ESC Sensor Nodes Placement and Location for Moving Incumbent Protection in CBRS

Satya Joshi, Shashika Manosha, Markku Jokinen, Tuomo Hänninen, Pekka Pirinen, Harri Posti, and Matti Latva-aho

{sjoshi, manosha, markku.jokinen, tuomo.hanninen, pekka.pirinen, harri.posti, matti.latva-aho}@ee.oulu.fi

Centre for Wireless Communications, University of Oulu, Finland

Introduction

- **Citizens Broadband Radio Service (CBRS):** share the spectrum between federal incumbent and commercial users

- Incumbents: ship borne radar, group based radar, fixed satellite service earth station, wireless broadband services

- key to **success of Spectrum Access System (SAS)** – protection of incumbent users from the harmful interference generated by CBSDs
  - protection via exclusion zone
  - protection via a use of environmental sensing capability (**ESC**) network
  - ESC network converts the exclusion zone into a protection zone

Introduction

- **Citizens Broadband Radio Service (CBRS):** share the spectrum between federal incumbent and commercial users

- Incumbents: ship borne radar, group based radar, fixed satellite service earth station, wireless broadband services

- key to **success of Spectrum Access System (SAS)** – protection of incumbent users from the harmful interference generated by CBSDs
  - protection via exclusion zone
  - protection via a use of environmental sensing capability (**ESC**) network
  - ESC network converts the exclusion zone into a protection zone

Introduction

- **Citizens Broadband Radio Service (CBRS):** share the spectrum between federal incumbent and commercial users

- Incumbents: ship borne radar, group based radar, fixed satellite service earth station, wireless broadband services

- key to **success of Spectrum Access System (SAS)** – protection of incumbent users from the harmful interference generated by CBSDs
  - protection via exclusion zone
  - protection via a use of environmental sensing capability (**ESC**) network
  - ESC network converts the exclusion zone into a protection zone

Introduction

- Challenges in the deployment of ESC network
  - moving incumbents
  - detecting the location of the federal naval incumbent is forbidden
  - optimum number of sensors and their locations

Introduction

- Challenges in the deployment of ESC network
  - moving incumbents
  - detecting the location of the federal naval incumbent is forbidden
  - optimum number of sensors and their locations

Introduction

- Challenges in the deployment of ESC network
  - moving incumbents
  - detecting the location of the federal naval incumbent is forbidden
  - optimum number of sensors and their locations

Our Work

- ESC sensor placement problem in coastal areas for the moving incumbent protection in CBRS
  - protection – by deploying minimum number of sensors
  - robustness agaist sensor failure

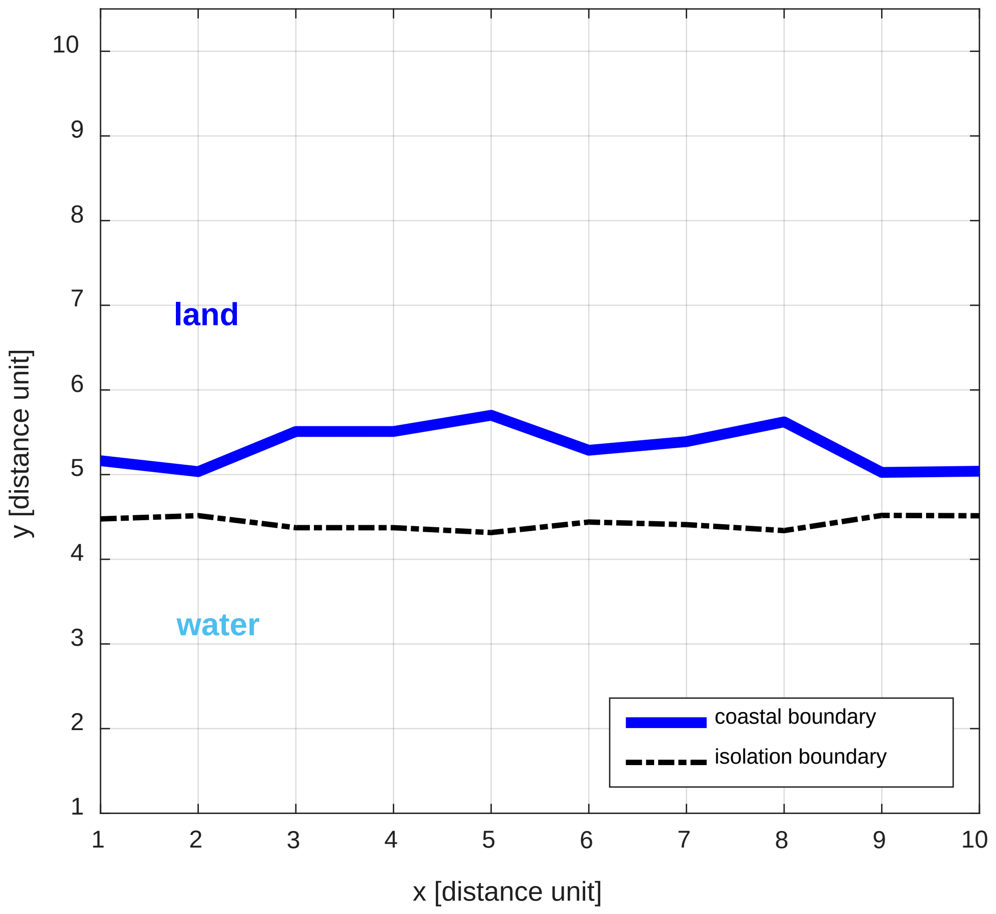
Our Work

- ESC sensor placement problem in coastal areas for the moving incumbent protection in CBRS
  - protection – by deploying minimum number of sensors
  - robustness agaist sensor failure

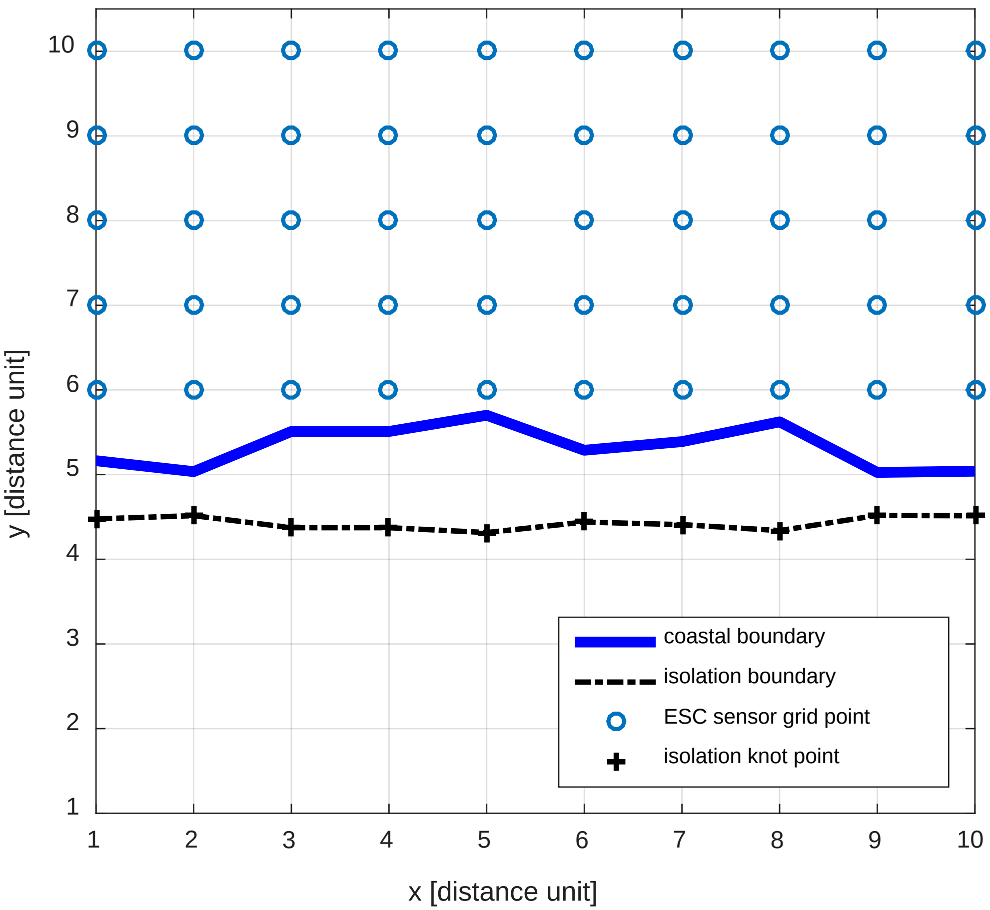
Our Work

- ESC sensor placement problem in coastal areas for the moving incumbent protection in CBRS
  - protection – by deploying minimum number of sensors
  - robustness agaist sensor failure

