Peer-to-Peer Architecture

Problem:

Communication between Every Pair of Peers

Idea (old): A peer p only needs to communicate with another peer q if p is relevant to q

Recall: In C/S Architecture, the server has global information and decide who is relevant to who.

Problem: No global information in P2P architecture.

Naive Solution: Every peer keeps global information about all other peers and make individual decision.

Maintaining global information is expensive (and that’s what we want to avoid in the first place!)

Smarter solution: exchange position, then decide when should the next position exchange be.

Idea: Assume B is static. If A knows B's position, A can compute the region which is irrelevant to B. Need not update B if A moves within that region.

what if B moves?

It still works if B also knows A position and computes the region that is irrelevant to A.

Position exchanges occur once initially, and when a player moves outside of its irrelevant region wrt another player.

Frontier Sets

cell-based, visibility-based IM

Previously, we learnt how to compute cell-to-cell visibility.

Frontier for cells X and Y consists of two sets F_{XY} and F_{YX}

No cell in F_{XY} is visible from a cell in F_{YX}, and vice versa.

F_{XY} and F_{YX} are disjoint

if X and Y are not mutually visible.

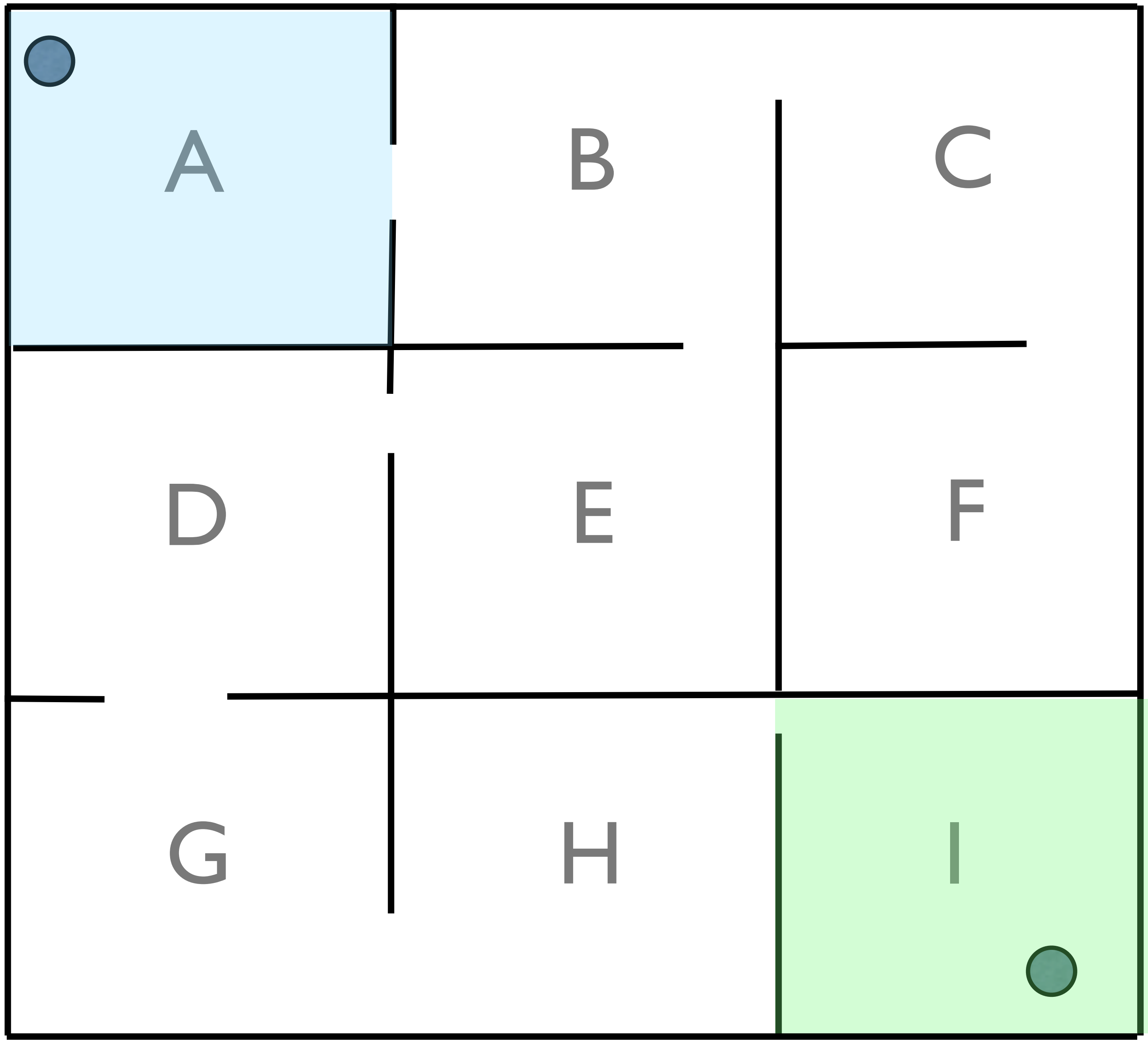
F_{XY} and F_{YX} are empty

if X and Y are mutually visible.

