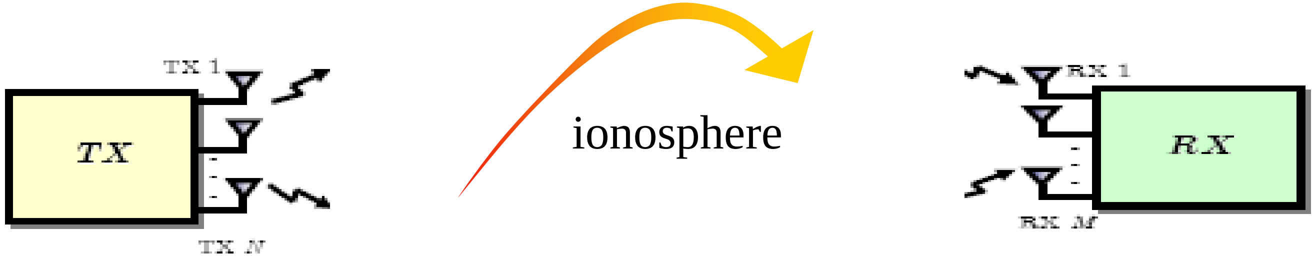
- limited coherence bandwidth (some kHz) $\Rightarrow$ modems with moderate data rates

  typical performances : 4.8 kbps in a 3 kHz bandwidth

  Need for improved data rate

- Possible investigation : benefit of array processing ; multi channel receivers

  SIMO or MIMO architectures



Statement :

Context of high level of spatial correlation (small angular separation of incident waves)

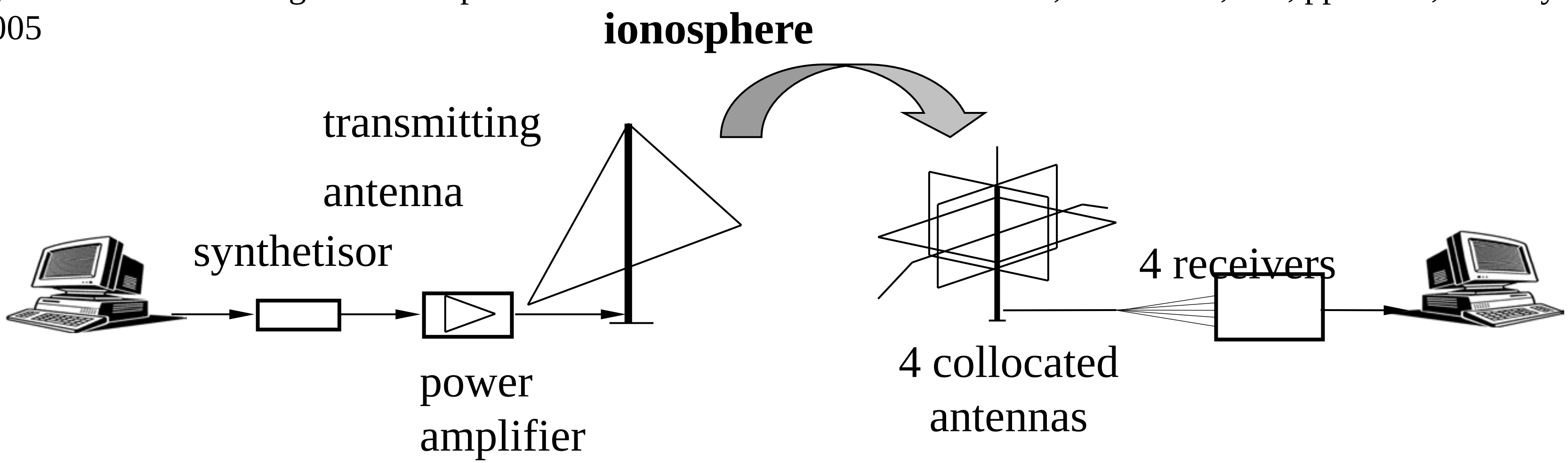
$\Rightarrow$ inter element spacing equal to dozens of λ (λ=100 m for fo=3 MHz !)

