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Self-orientation of Directional Antennas, Assisted by Mobile Robots, for Receiving the Best Wireless Signal Strength

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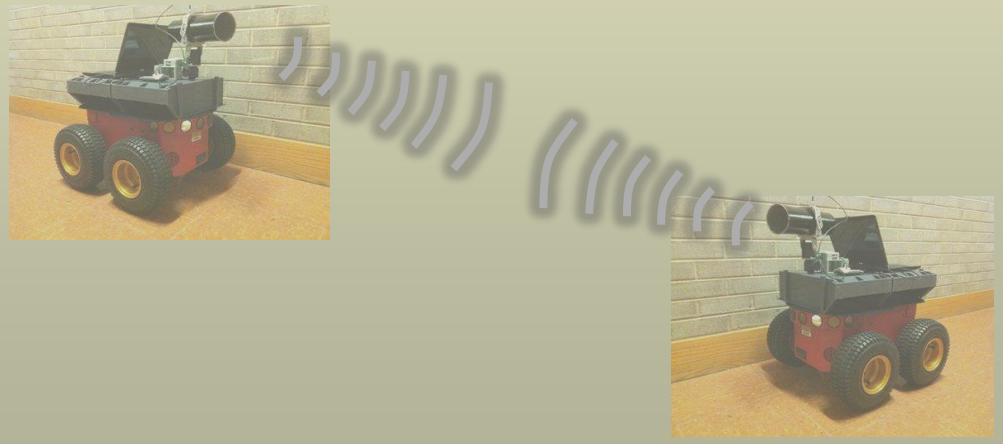


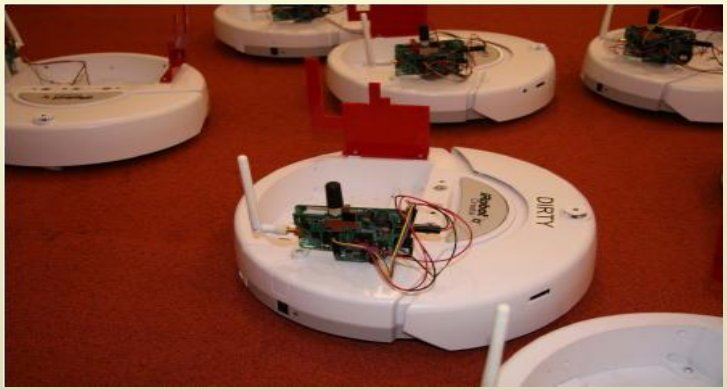
John Lewis
February 7, 2012

Outline

- Introduction
- AWARE: Autonomous Wireless Agent Robotic Exchange
- Pattern Based Search Algorithm
  - Formulating Problems
  - Pattern Based Search Algorithm
- Experimental Setup and Results
  - Experimental Setup
  - Results
- Conclusions and Further Works

Introduction

- Wireless Sensor Networks (WSNs)
- Directional Wireless Networks (DWNs)
- WSN installment with robots



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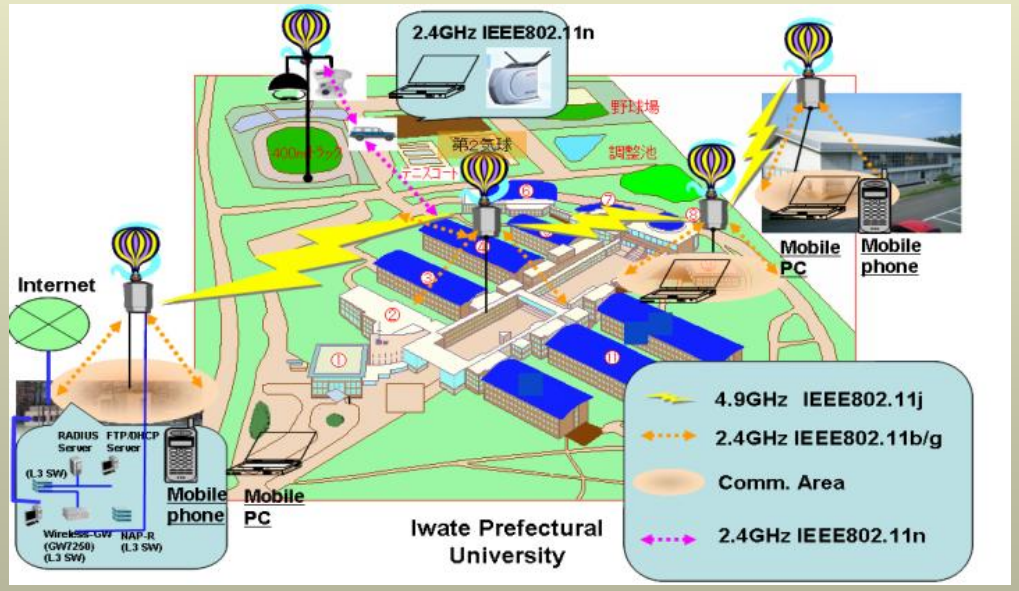
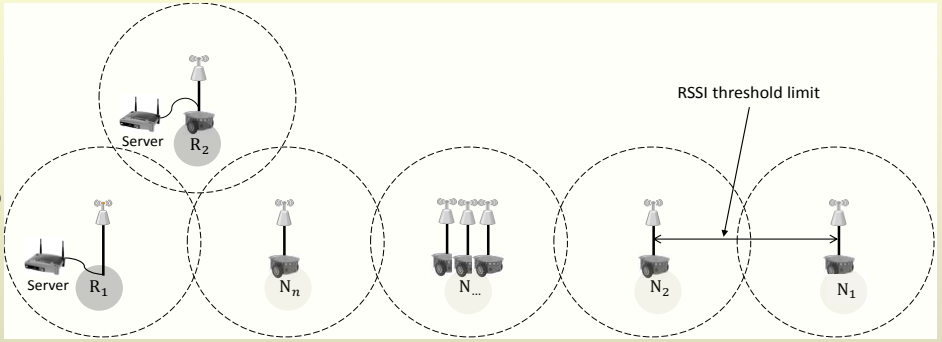