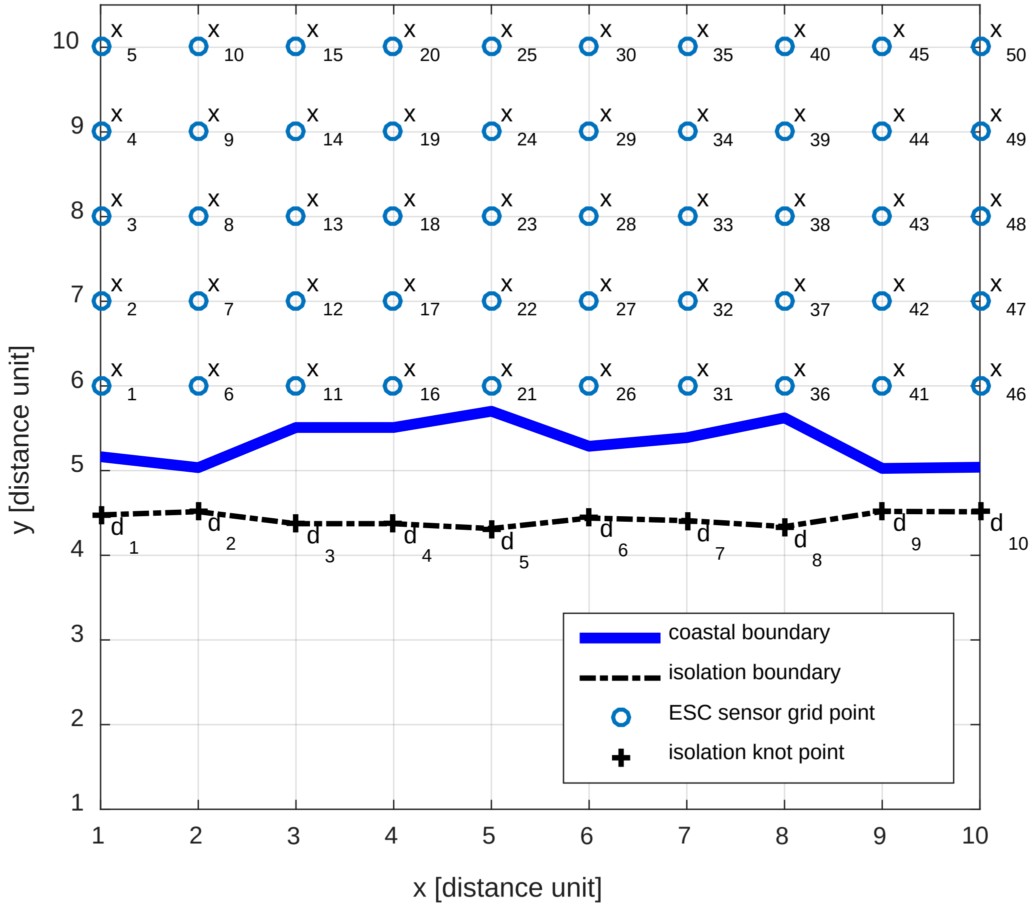
System Model



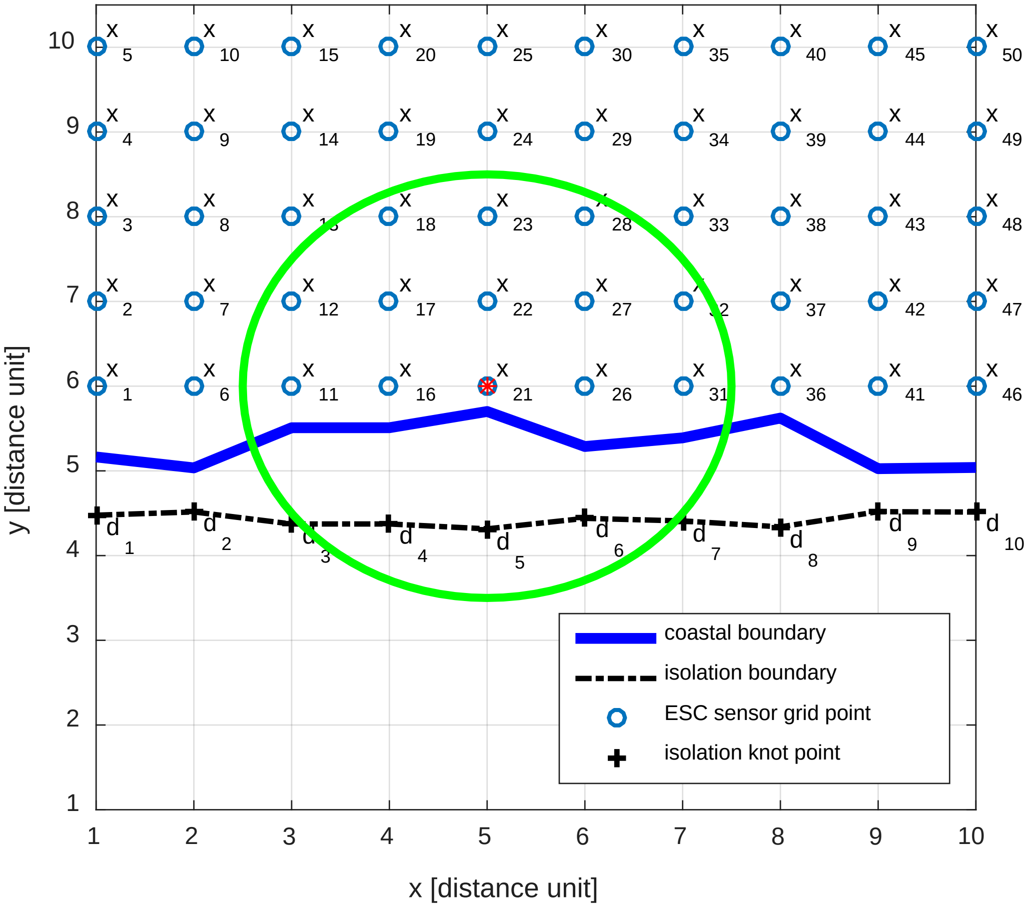
System Model



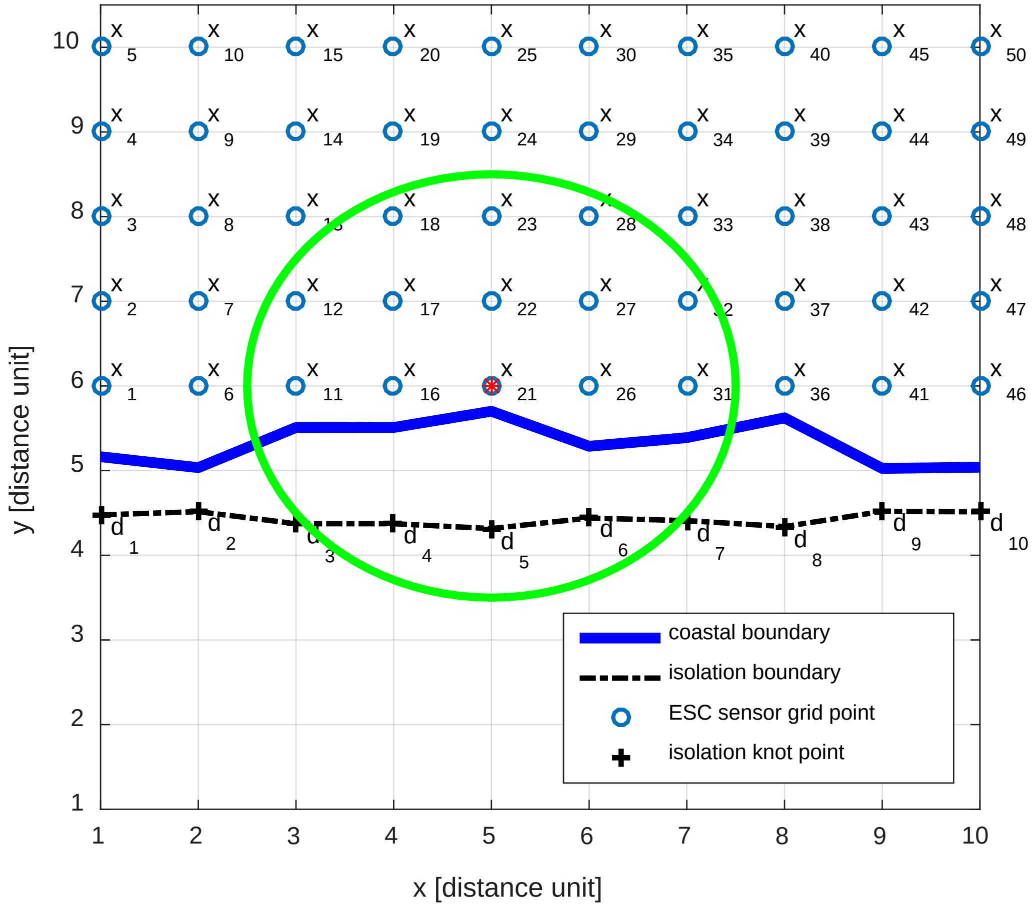
System Model



System Model



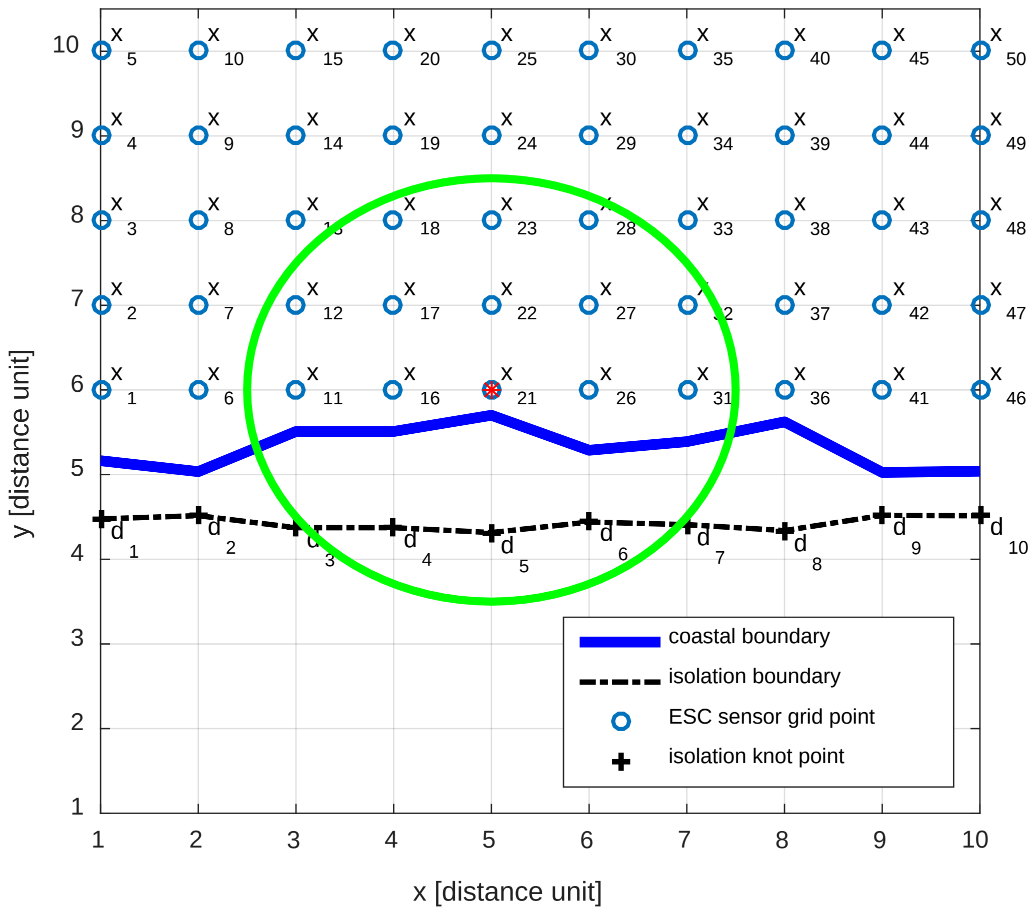
System Model



x_s : ESC sensor place

d_i : isolation knot point

System Model



x_s : ESC sensor place

d_i : isolation knot point

S : number of sensor places