Suppose X and Y are not mutually visible, then a simple frontier is

$F_{XY} = \{X\} \quad F_{YX} = \{Y\}$

(many others are possible)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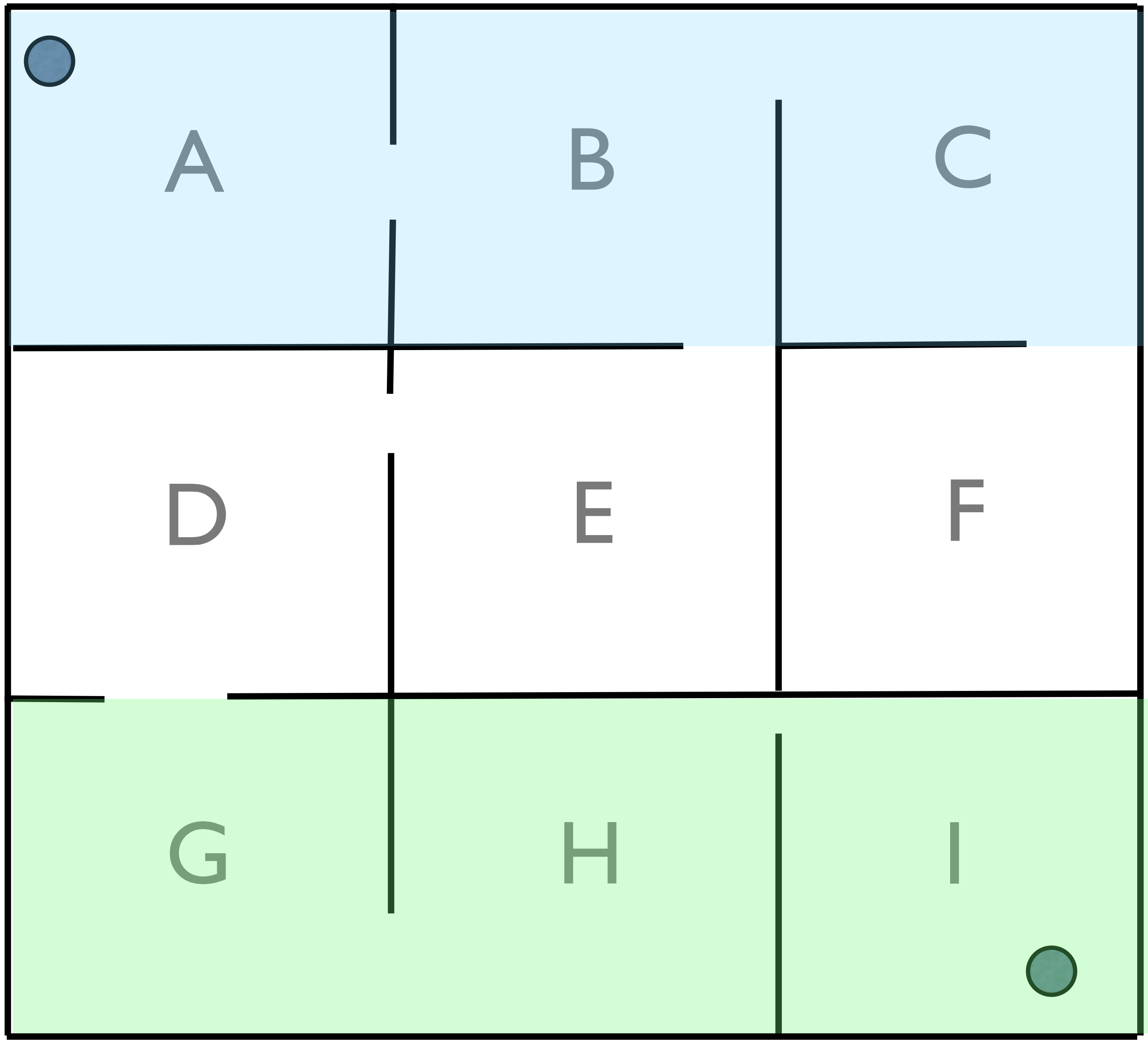
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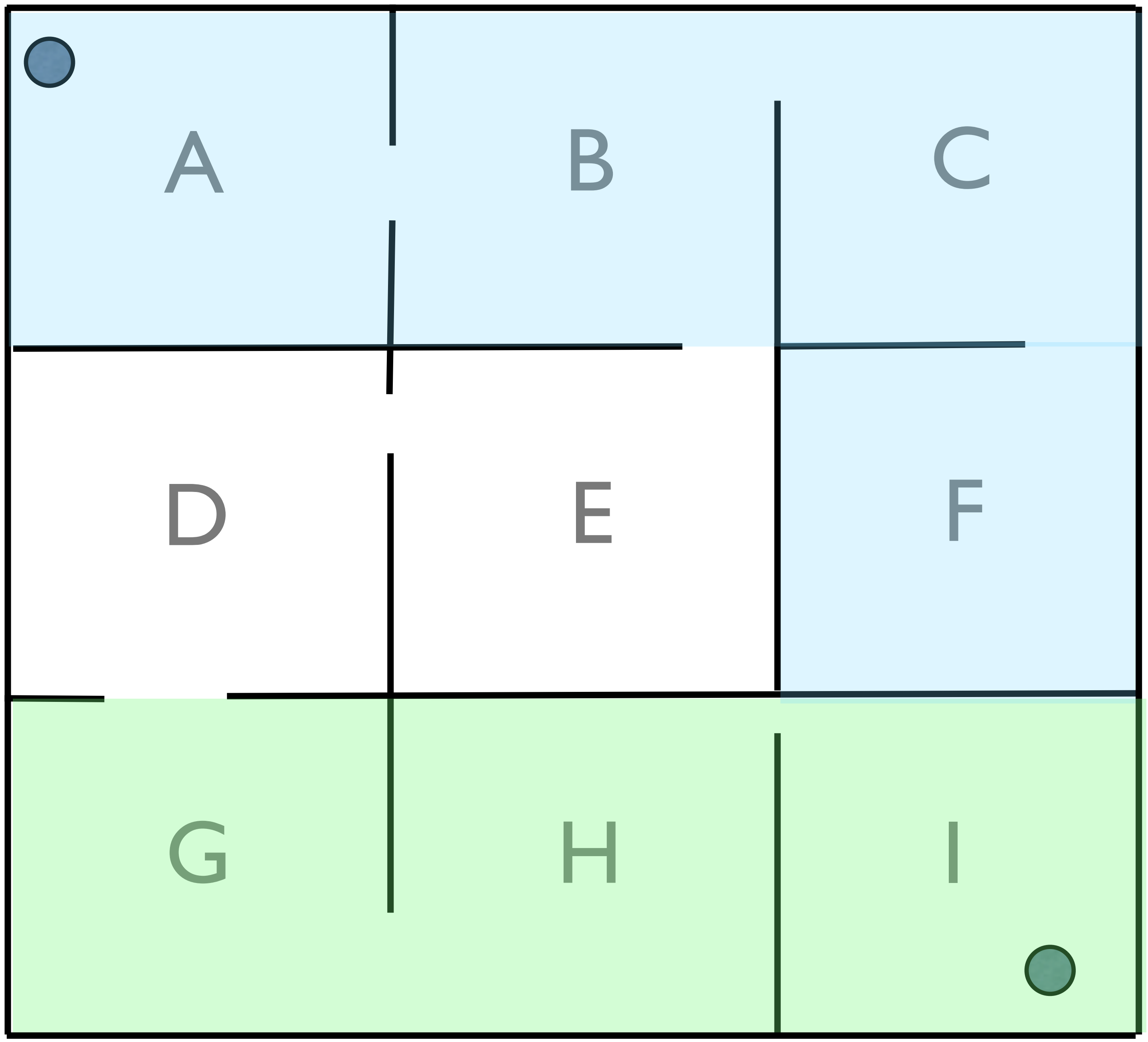
