Sonar Placement in Ports and Waterways

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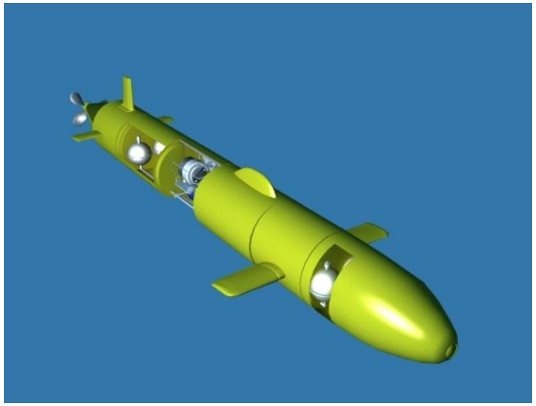
CAIT-DIMACS Laboratory for Port Security

Protect against terrorist attacks

- Divers
- AUV's
- Hull mounted objects

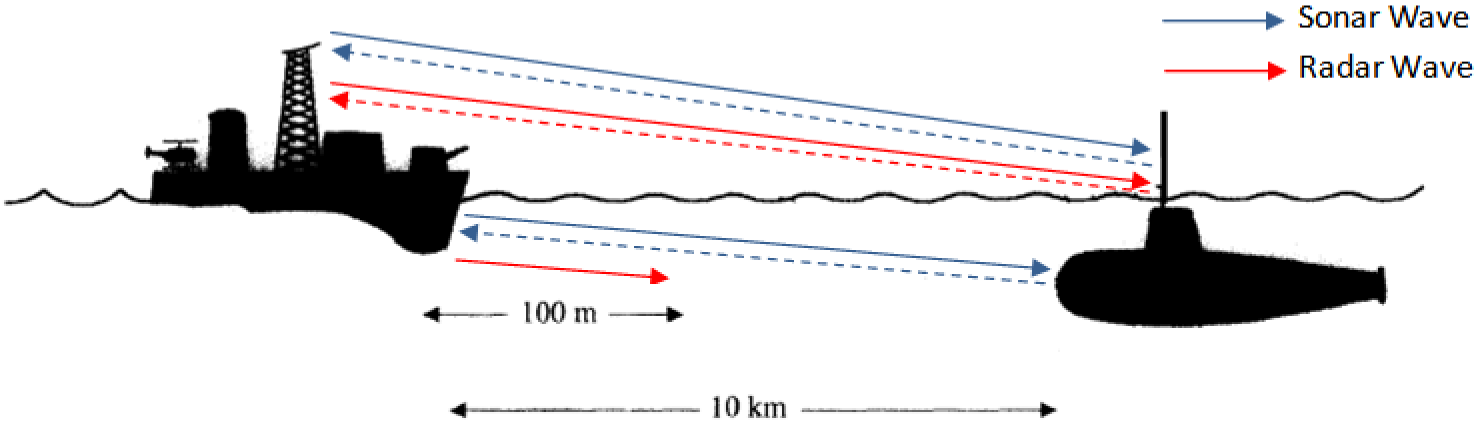


Environment

- Infeasibility of electromagnetic sensors
- A type of sensor called SONAR (**SO**und **NA**vigation and **R**anging) is used
- Sonars work based on sound waves