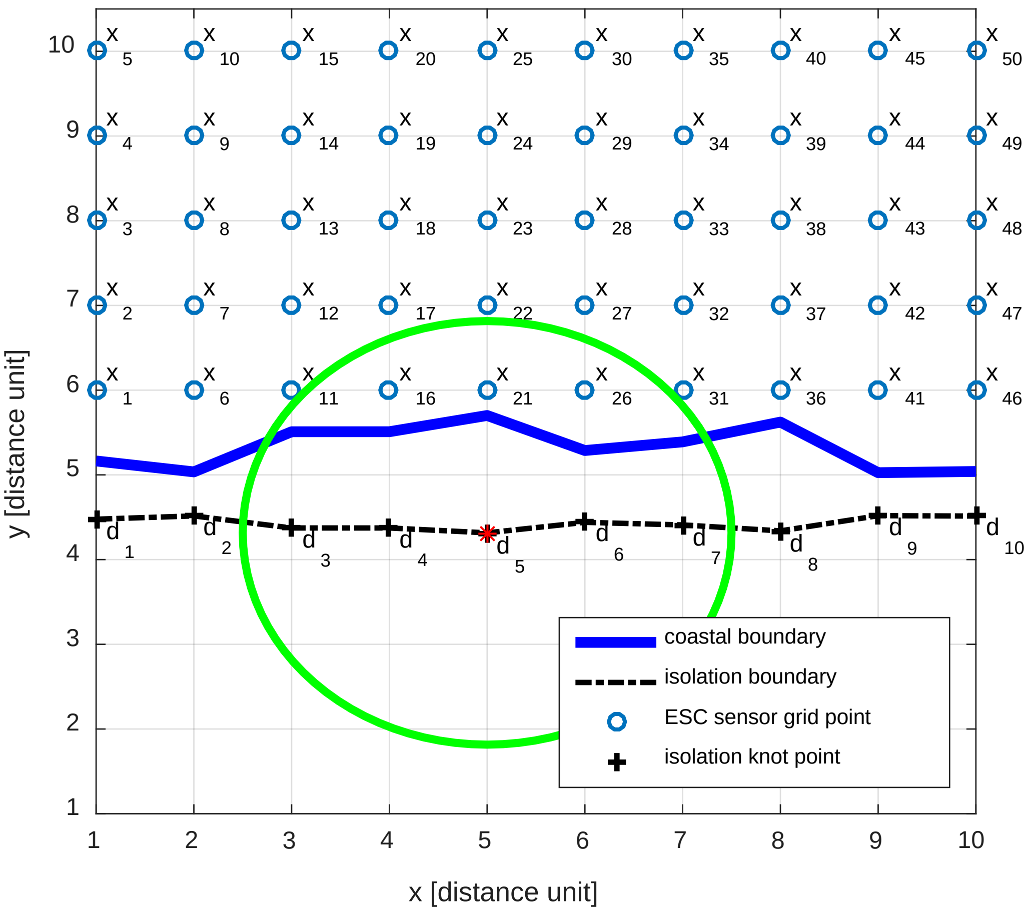
$\mathcal{S}$: set of sensor places

D : number of isolation knot points

$\mathcal{D}$: set of isolation knot points

R : radius sensing region

System Model



x_s : ESC sensor place

d_i : isolation knot point

S : number of sensor places

$\mathcal{S}$: set of sensor places

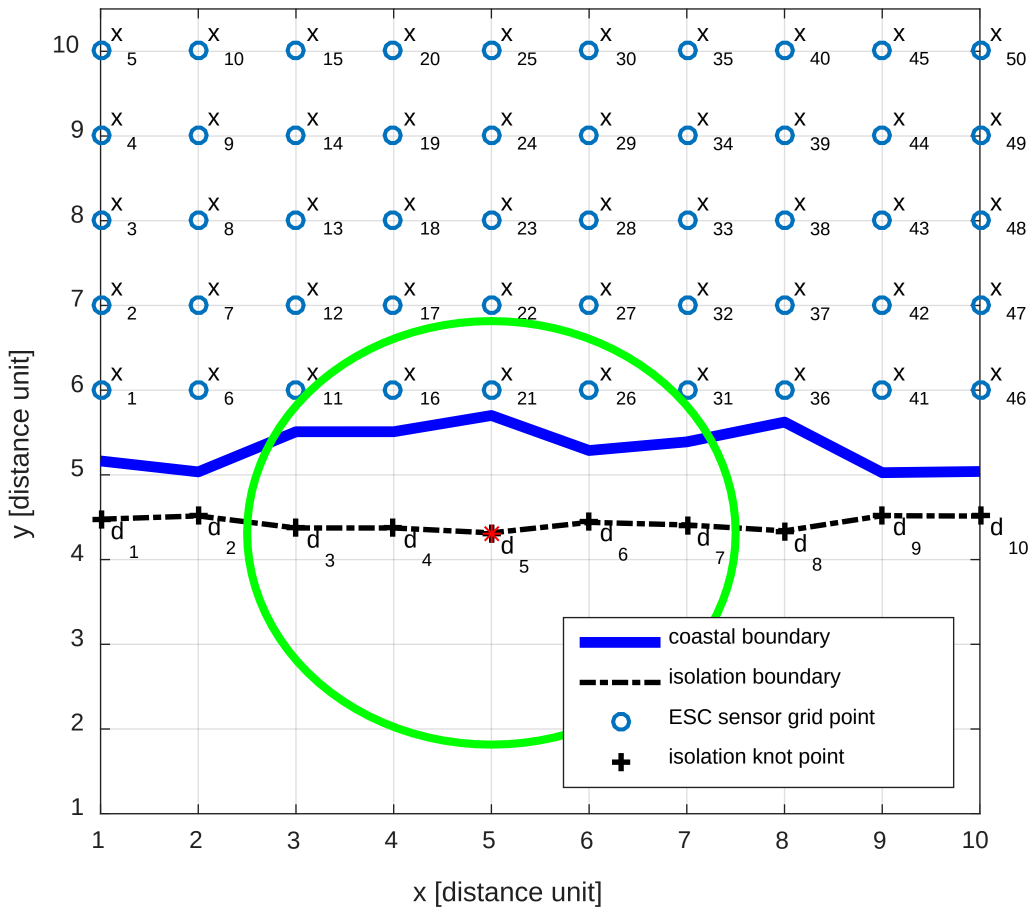
D : number of isolation knot points