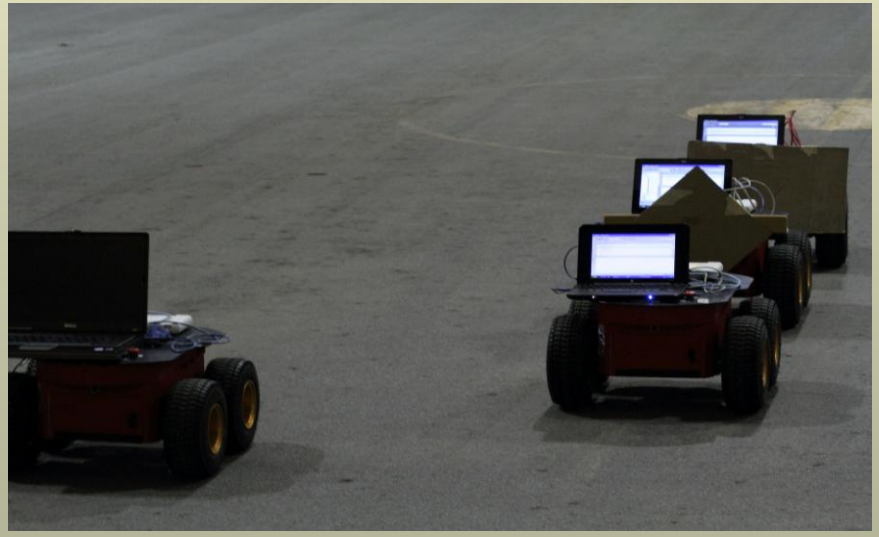
[5]

[3] N. Correll, J. Bachrach, D. Vickery, and D. Rus, "Ad-hoc wireless network coverage with networked robots that cannot localize," *in Proc. IEEE ICRA*, May 2009.
[4] Vijay Kumar, Daniela Rus, and Sanjiv Signh, "Robot and Sensor Networks for First Responders", *IEEE Pervasive Computing*, Vol.3, No. 4, pp. 24-33, 2004.
[5] Y Shibata, Y Sato, N Ogasawara, G Chiba, K Takahata, "A new ballooned wireless mesh network system for disaster use", *Proc. of AINA '09*, pp. 816–821,2009.

AWARE: Autonomous Wireless Agent Robotic Exchange

- In our previous work we showed autonomous, self-organizing wireless networks using multiple mobile robots with omni-directional antennas.
  - It provides the desired wireless coverage in the form of a mesh network.





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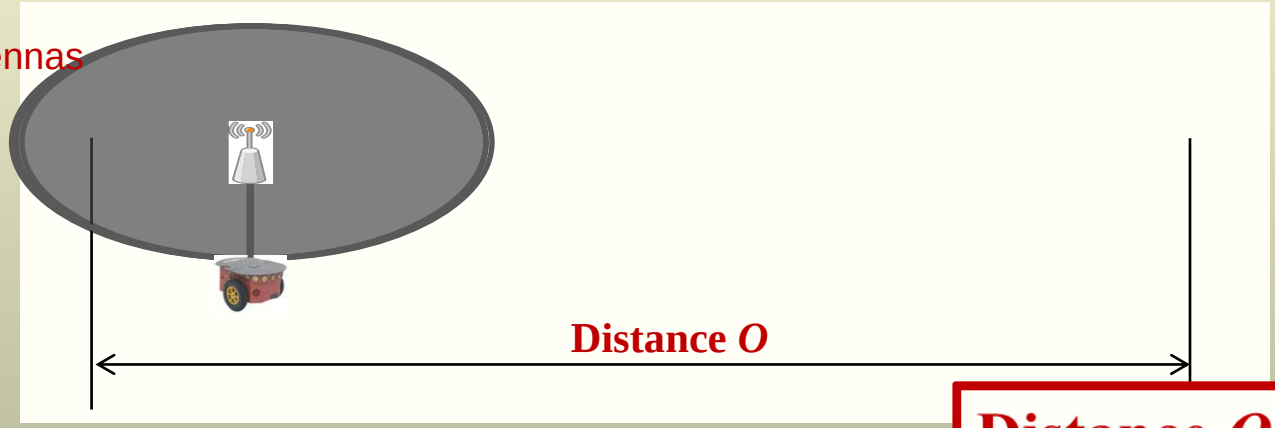
[9] E. Matson, C. Nguyen, B. Leong, A. Smith, J. Wachs, "Integration of Agent Organization and Autonomous Robots to Enable Self-organizing Broadband Networks", *International Conference on Control, Automation an Systems 2010 (ICCAS 2010)*, Gyeonggi-do, South Korea, October 27-30 2010.

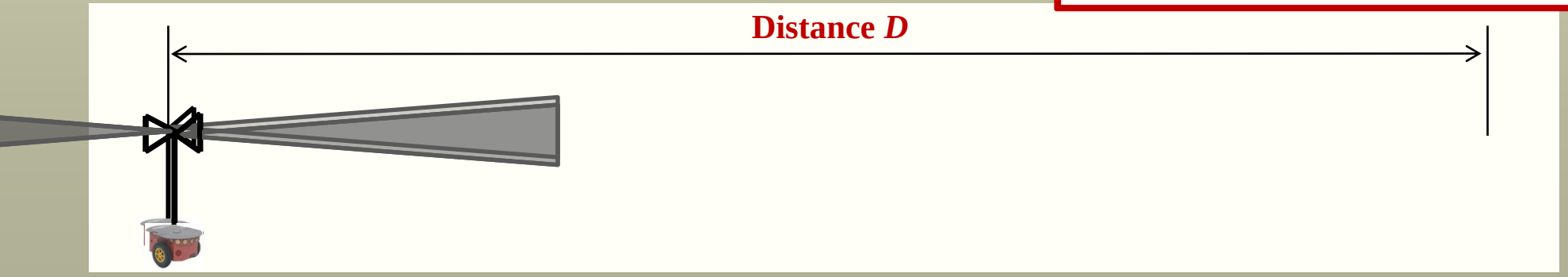
AWARE: Autonomous Wireless Agent Robotic Exchange

