Simultaneous Power-Based Localization of Transmitters for Crowdsourced Spectrum Monitoring

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Need for spectrum monitoring

As SDR becomes ubiquitous

Present: externally attached SDR

Future: mobile devices with integrated SDR

More threats will appear

- Virus affected multiple SDRs leading to jamming
- Selfish users altering SDR radio

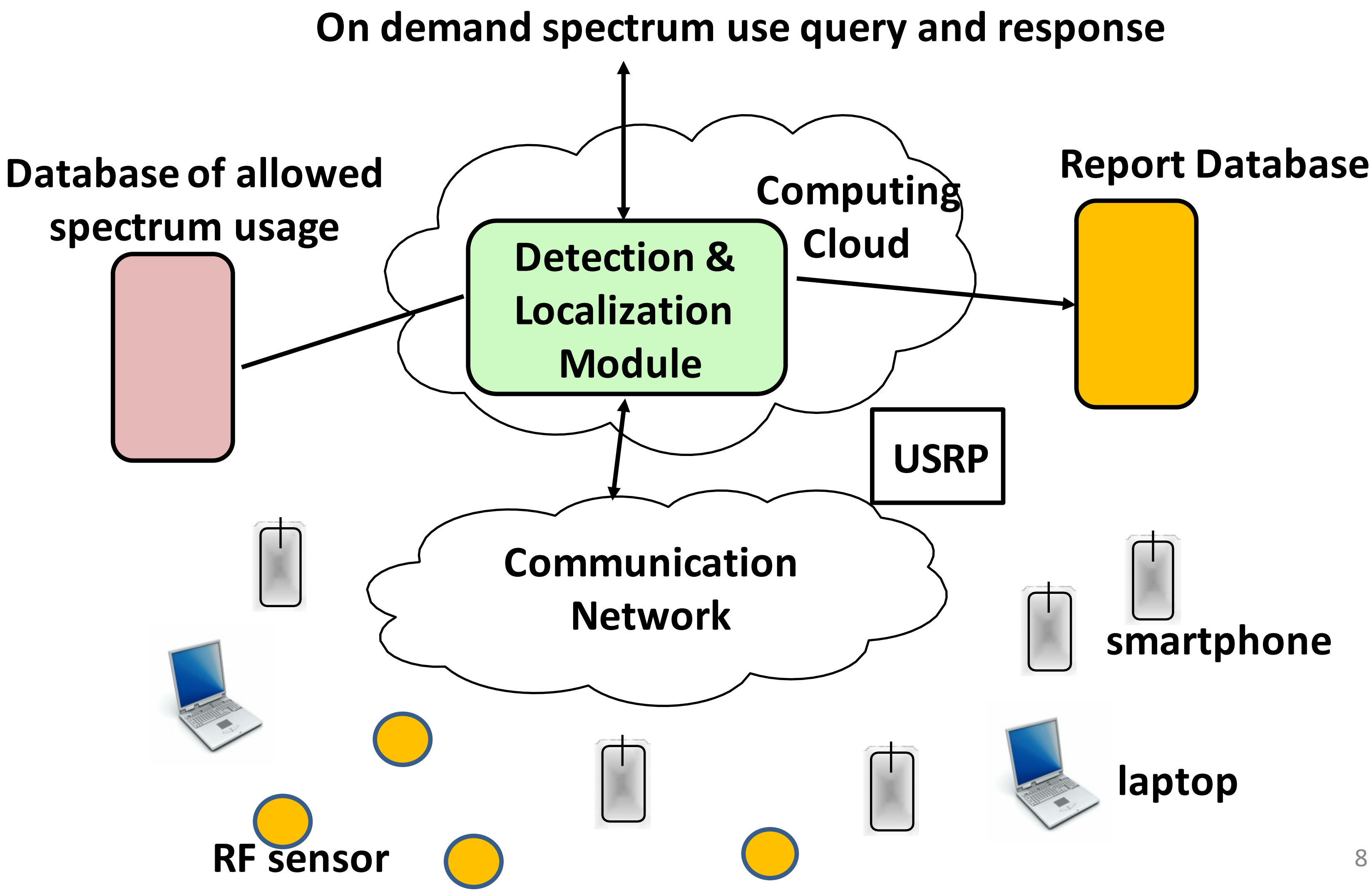
How to prevent spectrum offence?

What method exists?

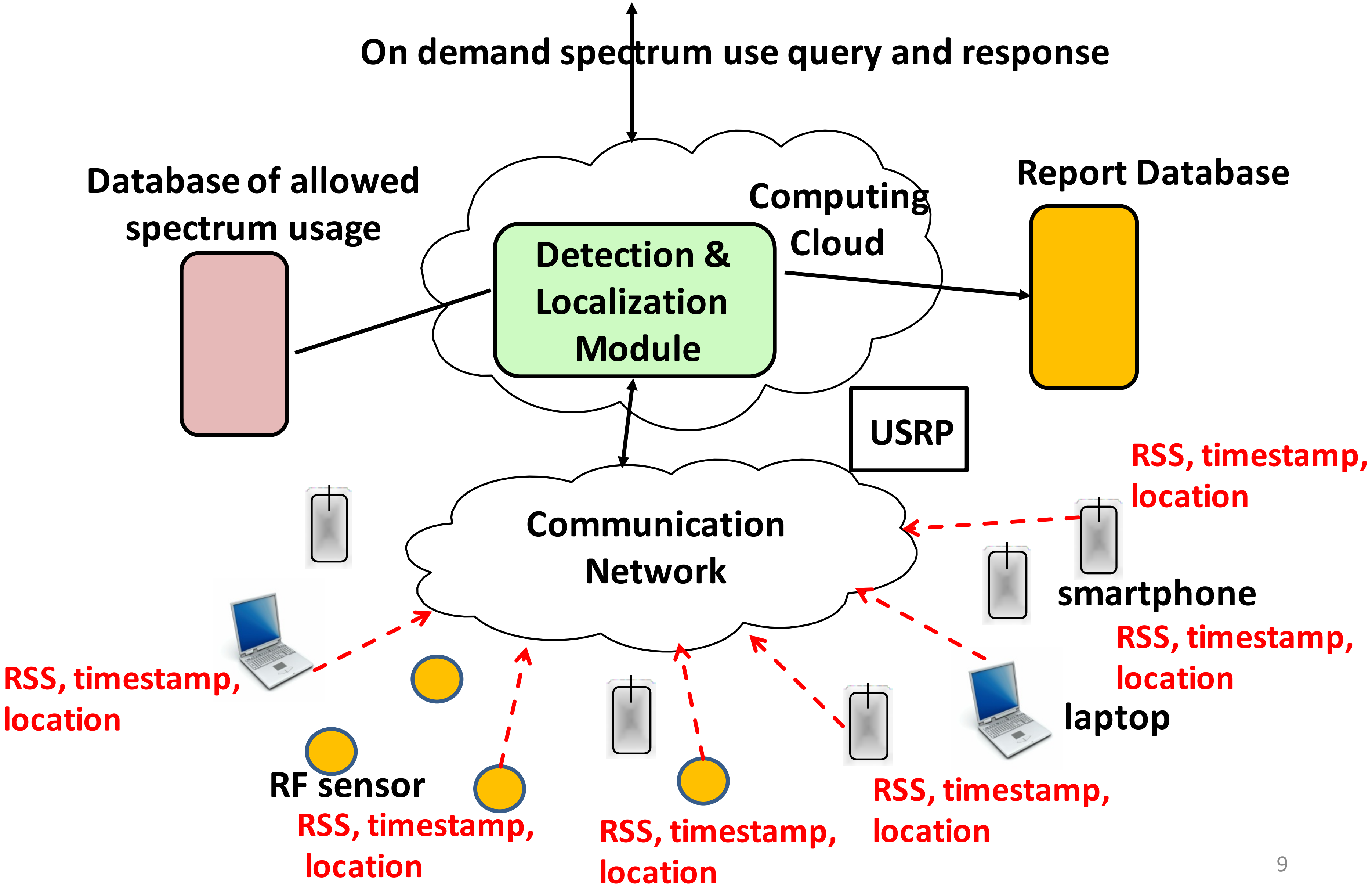
- FCC enforcement bureau
  - Relies on complaints and manual investigation
- Drawbacks
  - Time consuming
  - Human extensive
  - Expensive

Need **efficient** spectrum monitoring

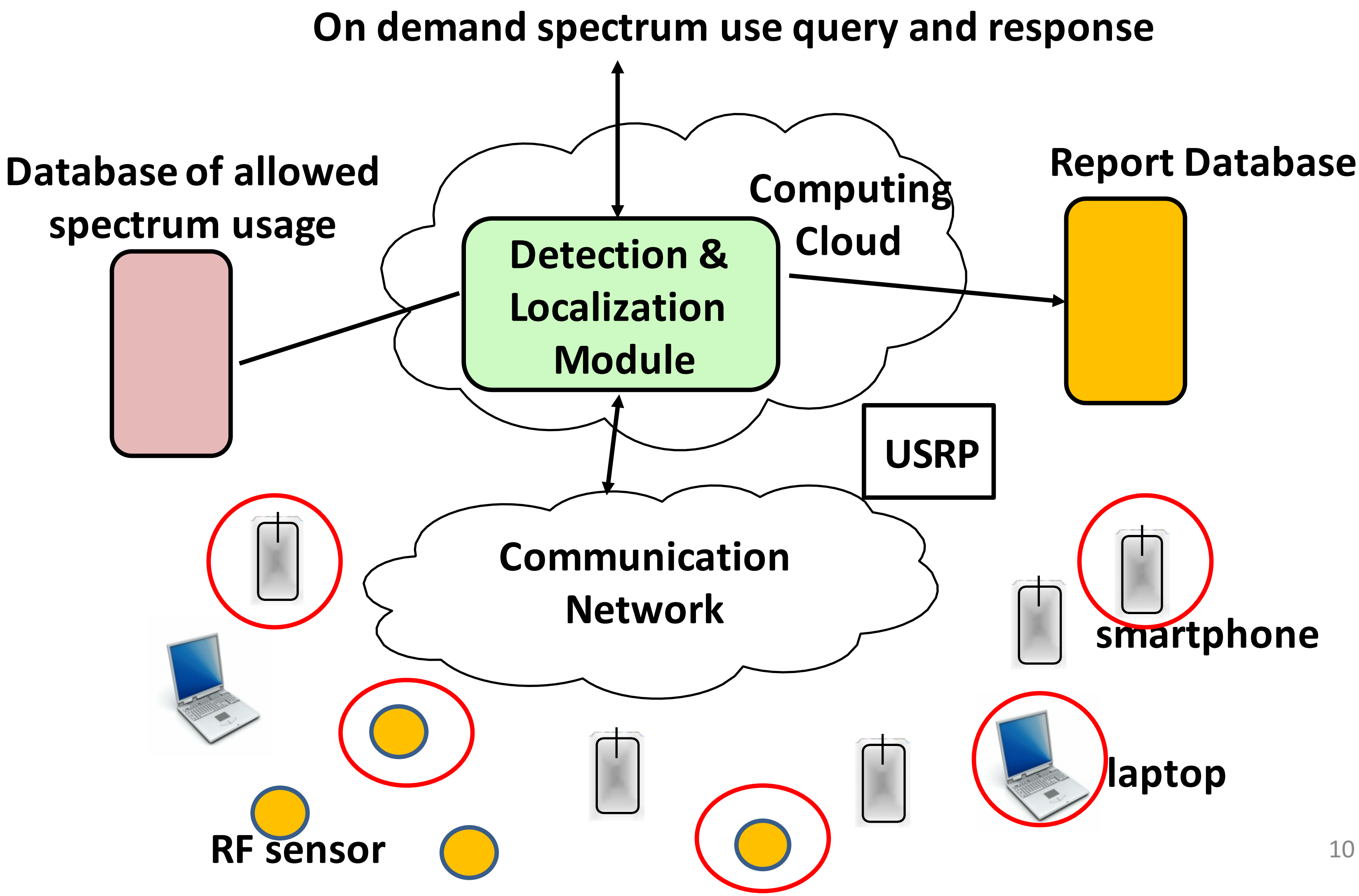
Detecting, localizing spectrum offenders using Crowdsourcing



