

COMPLEX ELECTRONIC SYSTEMS MODELLING

Electromagnetic game modelling through
Tensor Analysis of Networks and Game Theory

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1. Introduction
2. Problem statement
 - Physical issue
 - Generalization
3. Human factor
 - Evolution Tree
 - EM game modelling
4. Numerical application
 - Description
 - Results & Discussion
5. Conclusion & Prospects

EM threats in future E-city developments

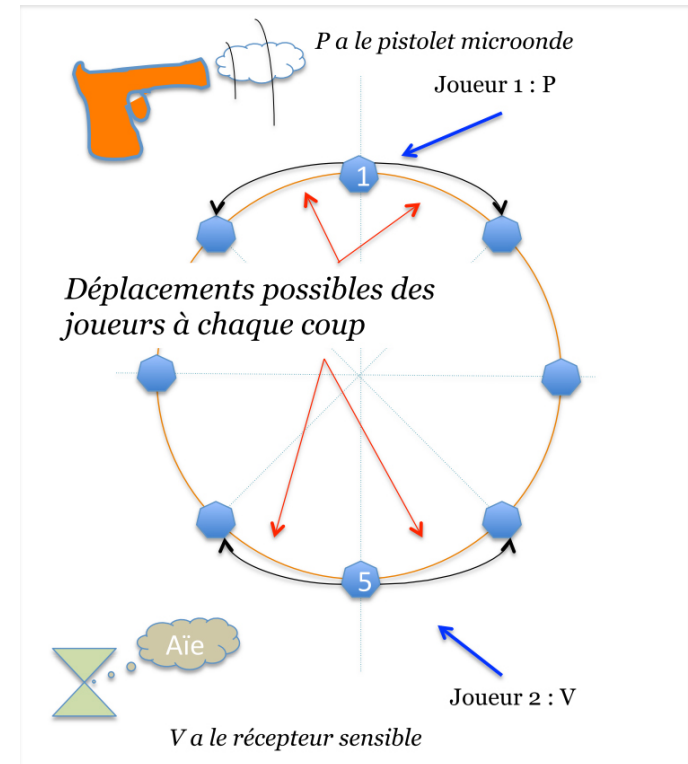
- Technological development, design of high-power EMI sources
- Dependability of modern society on IT-technology
- Rise of criminal and terrorist threats

Use of EM sources to generate Intentional EM Interference (IEMI)

F. Sabath, Threat of electromagnetic terrorism – lessons learned from documented IEMI attacks, EUROEM 2012, Toulouse, France, 2012

- Mobile phone as EM weapon for hi-fi!!!

⇒ **Attempting to jointly model complexity and human factors**

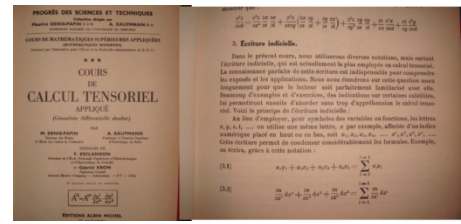


O. Maurice, Introduction d'une théorie des jeux dans des topologies dynamiques, PhD Thesis, University of Limoges, September 2013

- Tensorial Analysis of Networks (TAN)
Ancient formalism → Topical problems

- Complex systems analysis with multi-physics, multi-scales purposes

G. Kron, *A short course in tensor analysis*, John Wiley and Sons, New York, 1942



- Game Theory → « Psychology »

- Prisoner's dilemma

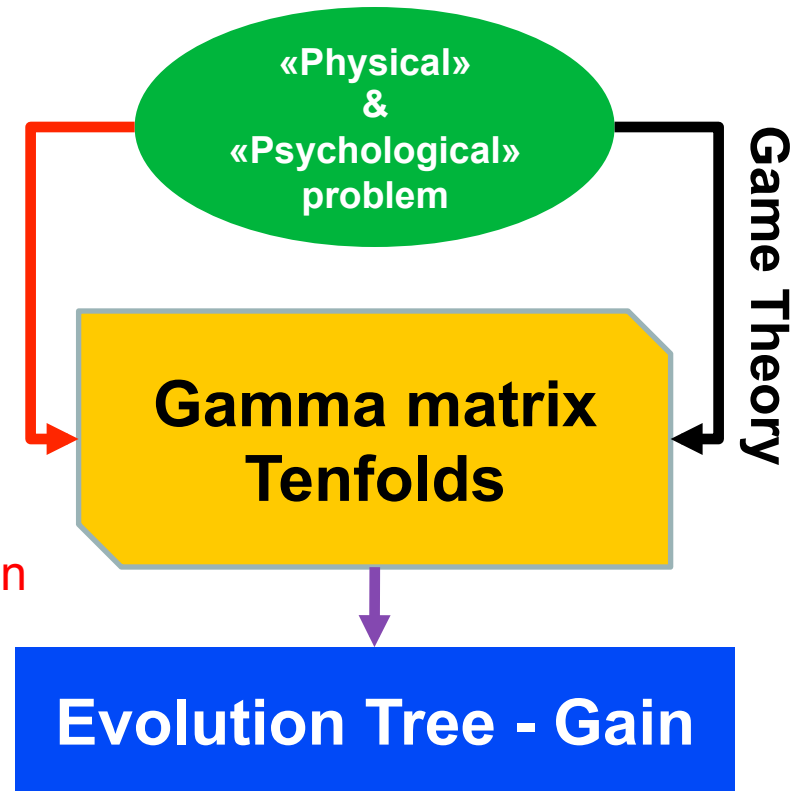
2 strategies:

C = Confess
D = Deny

		Player 2	
		C	D
Player 1	C	(15, 15)	(5, 30)
	D	(30, 5)	(0, 0)

→ Player 1's gain → Player 2's gain

Proposed « Methodology »