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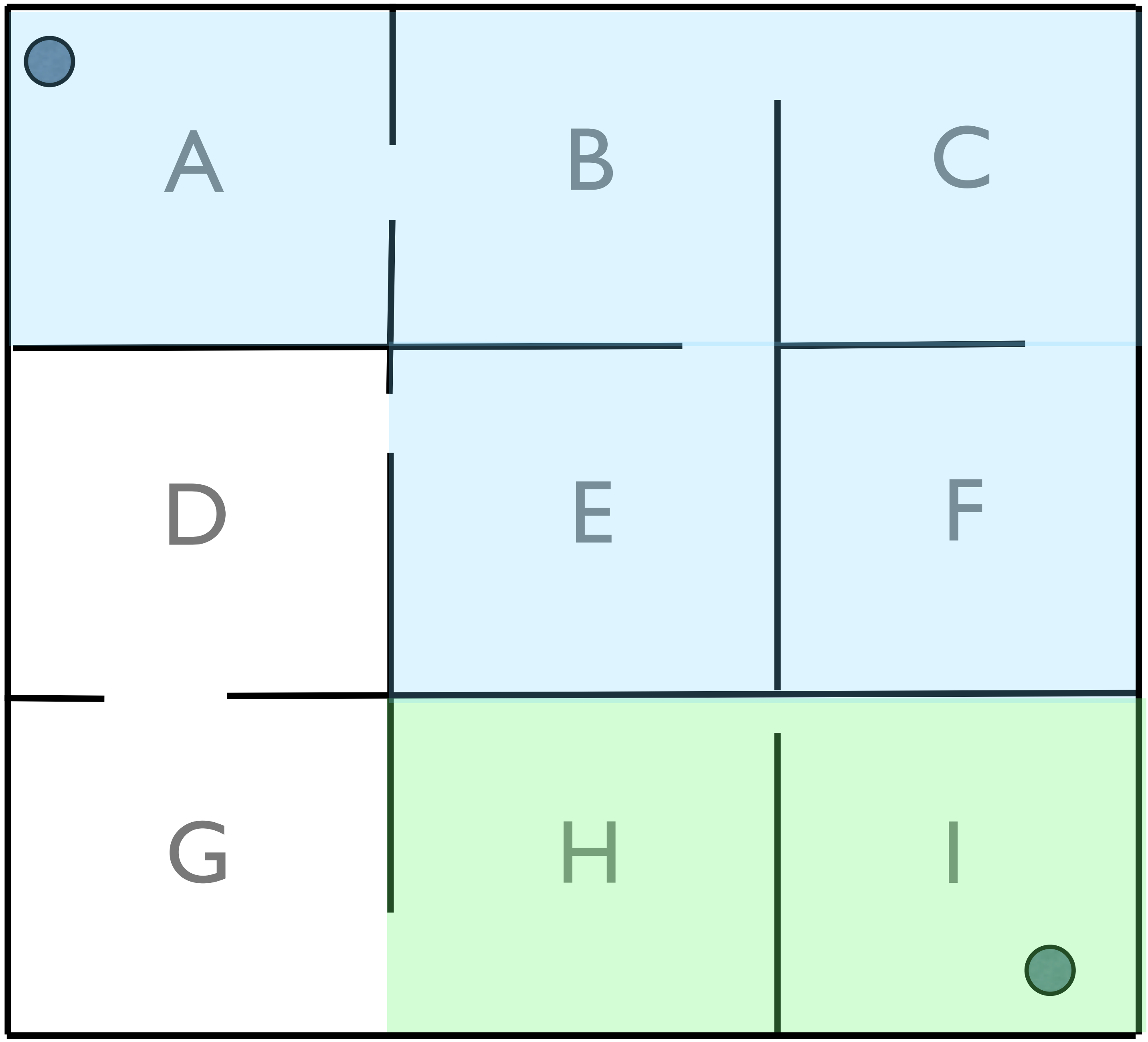
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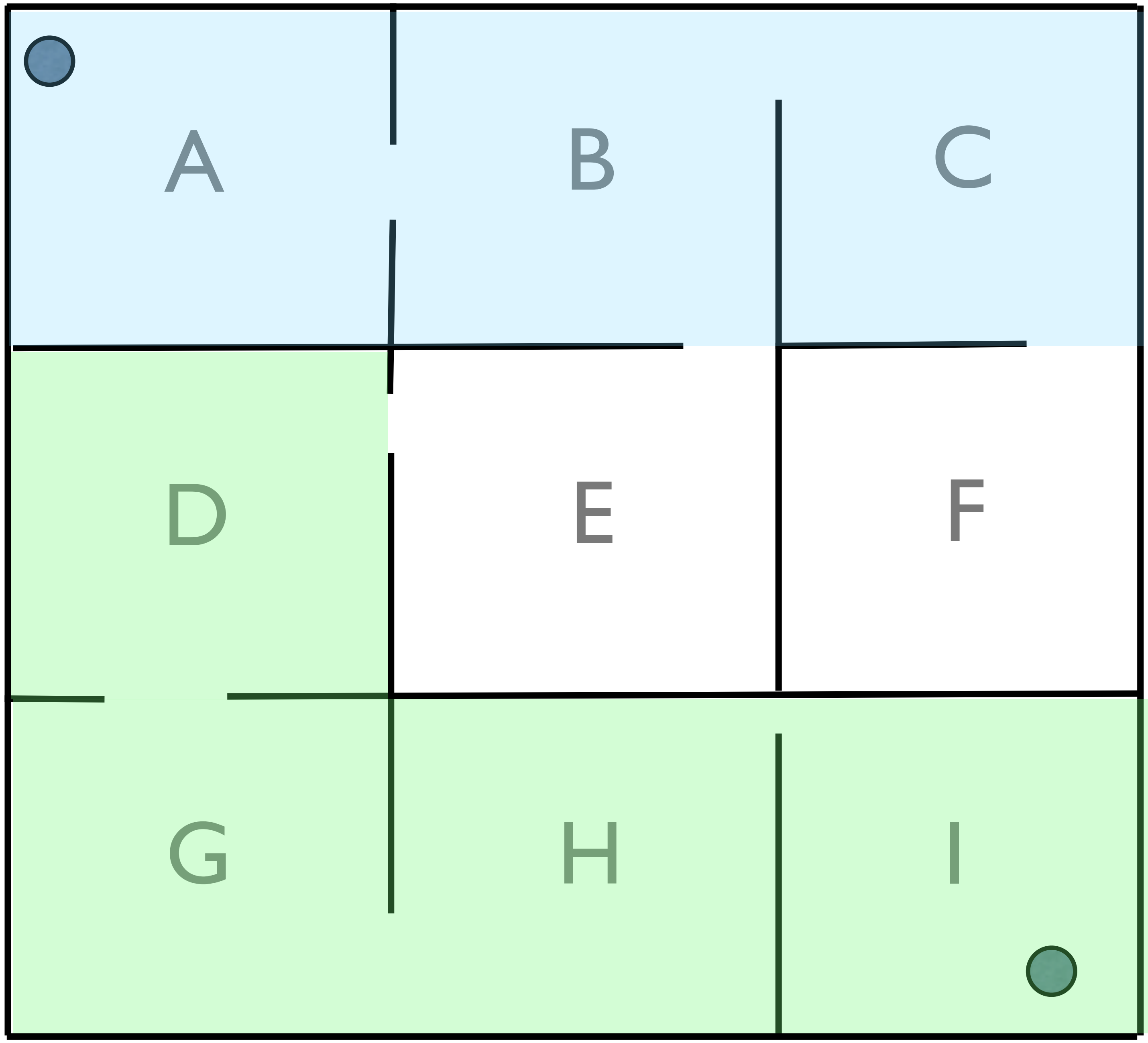
NOT a frontier for A and I (D is visible from B).