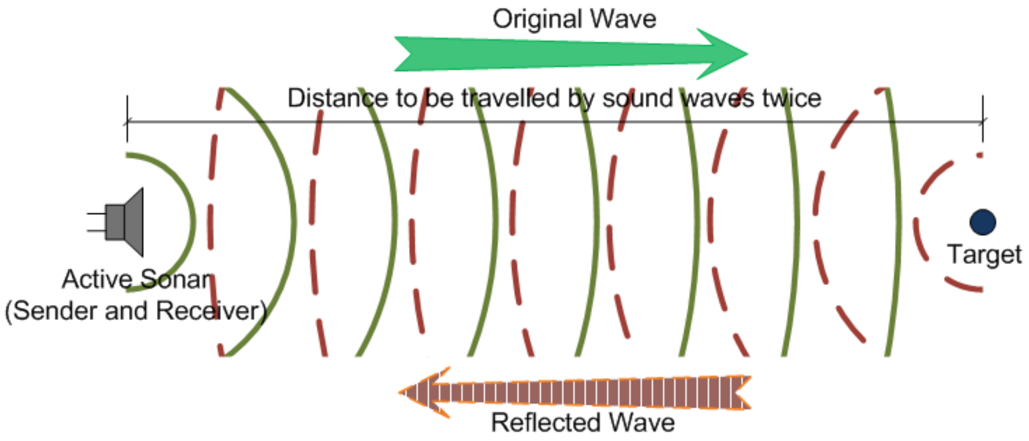
Sonar's advantage over radar

- Electromagnetic waves get stuck in sea water
- Sound waves can travel in sea water even for tens of miles