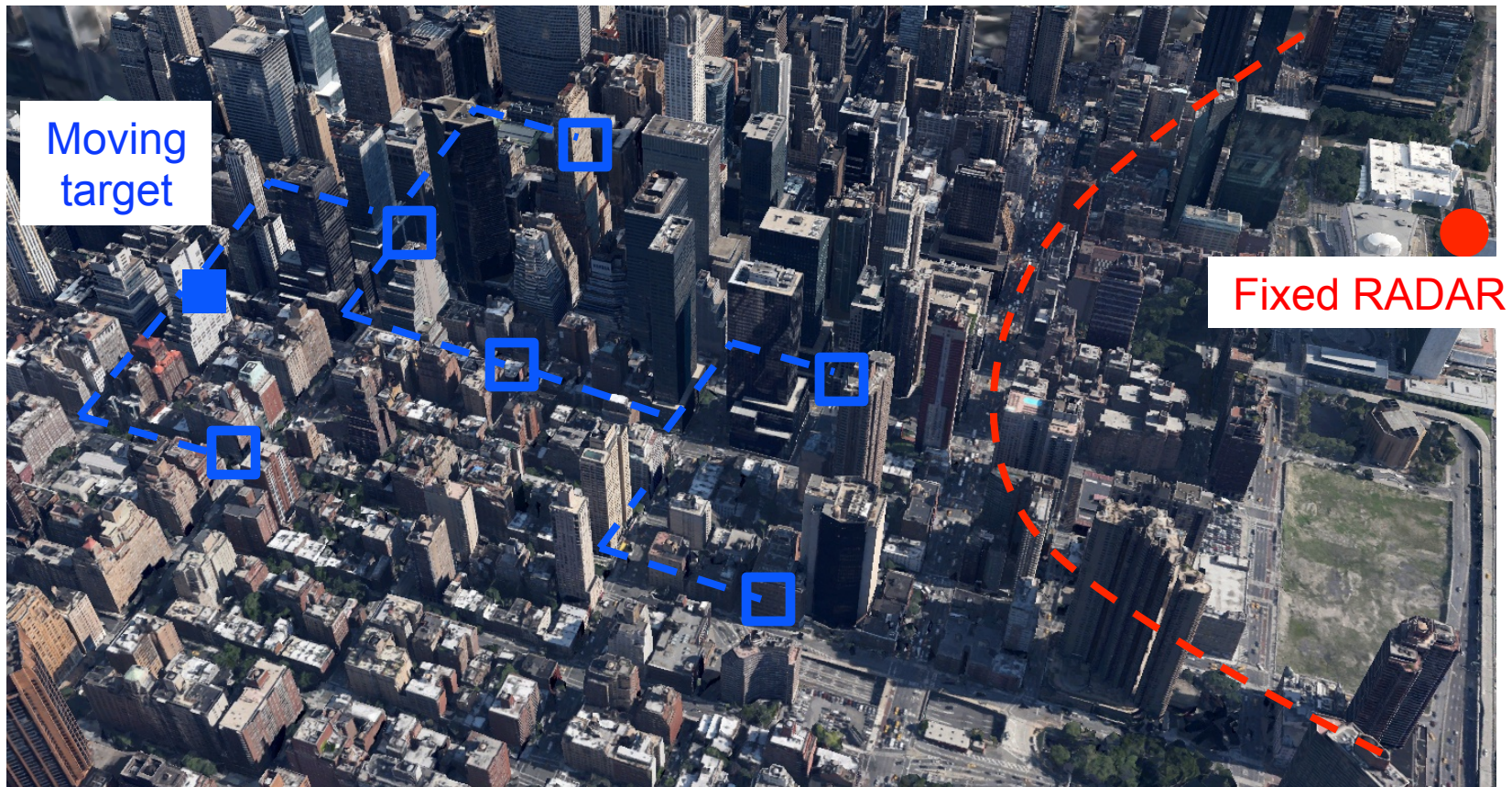


Conclusions

« Neutral » players ⇒ Optimal strategy = « CC »
« External » view ⇒ « DD » choice ...

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- System description: « Moving target detection »
 - Fixed RADAR (emitting function)
 - Target model (receiving function)
 - Model for RADAR / target interactions



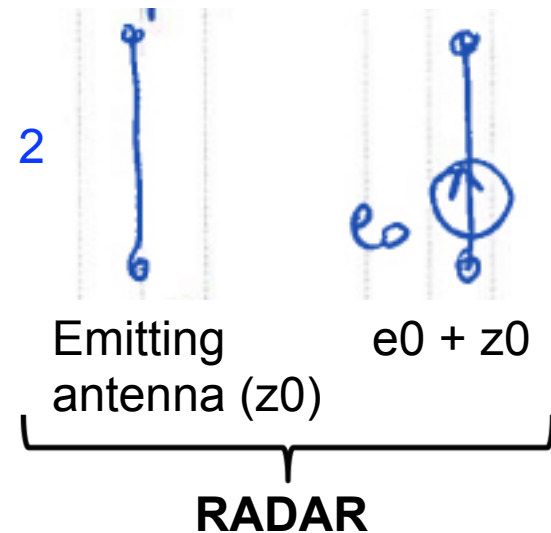
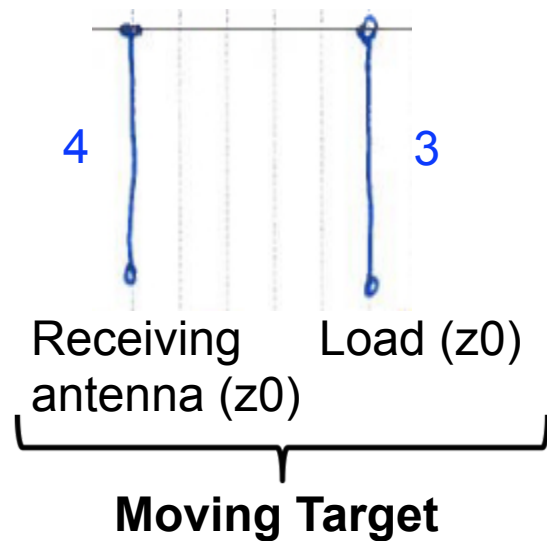
- **RADAR: « amplifier + driving electronics »**
 - Hyperfrequency source + internal impedance (50 Ω)
 - Matched Radiation Resistance (50 Ω)

- **Target: « antenna + electronics »**
 - Receiving antenna (Radiation Resistance, 50 Ω)
 - Matched load (50 Ω)

- **System finalization**
 - Definition of networks coordinates
 - EM interaction between networks (antennas)

■ Definition of Primitive Elements (PE)

- Assuming $z_i (I, V, f, \dots)$ an impedance function linking the radioelectrical behavior of a given object with outputs and an energy source e_i
- PE = branch or network modelling a given object functioning
- PE = $\{(z_1, e_1), (z_2, e_2), \dots, (z_n, e_n)\}$ in R, R: set of networks