Position exchanges occur once initially, and when a player moves outside of its irrelevant region wrt another player.

Initialize:

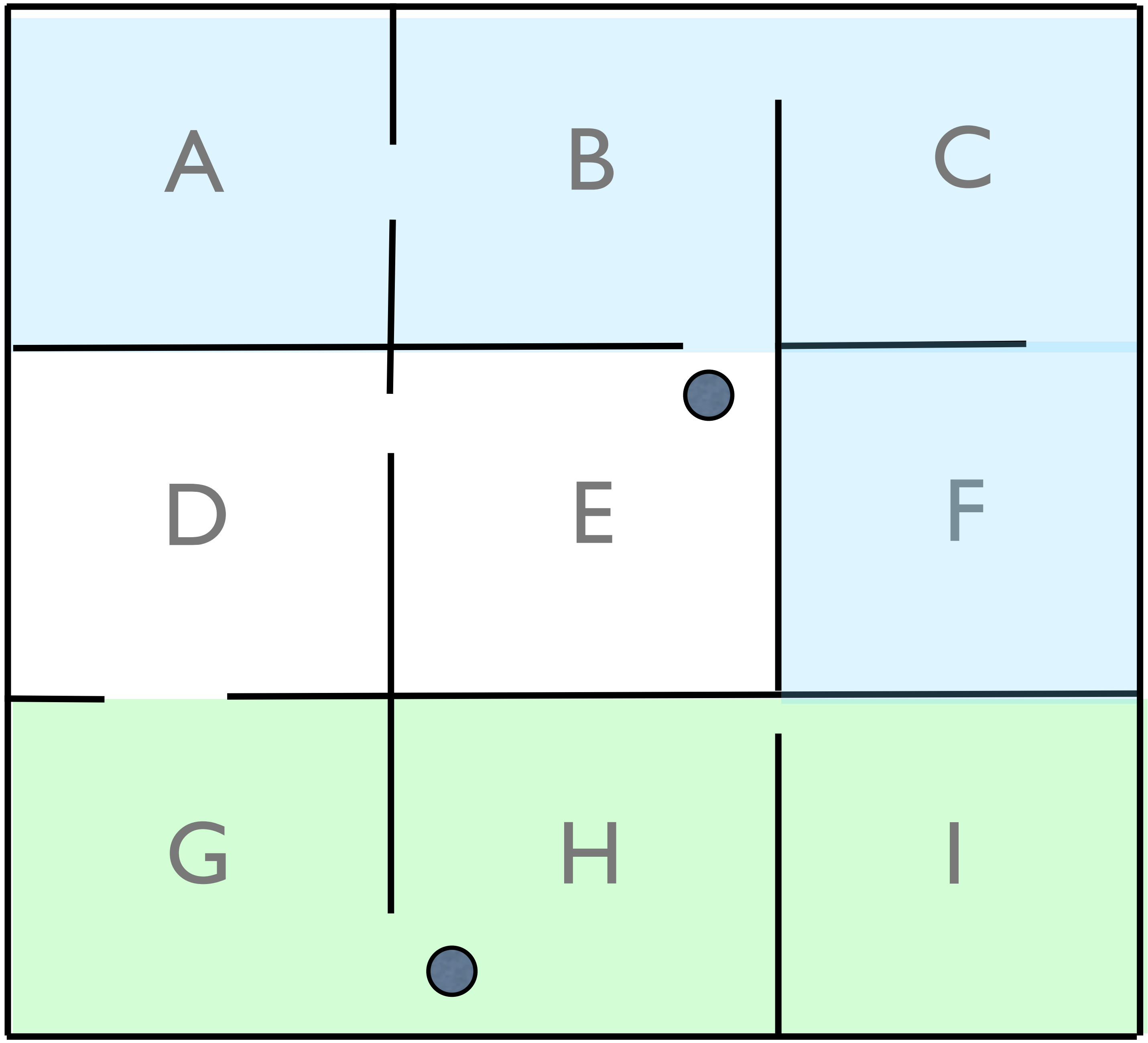
```
Let player P be in cell X
For each player Q
    Let cell of Q be Y
    Compute $F_{XY}$ (or simply $F_Q$)
```