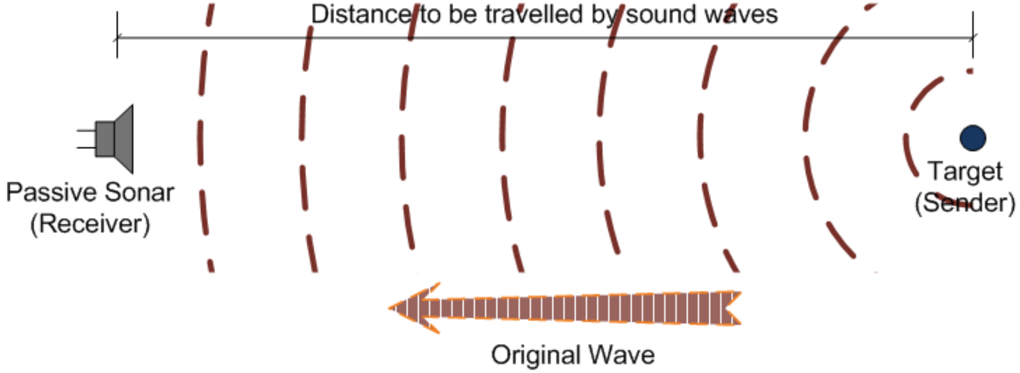


Sonar Types

- Active



- Passive

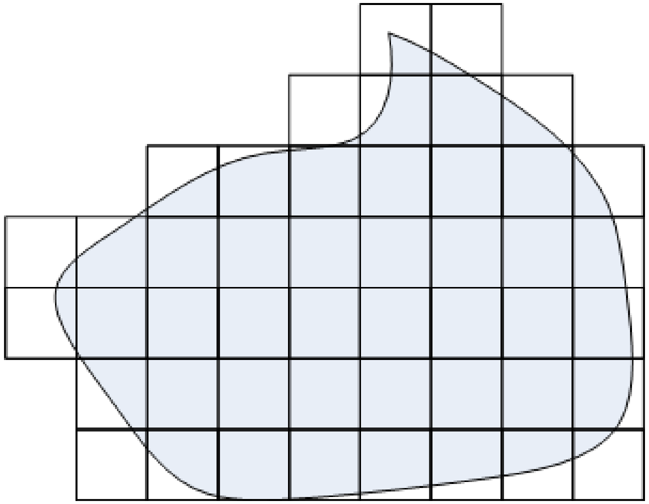


Model

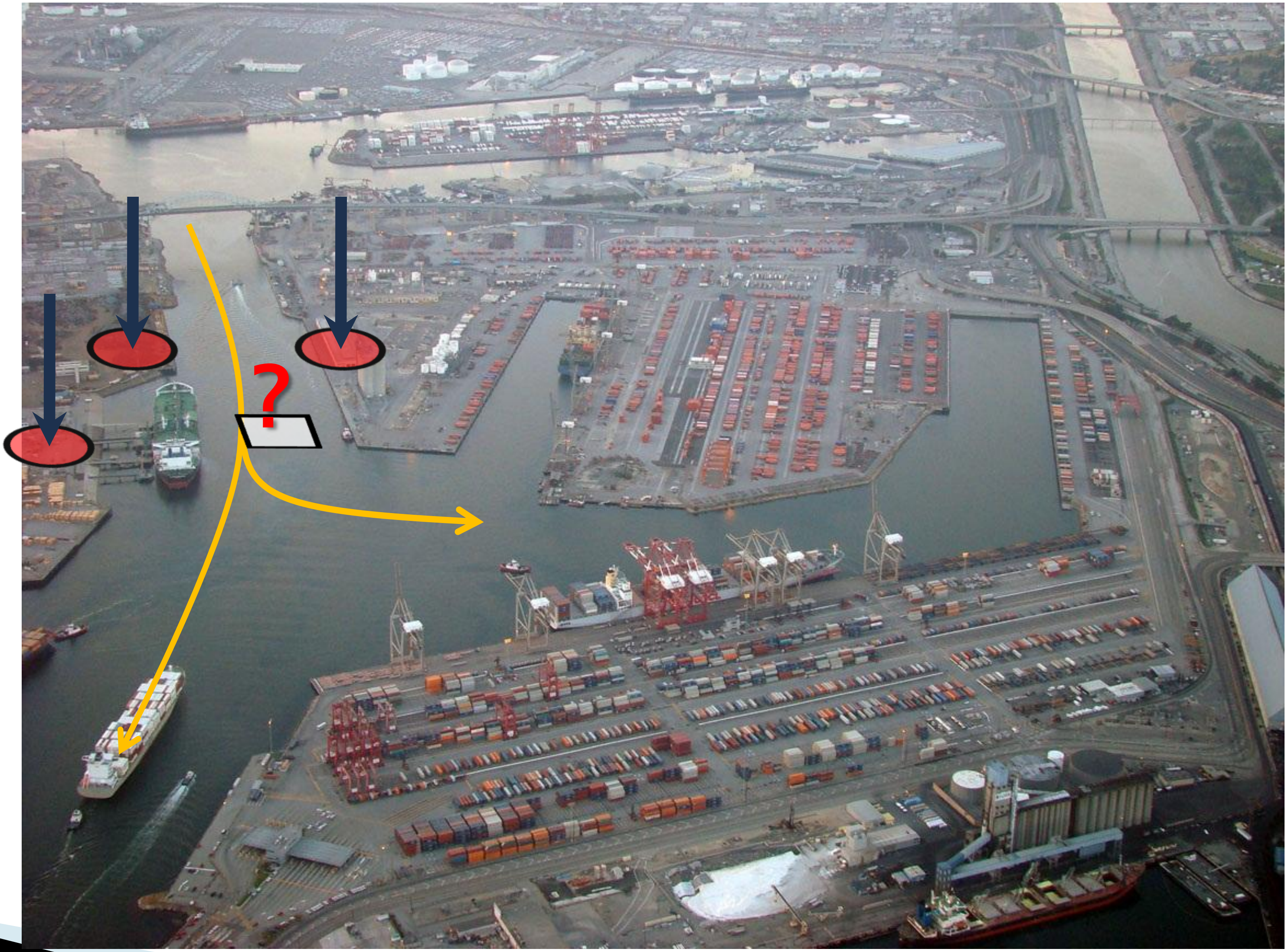
- A Risk Minimization problem, with integer (binary) decision variables
- With:
  - Multiple coverage
  - Detection probability reduces by distance from the sonar
  - Various properties of sonars
  - Different sonar types

  Are considered in the model.