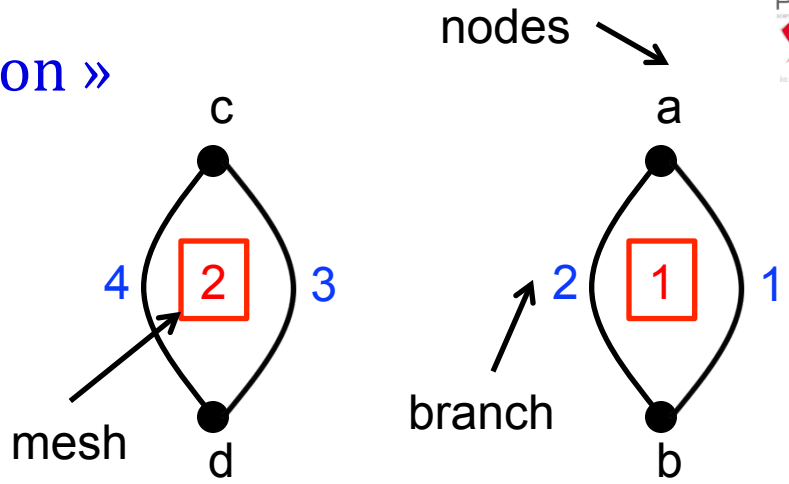


GENERALIZATION WITH TAN (2/4)

■ PE assembly \Leftrightarrow « Transformation »

- Direct sum of PE impedances
- Addition of coupling interactions

$$z = \begin{bmatrix} z0 & 0 & 0 & 0 \\ 0 & z0 & 0 & 0 \\ 0 & 0 & z0 & 0 \\ 0 & 0 & 0 & z0 \end{bmatrix}$$



\Rightarrow Metric definition: $e = z i$

- Definition of « connectivity » matrix

« Transformation »
(from branch space to mesh space)

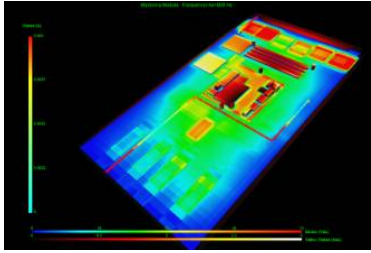
	mesh	
	1	2
1	1	
2	1	
3		1
4		1

$$\Lambda = \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$$

$$z' = \Lambda^T z \Lambda$$

$$z' = \begin{bmatrix} 2z0 & 0 \\ 0 & 2z0 \end{bmatrix}$$

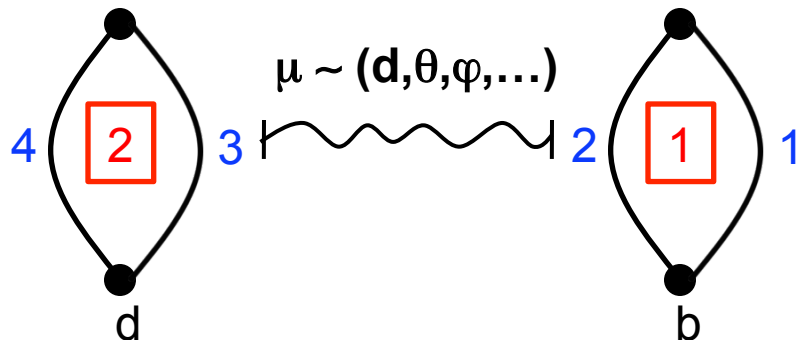
- Addition of « branch » coupling (branch space)
 - Near Field (NF) coupling, welding with resistance, parasitic capacity, ...
 - Direct sum of connectivity matrices



No NF coupling here

- Addition of « cord » coupling (branch space)
 - Far field coupling \leftrightarrow Matrix μ (extra diagonal terms)
 - Antennas reciprocity: $Z_{32} = Z_{23}$

$$z_a = z + \mu = \begin{bmatrix} z0 & 0 & 0 & 0 \\ 0 & z0 & z_{23} & 0 \\ 0 & z_{32} & z0 & 0 \\ 0 & 0 & 0 & z0 \end{bmatrix}$$



\Rightarrow Final « Transformation »

$$z'_a = \begin{bmatrix} 2z0 & z_{32} \\ z_{32} & 2z0 \end{bmatrix}$$

Final computation

- Solving system:

$$\begin{bmatrix} e_0 \\ 0 \end{bmatrix} = \begin{bmatrix} 2z_0 & z_{32} \\ z_{32} & 2z_0 \end{bmatrix} \cdot \begin{bmatrix} i^1 \\ i^2 \end{bmatrix}$$

unknowns

« Tenfold » definition

- Gathering previous descriptions in 1 unique « list » ↔ Tenfold
- System evolution requires new « Transformations »
- « Transformations » weighted by probability depicting « human » factor

« Tenfold » characteristics

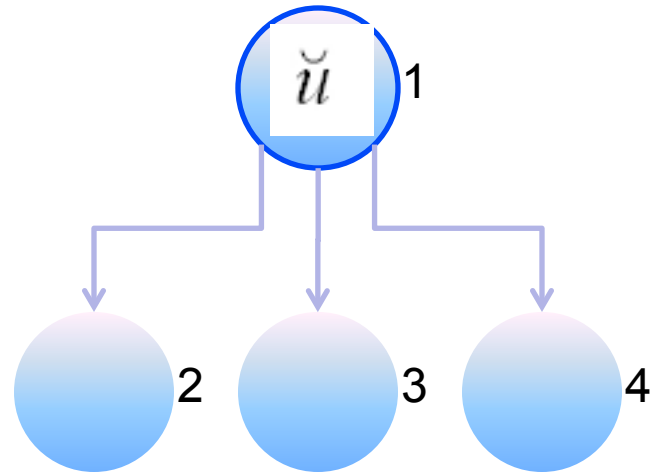
- Topology (connectivity, incidence, ...) T
- Metric (« Z » branch and/or « Z' » mesh)
- Sources (internal) E

$$\check{u} = (T, Z, E)$$

$$\check{u} = \left(T, \begin{bmatrix} 2z_0 & z_{32} \\ z_{32} & 2z_0 \end{bmatrix}, \begin{bmatrix} e_0 \\ 0 \end{bmatrix} \right)$$