$\mathcal{D}$: set of isolation knot points

R : radius sensing region

$\mathcal{S}_i$: subset of $\mathcal{S}$

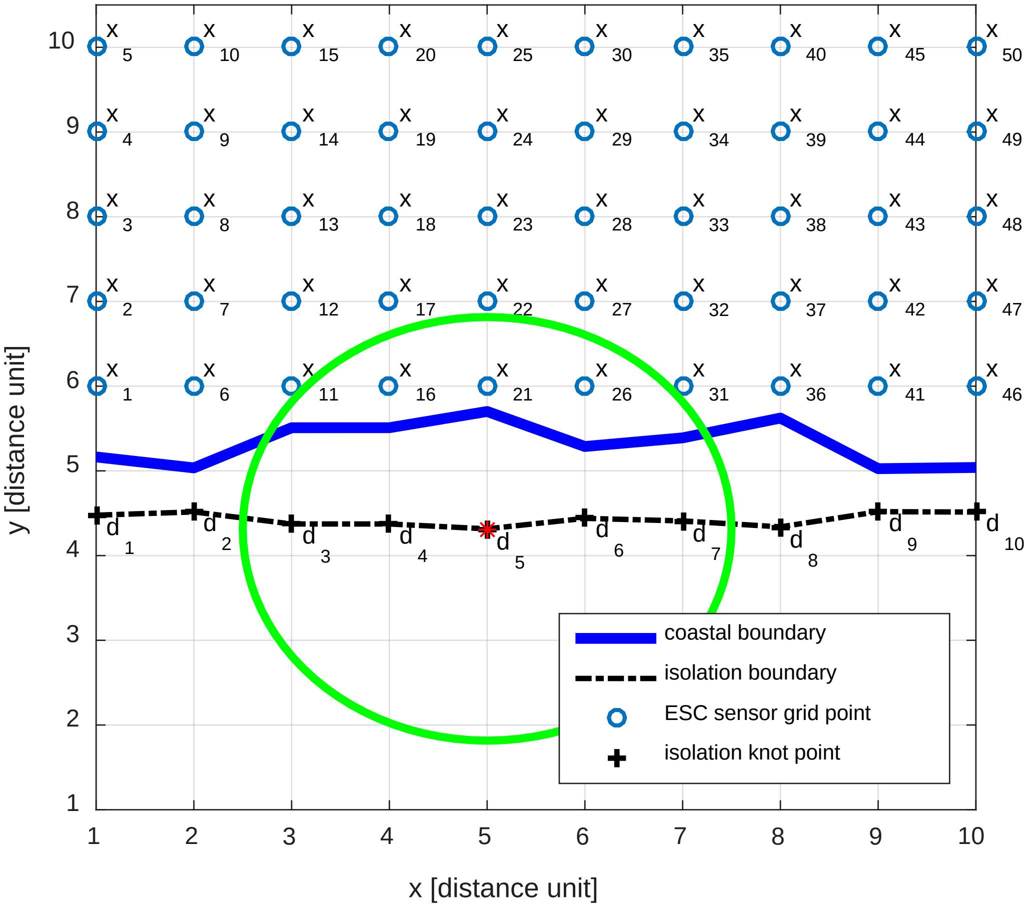
System Model



Euclidean distance from d_i to x_s

$$\mathbf{dist}(d_i, x_s) = \|d_i - x_s\|_2$$

System Model



Euclidean distance from d_i to x_s

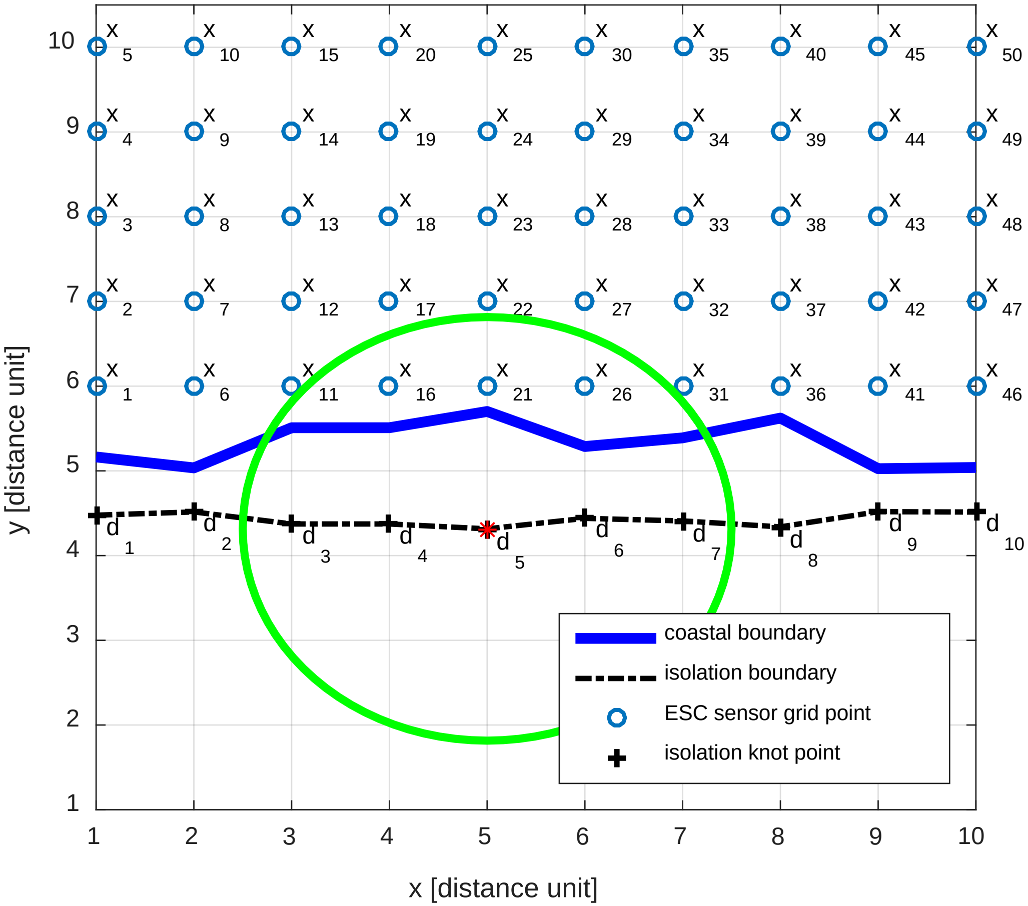
$$\mathbf{dist}(d_i, x_s) = \|d_i - x_s\|_2$$