- Using omni-directional antennas is not effective in covering a sufficient distance.
- We introduce the use of directional antennas to increase the range of the wireless network.

use of omni-directional antennas



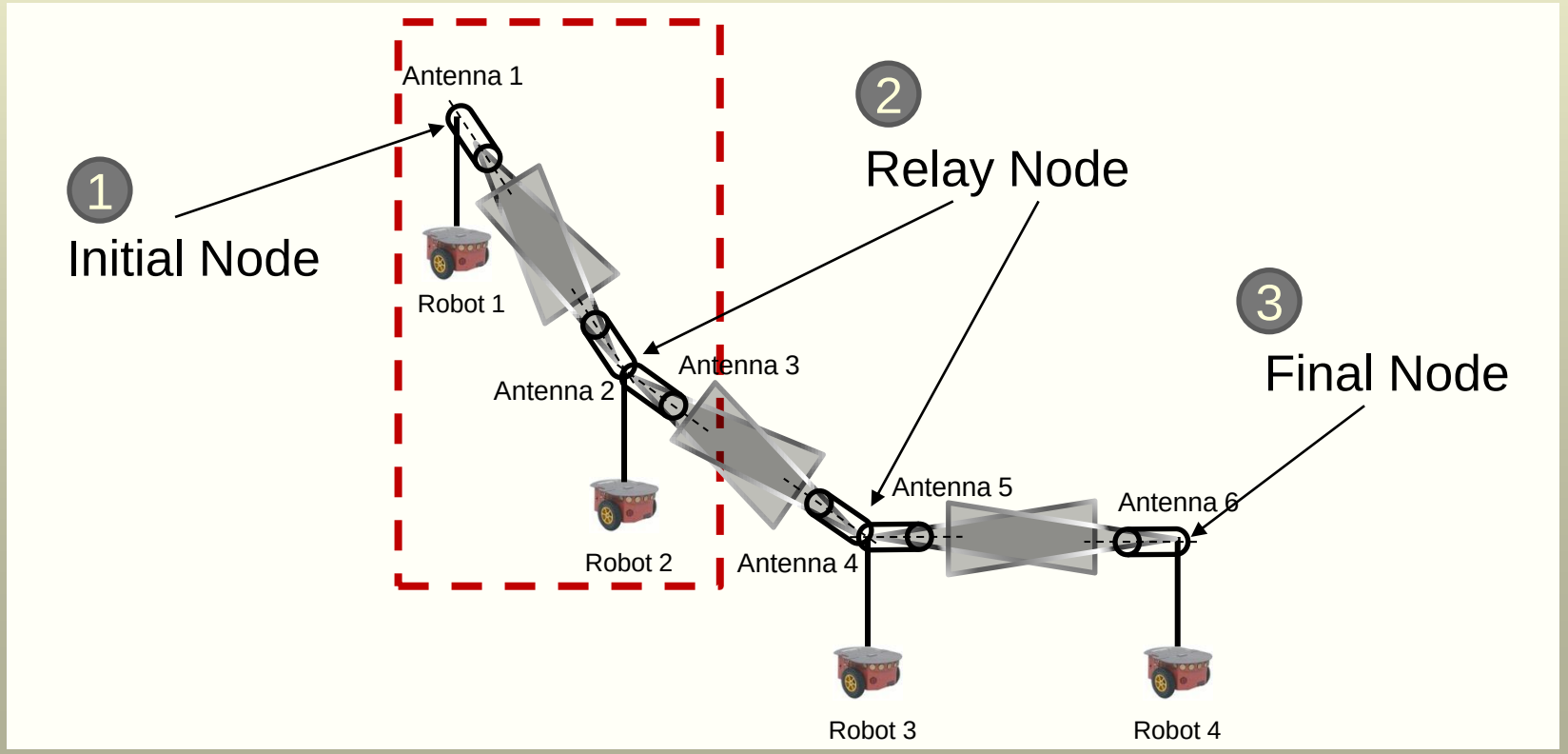
use of directional antennas



Distance O $\ll$ Distance D

Formulating Problems

- For the extended range to be beneficial, directional antennas must be oriented in a specific angle and direction.
- Therefore, the problem of finding the best orientation is taken into consideration here.