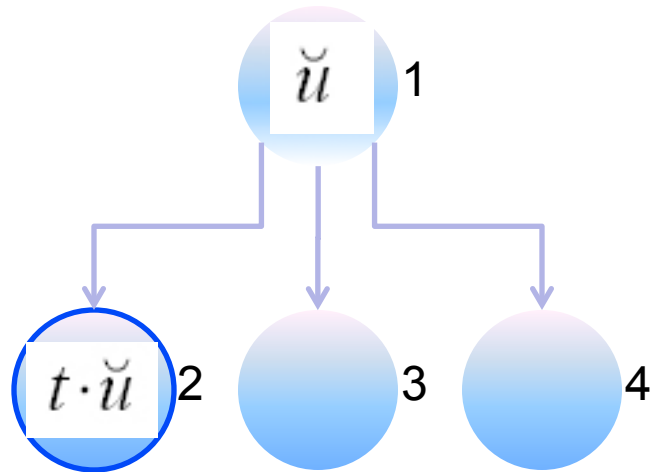
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EVOLUTION TREE (1/2)



$$I = \begin{bmatrix} \check{u} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Information vector

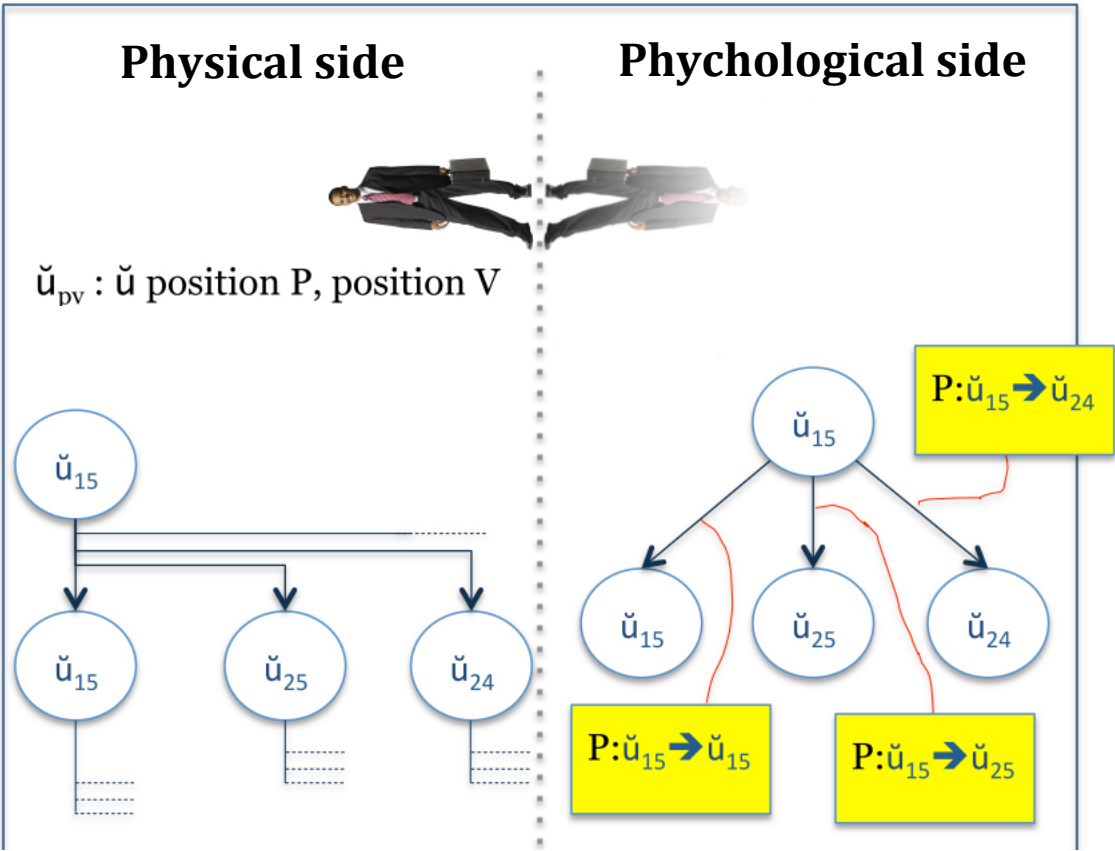
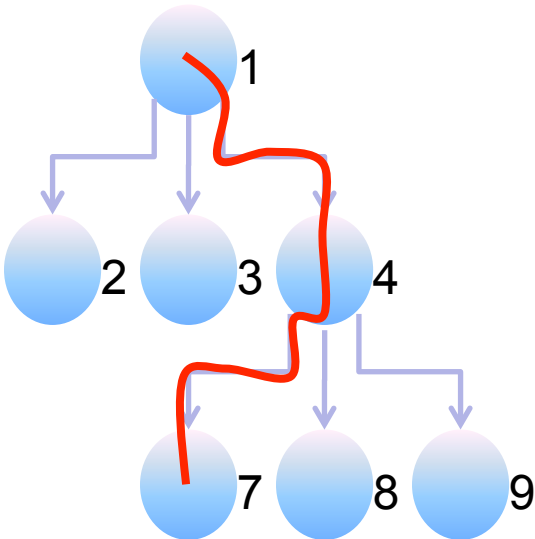


$$\gamma = \begin{bmatrix} 0 & 0 & 0 & 0 \\ t & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

