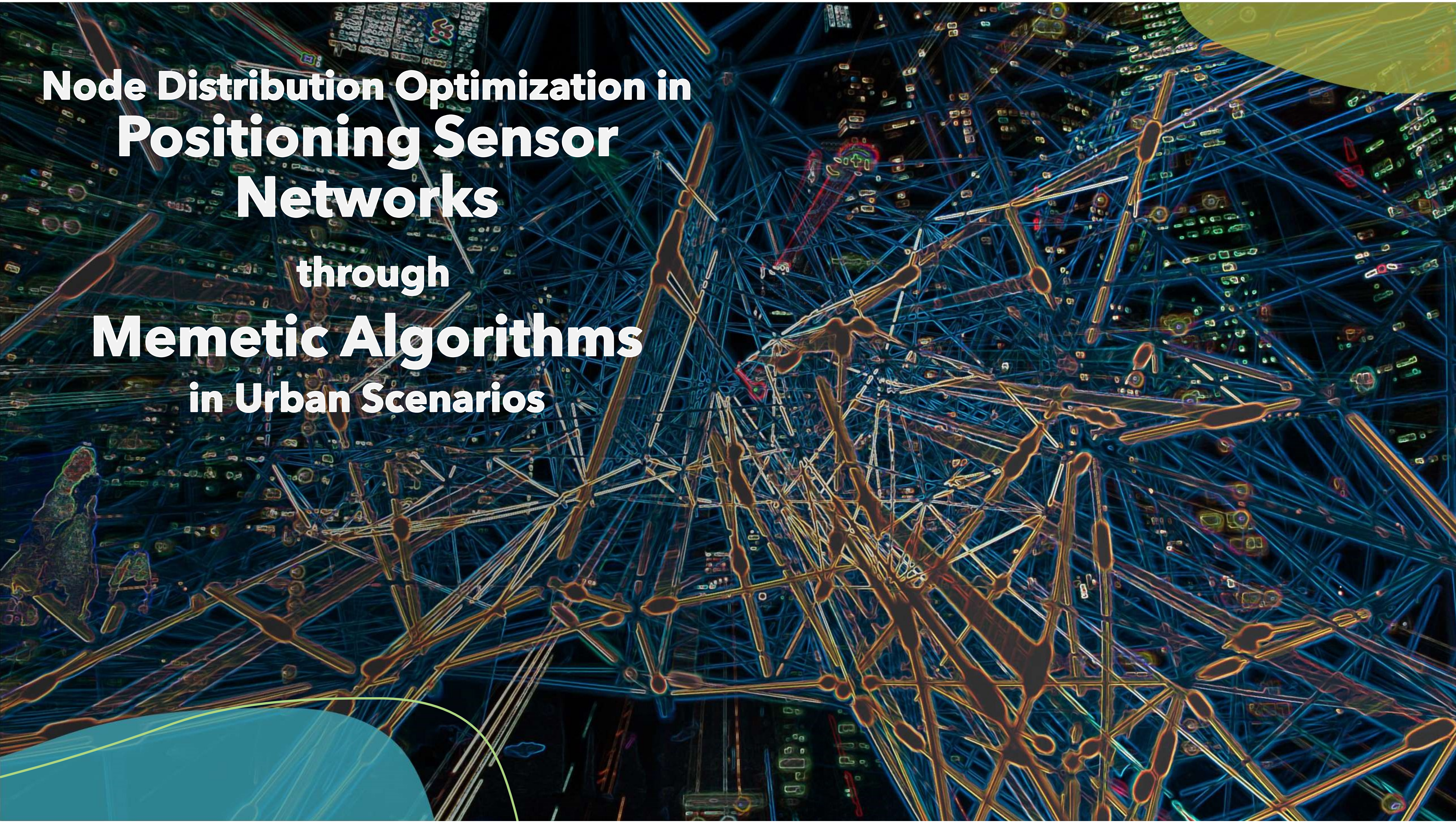
Node Distribution Optimization in Positioning Sensor Networks through Memetic Algorithms in Urban Scenarios



1. Introduction

We analyze the deployment of a synchronous TDOA architecture in urban scenarios.