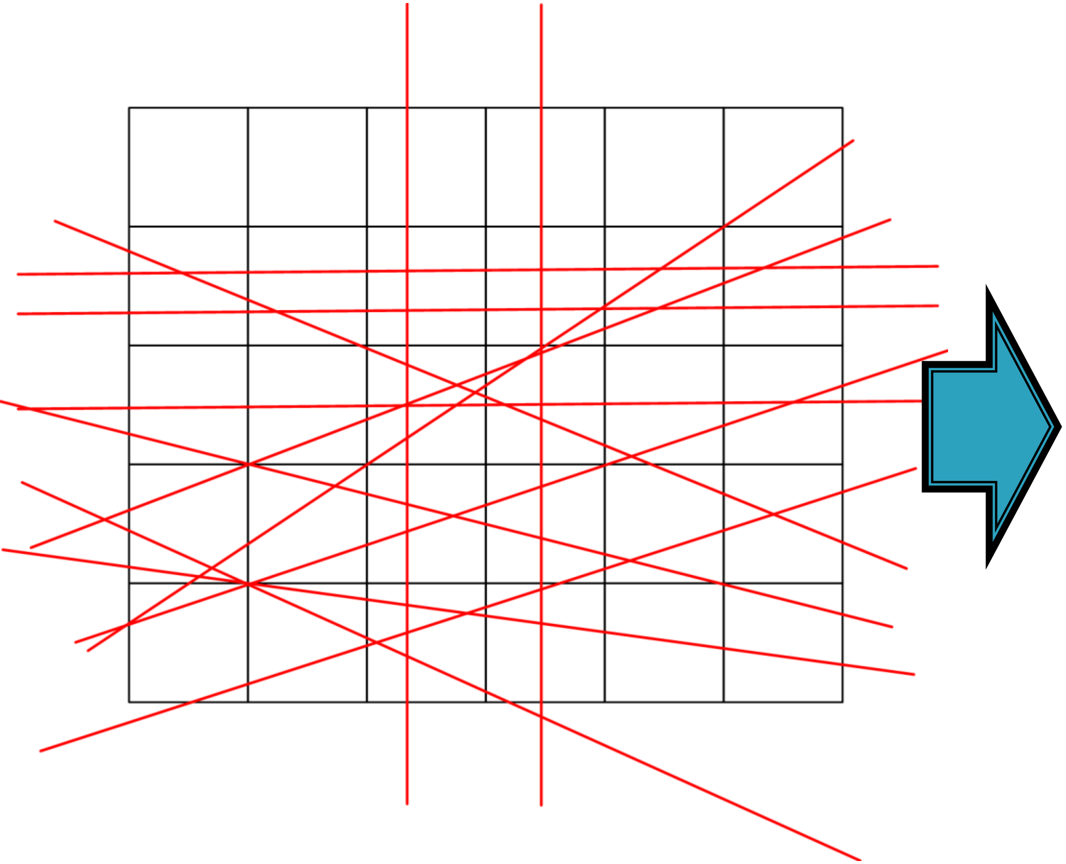
- Discretization



Chracteristic Values



Assessing a_{ij} Values



0	0	1	1	0	1
3	3	3	5	4	3
2	2	5	6	3	2
4	3	3	4	3	2
3	3	4	4	1	2

A Simple Model!

Notation

$a_{ij} = characteristic\ value\ of\ cell\ i, j$

$p = detection\ probability\ of\ a\ sonar$

$c = budget\ for\ placing\ sonars$

$n = number\ of\ cells\ a\ sonar\ can\ cover$

$NC_{ij} = set\ of\ neighboring\ cells\ of\ i, j\ that\ a\ sonar$
$positioned\ at\ cell\ i, j\ can\ cover\ including\ i, j\ itself$

$$x_{ij} = \begin{cases} 1 & if\ a\ sonar\ is\ placed\ at\ cell\ i, j \\ 0 & otherwise \end{cases}$$

$$y_{ij} = \begin{cases} 1 & if\ cell\ i, j\ is\ covered\ by\ a\ sonar \\ 0 & otherwise \end{cases}$$