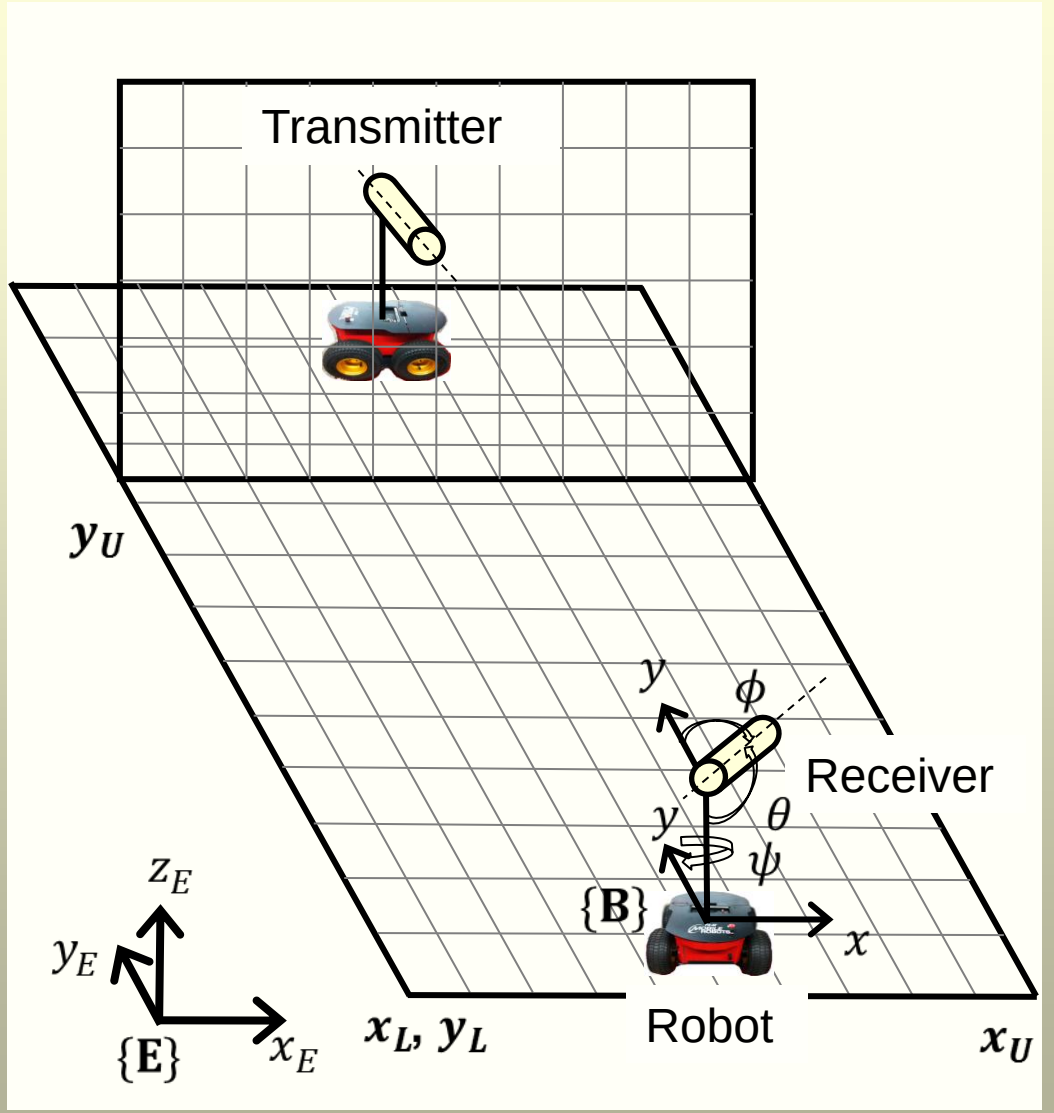


Formulating Problems

- **Problem:** Find a minimized objective $f(\mathbf{X})$ indicating the location and orientation to receive the best RSSI.
- **Subject to**:

$$x_L \le x \le x_U$$
$$y_L \le y \le y_U$$
$$\phi_L \le \phi \le \phi_U$$
$$\theta_L \le \theta \le \theta_U$$

$$\mathbf{X} = \begin{bmatrix} \phi \text{ (roll angle of the antenna)} \\ \theta \text{ (pitch angle of the antenna)} \\ x \text{ (position of the robot)} \\ y \text{ (position of the robot)} \\ \psi \text{ (heading angle of the robot)} \end{bmatrix}$$



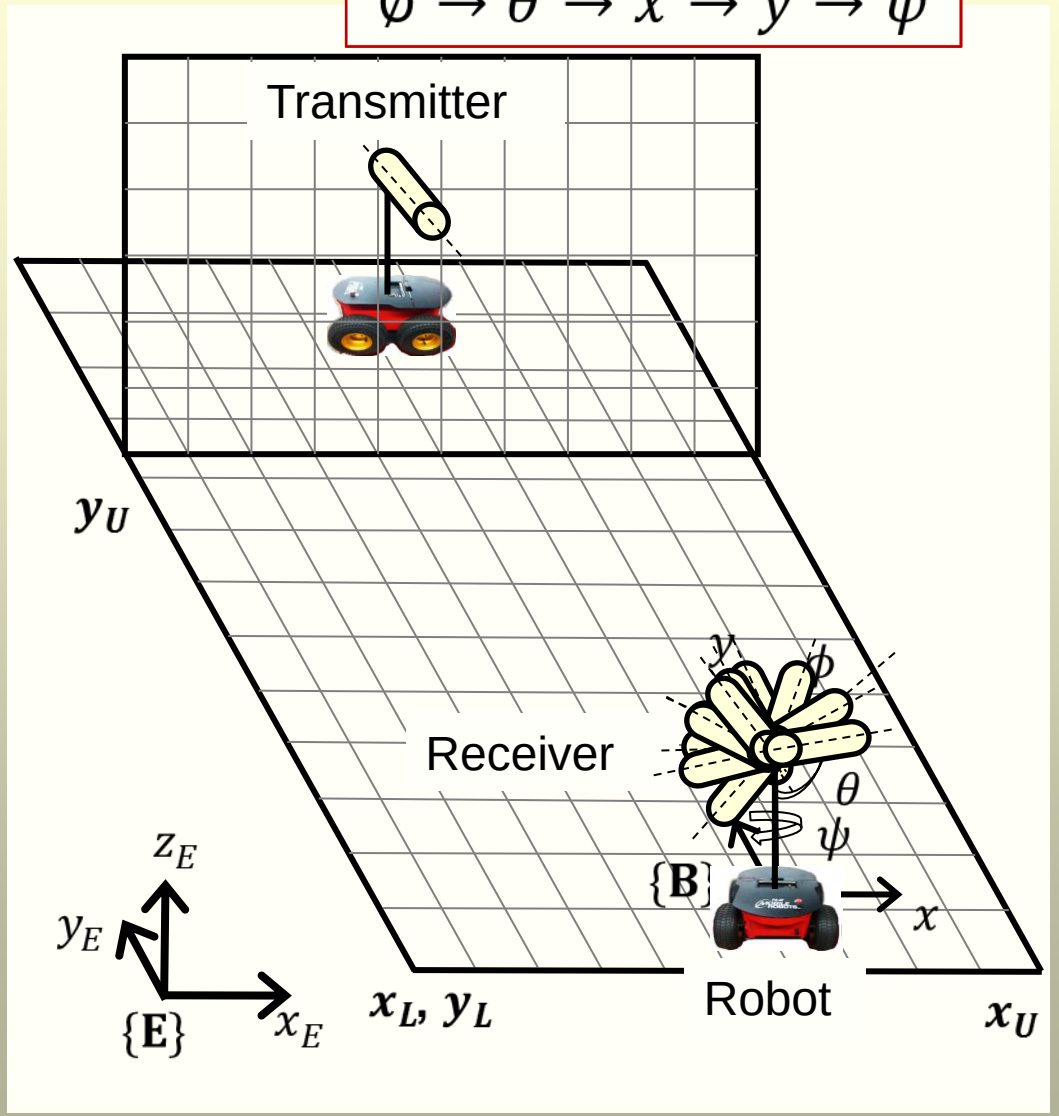
A simplified model for self-configurable wireless networks