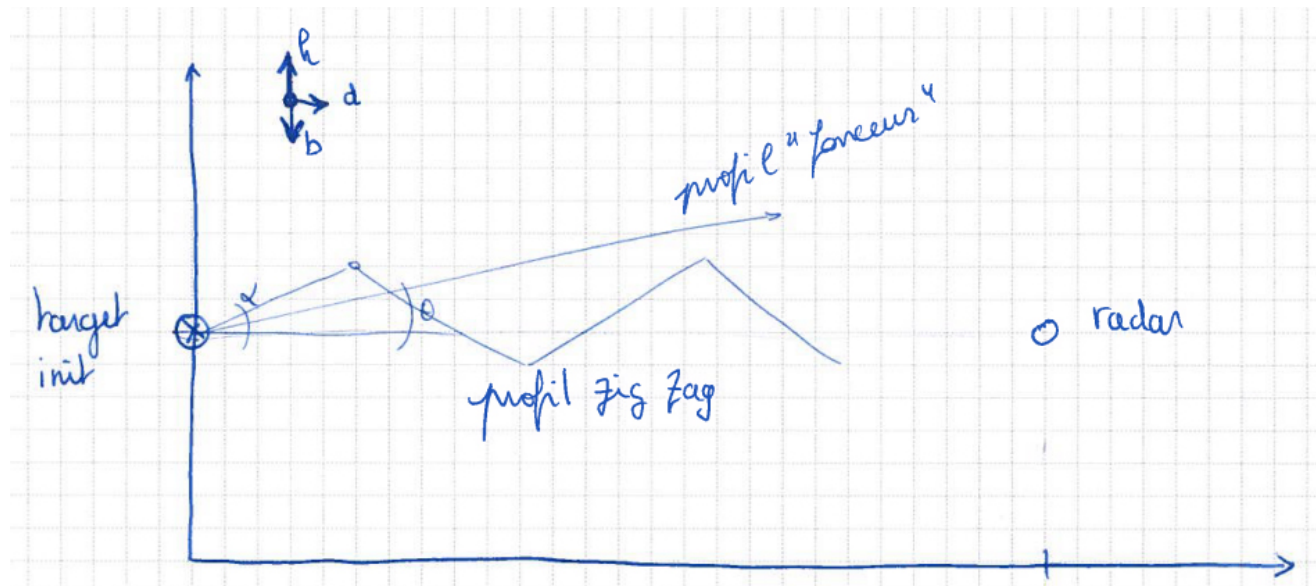
Propagator

$$\gamma \cdot I = \begin{bmatrix} 0 \\ t \cdot \check{u} \\ 0 \\ 0 \end{bmatrix}$$

- Paths deduced from « gamma » matrix
 - Segments given by $\{diag(\gamma \cdot \gamma^T)\}$
 - Entire probability of a given path \rightarrow Product of segments probability
 - Path C_i (red colored)
 - $= (1:4) \cdot (4:7)$
 - $P(C_i) = P_{14} P_{47}$



- Objective: « *Moving target should come closer to RADAR without disturbances* »
- Elements: 1 RADAR, 1 target, 1 playground
- Rules
 - Displacement: 1 step (sampling) by game-turn
 - End of game in case of « Target » disturbance (susceptibility threshold)
 - Objects (RADAR, electronics) used in initial state
→ Ban: increasing power of emitting antenna, shielding, changing antennas factors, ...)



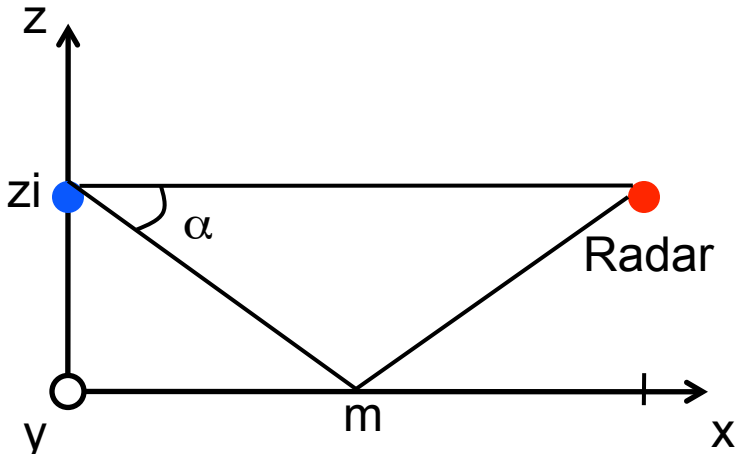
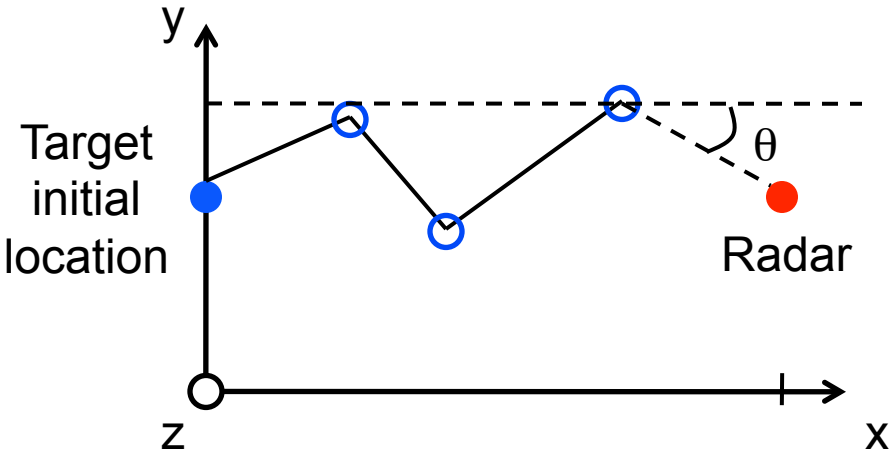
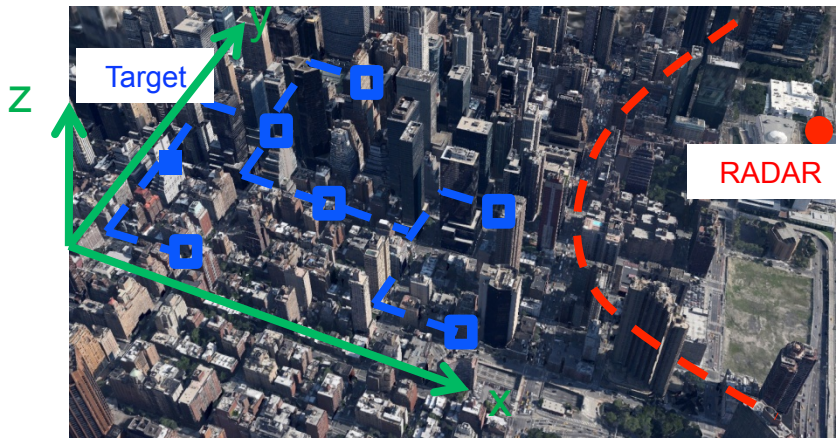
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- RADAR / Moving target interactions

$$z_{32} = h_3 h_2 \cos(\theta) \left[\frac{\exp(-jkr)}{r} + \cos(\alpha) \frac{\exp(-jkd_s)}{d_s} \right]$$