Formulation

$$Min \sum_{i} \sum_{j} a_{ij} (1 - p.y_{ij})$$

Objective Function

$$n.x_{ij} \leq \sum_{k,l \in NC_{ij}} y_{kl} \qquad (1)$$

$$y_{ij} \leq \sum_{k,l \in NC_{ij}} x_{kl} \qquad (2)$$

Placement Constraints

$$c \sum_{i} \sum_{j} x_{ij} \leq b \qquad (3)$$

Cost Constraint

$$x_{ij}, y_{ij} \in \{0,1\}$$

Decision Variables

Explanation

$$Min \sum_i \sum_j a_{ij} (1 - p.y_{ij})$$

- This objective function minimizes a risk-like measure according to cell coverage and also the importance of cells (a_{ij} values)

$$R = E[C] = E[C \mid Successful\ \ Attack] \cdot P(Successful\ \ Attack) =$$

$$E[C \mid Successful\ \ Attack] \cdot P(Successful\ \ Attack \mid Attack\ \ Happens) \cdot P(Attack\ \ Happens) = C \cdot V \cdot T$$

Main Model

- Featuring
  - Multiple detection of sonars
  - Range dependent detection probability
  - Various types of sonars

Optimization Model

$$Min\sum_{i}\sum_{j}a_{ij}\{1-[((1-t_{ij})\cdot\sum_{n}dp_{n}\cdot y_{ijn})+t_{ij}\cdot dp_{\max}]\}$$

$St:$

$$d_{mn}\cdot x_{ijm}\le\sum_{(k,l)\in N_{ijmn}}y_{kln}\qquad\forall i,j,m,n$$

$$y_{ijn}\le\sum_{m}\sum_{(k,l)\in N_{ijmn}}x_{klm}\qquad\forall i,j,n$$

Placement Constraints

$$\sum_{i}\sum_{j}\sum_{m}c_{m}\cdot x_{ijm}\le b$$

Cost Constraint

$$\sum_{n}y_{ijn}-1\le M\cdot t_{ij}\qquad\forall i,j$$

$$M(1-t_{ij})+\sum_{n}y_{ijn}\ge 2\qquad\forall i,j$$

Multiple Coverage Constraints

$$x_{ijm},y_{ijn},t_{ij}\in\{0,1\}$$

Decision Variables

Decision Variables

$$x_{ijm} = \begin{cases} 1 & if\ a\, sonar\, of\ \ type\ m\, is\ placed\ in\, cell\, (i,\ j) \\ 0 & otherwise \end{cases}$$