Pattern Based Search Algorithm

/*Pattern Based Search Algorithm*/

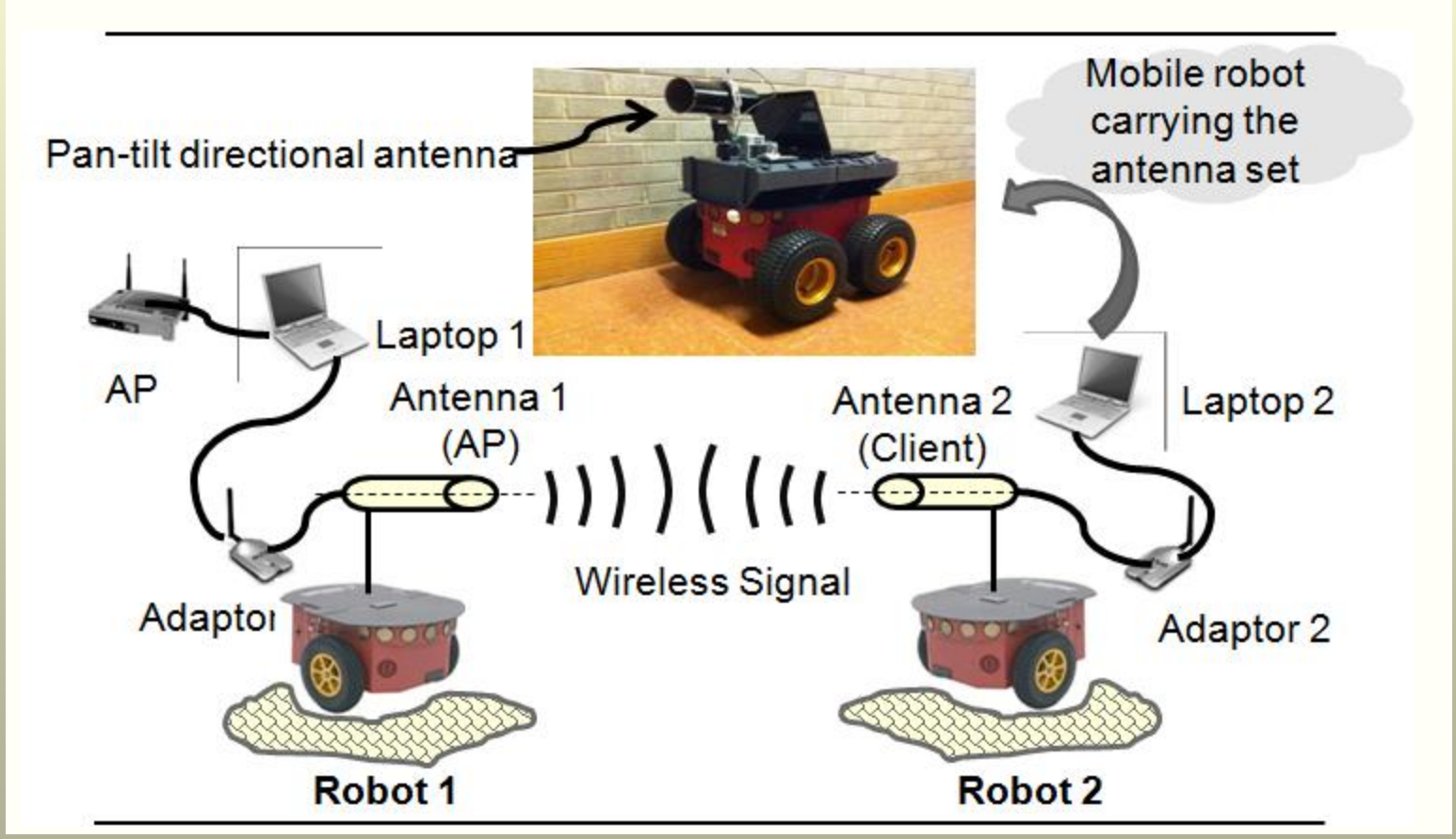
Choose $\mathbf{X}_0$
$i = 1, n = 5$ /* *Number of directions* */
/* *Repeatedly scanning in* ϕ, θ, x, y, ψ *direction order until requirement is satisfied* */
Repeat each cycle C
  Set $\mathbf{S}_i$ and α_i
  $\mathbf{X}_1 = \mathbf{X}_0 + \alpha_i \mathbf{S}_i$
  /* *Determine a favorable direction* */
  If $f(\mathbf{X}_1) > f(\mathbf{X}_0)$; $\mathbf{S}_i = -\mathbf{S}_i$
  Repeat each loop j
    $\mathbf{X}_j = \mathbf{X}_{j-1} + \alpha_i \mathbf{S}_i$
    $j \leftarrow j + 1$
  If $f(\mathbf{X}_{j-1}) - f(\mathbf{X}_j) \le \varepsilon_1$ or $X_{j_i} \le L_i$ or $X_{j_i} \ge U_i$;
  Stop loop j /* *where* X_{j_i} *is current design value and* L_i, U_i *are its lower and upper boundaries*/
  $f_C(\mathbf{X}) \leftarrow$ Best $f(\mathbf{X})$
  $\mathbf{X}_0 \leftarrow f_C(\mathbf{X})$
  $i \leftarrow i + 1$ /* *Search* $\phi \rightarrow \theta \rightarrow x \rightarrow y \rightarrow \psi$ */
  If $i = 5$; $i \leftarrow 1$ /* *Reset the order of searching* */
  $C \leftarrow C + 1$
If $f_{C+1}(\mathbf{X}) - f_C(\mathbf{X}) \le \varepsilon_2$; *Stop* cycle C