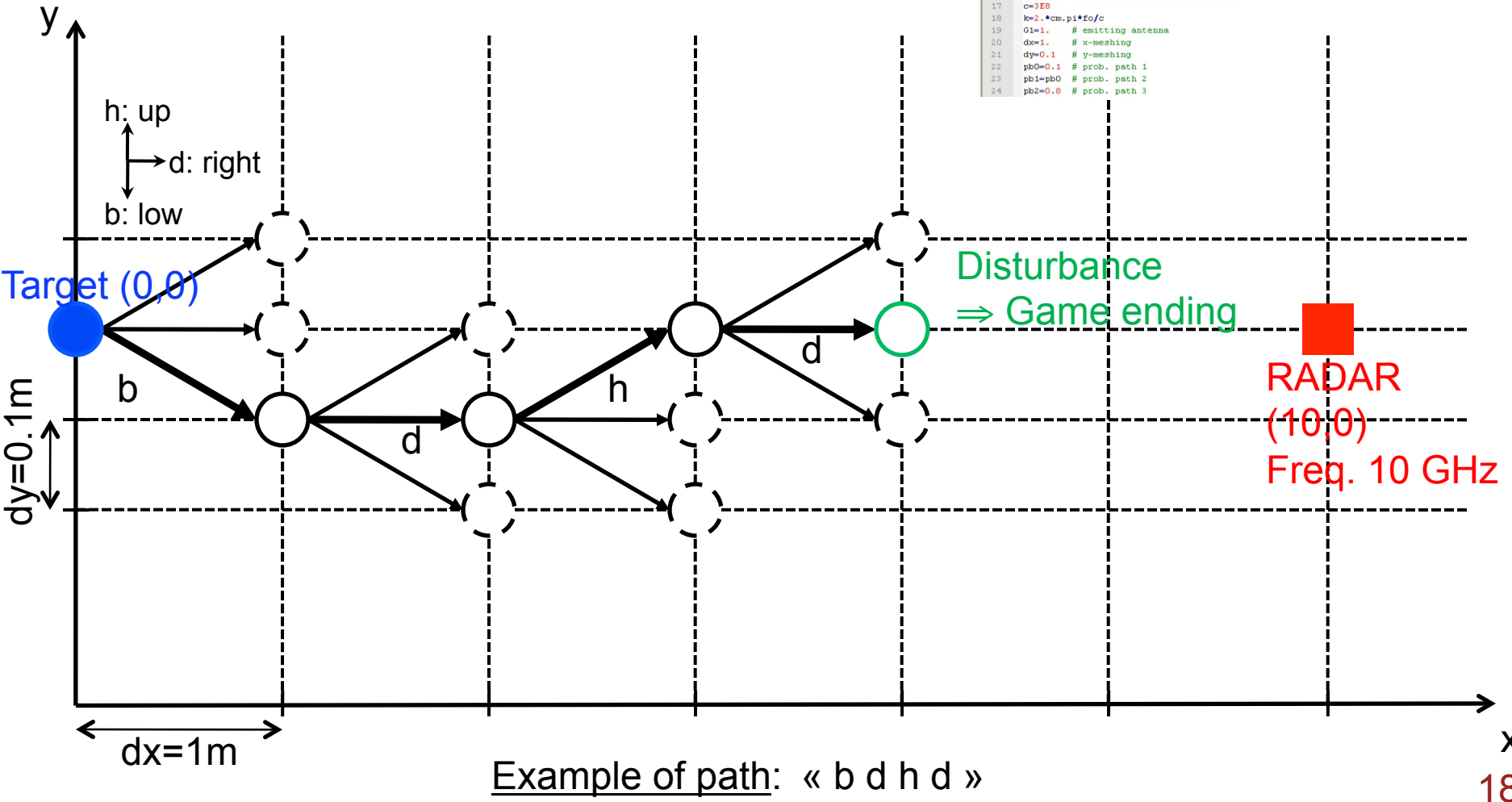
Directivity \rightarrow $\cos(\theta)$
 Soil effect \rightarrow $\cos(\alpha)$
 Receiving antenna \rightarrow h_3
 Emitting antenna \rightarrow h_2
 Green Function \rightarrow $\frac{\exp(-jkr)}{r}$

$$z'_a = \begin{bmatrix} 2z_0 & z_{32} \\ z_{32} & 2z_0 \end{bmatrix}$$



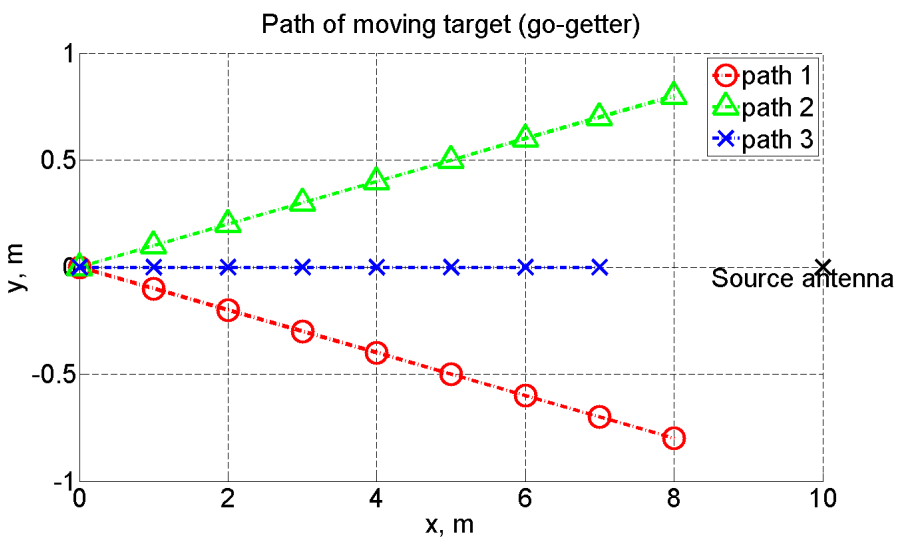
- modelling displacement (meshing)
 - « Open » playground (no hiding)
 - « Python » computation

```
radio14_2306_oral.py
1 # O. Maurice - S. Lallechere
2 # February 2014
3 # URSI RADIO 2014
4 #
5 import numpy as np
6 import cmath as cm
7 import pylab as plt
8 #
9 # declaration
10 fo=10E9 # frequency = 10 GHz
11 Xc=10. # xradar
12 xco=0. # moving target initial location
13 yco=0. # moving target initial location
14 xr=10. # fixed radar location
15 yr=0. # fixed radar location
16 ho=1. # target height = radar height
17 c=3E8
18 k=2.*cm.pi*fo/c
19 G1=1. # emitting antenna
20 dx=1. # x-meshing
21 dy=0.1 # y-meshing
22 pb0=0.1 # prob. path 1
23 pb1=pb0 # prob. path 2
24 pb2=0.8 # prob. path 3
```