Report RSS, timestamp, location



Multi transmitter localization and selection of receivers



SPLOT

Simultaneous Power-Based **Localization** of Transmitters for **Crowdsourced** Spectrum Monitoring

Outline

- SPLOT
  - Multi-source localization
- Selecting receivers and incentivizing them
  - For coverage of monitored area
  - Motivation to participate
- Experiments
  - Indoor, outdoor and test bed
- Summary

Heart of SPLOT

Localization of **simultaneously active unknown** number of transmitters

Challenges in multi source localization

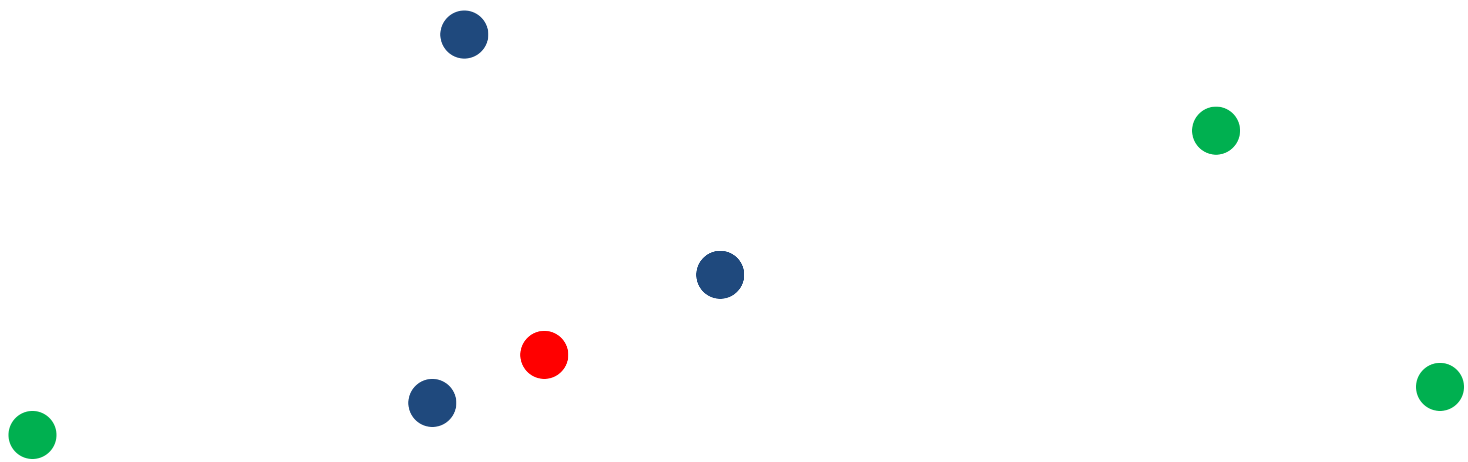
- Unknown number of transmitters
- Received power not separable at receiver
- Mobility of transmitters and receivers
- Unpredictability of receivers participation

Related work

- Quasi Expectation Maximization [Nelson’2009]
    - Number of transmitters known
- Locating multiple transmitters using mobile robots [Kim’2014]
    - Receiver’s motion controlled, predictable

Multi source localization in SPLOT

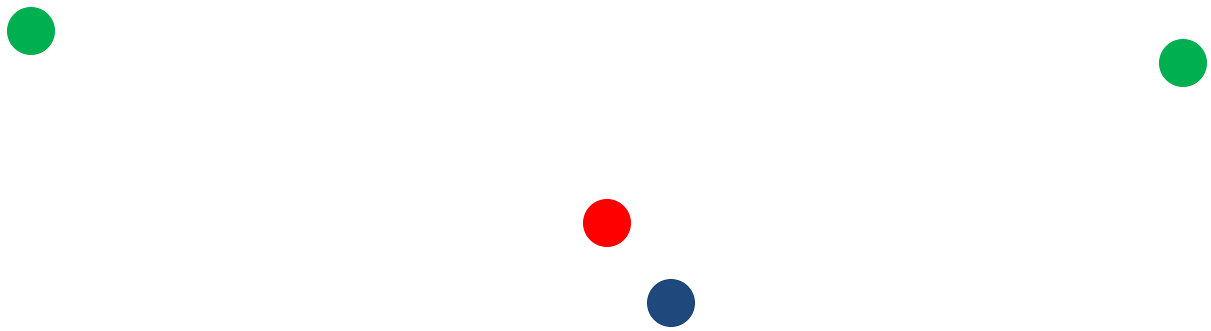
- Observation 1 - receivers near transmitter observe higher power



- Transmitter
- Receiver with high received power
- Receiver with low received power

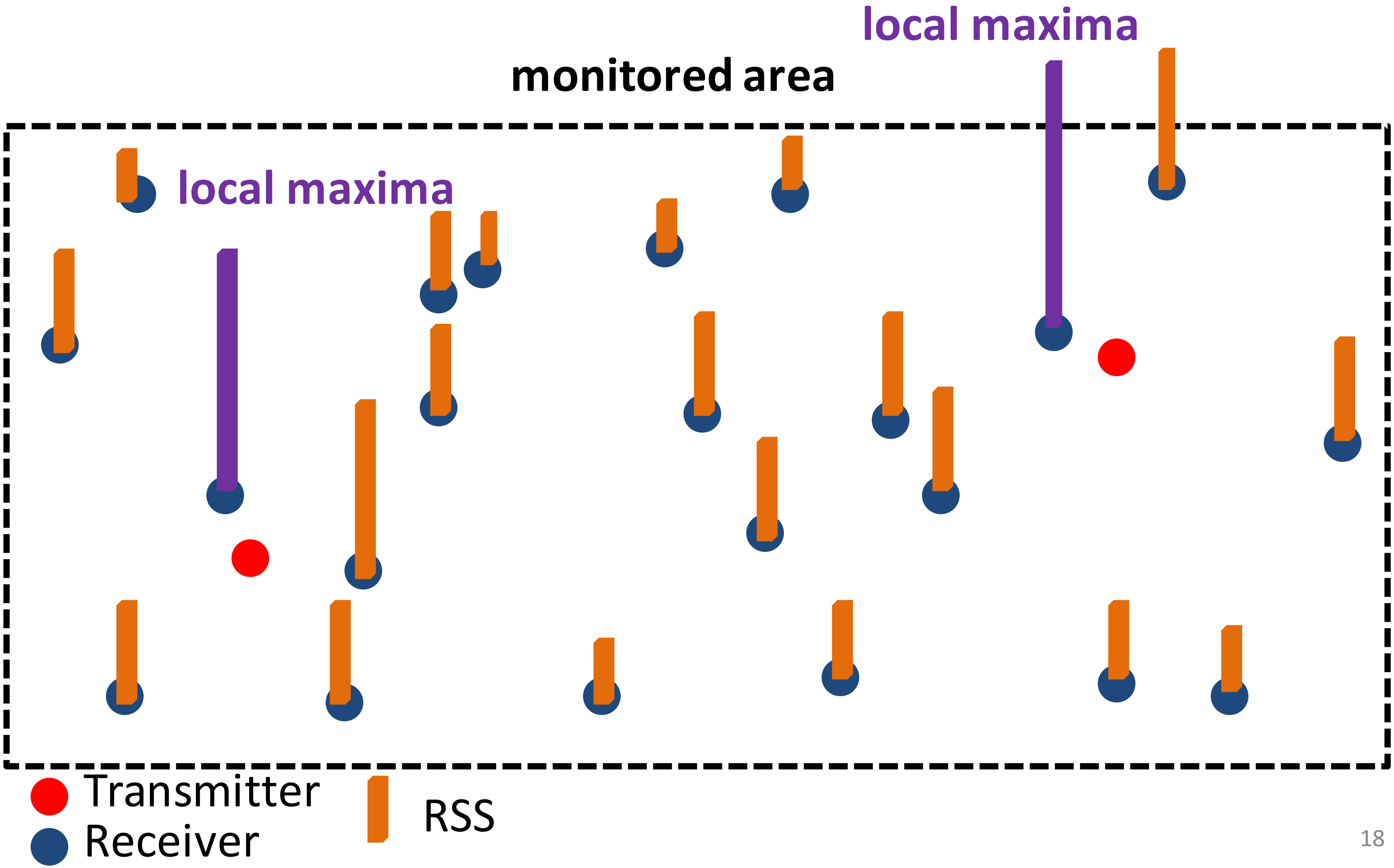
Multi source localization in SPLOT

- Observation 2 - RSS at receiver primarily affected by nearest transmitter



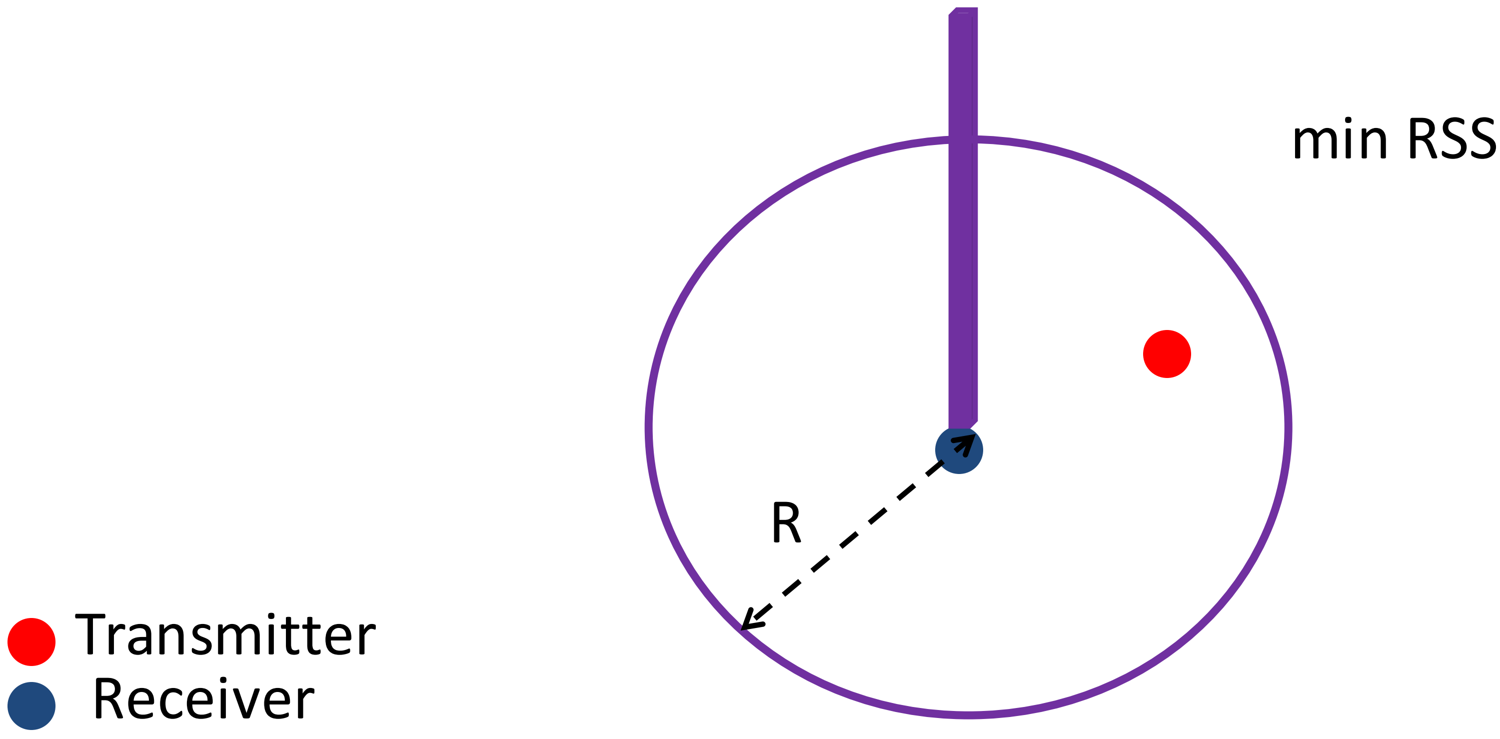
- Transmitter with high impact on receiver’s RSS
- Transmitter with low impact on receiver’s RSS
- Receiver