$$\emptyset \rightarrow \theta \rightarrow x \rightarrow y \rightarrow \psi$$



Experimental Setup

- Can antenna “cantenna”, Laptop, Adaptor
- P3AT robot and the Robotis servo motor tracking arm



A configuration of experimental setup and a mobile robot carrying the pan-tilt antenna set

Experimental Setup

- Linux was chosen as the operation system for testing.

```
iwconfig wlan0
wlan0     IEEE 802.11bgn  ESSID:"          "
          Mode:Managed  Frequency:2.462 GHz  Access Point:
          Bit Rate=54 Mb/s   Tx-Power=20 dBm
          Retry  long limit:7   RTS thr:off   Fragment thr:off
          Encryption key:off
          Power Management:on
          Link Quality=61/70  Signal level=-49 dBm
          Rx invalid nwid:0  Rx invalid crypt:0  Rx invalid frag:0
          Tx excessive retries:0  Invalid misc:0   Missed beacon:0
```

(a) Simple command line operation

```
iwconfig wlan0 | grep Signal| cut -d '-' -f2 |cut -d ' ' -f1
50
```

(b) Additional command line parsing a single instruction

Experimental Setup

/*Pattern Based Search Algorithm*/

Choose $\mathbf{X}_0$

$i = 1, n = 5$ /* *Number of directions* */

/* *Repeatedly scanning in* ϕ, θ, x, y, ψ *direction order until requirement is satisfied* */

Repeat each cycle C

  Set $\mathbf{S}_i$ and α_i

  $\mathbf{X}_1 = \mathbf{X}_0 + \alpha_i \mathbf{S}_i$

  /* *Determine a favorable direction* */

  If $f(\mathbf{X}_1) > f(\mathbf{X}_0)$; $\mathbf{S}_i = -$

  Repeat each loop j

    $\mathbf{X}_j = \mathbf{X}_{j-1} + \alpha_i \mathbf{S}_i$

    $j \leftarrow j + 1$

  If $f(\mathbf{X}_{j-1}) - f(\mathbf{X}_j) \le \varepsilon_1$ or $X_{j_i} \le L_i$ or $X_{j_i} \ge U_i$;

  Stop loop j /* *where* X_{j_i} *is current design value and* L_i, U_i *are its lower and upper boundaries**/

  $f_C(\mathbf{X}) \leftarrow$ Best $f(\mathbf{X})$

  $\mathbf{X}_0 \leftarrow f_C(\mathbf{X})$

  $i \leftarrow i + 1$ /* *Search* $\phi \rightarrow \theta \rightarrow x \rightarrow y \rightarrow \psi$ */

  If $i = 5$; $i \leftarrow 1$ /* *Reset the order of searching* */

  $C \leftarrow C + 1$

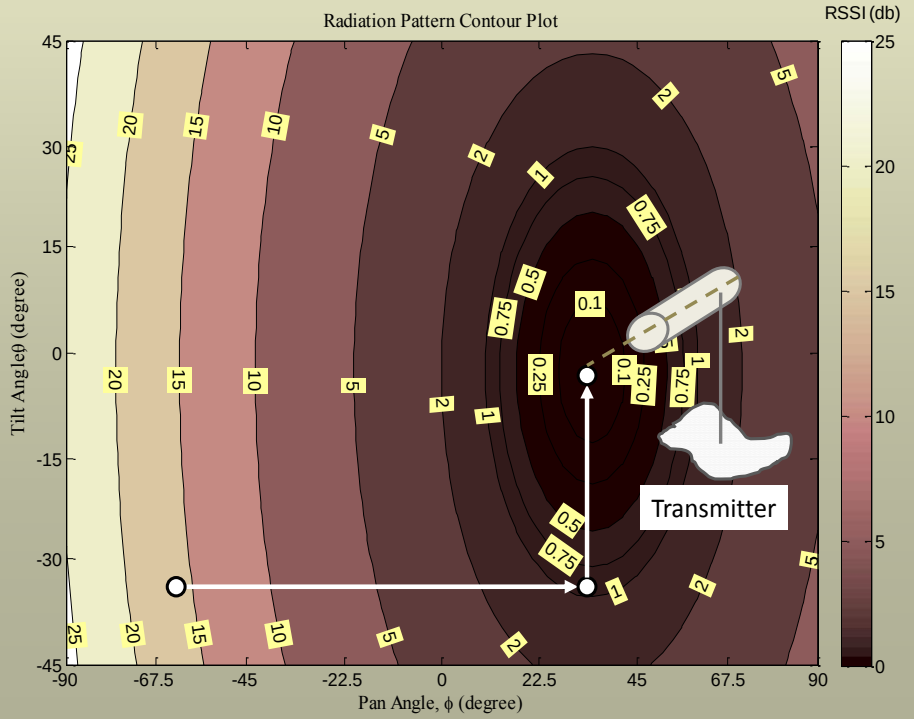
If $f_{C+1}(\mathbf{X}) - f_C(\mathbf{X}) \le \varepsilon_2$; *Stop* cycle C