- **Gain**
 - Inverse of the lowest distance reached
- « Choice / gain » projection
 - Definition of criteria to range similar families
 - Choosing « evolution directions »
 - Straightforward (« bb... bb », « dd...dd »)...
 - Change of direction (« bdh...bh »...)
- « Go-getter »
 - Straightforward path following: $g1 \rightarrow \ll b \gg$, $g2 \rightarrow \ll h \gg$ or $g3 \rightarrow \ll d \gg$
 - Probability: $P(\ll g1 \gg) = 0.1$, $P(\ll g2 \gg) = 0.1$, $P(\ll g3 \gg) = 0.8$
- « Undecided »
 - Ups and downs paths: $u1$, $u2$, $u3$
 - Probability: $P(\ll u1 \gg) = 0.25$, $P(\ll u2 \gg) = 0.25$, $P(\ll u3 \gg) = 0.5$
- « Random »
 - Randomly distributed choices, 3 simulations: $r1$, $r2$, $r3$
 - Probability: $P(\ll r1 \gg) = 1/3$, $P(\ll r2 \gg) = 1/3$, $P(\ll r3 \gg) = 1/3$

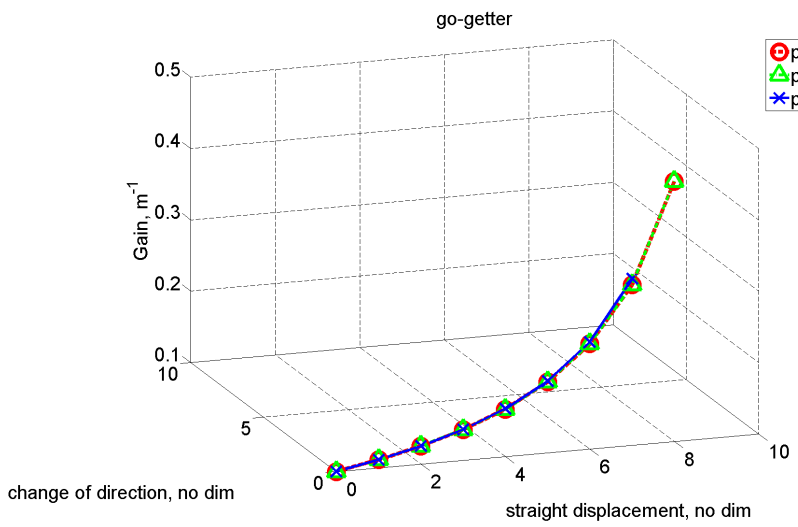
NUMERICAL RESULTS: « GO-GETTER »



Gain = $1/d_{\min}$
 EGP = Partial Gain Expectation
 (including probability)
 EG = $\sum_i(EGP_i)$

i	1	2	3
d_{\min}	2.15	2.15	3.00
EGP_i	4.64×10^{-9}	4.64×10^{-9}	6.99×10^{-2}

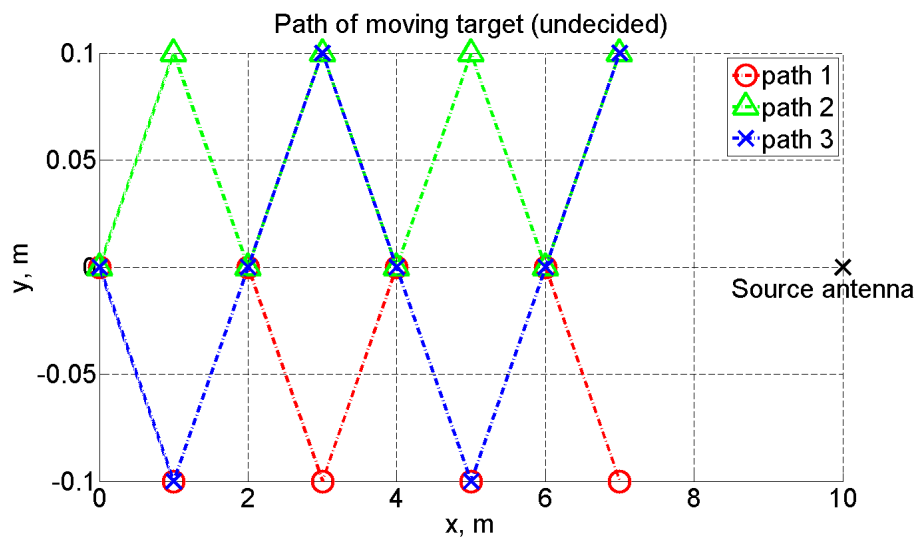
$EG = 6.99 \times 10^{-2}$



Potential gain higher for paths 2 and 3
 (symmetrical)

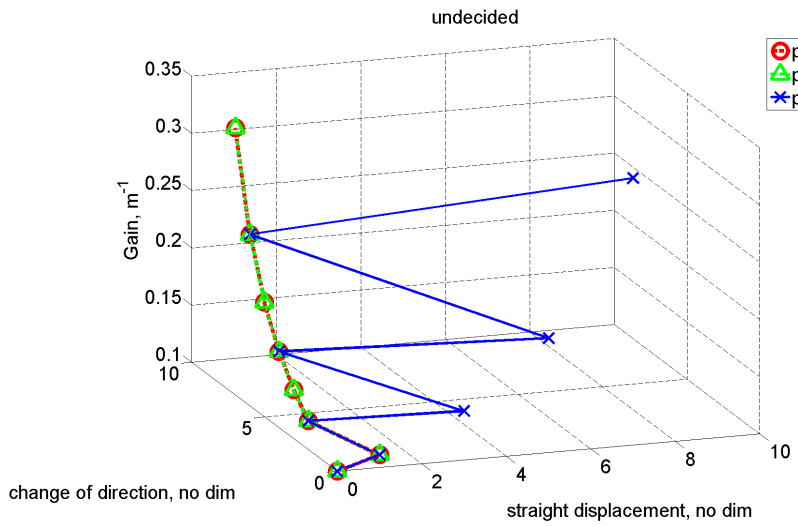
Highest EGP for path 3 (straightforward)