Need for an alternative solution compatible with a limited array aperture

Introduction (2/2)

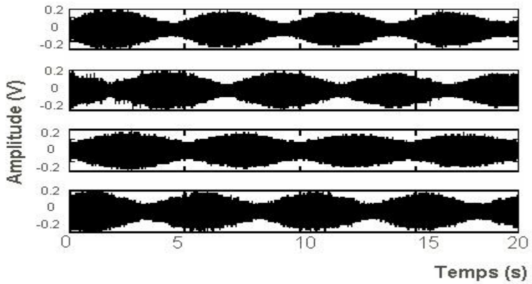
Example of SIMO realization : array of collocated receive antennas

"Image transmission through the ionospheric channel " I.E.E. Electronics Letters, volume 41, n°2, pp 80-82, January 2005



Rx antennas with different sensitivities to the incoming (elliptical) polarizations : acquisitions with a low level of correlation (suitable for array processing) in absence of spatial diversity

Example of acquisitions



Former project Trilion : 4 channel D=25 kbps/s in a bandwidth extended to 9 kHz

This work : choice of the most efficient receive antennas for SIMO systems

Channel impulse response

Point to point radio link : propagation previsions by VOACAP (method 25)

Input parameters : Tx and Rx geographical coordinates, year, date, hour and frequency
Outputs : number of paths, path loss, time delay, elevation

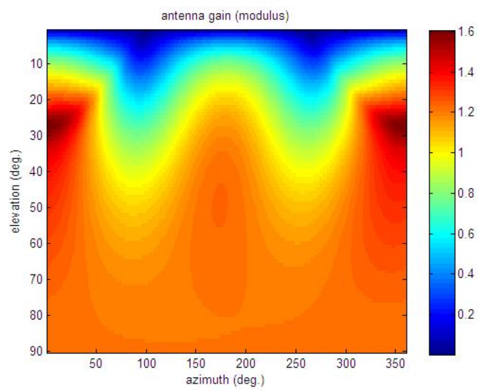
In addition : receive antenna gain (see ref. [3) in the paper)

- Elliptical polarizations identified with 2 parameters : polarization ratio η and inclination angle α
- Computation η and α : Rx position, angles of arrival θ = (Az, El), frequency fo and data base of B_T. 2 different polarization types O and X (sign +/- in calculation of η)

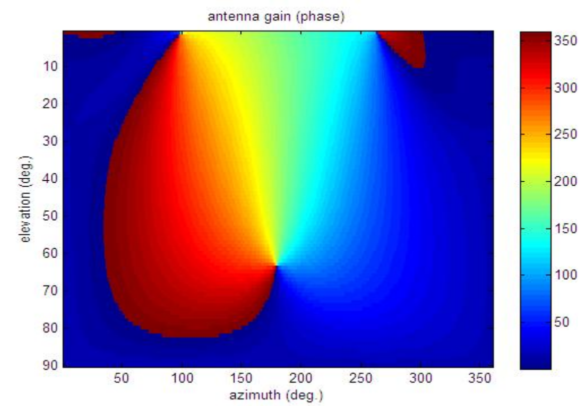
- Antenna directional response : NEC-2D
Description of the antenna (simple) geometry + incident elliptical polarizations + ground effect (standard characteristics) : directional response F_{rx}(Az, El, f_o) ; complex valued

Ex : ***vertical NS oriented loop antenna ; fo=9 MHz***

abs(F_{rx})



arg(F_{rx})



Channel impulse response

Expression of the CIR (receive antenna with index i):