nearest sensor place for d_i

$$r_i^{\min} = \inf_{s \in \mathcal{S}} \mathbf{dist}(d_i, x_s)$$

$$= \inf_{s \in \mathcal{S}_i} \mathbf{dist}(d_i, x_s)$$

System Model



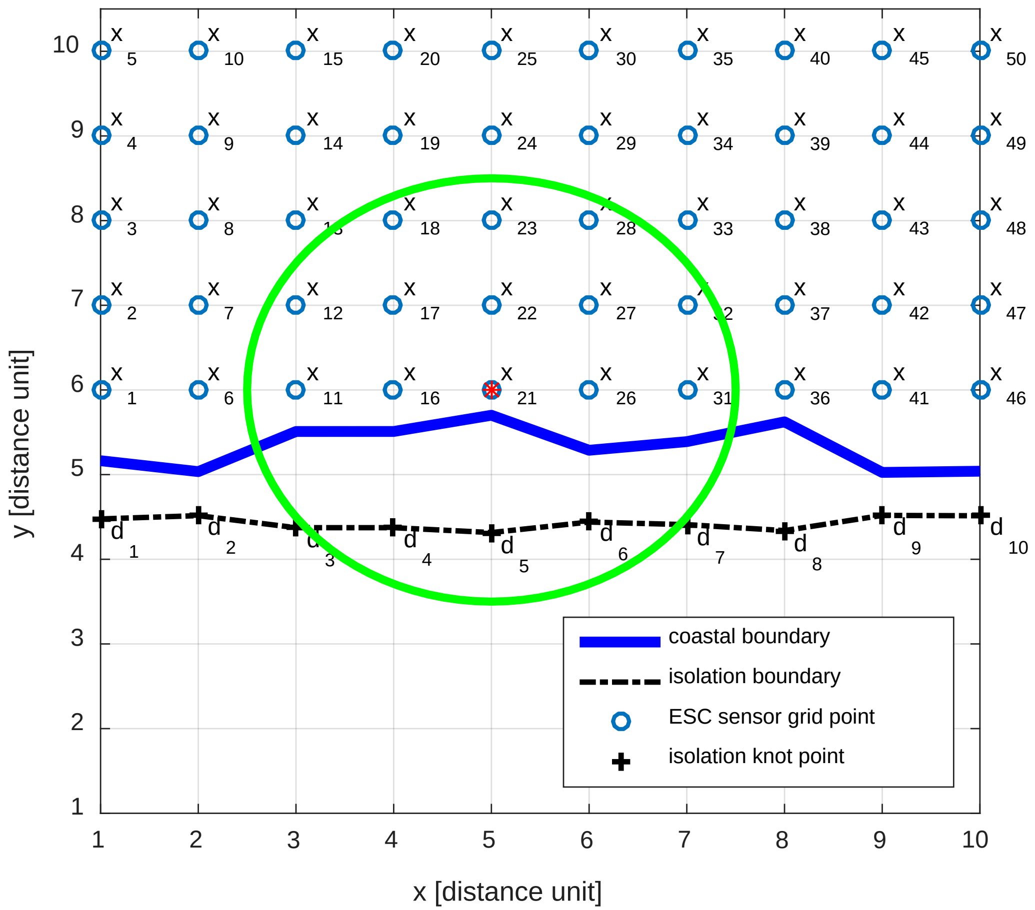
a sensor position that can detect incumbent at d_i

$$r_i^{\min} \leq \sum_{s \in \mathcal{S}_i} b_{is} \|d_i - x_s\|_2 \leq R$$

$$\sum_{s \in \mathcal{S}_i} b_{is} = 1$$

$$b_{is} = \{0, 1\}, \quad s \in \mathcal{S}_i$$

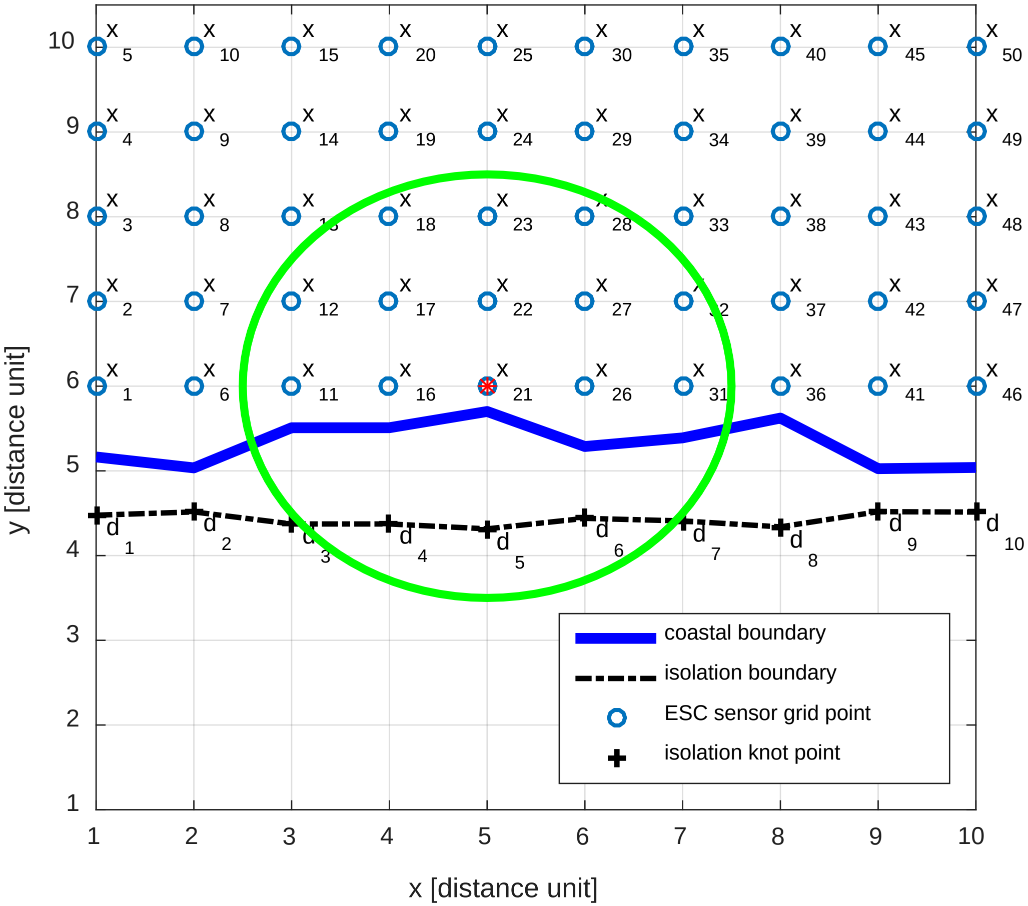
System Model



place sensor at x_s:

$$a_s = \begin{cases} 1 & \text{if } b_{is} = 1 \text{ for any } i \in \mathcal{D} \\ 0 & \text{otherwise} \end{cases}$$