NUMERICAL RESULTS: « UNDECIDED »



	1	2	3
d_{\min}	3.00	3.00	3.00
EGP_i	$2.03e-5$	$2.03e-5$	$2.60e-3$

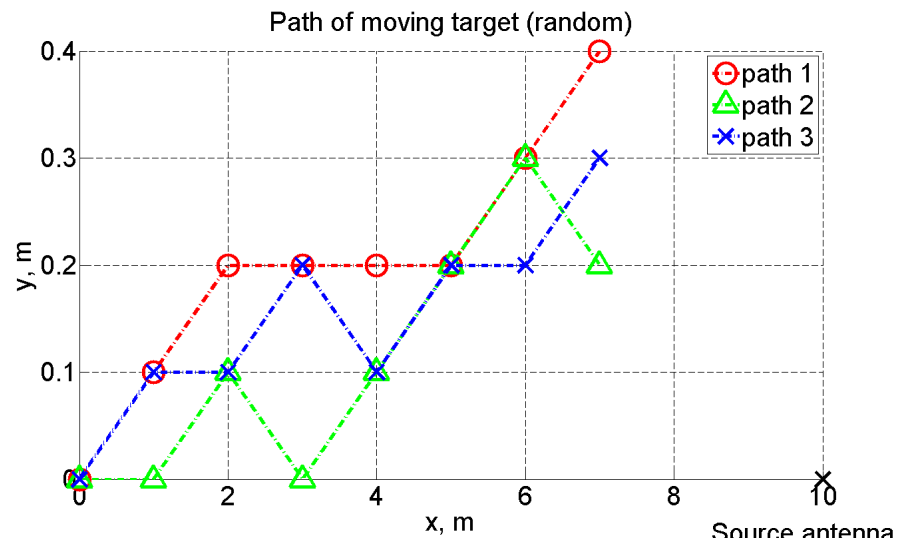
$EG = 2.64e-3$



Similar results for paths 1, 2 & 3

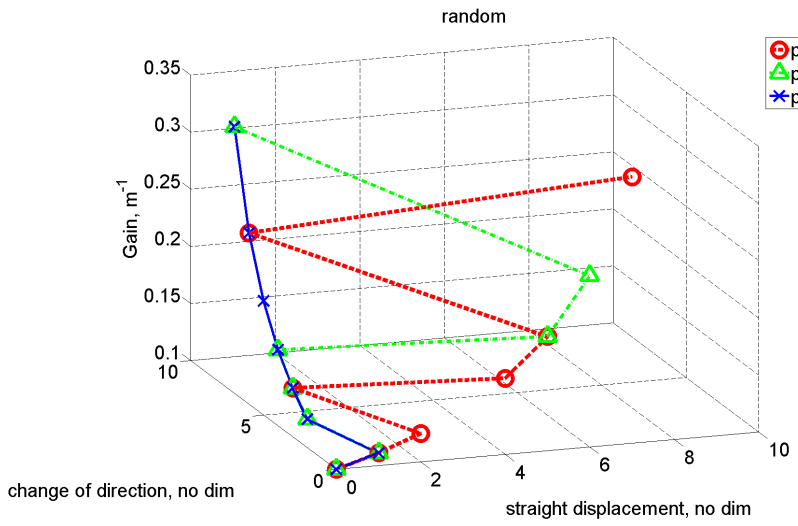
Lower EGP & EG than in case « Go-getter »

NUMERICAL RESULTS: « RANDOM »



	1	2	3
d_{min}	3.00	3.00	3.00
EGP_i	$1.52e-4$	$1.52e-4$	$1.52e-4$

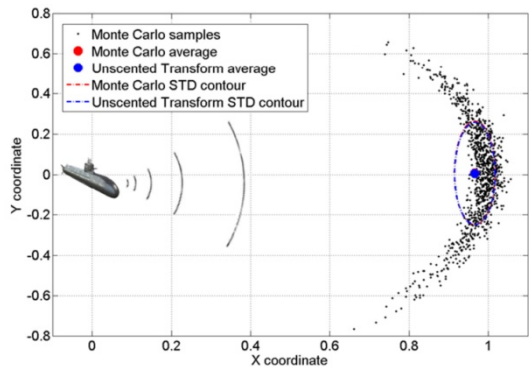
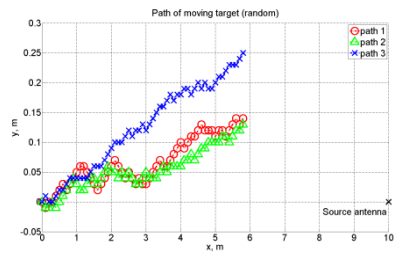
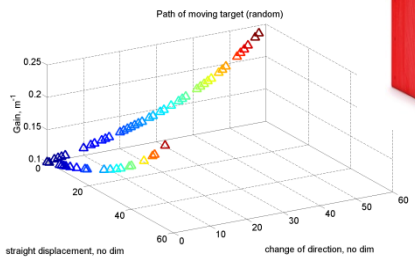
$EG=4.57e-4$



Equivalent results for paths 1, 2 & 3 (expected)

Lowest EGP & EG
 ⇒ No decision about priority paths...

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■ Toolbox for complex processes modelling

- Huge diversity of models (codes, analytical formalisms, ...)
- Aims \neq Common & Universal modelling

■ Illustration from EM game modelling

- Tensorial Analysis of Networks formalism
- Gamma matrix, tenfolds
- Evolution tree, probability & gain

■ Forthcoming works

- Complete description of complex issue (electronic war...)
- Enriching previous models
→ Probability, uncertainty, reliability...

M. Ferber, Méthodologie de prise en compte a priori de la CEM dans l'optimisation robuste de systèmes d'électronique de puissance, PhD Thesis, University of Lyon, December 2013

B. Ravelo et al., modelling of complex RF environment effect on RF circuits EMC analysis, RADIO2014, Mauritius, 2014