Spatial RSS map

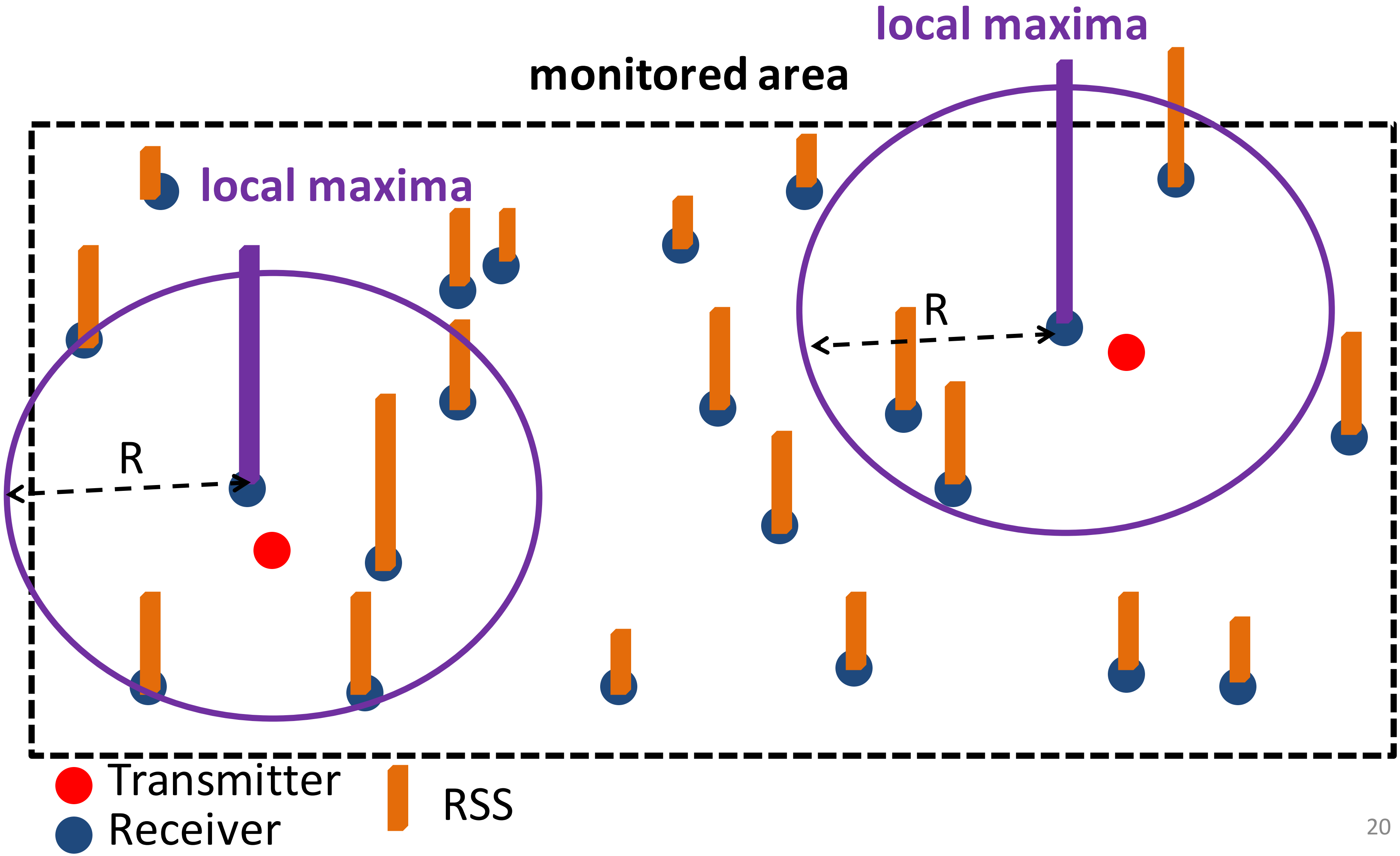


What is local maxima?

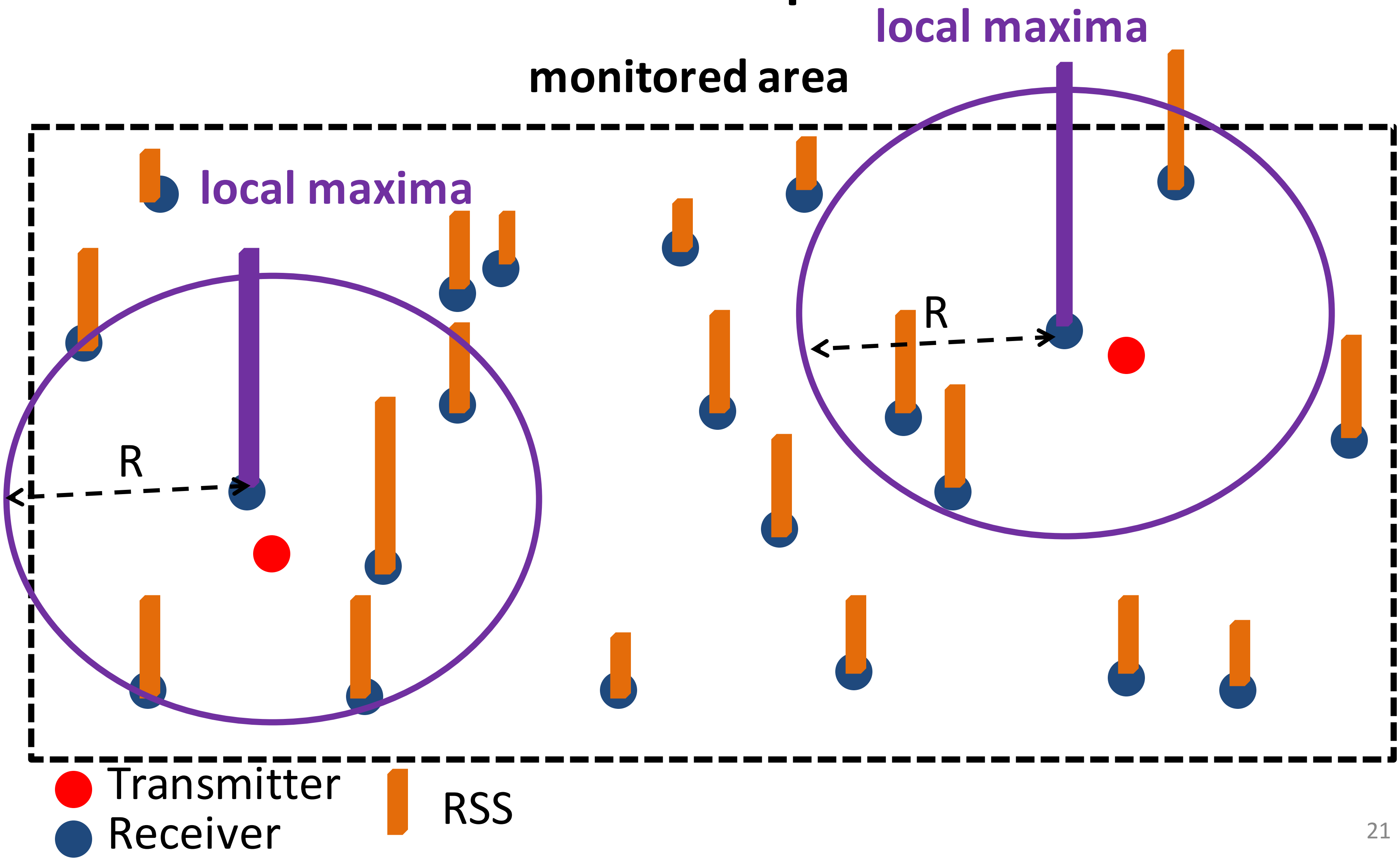
- If above minimum RSS that receiver would observe when there is a transmitter nearby and maximum locally



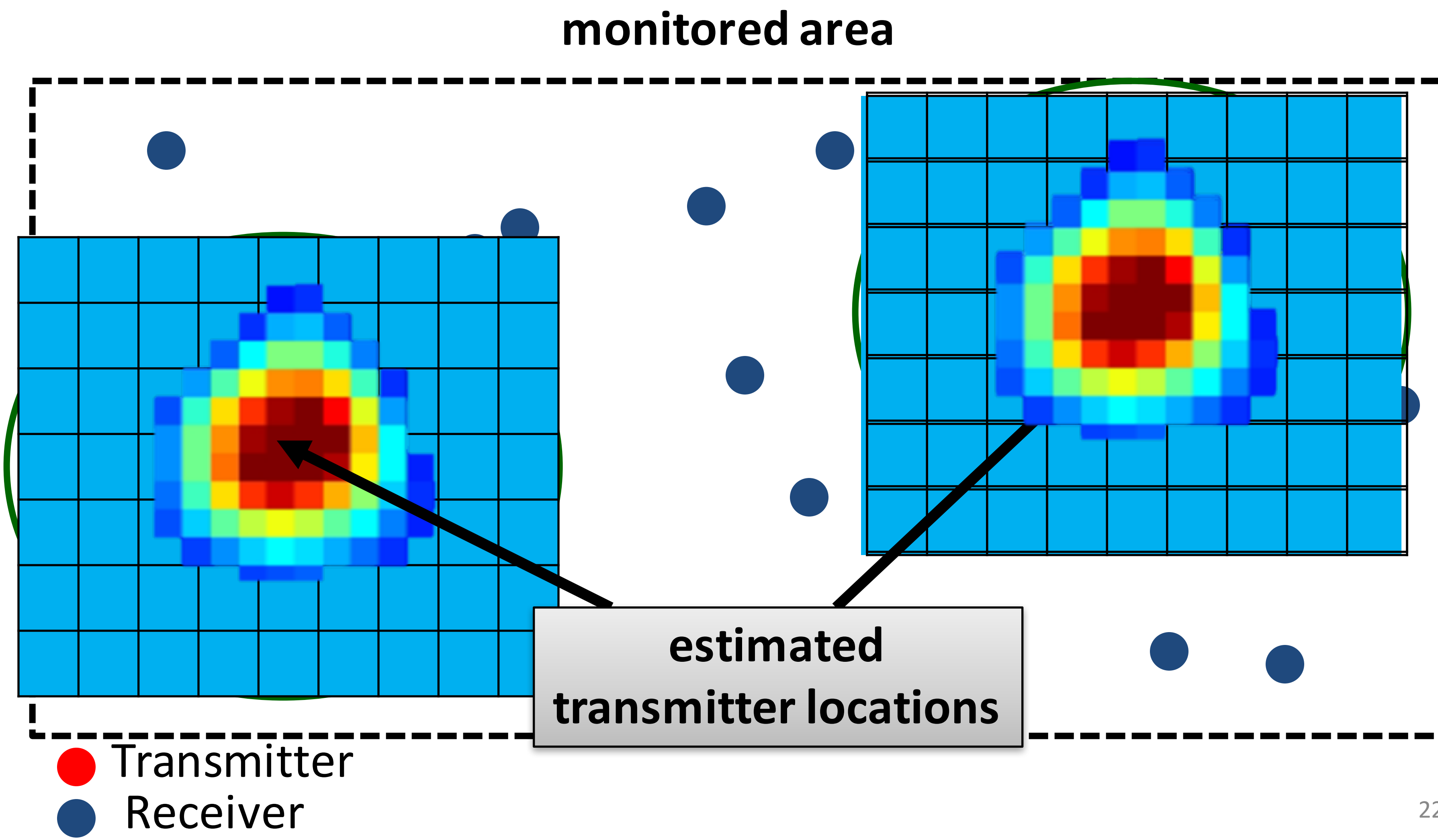
Approximate region of presence for each transmitter