It is necessary an ad-hoc sensor distribution which must be achieved through the solution of the Node Location Problem (NLP) that is a combinatorial problem that has been assigned as NP-Hard.

2. Cramèr-Rao Bound

for the TDOA Architecture

Its use is widespread since it provides the least achievable error by any positioning algorithm in a defined sensor distribution

$$J_{mn} = \left(\frac{\partial h(TS)}{\partial TS_m}\right)^T \boldsymbol{R}^{-1}(\boldsymbol{TS}) \left(\frac{\partial h(TS)}{\partial TS_n}\right) + \frac{1}{2} tr\left(\boldsymbol{R}^{-1}(\boldsymbol{TS}) \left(\frac{\partial R(TS)}{\partial TS_m}\right) \boldsymbol{R}^{-1}(\boldsymbol{TS}) \left(\frac{\partial R(TS)}{\partial TS_n}\right)\right)$$

Covariance matrix must be modeled according to the system uncertainties: noise in Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) environments and clock error.

$$\sigma_{TDOA_{ij}}{}^2 = \frac{c^2}{B^2 \left(\frac{P_T}{P_n}\right)} PL(d_0) \left[\left(\frac{d_{i_{LOS}}}{d_0}\right)_{CS_i} + \left(\frac{d_{i_{NLOS}}}{d_0}\right)_{CS_i}^{\frac{n_{NLOS}}{n_{LOS}}} + \left(\frac{d_{j_{LOS}}}{d_0}\right) + \left(\frac{d_{j_{NLOS}}}{d_0}\right)^{\frac{n_{NLOS}}{n_{LOS}}} \right]^{n_{LOS}}$$

$$+ \frac{1}{l} \sum_{k=1}^{l} \{ |T_i - floor_{TR}(T_i + U_i - U_0 + T_0(\eta_i - \eta_0) + T_i \eta_i)| c^2 \} + \frac{1}{l} \sum_{k=1}^{l} \{ |T_j - floor_{TR}(T_j + U_j - U_0 + T_0(\eta_j - \eta_0) + T_j \eta_j)| c^2 \}$$

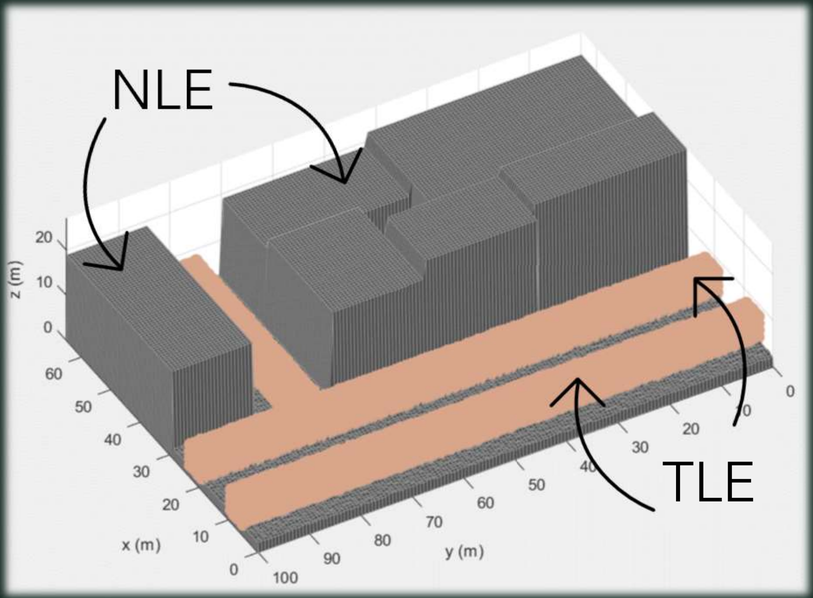
3. The scenario of simulations

Node Location Environment (NLE) - The possible locations for the architecture sensors