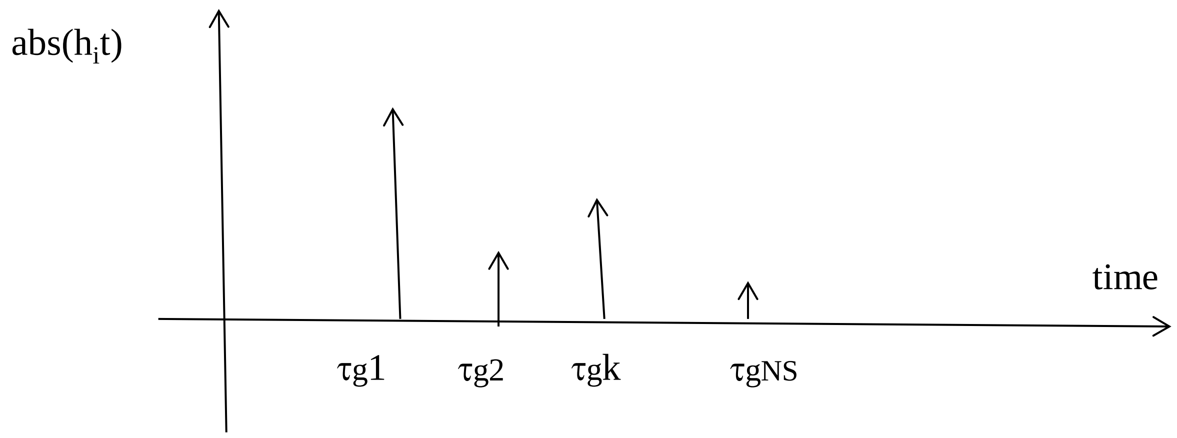
$$h_i(t) = \sum_{k=1}^{NS} A_k \delta(t - \tau_{gk}) F_{ik}(\theta_k, P_k)$$

NS = number of identified paths

A_k= amplitude for path k (depends on path loss)

τ_{gk} : time delay

F_{ik} (θ_k,P_k) gain of antenna i for path k with AOA θ_k and polarization type P_k= O or X.



Transposition in the frequency domain : channel complex gain $\underline{Hc}_i(f) = FFT(\underline{h}_i)$

Obtaining a large number of trials for CIR

Need for a large collection of CIR estimations (statistics of SIMO channels)

For a given receiver location, possible variations of :

Year : 3 years corresponding to different solar activities
Month : 4 months corresponding to the 4 seasons
Hour : one prediction every hour ; 24 cases
Azimuth : variations within the [0°-360°] interval with a 15° step (24 values)

Maximum number of trials = 3x4x24x24=6912
Validation only for effective radio links with a reasonable path loss (f.e. less than 140 dB)
Typical number : several 10^2 to some 10^3

Additional parameter variations
Distance : from 300 km to 1500 km ; step=300 km (5 values)
Carrier frequency : from 3 MHz to 15 MHz ; step 3 MHz (5values)

Outage Capacity

Shannon capacity of a radio channel : maximum error free data rate in a 1 Hz bandwith (theoretical)

Basic expression : $C_{siso}(nr) = \log_2(1 + \frac{Pe.|h_{ref}(nr)|^2}{No})$ non dispersive SISO channel

Pe : transmitted power in a 1 Hz bandwidth
No : noise power density spectrum
$h_{ref}(nr)$: channel gain for trial index nr ; constant relatively to frequency ; Rx antenna= reference

1xNC SIMO configuration ; dispersive channel (Nf frequency bins)

NC channel gains for each frequency bin (index nf)

$$\underline{Hc}(nf, nr) = \begin{pmatrix} Hc_{ref}(nf, nr) \\ Hc_2(nf, nr) \\ .... \\ Hc_{NC}(nf, nr) \end{pmatrix}$$

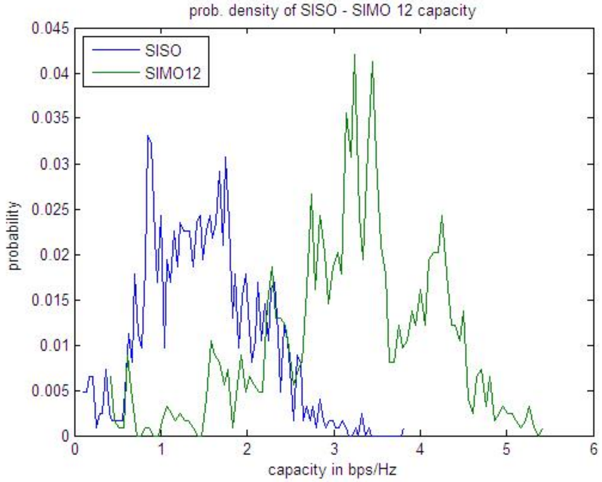
SIMO Shannon capacity : $C_{simo}(nf, nr) = \log_2\left(1 + \frac{Pe.\|\underline{Hc}(nf, nr)\|^2}{No}\right)$