Set of single transmitter localization problems



Solve using matrix inversion



Matrix inversion approach

weight matrix

RSS observed by L receivers

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ y_L \end{bmatrix} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1Q} \\ w_{21} & w_{22} & \cdots & w_{2Q} \\ \cdots & \cdots & \cdots & \cdots \\ w_{L1} & w_{L1} & \cdots & w_{LQ} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_Q \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \cdots \\ n_L \end{bmatrix}$$

noise and fading

transmit power field

where

$$W_{ij} = \begin{cases} d_{ij}^{-\eta_p} \; for \; d > \min PL \\ \min PL^{-\eta_p} \quad otherwise \end{cases}$$

Matrix inversion approach

weight matrix

RSS observed by L receivers

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ y_L \end{bmatrix} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1Q} \\ w_{21} & w_{22} & \cdots & w_{2Q} \\ \cdots & \cdots & \cdots & \cdots \\ w_{L1} & w_{L1} & \cdots & w_{LQ} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_Q \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \cdots \\ n_L \end{bmatrix}$$

noise and fading

transmit power field

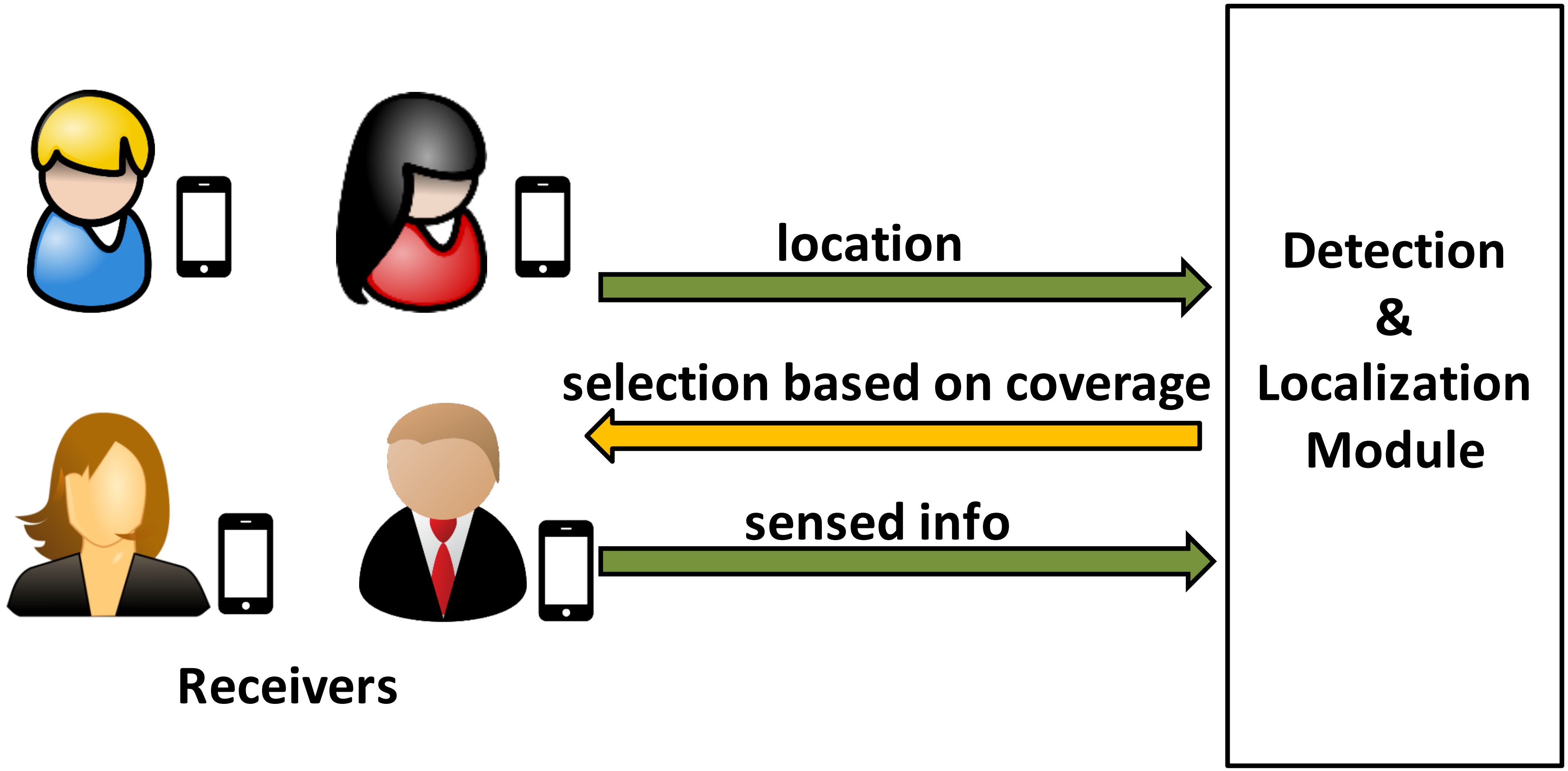
- Estimate $\hat{x}$ from y
- Estimated transmitter location = $\arg\max X$
- Ill-posed inverse – use least square regularization

Selection of receivers

Which devices to select for Crowdsourcing?