Target Location Environment (TLE) - The covered region for the navigation of the targets

Hyperparameters

Frequency of emission	5.465 GHz
Transmission power	1 W
Bandwidth	100 MHz
Receptor sensibility	-90 dBm
Mean noise power	-94 dBm
LOS path loss exponent	2.1[1]
NLOS path loss exponent	4.1[2]
Clock frequency	1 GHz
Frequency–drift	U{-15, 15} ppm



4. Memetic Algorithm

MA uses a GA combined with a local search procedure to obtain an optimized sensor distribution in the NLP problem.

$$ff = 1 - \left(\frac{\overline{RMSE}}{RMSE_{ref}}\right)^2$$

The quality of each individual of the population is measured through a fitness function evaluation considering the Root Mean Square Error (RMSE) which is obtained through the trace of the CRB model

Local Search (LS)

VND

It explores the neighborhood to obtain the best-adapted individual in a bounded region

Pseudo-fitness function

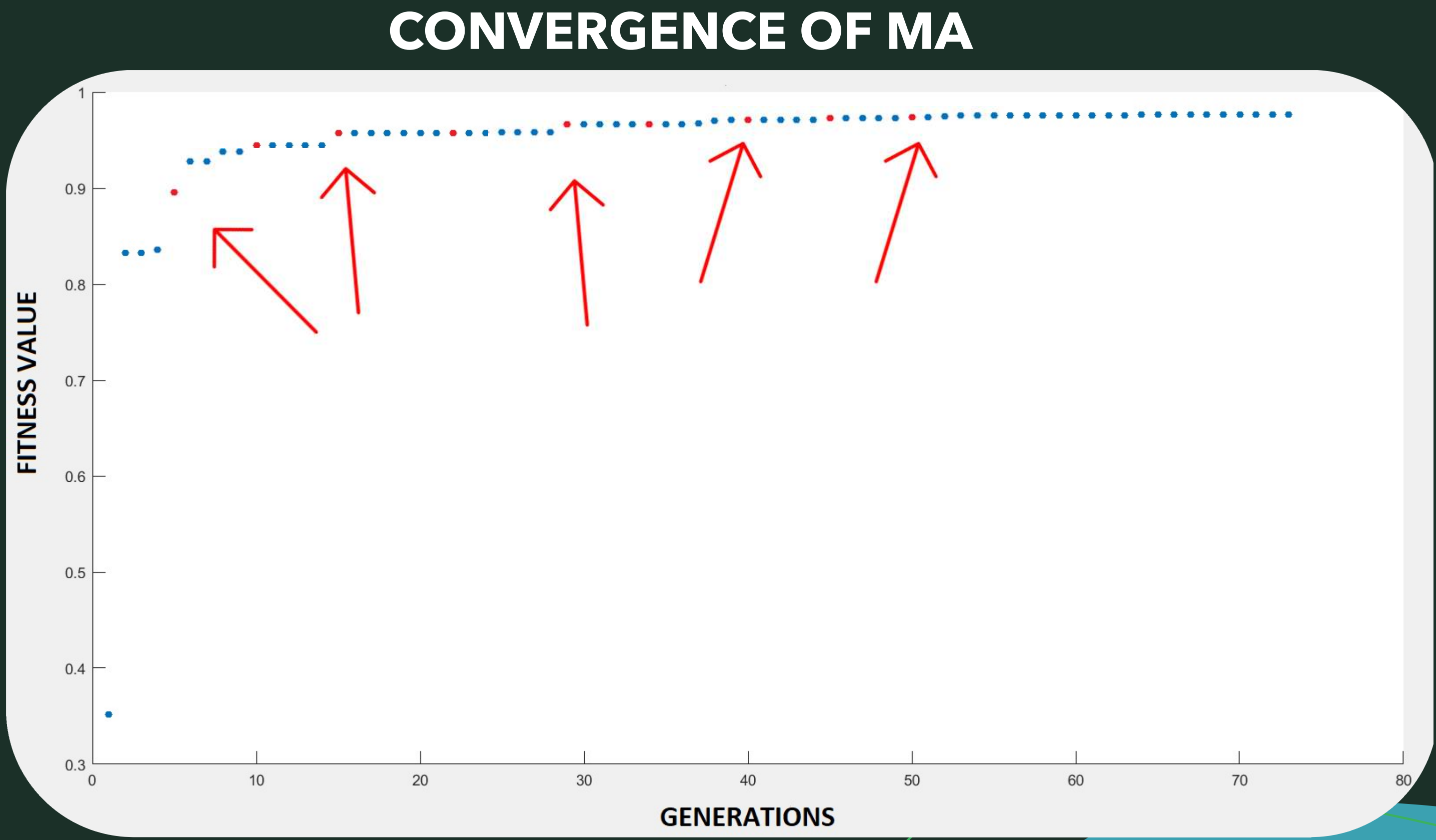
It is based on the exclusive analysis of the LOS/NLOS links