$$i = 1, n = 2$$
$$, \text{i. e}, [\phi, \theta]$$

- S_i, search direction
- a_i, step size

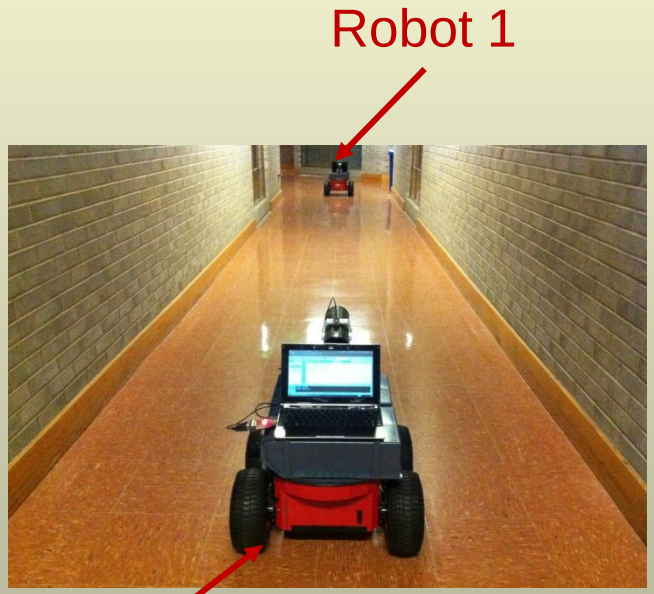
$[°(\text{degree}),\ °, m(\text{meter}),\ m,\ °]$

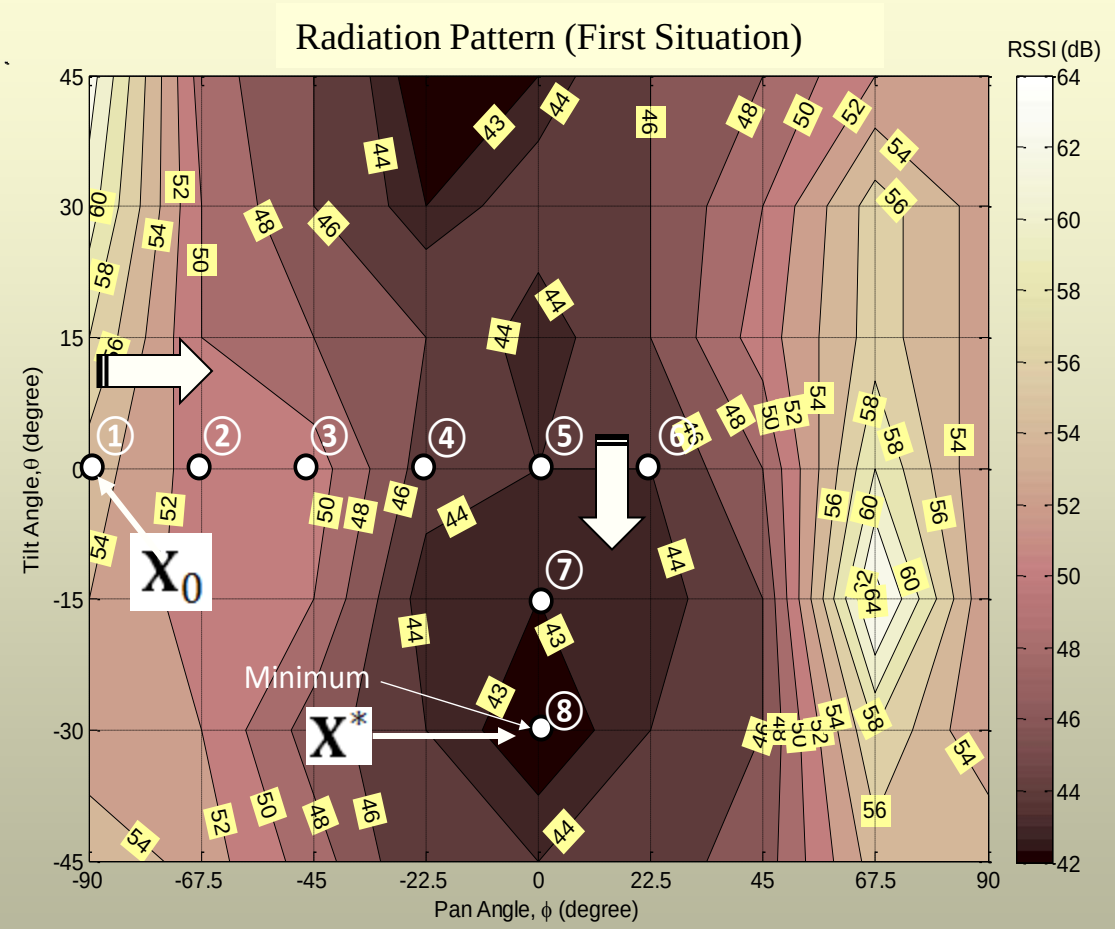
$$\alpha_1 = 22.5, \quad \mathbf{S}_1 = [0,\ 0,\ 1,\ 0,\ 0]^T$$
$$\alpha_2 = 10, \quad \mathbf{S}_2 = [0,\ 0,\ 0,\ 1,\ 0]^T$$
$$\alpha_3 = 0.5, \quad \mathbf{S}_3 = [1,\ 0,\ 0,\ 0,\ 0]^T$$
$$\alpha_4 = 0.5, \quad \mathbf{S}_4 = [0,\ 1,\ 0,\ 0,\ 0]^T$$
$$\alpha_5 = 90, \quad \mathbf{S}_5 = [0,\ 0,\ 0,\ 0,\ 1]^T$$



Results (first case)