maximum spatial coverage

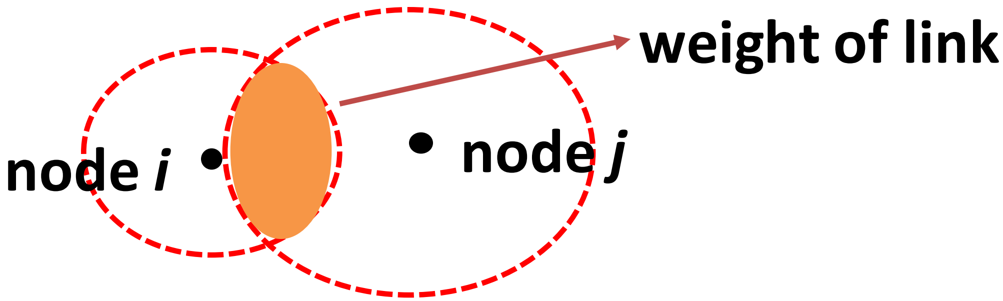
Sampling model



Sampling is repeated after time interval T

Receivers selection overview

- Construct weighted graph $G = (V, E, W)$



- Define new metric - degree expansion

$$DX(S) = \sum_{i \in N(S)} \min_{j \in S} w_{i,j}$$

  - Minimum overlap a set with its neighbors

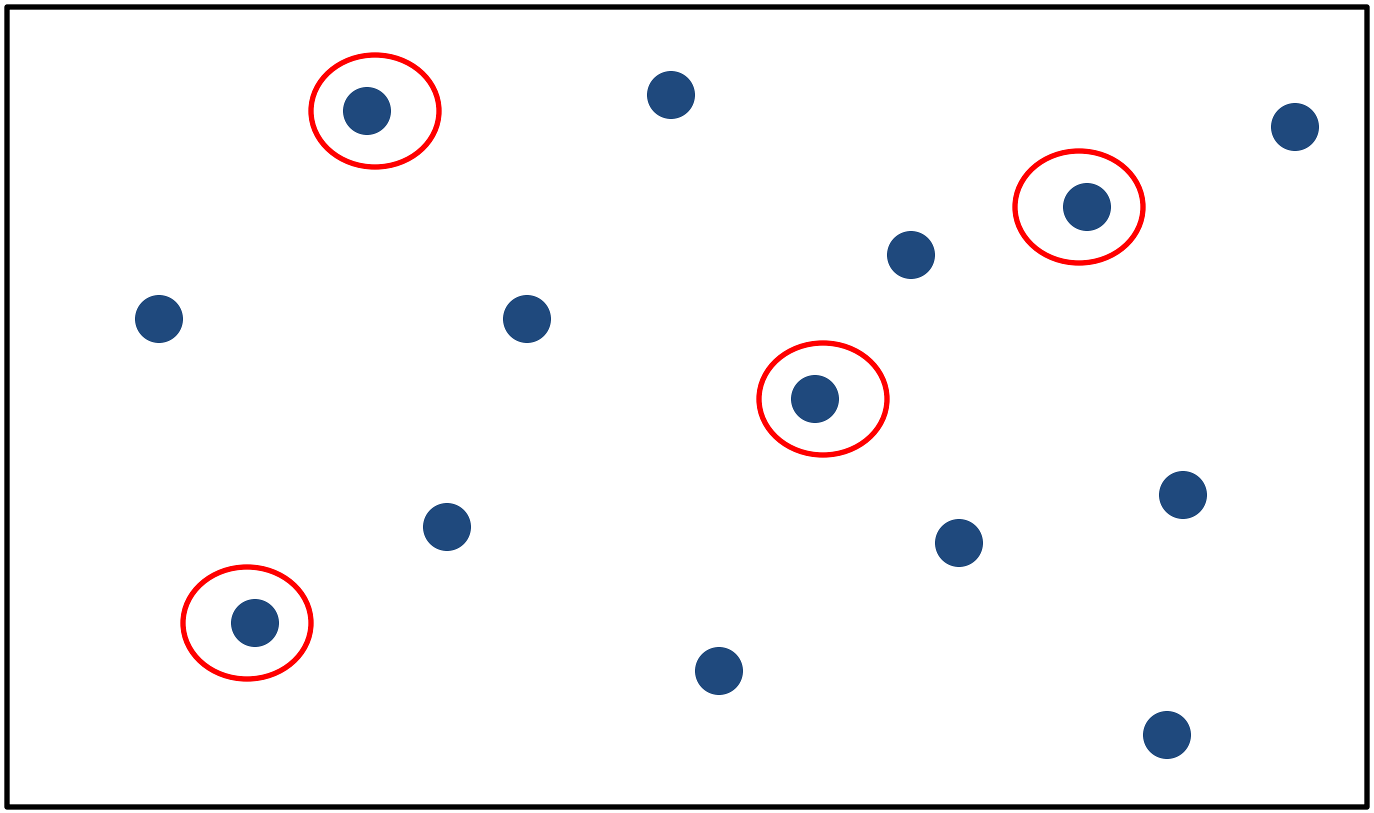
neighborhood of a set

Maximizing coverage

- For maximizing coverage solve: $\arg\max_{S \subset V} DX(S)$

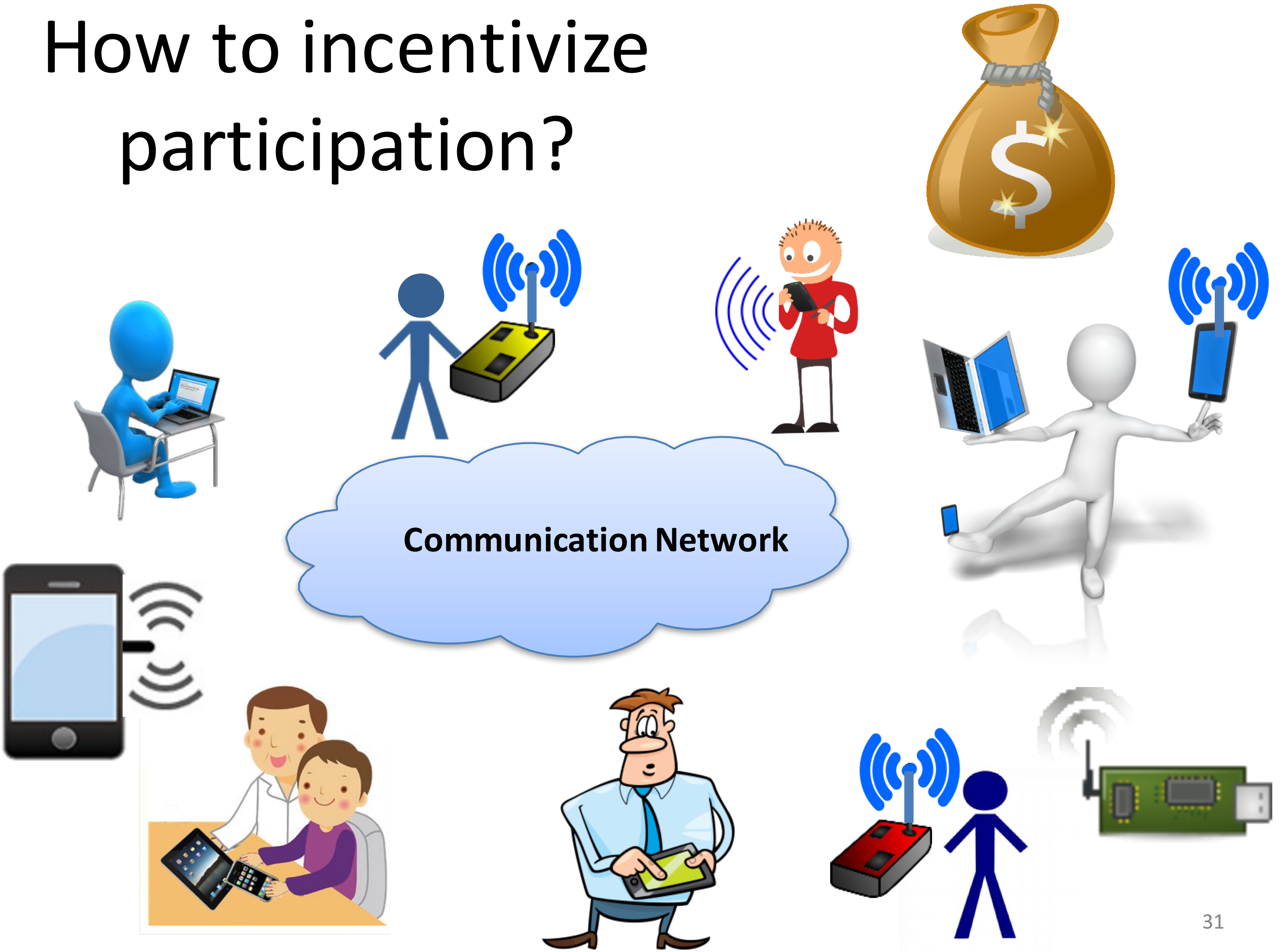
NP-hard problem

Receiver selection by Greedy algorithm

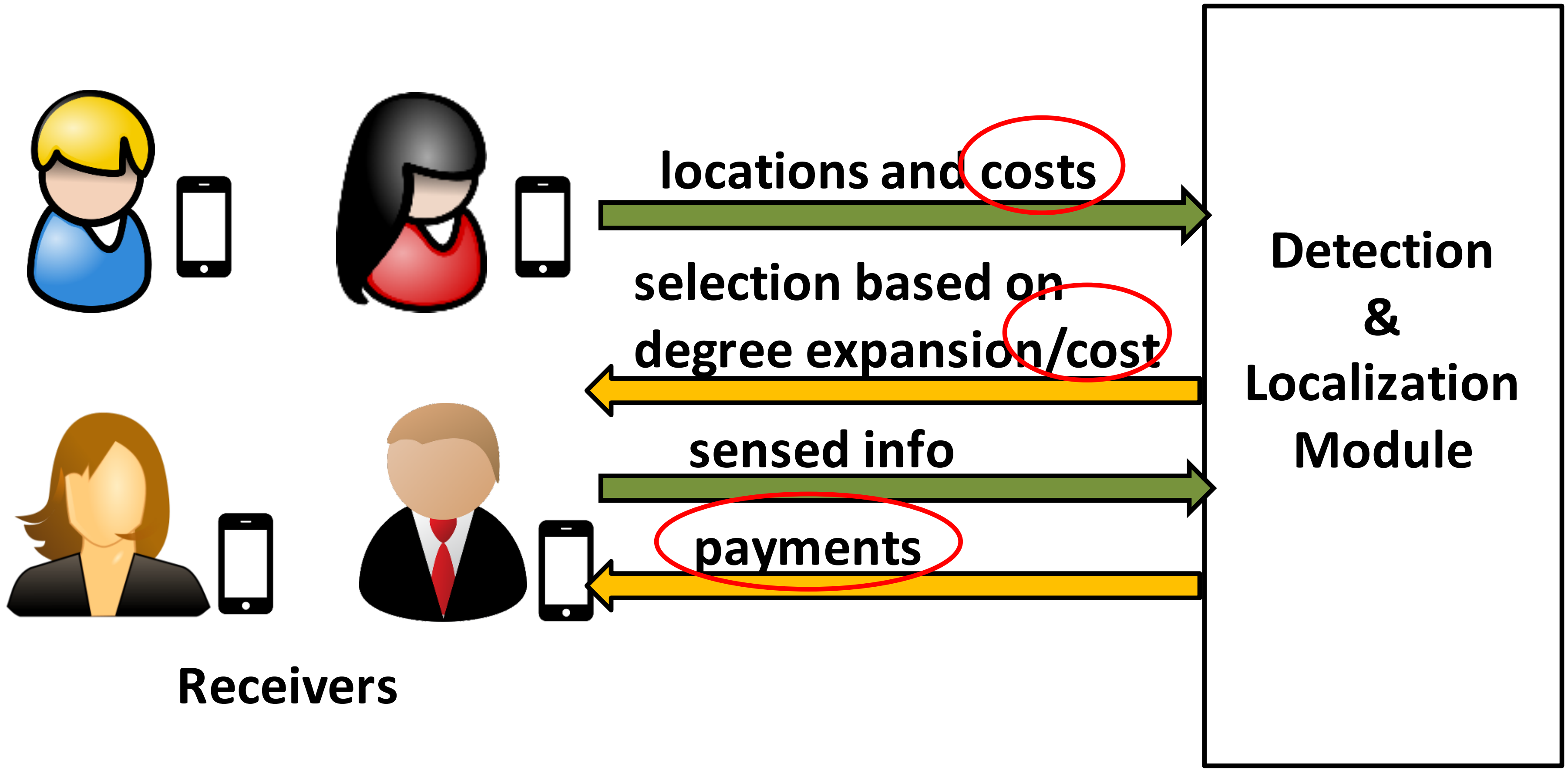


Greedy heuristic, selects RXs based on marginal contributions m_i to degree expansion

How to incentivize participation?



Sampling and incentive model



Sampling is repeated after time interval T

Truthful receiver selection

- Need algorithm for selection that motivates truthful reporting of cost

Truthful greedy receiver selection

- Consider both cost, marginal degree expansion

$$\max_{S \in V} \sum_{i \in S} \frac{m_i}{c_i}$$

- Incentive compatibility (truthfulness) – motivates truthful reporting of cost

$$p_i(c_i) - c_i \geq p_i(c_i') - c_i \quad \forall i, c_i'$$

utility when acting truthfully

actual sensing cost

declared sensing cost

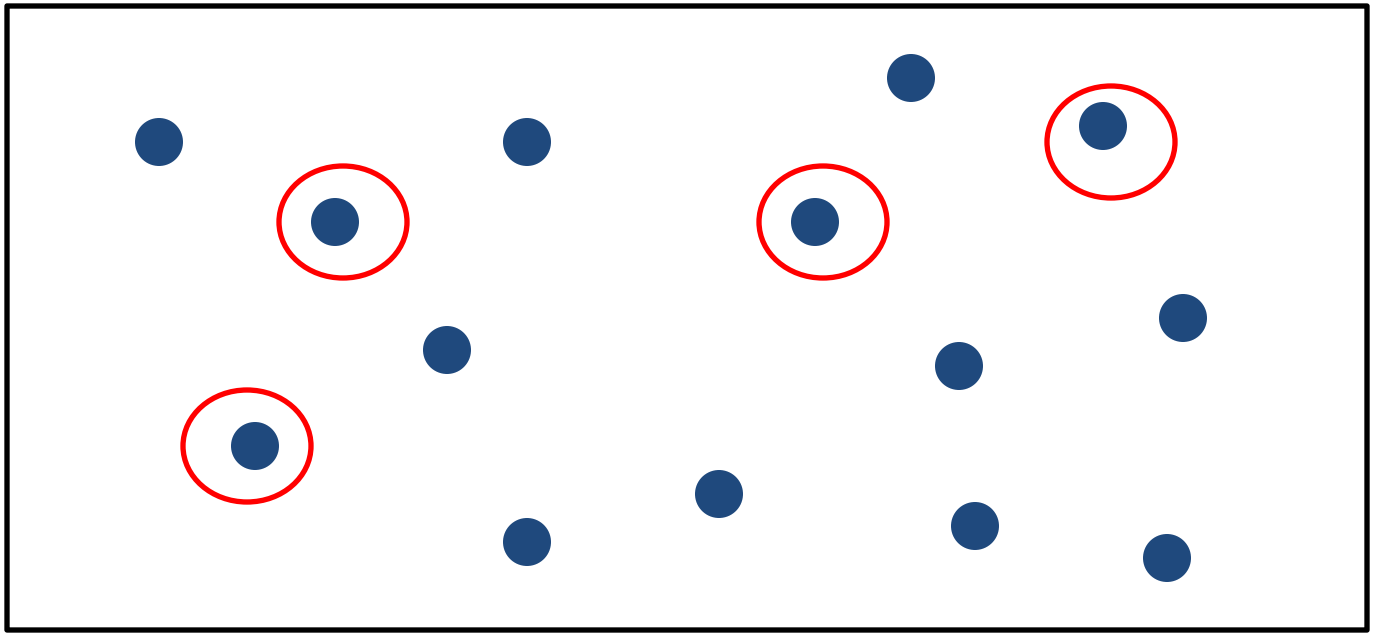
- Individual rationality (provides incentive to participate) - reward amount greater than cost

$$p_i(c_i) - c_i \geq 0 \quad \forall i$$

payment for *i*

Truthful greedy receiver selection

- **Sampling** - Greedy algorithm that minimizes cost and maximizes marginal degree expansion



Selects RXs based on $\frac{m_i}{c_i}$

Selected receivers

Available receivers

Truthful greedy receiver selection

- **Payment** – maximum value for cost that a node can declare and still win

Extensions to truthful greedy receiver selection

- Budget-feasible truthful greedy
  - Given budget ***B***, maximize ***DX(S)***
- Mobility aware budget-feasible truthful greedy
  - Maximize ***DX(S)*** under budget ***B,*** also available during ***T***
- Incentive compatibility (truthfulness)
- Individual rationality (reward greater than cost)