Move to new cell:

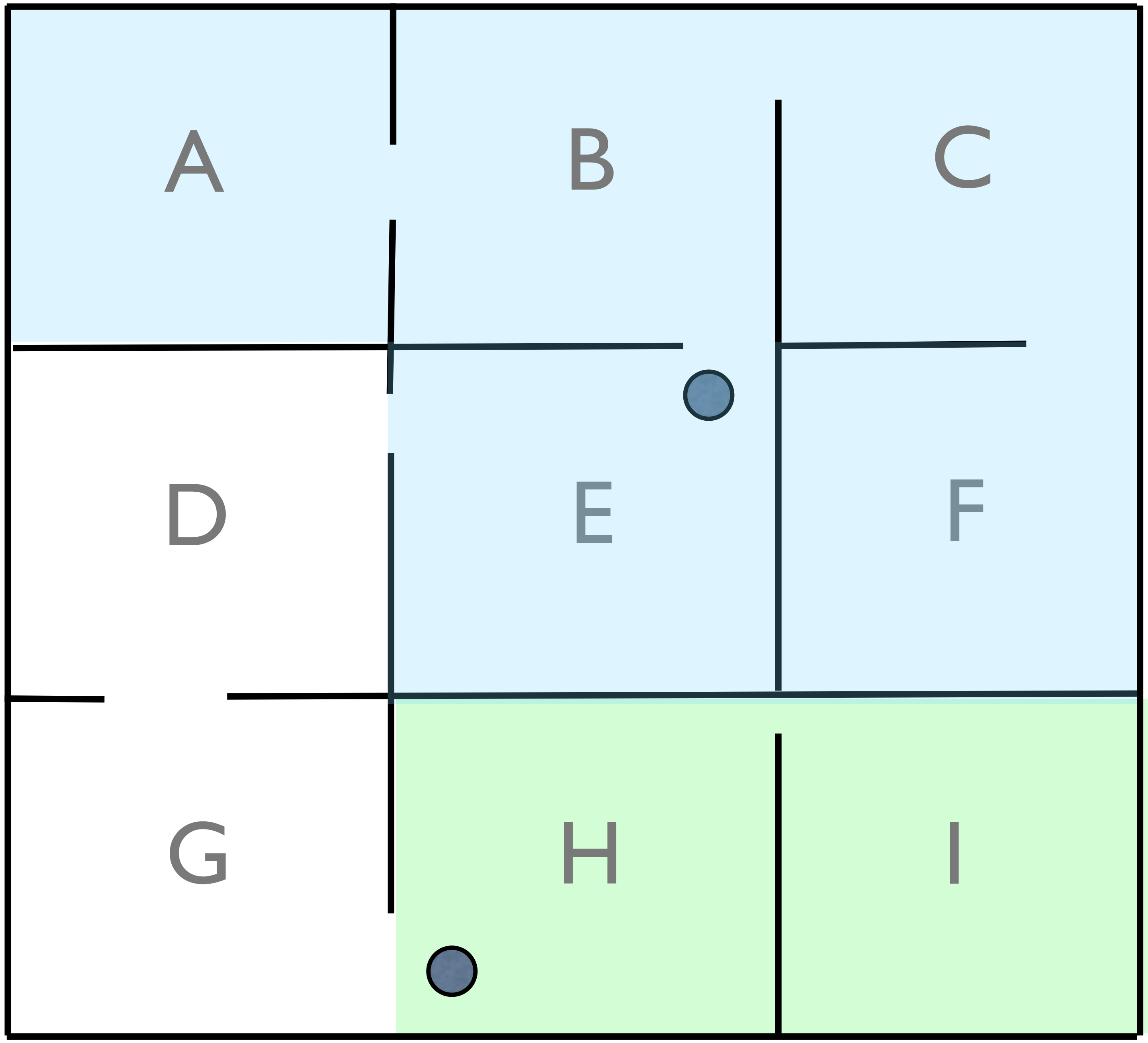
```
Let X be new cell
For each player Q
    If X not in $F_Q$
    Send location to Q
```

