Modeling and Control of Cyber-physical systems
Project I: Distributed localization in CPSs

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- In this project activity, the students will simulate an indoor localization/tracking system through a wireless sensor network (WSN). The sensors acquire the received signal strength (RSS) of a signal broadcast by a target to be located.
- Given the description of the physical setting (e.g., dimension of the room, RSS model), the students will simulate the system and analyse the obtained results
- Groups of 3-4-(5) students; it is required to write a short report ($3-4$ pages + code) with results, analysis and conclusions
- The project must be completed and uploaded (on the course web page) no later than 5 days before the exam

Aims of the Project

1. Simulation of a localization/tracking problem in WSNs
2. Implementation of a localization/tracking distributed algorithm
3. Analysis of the results

Physical setting

- Environment: square room of 100 m^2
- Grid: $p = 100$ square cells of 1 m^2
- Reference points: centers of the cells
- RSS model: indoor empirical model defined by the IEEE 802.15.4 standard

$$RSS(d) = \begin{cases} P_t - 40.2 - 20\log d + \eta & d \leq 8 \text{ m} \\ P_t - 58.5 - 33\log d + \eta & d > 08 \text{ m} \end{cases} \quad (1)$$

where $P_t = 25$, η is a Gaussian noise $\eta \sim \mathcal{N}(0, \sigma^2)$, $\sigma = 0.5$.

WSN

- $n = 25$ sensors
- Deployment
  - uniformly at random positions; each sensor is connected with sensors at distance $\leq r$. For example, $r = 4m$. Check whether the network is connected.
  - grid topology: the sensors are deployed on a grid 5×5; sensors are connected to 4 closest sensors (3 or 2 on the boundaries)

Training phase

- Each sensor takes $m = 1$ measurement for each reference point
- Global dictionary $A \in \mathbb{R}^{mn,p}$

TBD Orthogonalization of A

Runtime phase

- Each sensor takes one measurement from the target
- Runtime measurements $y = (y_1, \ldots, y_n)^T$

TBD Centralized localization: we assume to collect A and y in a central processing unit and we perform the localization using the iterative soft thresholding (IST) algorithm (parameters $\lambda = 10^{-4}$, $\tau = 0.7$)

TBD Decentralized localization: we perform the localization in-network using a distributed iterative soft thresholding (DIST) algorithm (parameters $\lambda = 10^{-4}$, $\tau = 0.7$)

TBD Tracking [...]

Results and analysis

- Run the experiments several times (e.g., 50) and collect some data:
  - Which is the rate of success (success = estimate the correct reference point)? When the algorithm is not successful, how far is the estimated target?
  - How many iterations are necessary on average? How many times each communication link is used on average?
  - Which is the relationship between the convergence time and the essential spectral radius (= 2nd eigenvalue) of the graph?

The points illustrated above are necessary/sufficient to complete the project activity.

Below, some possible extensions and further analyses are suggested. At least one extension is recommend to for larger groups (5 students).

Extensions

1. Change the paramaters, e.g., modify n, r, increase σ (add noise),...
2. Compare to other algorithms, e.g. nearest neighbors
3. Time-varying WSN topology: for example, what happens if some sensors switch off during the localization procedure?
4. Presence of broken sensors: non collaborative senors, sharing false information
5. Optimization of the communications: could you conceive strategies to reduce the number of transmitted messages?
6. Try to localize $k > 1$ targets