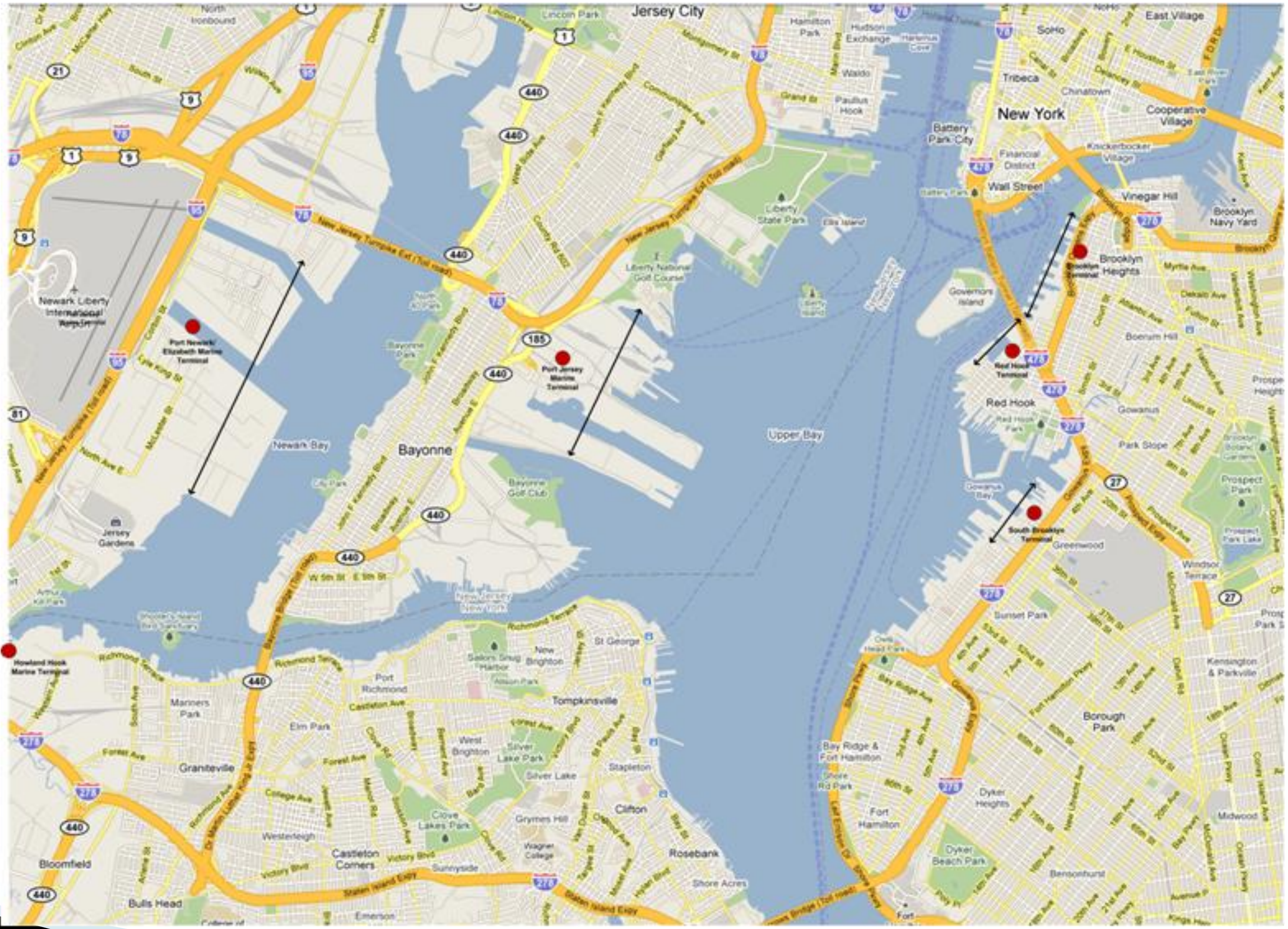
$$y_{ijn} = \begin{cases} 1 & if\ \ cell\, (i,\ j)\ is\, covered\ by\, coverage\, type\ n \\ 0 & otherwise \end{cases}$$

$$t_{ij} = \begin{cases} 1 & if\ \ cell\ (i,\ j)\ is\, coverd\ by\, more\, than\, one\, sonar \\ 0 & otherwise \end{cases}$$