Receive Update:
(location from Q)
Send location to Q
Recompute F_Q

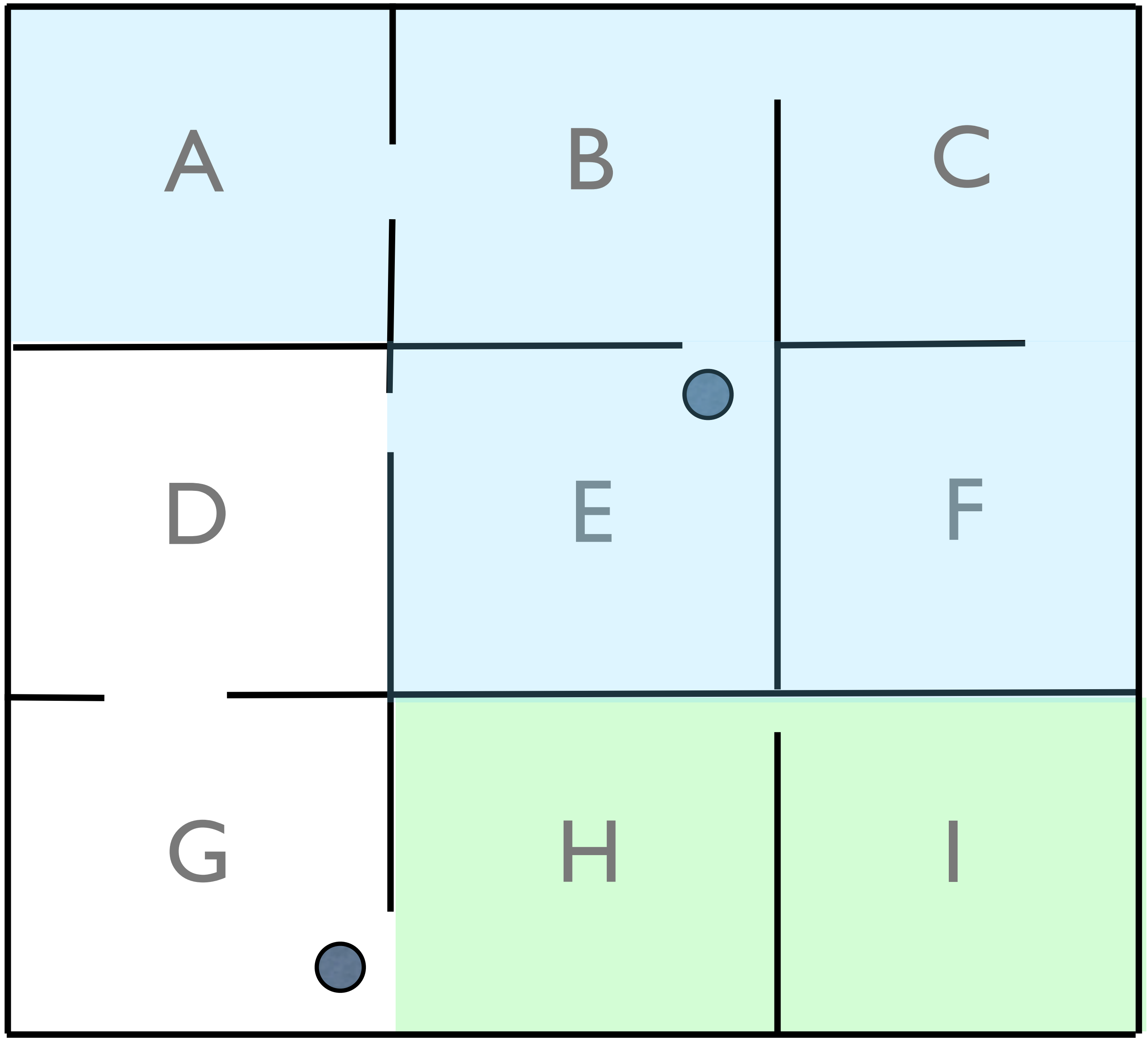
Update is triggered.



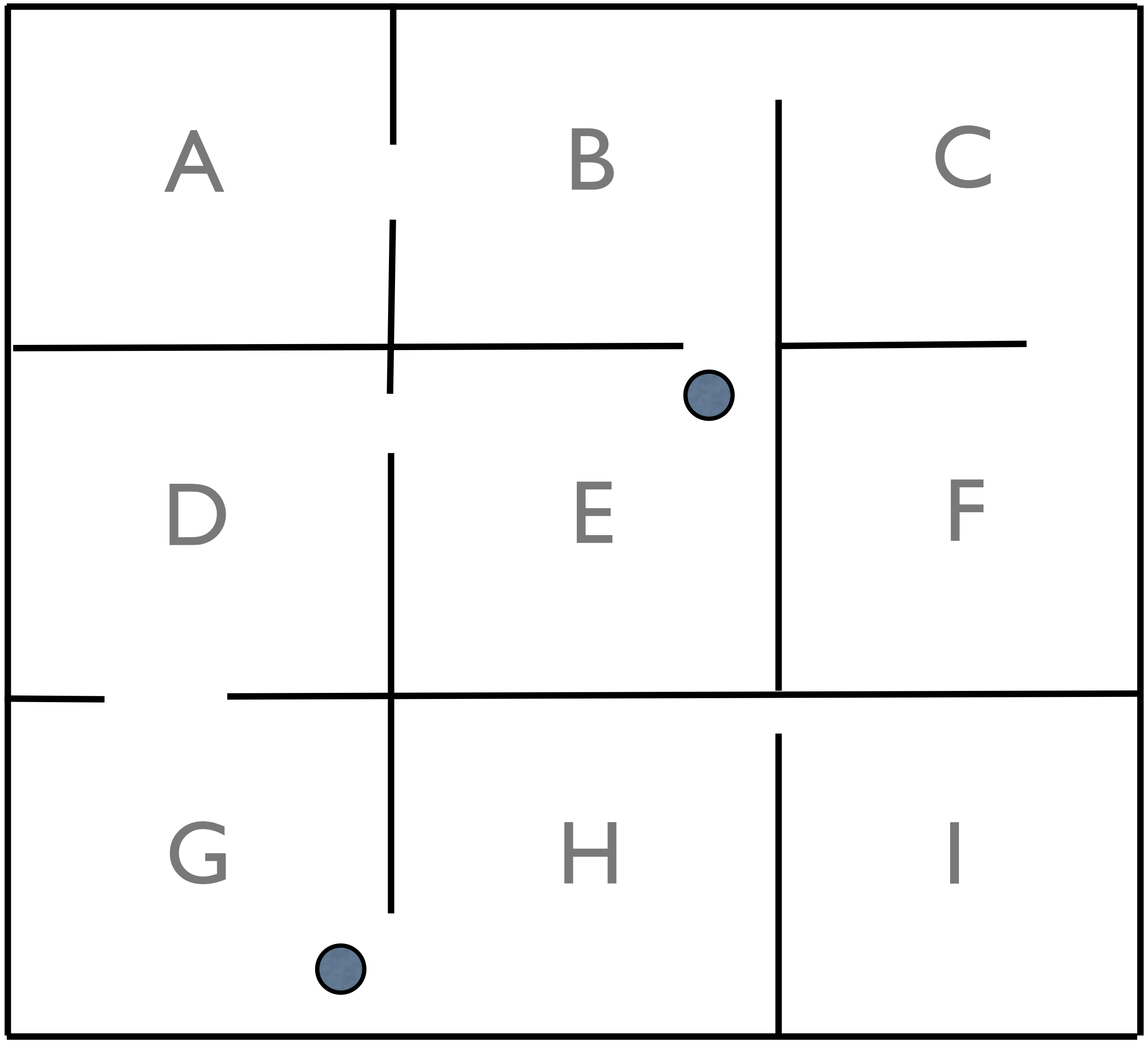
New Frontier.