Evaluation of SPLOT

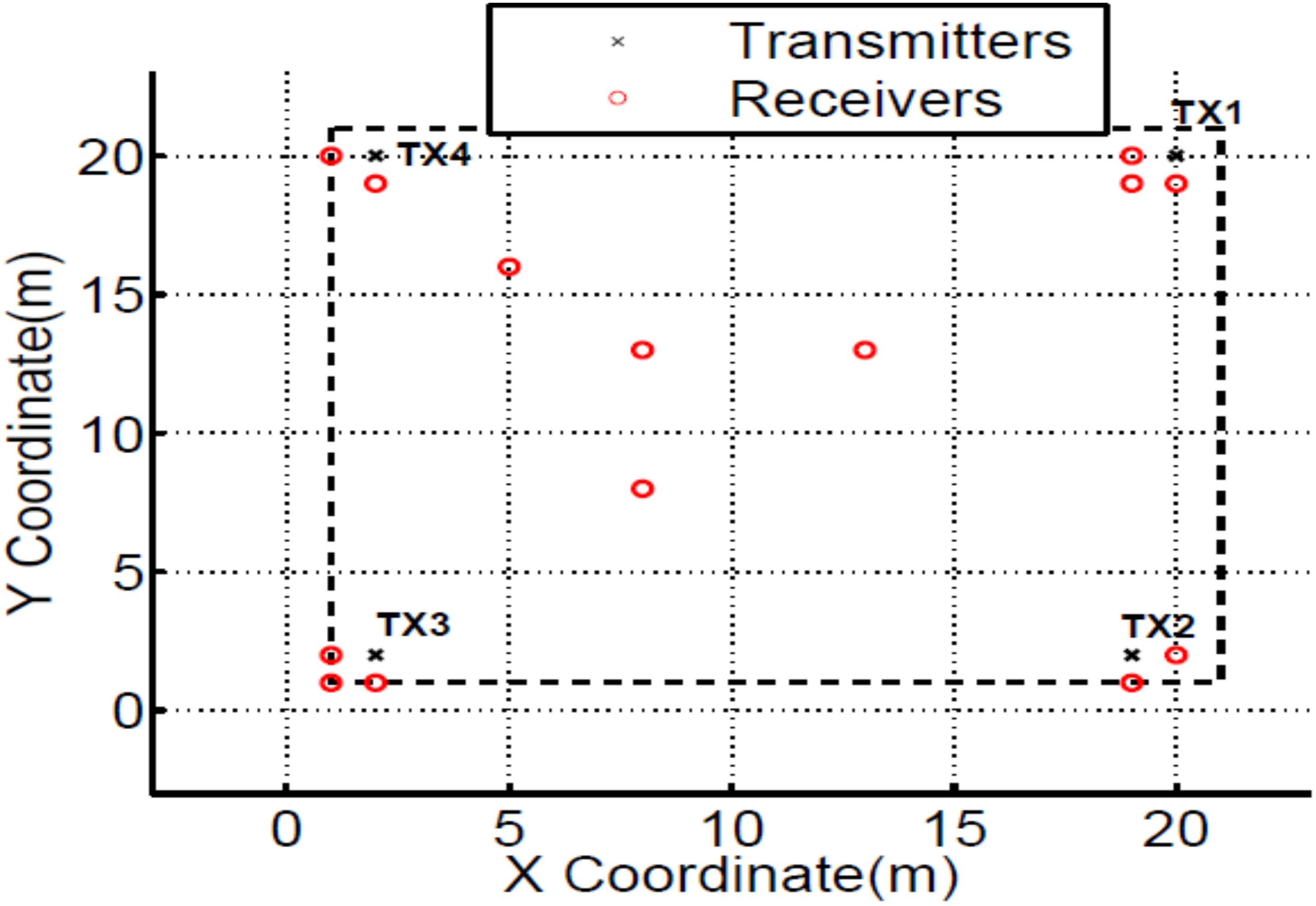
Evaluation metric

- **Localization error - **RMS error between estimated, actual transmitter location

- **Cardinality error** - fraction of time when number of estimated transmitter incorrect

- **Optimal Sub-Pattern Assignment (OSPA) metric** - penalizes error in number of estimated TX
  - localization error, cardinality error combined

Setup 1 : Orbit test bed



- Open environment, no obstructions and USRP2 nodes used

Setup 1: Localization error for single transmitter

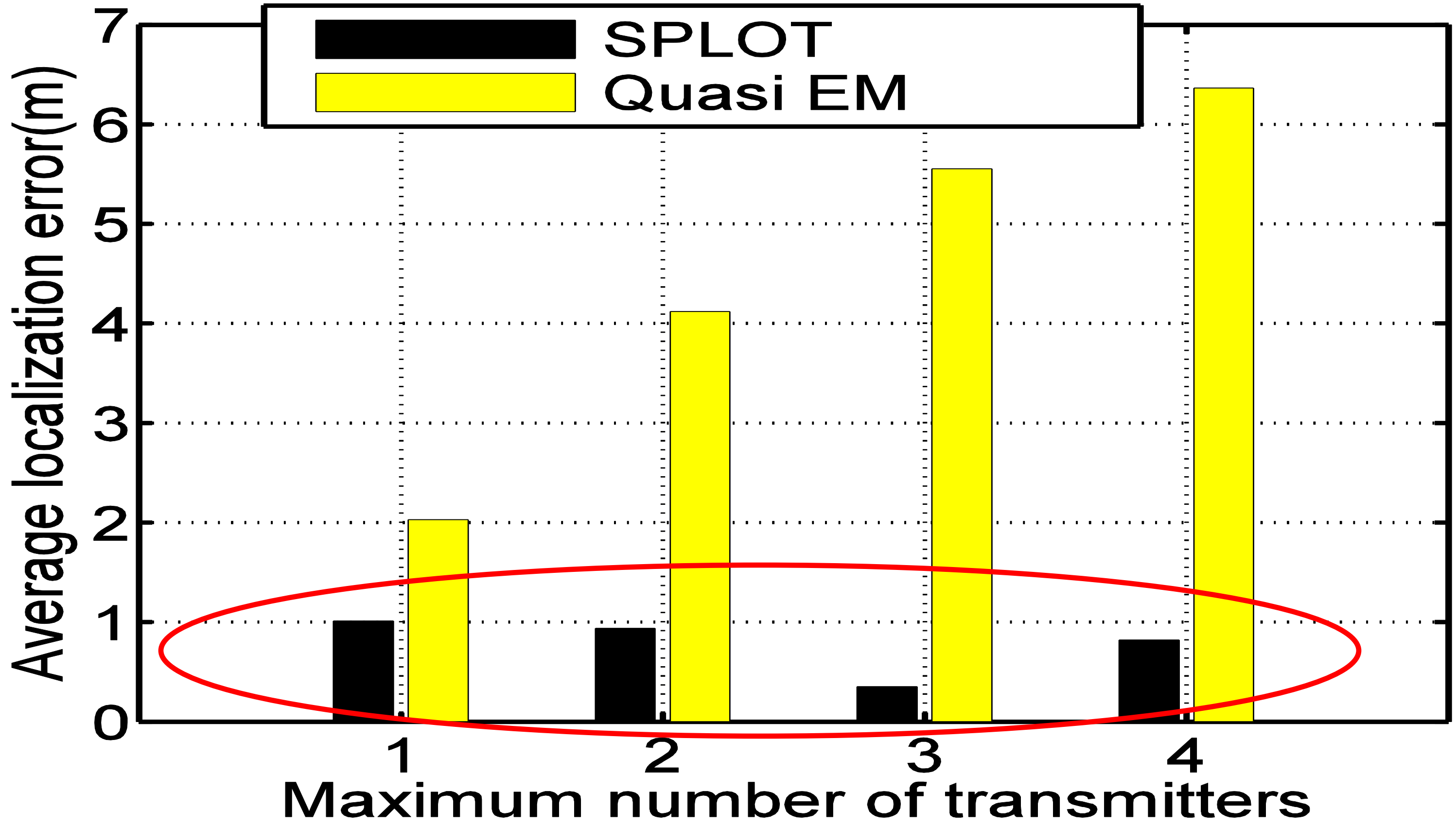
Transmitter	Localization error(m)	
	Matrix Inversion	MLE approach
TX1	1.41	1.01
TX2	0.5	1.03
TX3	1.11	0.97
TX4	1.41	5.08

average localization error **1.11m** and variance **0.18m**

average localization error **2.02m** and variance **4.1m**

matrix Inversion is better

Setup 1: Localization error for multiple transmitter



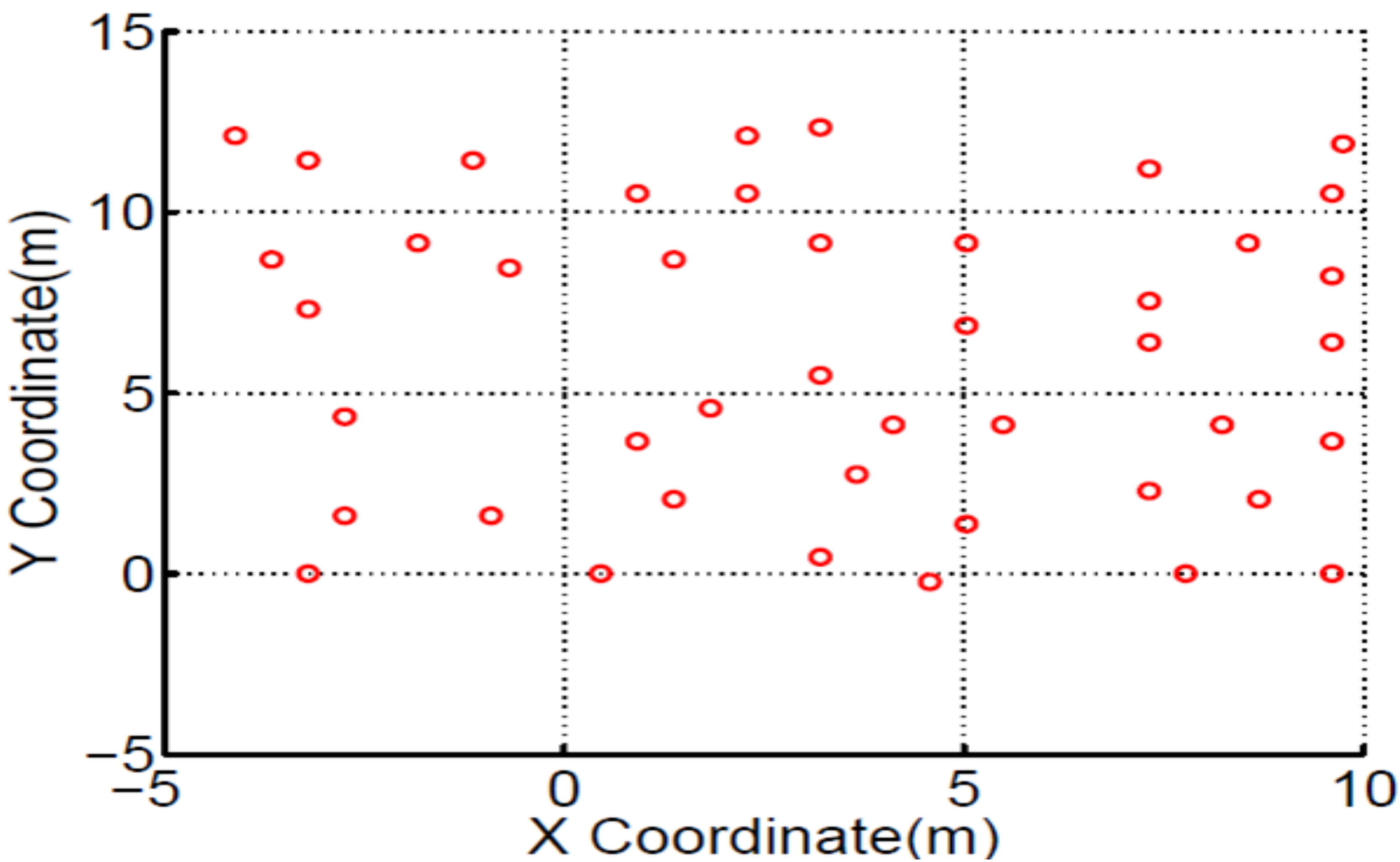
- SPLOT is independent of number of transmitter
- Unlike Quasi EM, SPLOT doesn't need number of transmitter