System Model



place sensor at x_s:

$$a_s = \begin{cases} 1 & \text{if } b_{is} = 1 \text{ for any } i \in \mathcal{D} \\ 0 & \text{otherwise} \end{cases}$$

let, $\mathbf{a} = [a_1, \ldots, a_S]^{\mathrm{T}}$

required sensors, $\mathbf{card}(\mathbf{a})$

Minimum number of ESC sensors

$$
\begin{aligned}
\text{minimize} \quad & \mathbf{card}(\mathbf{a}) \\
\text{subject to} \quad & r_i^{\min} \leq \sum_{s\in\mathcal{S}_i} b_{is}\|d_i - x_s\|_2 \leq R, \quad i \in \mathcal{D} \\
& \sum_{s\in\mathcal{S}_i} b_{is} = 1, \quad i \in \mathcal{D} \\
& b_{is} = \{0, 1\}, \quad i \in \mathcal{D}, s \in \mathcal{S} \\
& \max\{b_{1s}, \ldots, b_{Ds}\} = a_s, \quad s \in \mathcal{S},
\end{aligned}
$$

variables: $\{a_s\}_{s\in\mathcal{S}}$ and $\{b_{is}\}_{i\in\mathcal{D},s\in\mathcal{S}}$

Minimum number of ESC sensors

$$
\begin{aligned}
\text{minimize} \quad & \mathbf{card}(\mathbf{a}) \\
\text{subject to} \quad & r_i^{\min} \leq \sum_{s \in \mathcal{S}_i} b_{is} \| d_i - x_s \|_2 \leq R, \quad i \in \mathcal{D} \\
& \sum_{s \in \mathcal{S}_i} b_{is} = 1, \quad i \in \mathcal{D} \\
& b_{is} = \{0, 1\}, \quad i \in \mathcal{D}, s \in \mathcal{S} \\
& \max\{b_{1s}, \ldots, b_{Ds}\} = a_s, \quad s \in \mathcal{S},
\end{aligned}
$$

variables: $\{a_s\}_{s \in \mathcal{S}}$ and $\{b_{is}\}_{i \in \mathcal{D}, s \in \mathcal{S}}$

- ❑ combinatorial optimization problem
- ❑ exponential complexity – global solution

Minimum number of ESC sensors

$$
\begin{array}{ll}
\text{minimize} & \mathbf{card}(\mathbf{a}) \\
\text{subject to} & r_i^{\min} \leq \sum_{s \in \mathcal{S}_i} b_{is} \| d_i - x_s \|_2 \leq R, \quad i \in \mathcal{D} \\
& \sum_{s \in \mathcal{S}_i} b_{is} = 1, \quad i \in \mathcal{D} \\
& b_{is} = \{0, 1\}, \quad i \in \mathcal{D}, s \in \mathcal{S} \\
& \max\{b_{1s}, \ldots, b_{Ds}\} = a_s, \quad s \in \mathcal{S},
\end{array}
$$

variables: $\{a_s\}_{s \in \mathcal{S}}$ and $\{b_{is}\}_{i \in \mathcal{D}, s \in \mathcal{S}}$

- combinatorial optimization problem
- exponential complexity – global solution

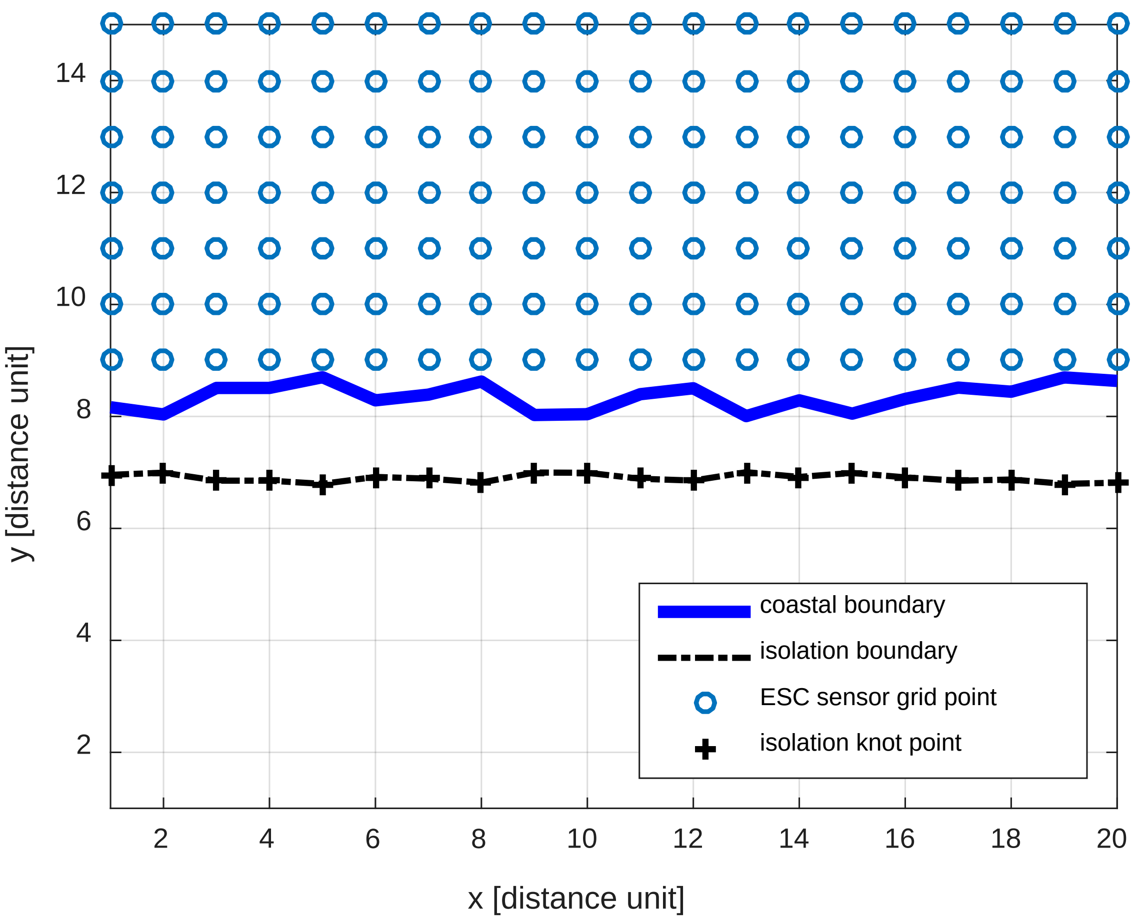
- propose: suboptimal but fast algorithm (sequential convex programming)

Robustness against sensor failures (N-measurements)

$$
\begin{aligned}
\text{minimize} \quad & \mathbf{card}(\mathbf{a}) \\
\text{subject to} \quad & r_i^{\min} \leq \sum_{s \in \mathcal{S}_i} b_{is} \|d_i - x_s\|_2 \leq NR, \quad i \in \mathcal{D} \\
& \sum_{s \in \mathcal{S}_i} b_{is} = N, \quad i \in \mathcal{D} \\
& b_{is} = \{0, 1\}, \quad i \in \mathcal{D}, s \in \mathcal{S} \\
& \max\{b_{1s}, \ldots, b_{Ds}\} = a_s, \quad s \in \mathcal{S},
\end{aligned}
$$

variables: $\{a_s\}_{s \in \mathcal{S}}$ and $\{b_{is}\}_{i \in \mathcal{D}, s \in \mathcal{S}}$