The dissimilarities among the individuals

The set of individuals of the LS is obtained through the measurement of the dissimilarities among the individuals of the population through the Hamming distance

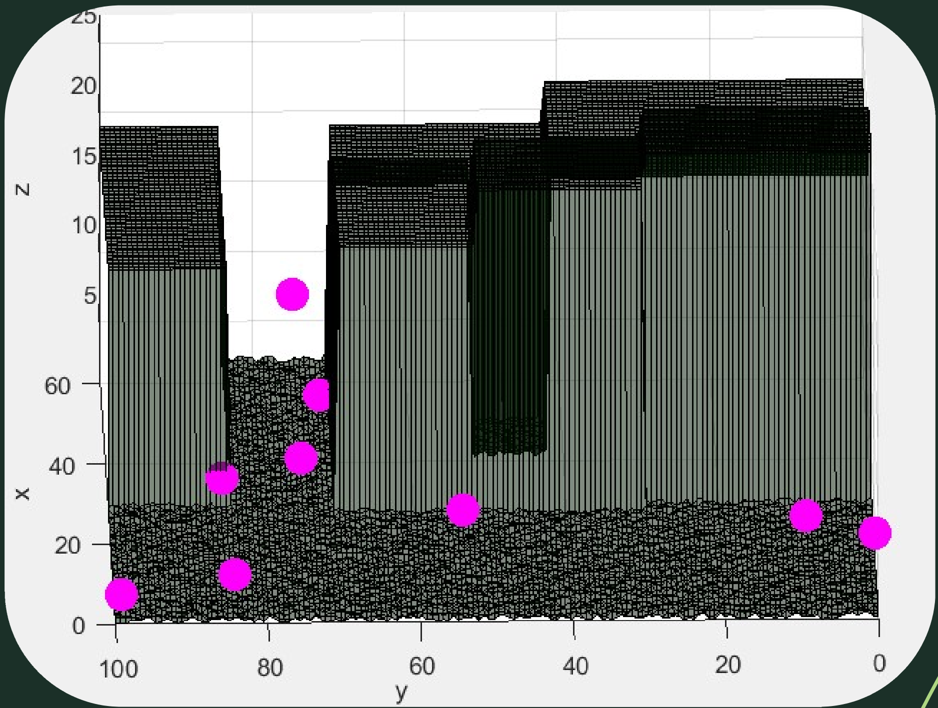
$$ff_{LS} = \frac{1}{\sum_{k=1}^{T}\sum_{i=1}^{N}\left[d_{iLOS}^{nLOS} + d_{iLOS}^{nLOS}\right] + \sum_{k=1}^{T}\sum_{j=1}^{N}\left[d_{jLOS}^{nLOS} + d_{jLOS}^{nLOS}\right]}$$

5. Results



CONVERGENCE OF MA
FITNESS VALUE
GENERATIONS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
10
20
30
40
50
60
70
80

Memetic Algorithm for the 9 sensor distribution



Optimal distribution