Setup 1: Cardinality error and OSPA metric

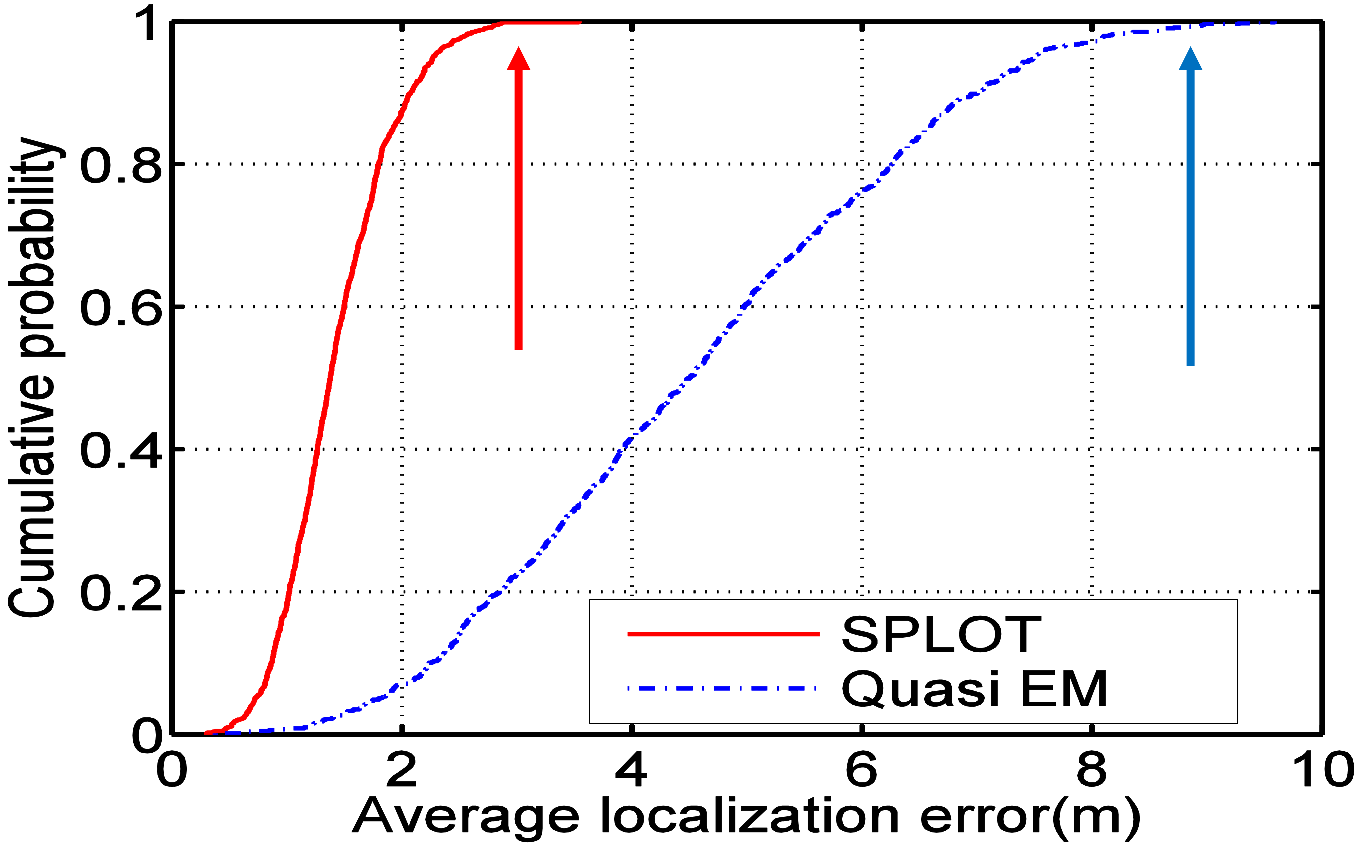
Maximum number of transmitters	OSPA metric			Cardinality error
	g= 1 (m)	g= 2 (m)	g= 5 (m)	
1	0.79	1.01	1.01	0
2	0.91	1.17	1.17	0
3	1.04	1.36	1.45	0.05
4	1.14	1.51	1.79	0.14

- Cardinality error increase with number of TX
- OSPA metric increases slightly for high penalty

Setup 2 : Cluttered office



Setup 2: Localization error for 2 transmitters

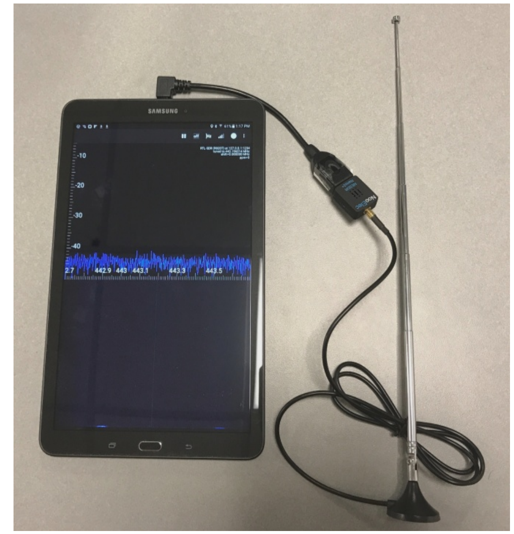


Average localization error of SPLOT significantly less than Quasi EM

Implementations with mobile transmitters and receivers

Implementation Equipments

BaoFeng BF-F8HP
Power 1W

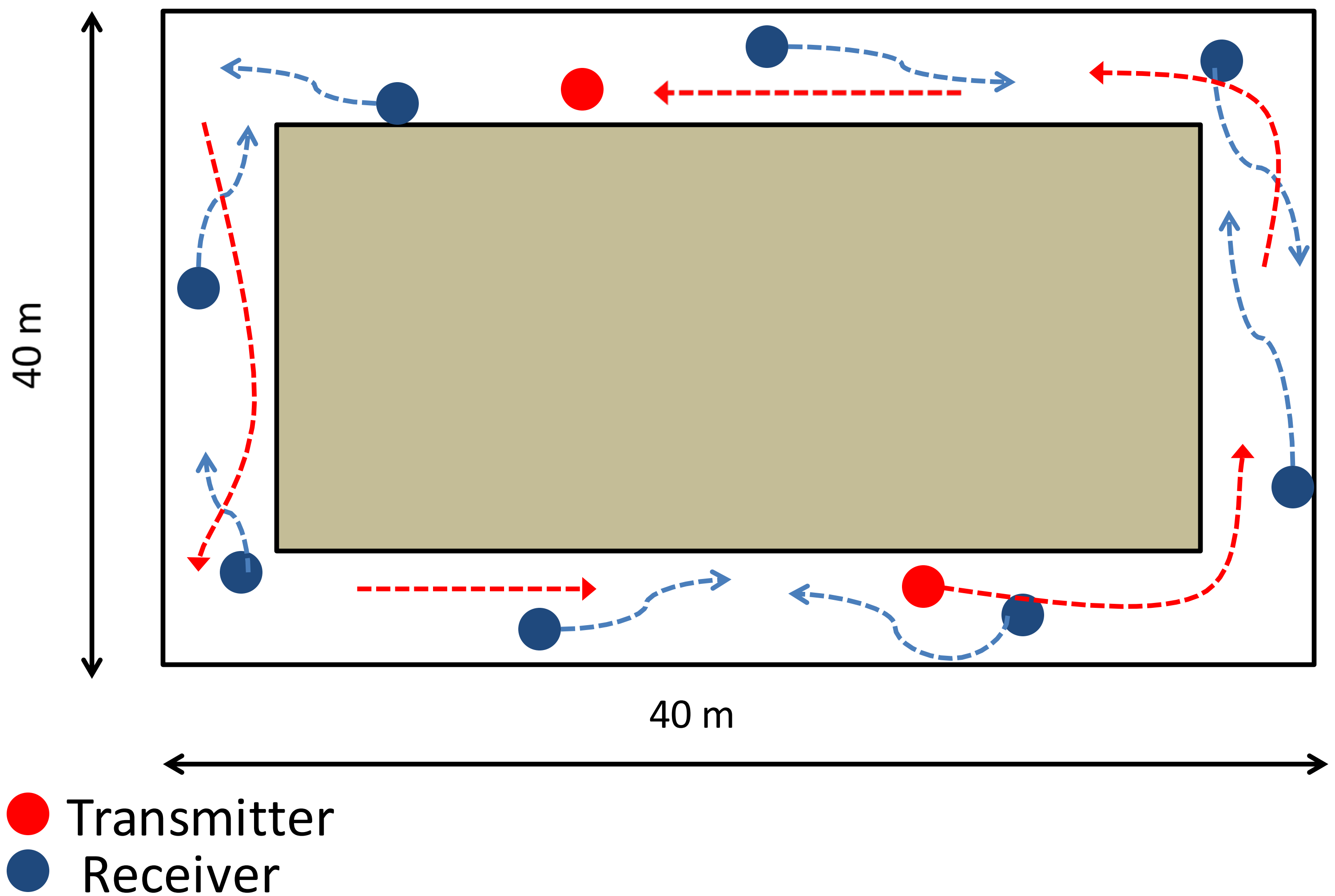


Realtek dongle (RTL-SDR) with USB cable

Android app

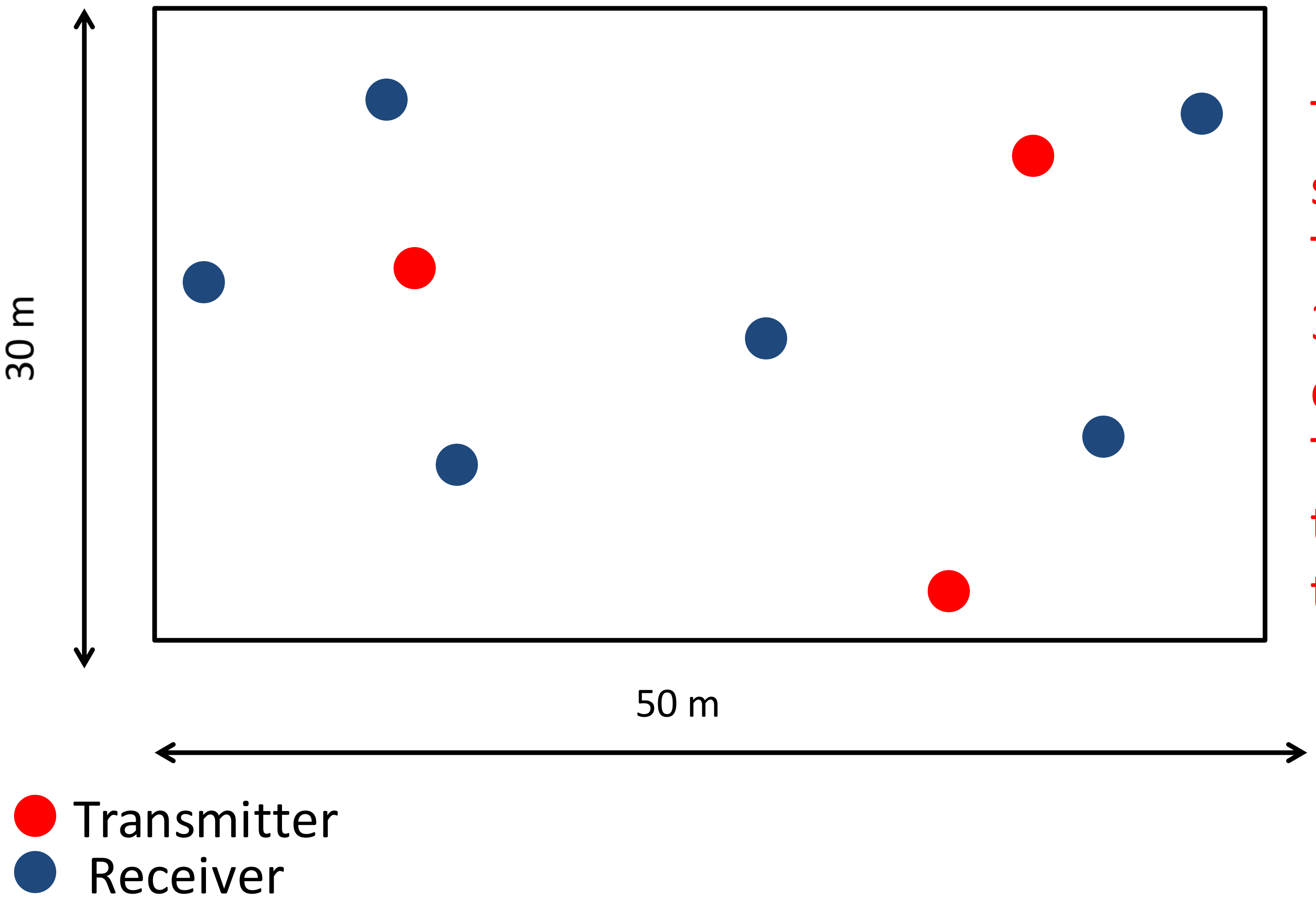
<time, location, RSS>

Experiment B (Environment 1) (Indoor, university building)