SIMO capacity (large band) : $C_{Simo\ LB}(nr) = \frac{1}{Nf} \sum_{nf=1}^{Nf} C_{simo}(nf, nr)$

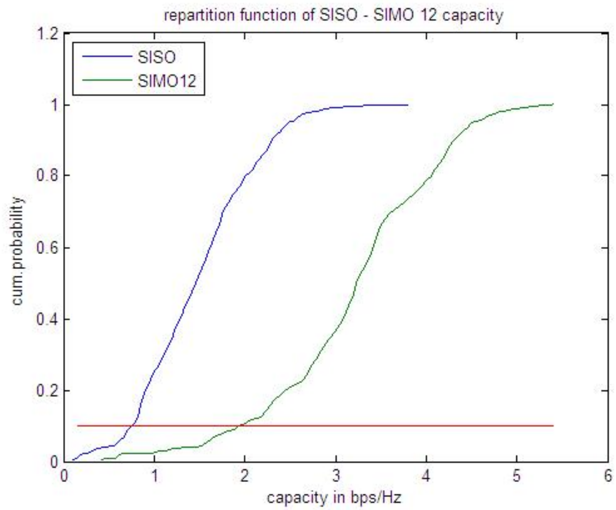
Outage Capacity

Histograms of SIMO/SISO Shannon capacities derived from a large number of trials

Probability density of Shannon capacity :



Cumulated probability function
of Shannon capacity :



Outage capacity (threshold ε=0.1) :

Theoretical and partially practical criterion (quality of service)

$$C_{outsimo\,\varepsilon} = \sup_{C \geq 0} \{ C : p[C_{simo\,LB} < C] \leq \varepsilon \}$$

Outage Capacity

Selected criterion : outage capacity gain

$$G_{cap.out.} = \frac{C_{out.simo}}{C_{out.siso}}$$

- Needs to choose a receive antenna for the SISO reference configuration
- Rem : following SIMO configs do not include systematically the reference Rx antenna

- For a given subset of trials, the best sorted values of G cap.out are close to each other

any Rx configuration ensuring $G_{cap.out.} > 0.8 * G_{cap.out.max}$ is selected as a potential candidate

- For the total set of trials, each antenna configuration is ranked with the number of occurences it appears as potential candidate (final criterion = number of occurences)

Set of antennas under test

Set of 15 antennas with a simple geometry (see paper for the list):

-Small size active loop antennas, active dipoles (various orientations)
- Passive monopole, dipoles (various design and orientations)

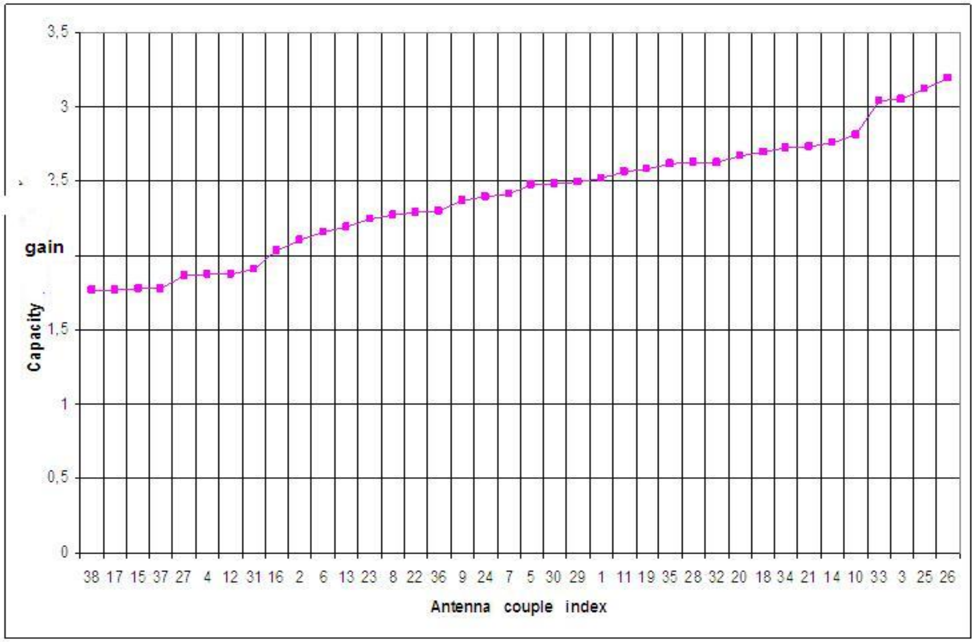
-Part of them are implemented in prototypes of collocated antennas developed in IETR laboratory in order to reduce the set up volume