Update triggered.



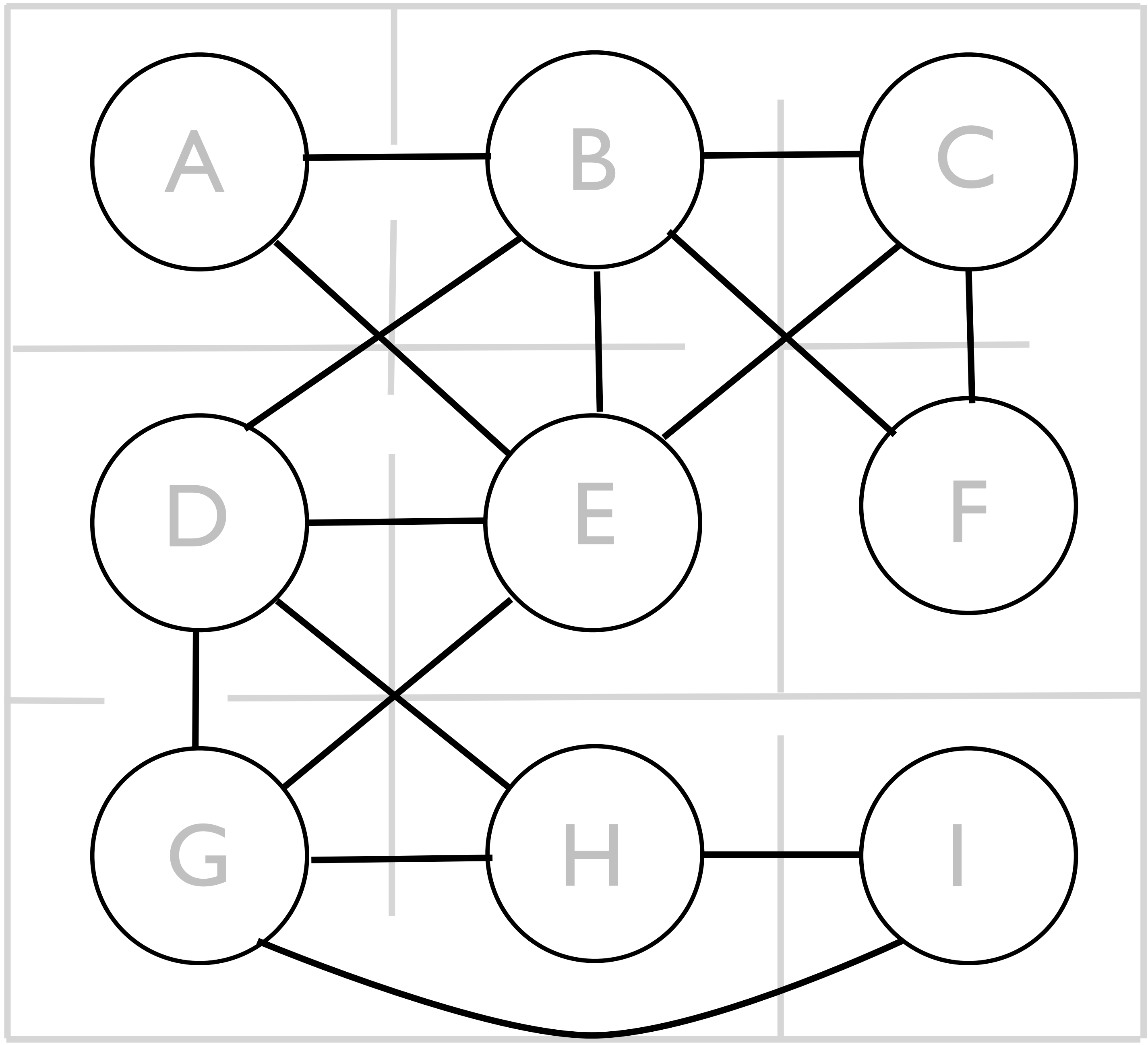
New frontier (empty since E can see G)



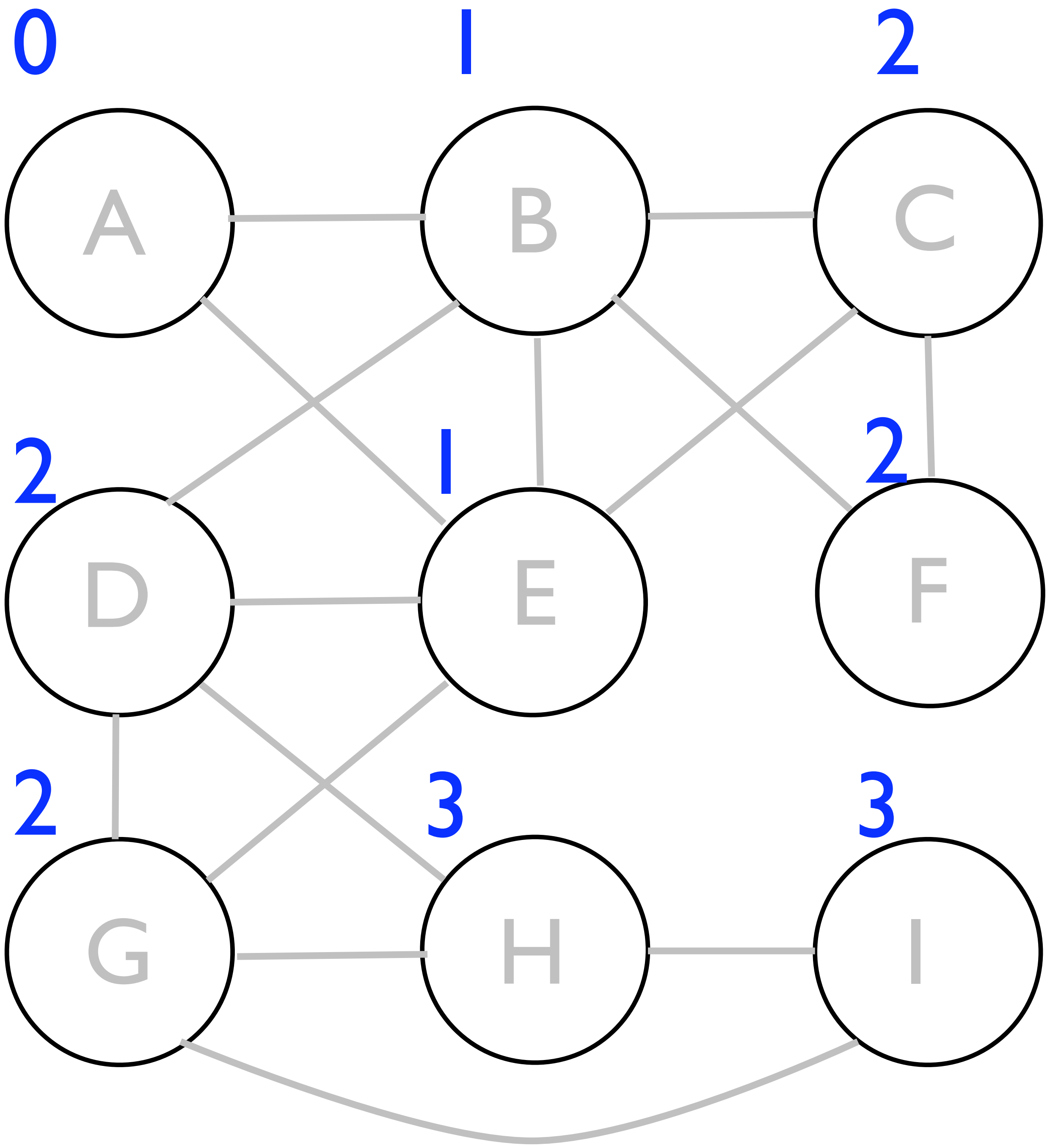
How to compute frontier?