Numerical Results

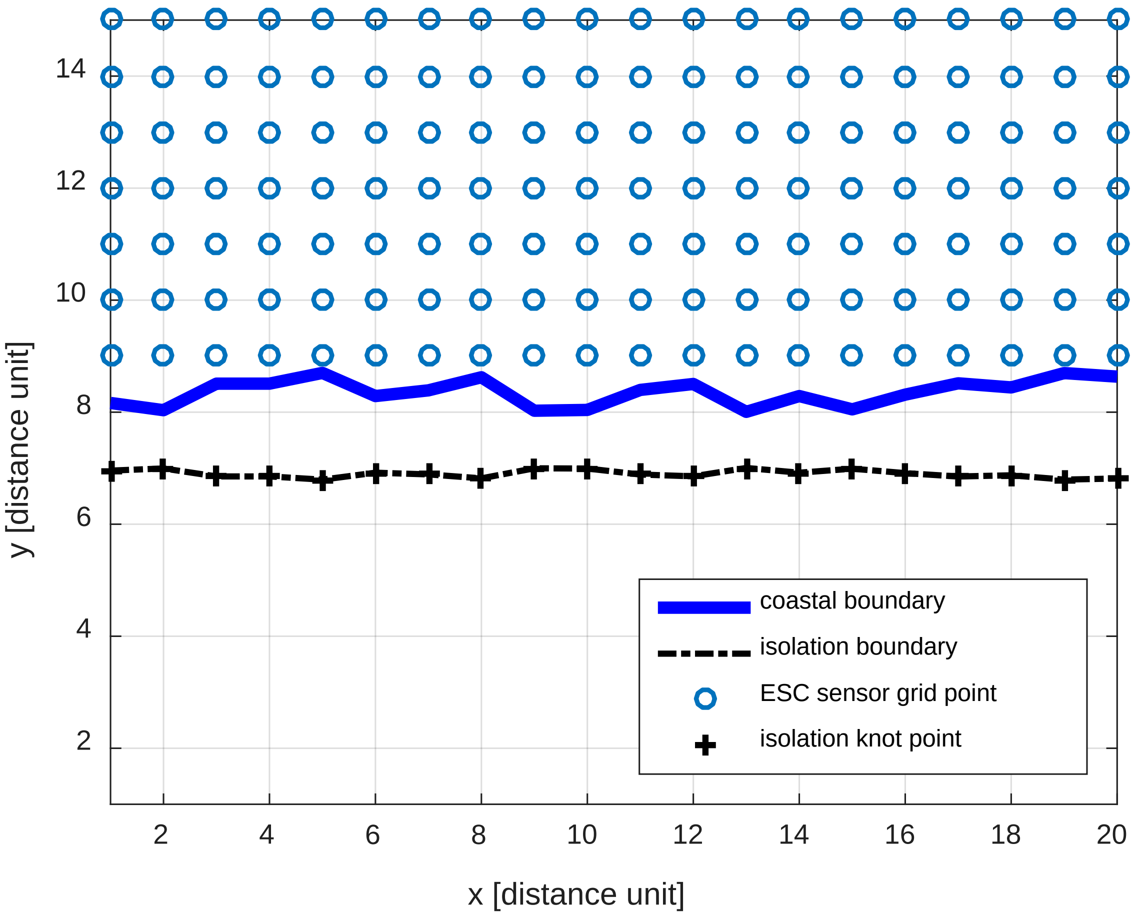


possible sensor positions

$$S = 140$$

$$D = 20$$

Numerical Results



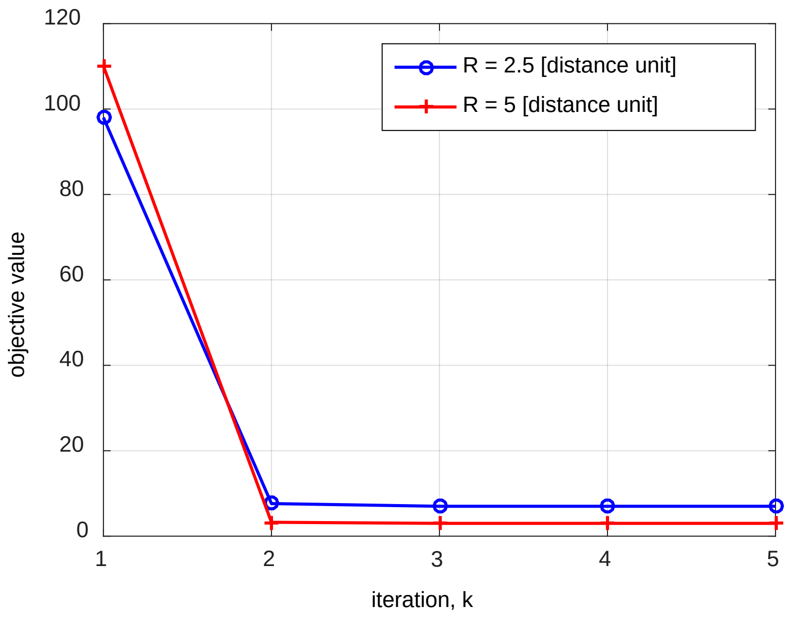
possible sensor positions

$$S = 140$$

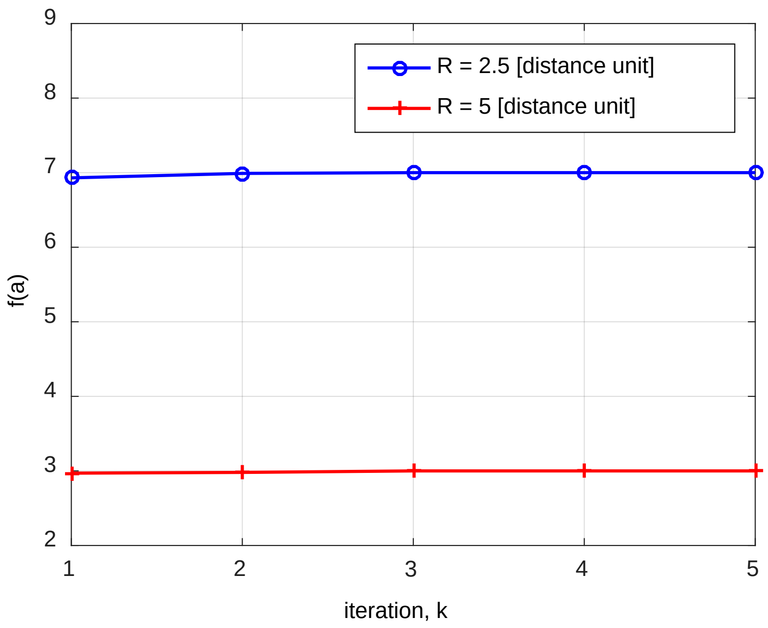
$$D = 20$$

R = 2.5 and 5 [distance unit]