-The rest have simply been simulated (NEC-2D)

Results : SIMO 1x2

38 couples of Rx antennas considered ; reference antenna for SISO = vertical passive dipole (antenna #6)

Example : outage capacity gain for given year, distance and frequency (687 valid trials)



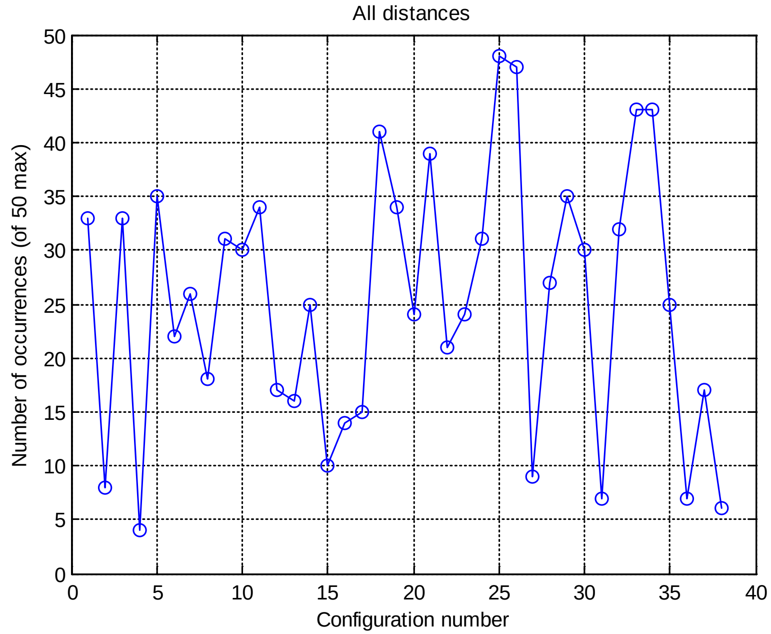
Gain max = 3.18 ; any couple providing a gain > 0.8*3.18=2.54 sees its occurrence number (of good ranking) increase by 1

Results : SIMO 1x2

Global results :

Number of simulations : 3 years x 5 distances x 5 frequencies = 75

Maximum number of occurences = 50 (propagation conditions + capacity histograms)



2 best configurations : - 2 horizontal orthogonal active dipoles (couple #25)
- 2 vertical orthogonal active loop antennas (couple #26)

Differences in the sensitivity to the incoming polarizations

worst config. : # 38 = couple of 2 identical vertical dipoles (no diversity gain)

Results : SIMO 1x2

Mean outage capacity gain (max)= 3.1 for configuration #25

- Superior to 2 as antenna #6 (reference for SISO) is not element of this config.

- SISO outage capacity (mean)=0.72 bps/Hz

SIMO outage capacity = **2.23 bps/Hz**

More than 6 kbps in a 3 kHz bandwidth should be possible in a SIMO 1x2 config.

Conclusion

This work :

- demonstrates the capacity gain of a SIMO 1x2 solution implemented on colocated antennas

- proposes a criterion to identify the best 2 receive antennas in a set of 15

- gives an estimation of the corresponding outage capacity

Current investigations

Carried out on SIMO 1x3 and 1x4 architectures

First results indicate a moderate increase in the outage capacity gain :
3.83 for NC=3 ; 4.31 for NC=4

THANK YOU FOR YOUR ATTENTION !