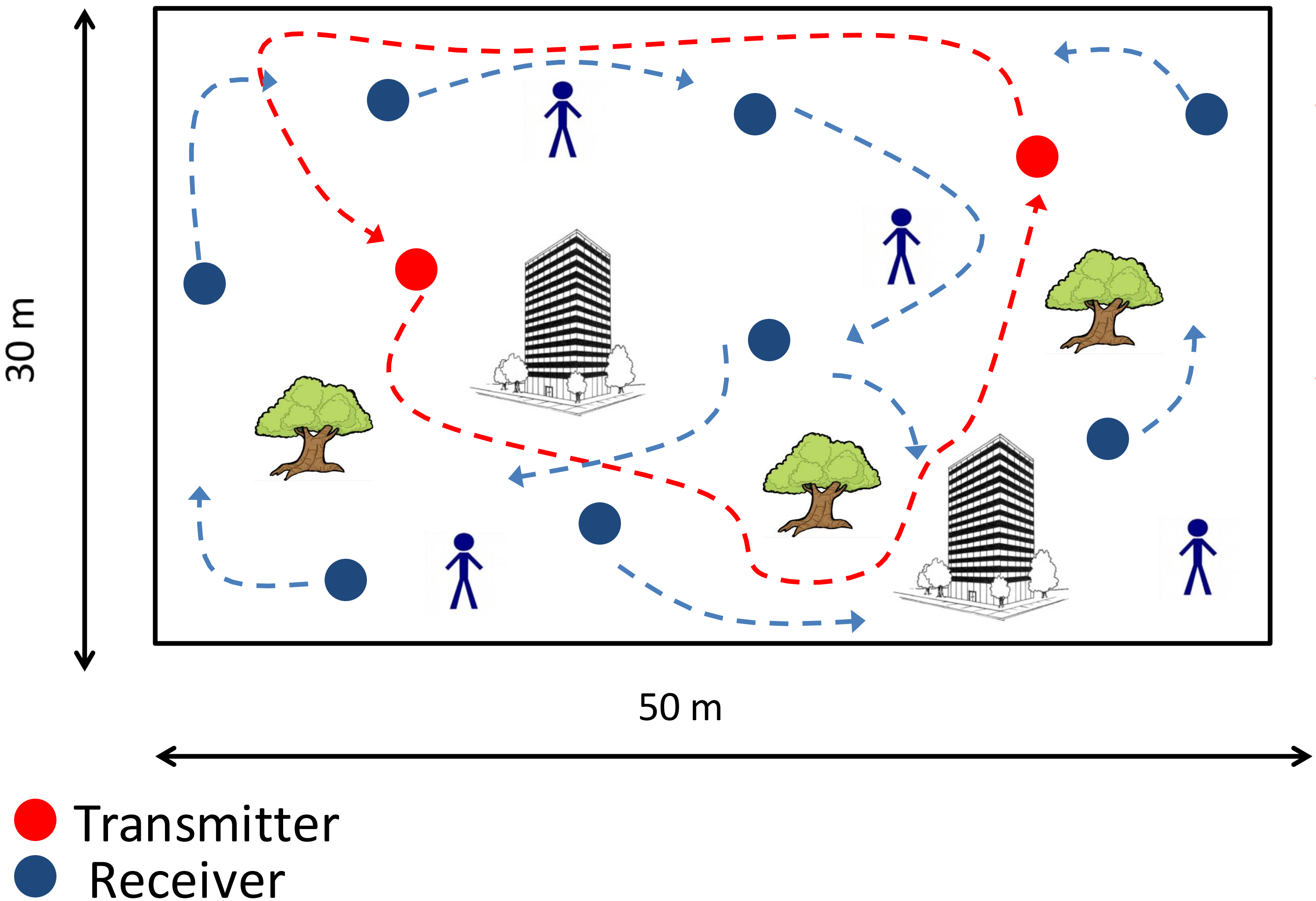
RXs move randomly, TXs use transcript for transmission

Experiment D (Environment 2) (Indoor, university food court)



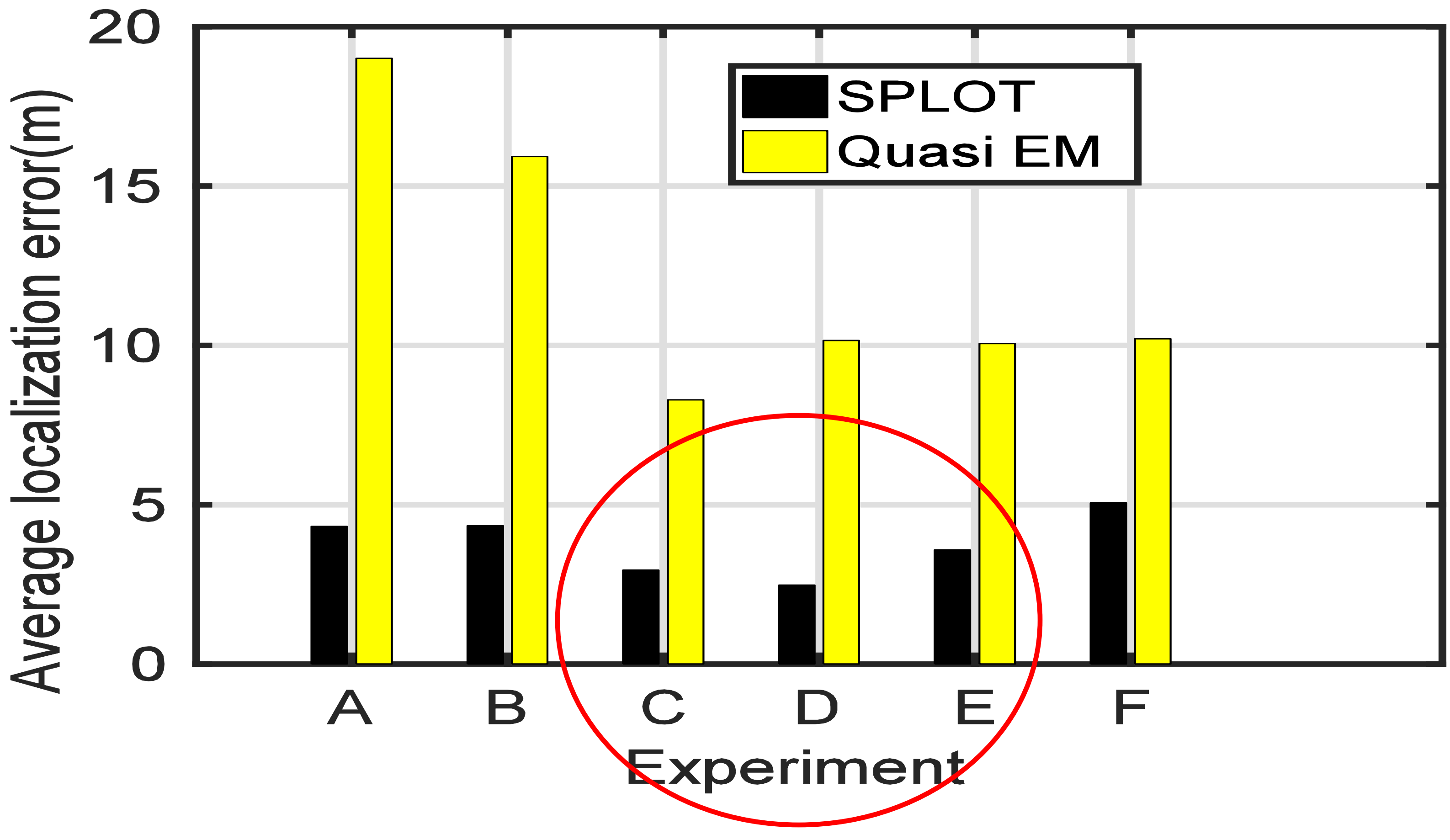
TXs and RXs static,
TXs located in 3 different corners,
TXs use transcript for transmission

Experiment F (Environment 3) (Outdoor, university campus)



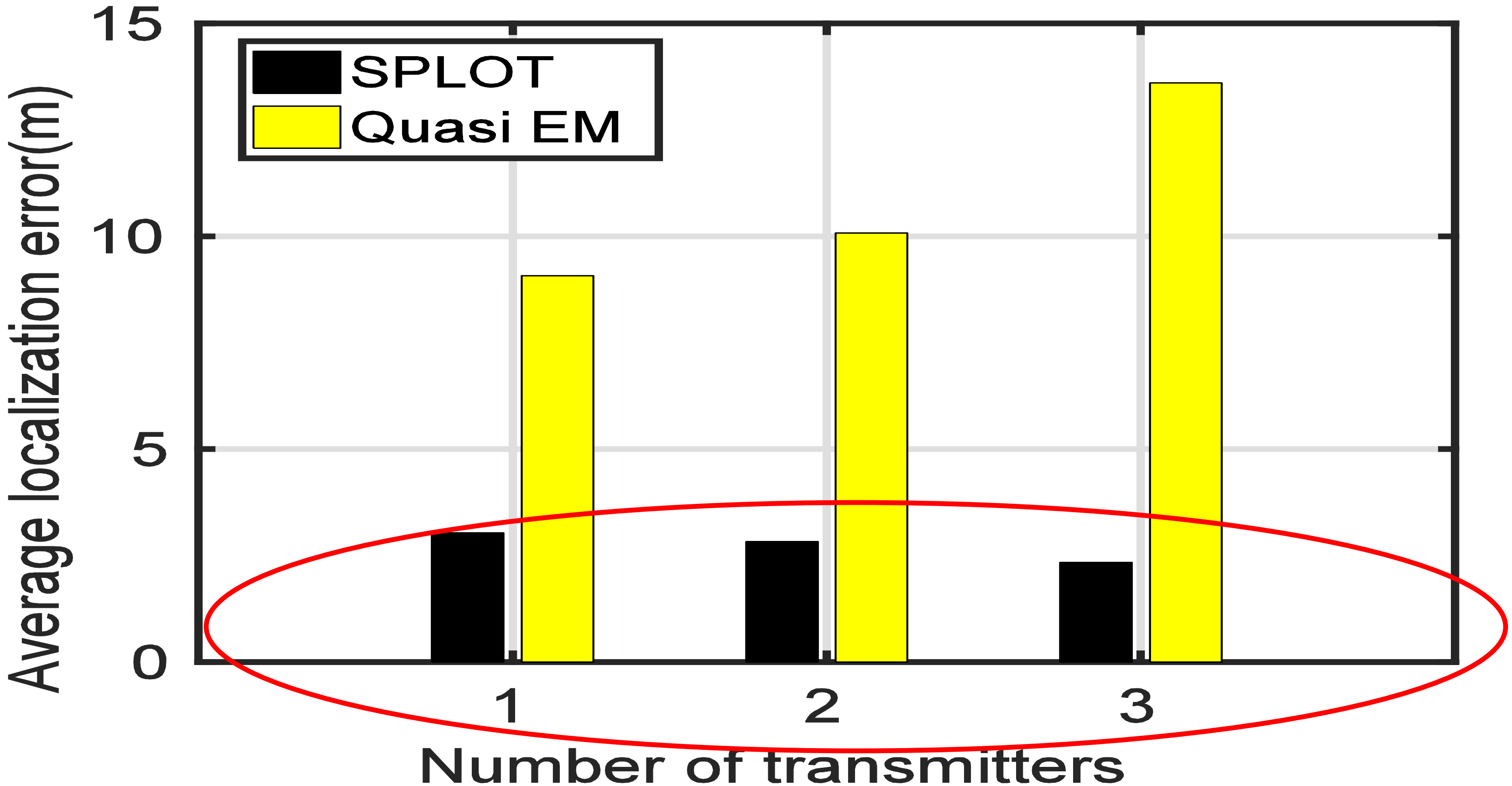
TXs, RXs move at normal walking speed for 7 minutes, TXs transmit continuously

Implementation results: Localization error



Decrease in localization error C, D, E (static)

Experiment D: Impact of number of transmitters



SPLOT is independent of number of transmitters

Conclusion

- **SPLOT** - simultaneous localization of multiple transmitters using crowdsourcing
- **Receiver selection –** selecting set of mobile sensing devices
- **Incentives** – for participating mobile sensing devices
- **Evaluation** – using multiple experiments

Advantages

- Using crowdsourcing to solve **multiple** transmitters localization problem
- Considering mobilitiy,truthfulness and coverage problem all together
- Using simple yet efficient and accurate method to solve real-time problem

Disadvantage

- Hard to guarantee numbers of receivers
- Hard to solve when two transmitters are very close from each other
- The number of transmitters tested is not that convincible
- How to guarantee they report range truth?

Thank You

Questions?