Robot 2 has a fixed heading angle of 0°

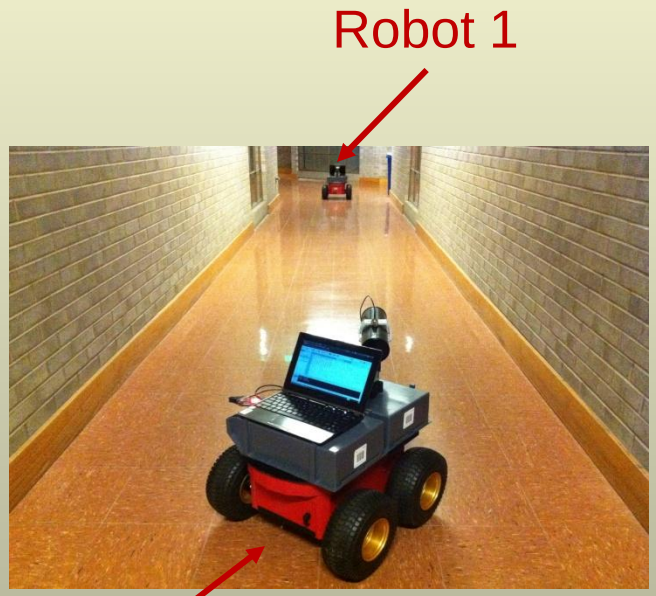


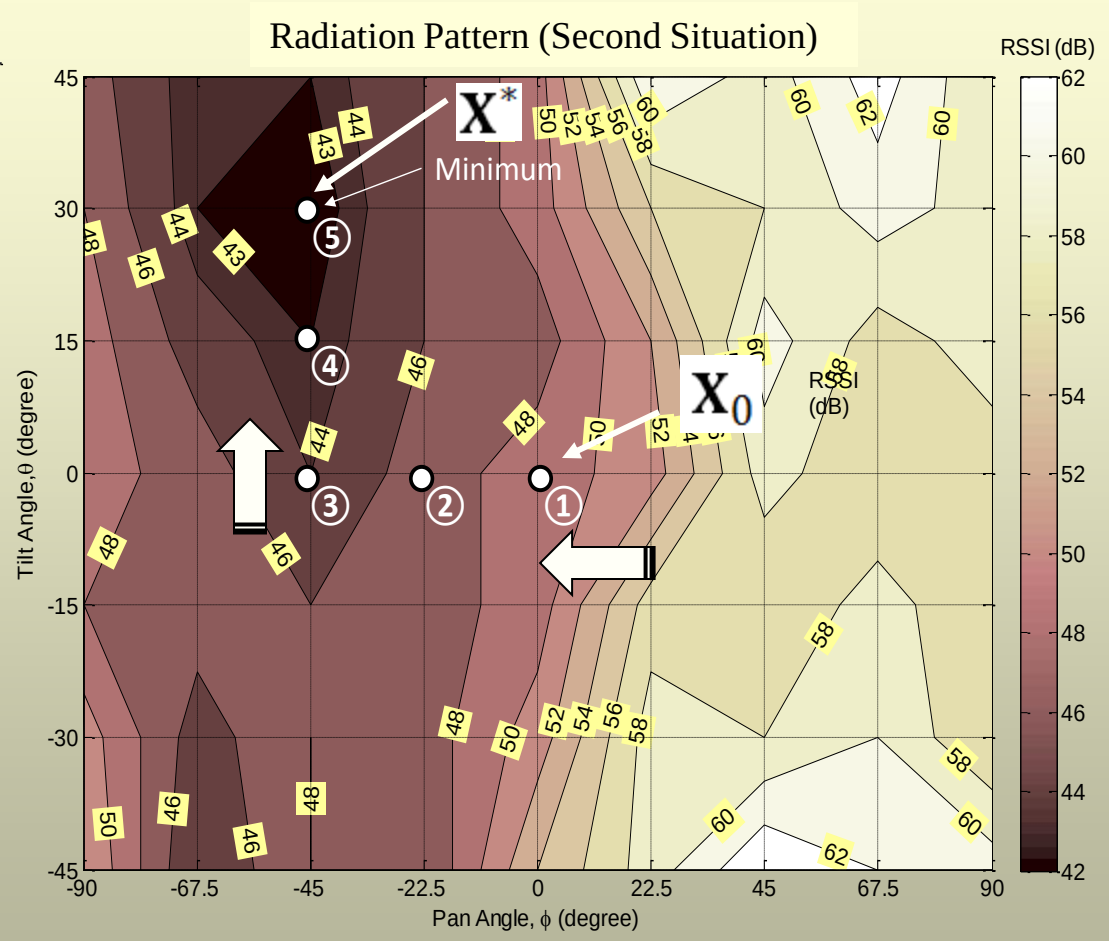


$$\mathbf{X}_0 = [-90°,\ 0°,\ 0_m,\ 0_m,\ 0°]$$
$$\mathbf{X}^* = [\ 0°,\ -30°,\ 0_m,\ 0_m,\ 0°]$$

Results (second case)

Robot 2 has a fixed heading angle of 45°





$$\mathbf{X}_0 = [\ 0°,\ 0°,\ 0_m,\ 0_m,\ 45°]$$
$$\mathbf{X}^* = [-45°,\ 30°,\ 0_m,\ 0_m,\ 45°]$$

Conclusions and Further Works

- In this paper, we
  - used the pattern based search algorithm to enable a directional antenna to find the best location and orientation to receive the best possible RSSI.
  - built a custom pan-tilt system having 2 DOF with two servomotors. Then, this system was incorporated into a mobile platform having 3 DOF.
- As a result, this objective function was minimized with some iteration to find the best orientation for receiving the best possible RSSI.
- For further works, we will deal with
  - Different initial point, using multiple robots, operation of both transmitter and receiver
  - Different optimization techniques such as Genetic Algorithm (GA) and Downhill Method.

Thank you!

Questions?

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