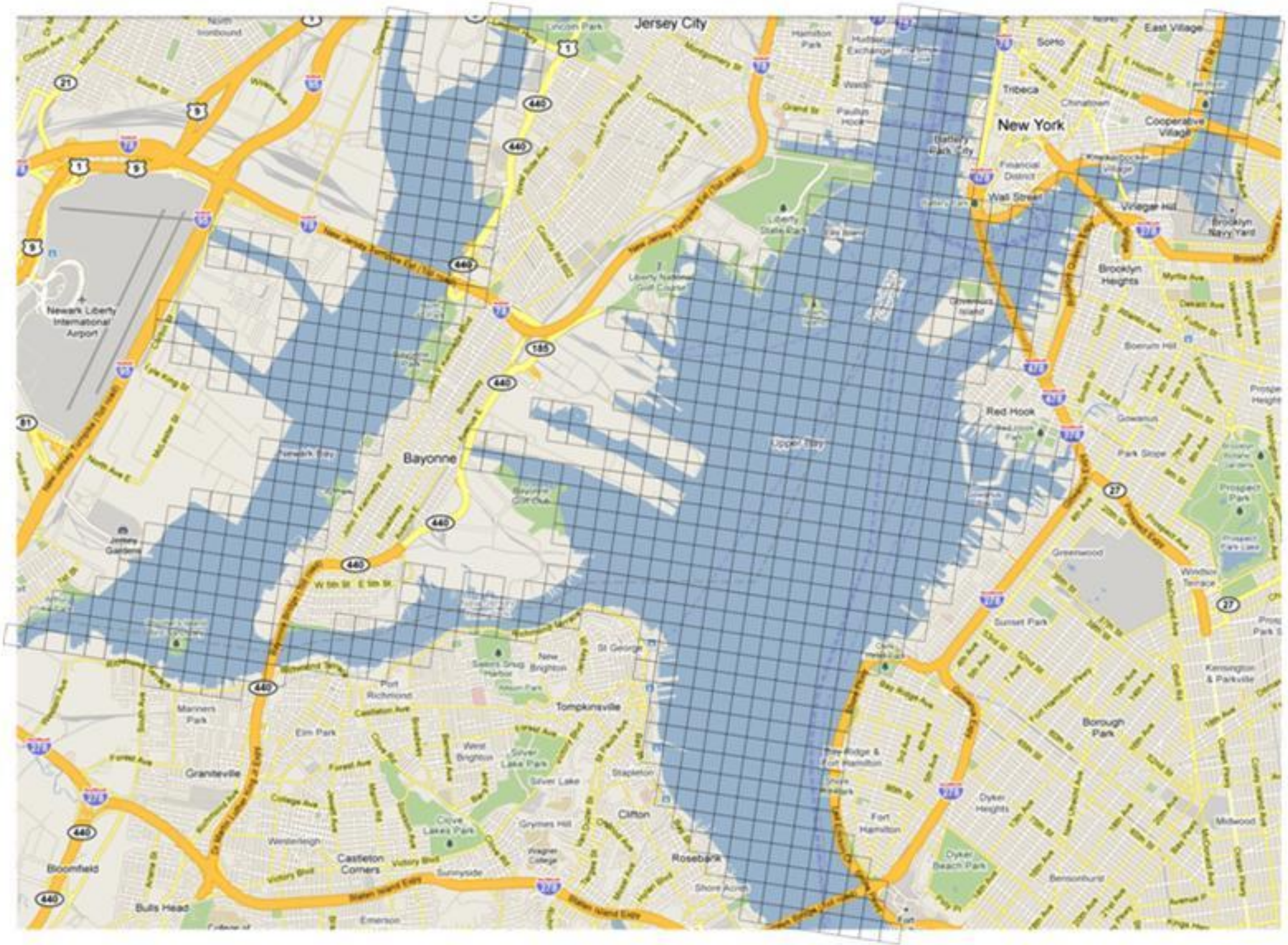
Test Case
New York Harbor

(as an example)

Terminals


Port Newark/ Elizabeth Marine Terminal
Port Jersey Marine Terminal
Brooklyn Terminal
Red Hook Terminal
South Brooklyn Terminal
Howland Hook Marine Terminal
Jersey City
New York
Bayonne
Newark Bay
Upper Bay
Newark Liberty International Airport
Governors Island
Red Hook
Brooklyn Heights