Numerical Results

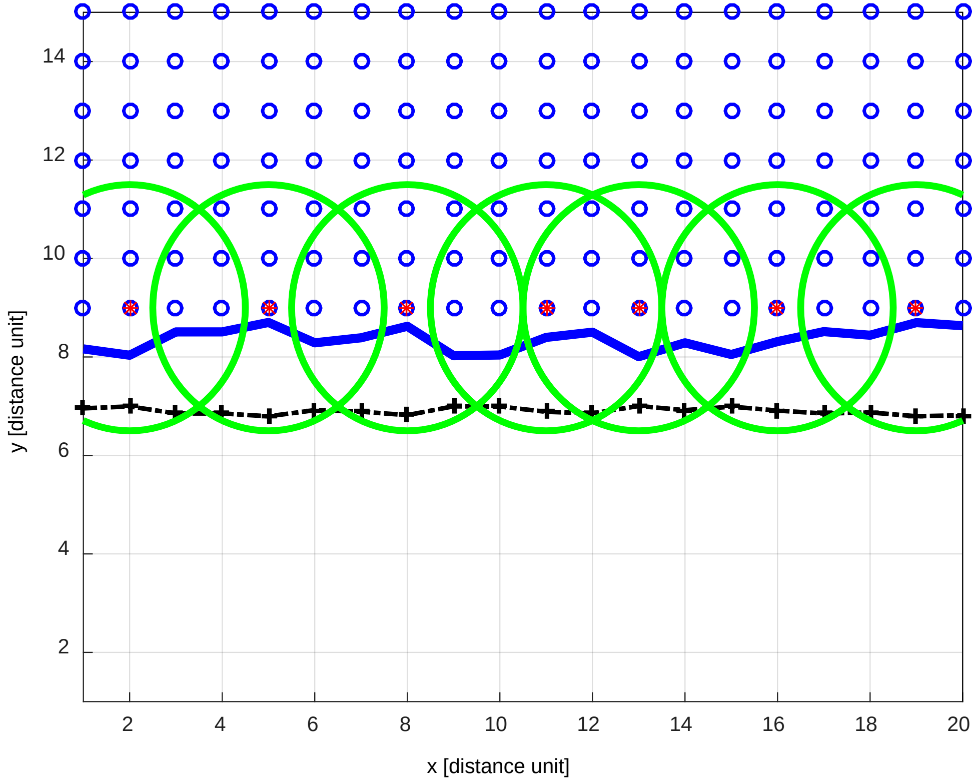


convergence of algorithm



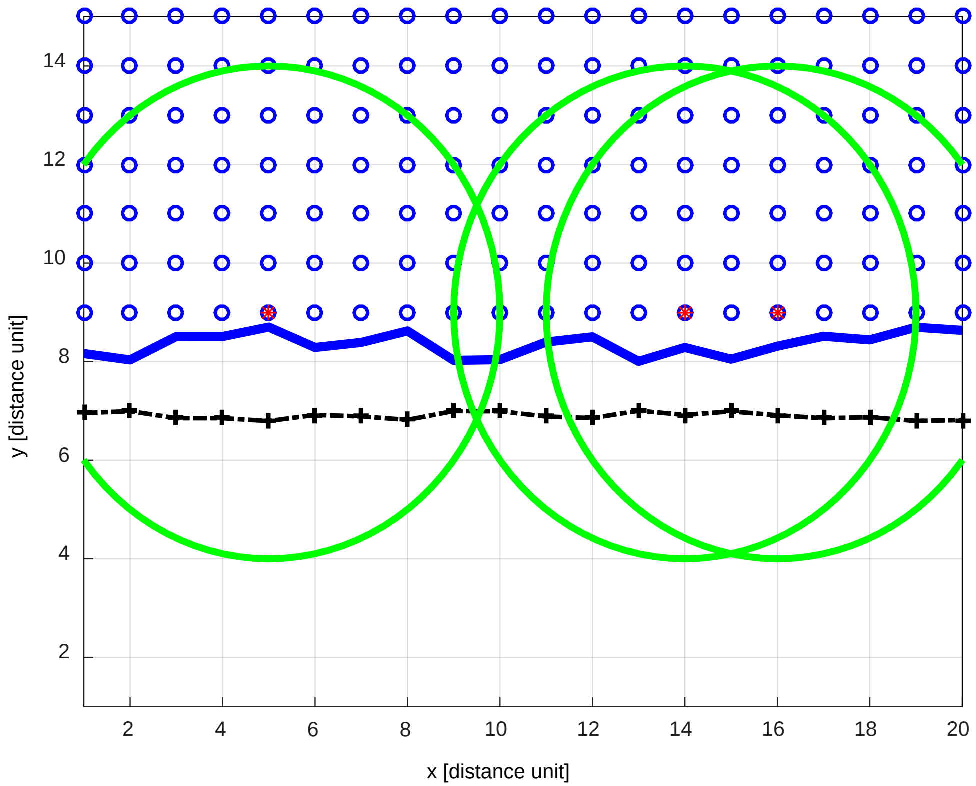
required sensors vs iterations

Numerical Results



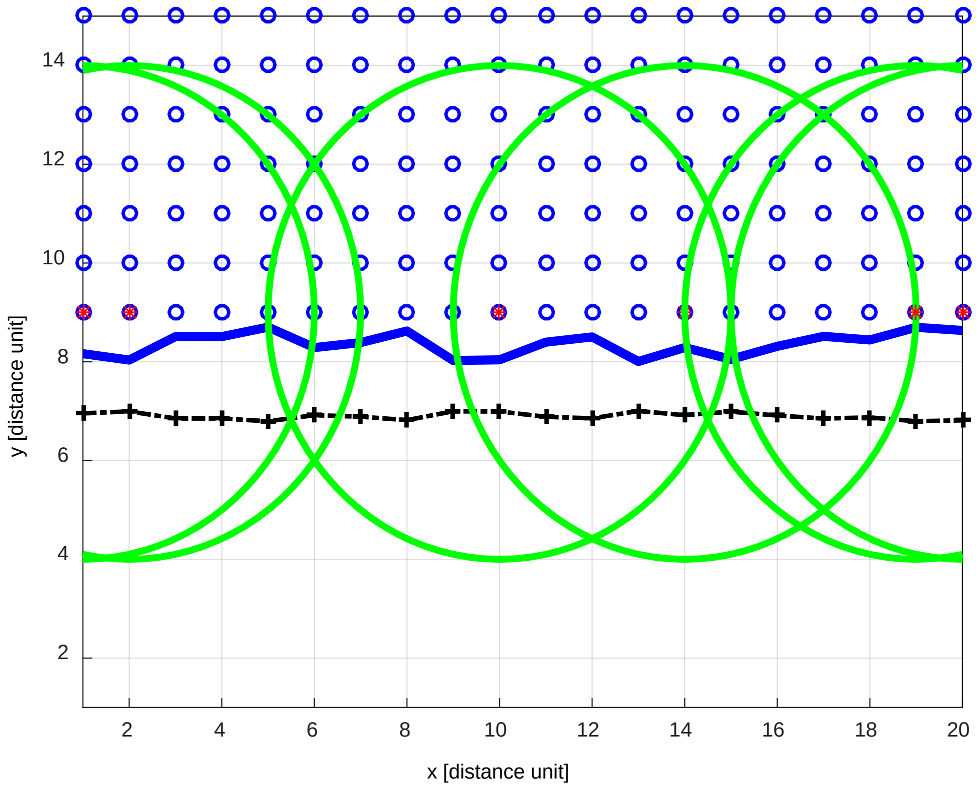
R = 2.5 [distance unit]

Numerical Results



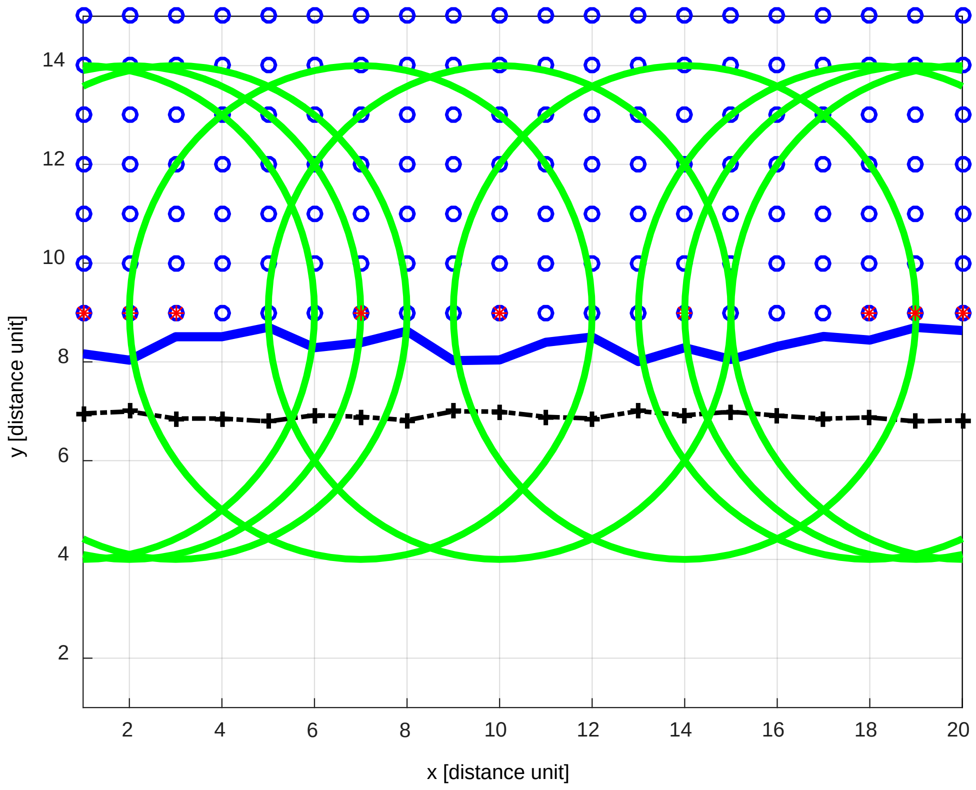
R = 5 [distance unit]

Numerical Results



R = 5 [distance unit]
N = 2
δ = 1

Numerical Results



R = 5 [distance unit]

N = 2

δ = 5

Conclusions

- sensor node placement in the coastal areas for the moving incumbent protection is considered
- problem of finding the minimum number of ESC sensors and their locations is a combinatorial optimization problem
- proposed a suboptimal but fast-converging algorithm based on sequential convex programming
- extend the proposed algorithm to overcome the sensor failures