Grid

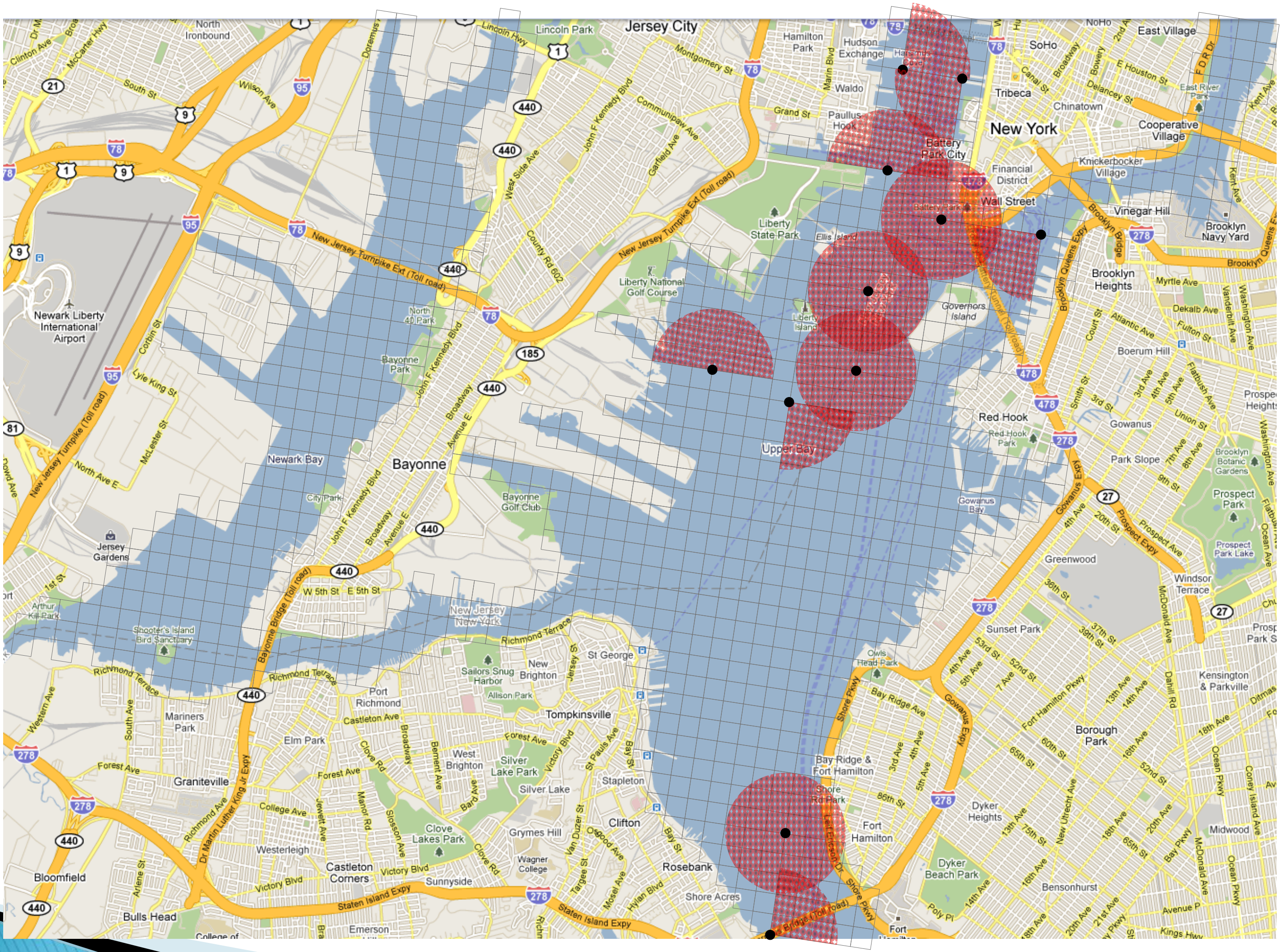


Jersey City
New York
Tribeca
SoHo
Chinatown
East Village
Cooperative Village
Financial District
Wall Street
Battery Park City
Paulus Hook
Liberty State Park
Governors Island
Brooklyn Heights
Brooklyn Navy Yard
Vinegar Hill
Boerum Hill
Red Hook
Gowanus
Park Slope
Prospect Park
Greenwood
Windsor Terrace
Sunset Park
Kensington & Parkville
Borough Park
Dyker Heights
Dyker Beach Park
Fort Hamilton
Bay Ridge & Fort Hamilton
Bensonhurst
Midwood
Upper Bay
Bayonne
Newark Bay
Newark Liberty International Airport
Jersey Gardens
W 5th St
E 5th St
St George
New Brighton
Port Richmond
Tompkinsville
Mariners Park
Elm Park
West Brighton
Silver Lake Park
Silver Lake
Stapleton
Graniteville
Grymes Hill
Clifton
Clove Lakes Park
Westerleigh
Castleton Corners
Wagner College
Rosebank
Shore Acres
Sunnyside
Bloomfield
Bulls Head
Emerson

Defining Criticality level of Cells

A Sonar Placement Scheme

A Sonar Placement Scheme



Thank you!