A good frontier is as large as possible, with two almost equal-size sets.

Build a visibility graph. Cells are vertices. Two cells are connected by an edge if they are visible to each other (EVEN if they don't share a boundary)



Let dist(X, Y) be the shortest distance between two cells X and Y on the visibility graph.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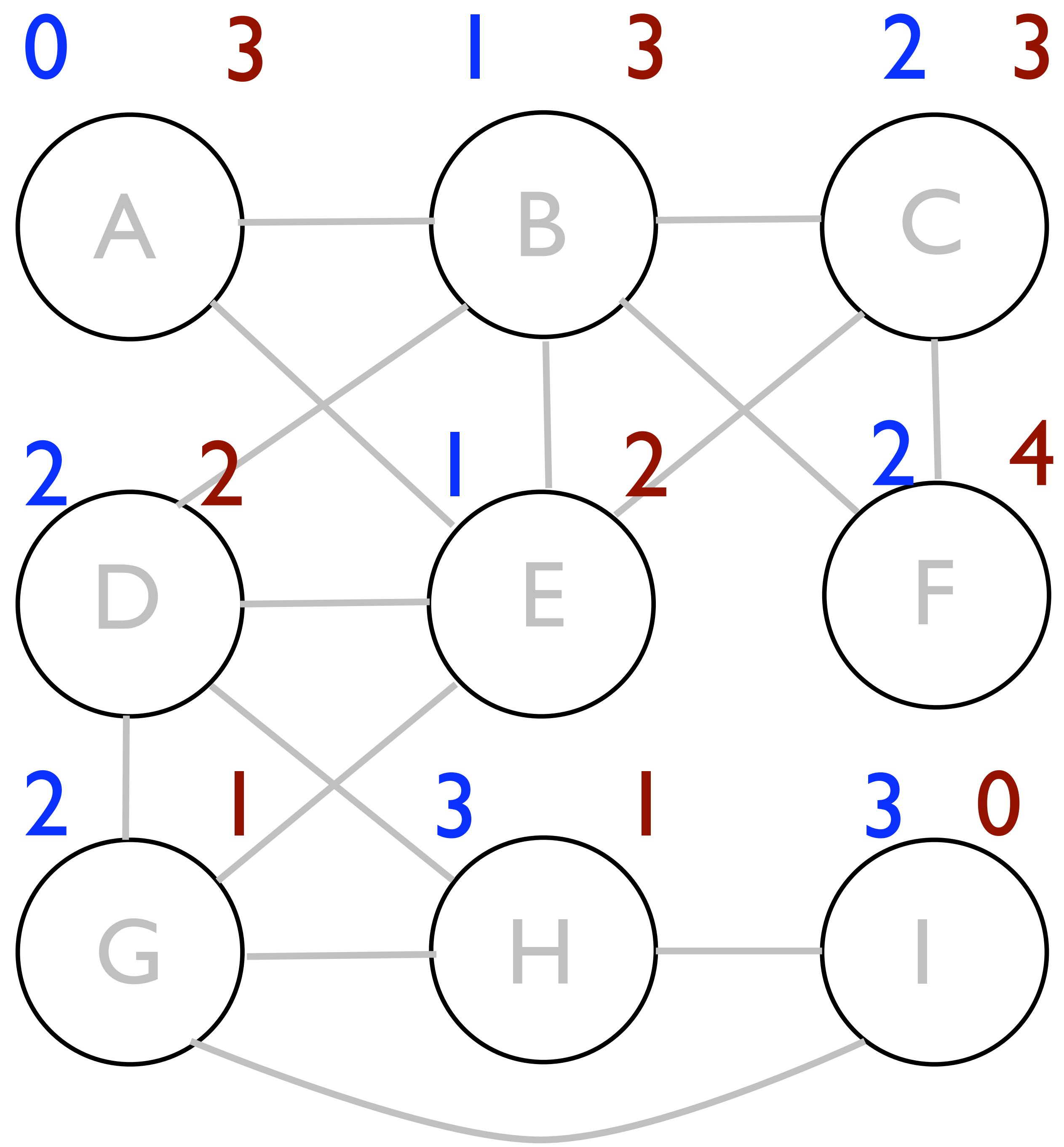
Theorem

$F_{XY} = \{ i \mid dist(X,i) <= dist(Y,i) - 1 \}$

$F_{YX} = \{ j \mid dist(Y,j) < dist(X,j) - 1 \}$

are valid frontiers.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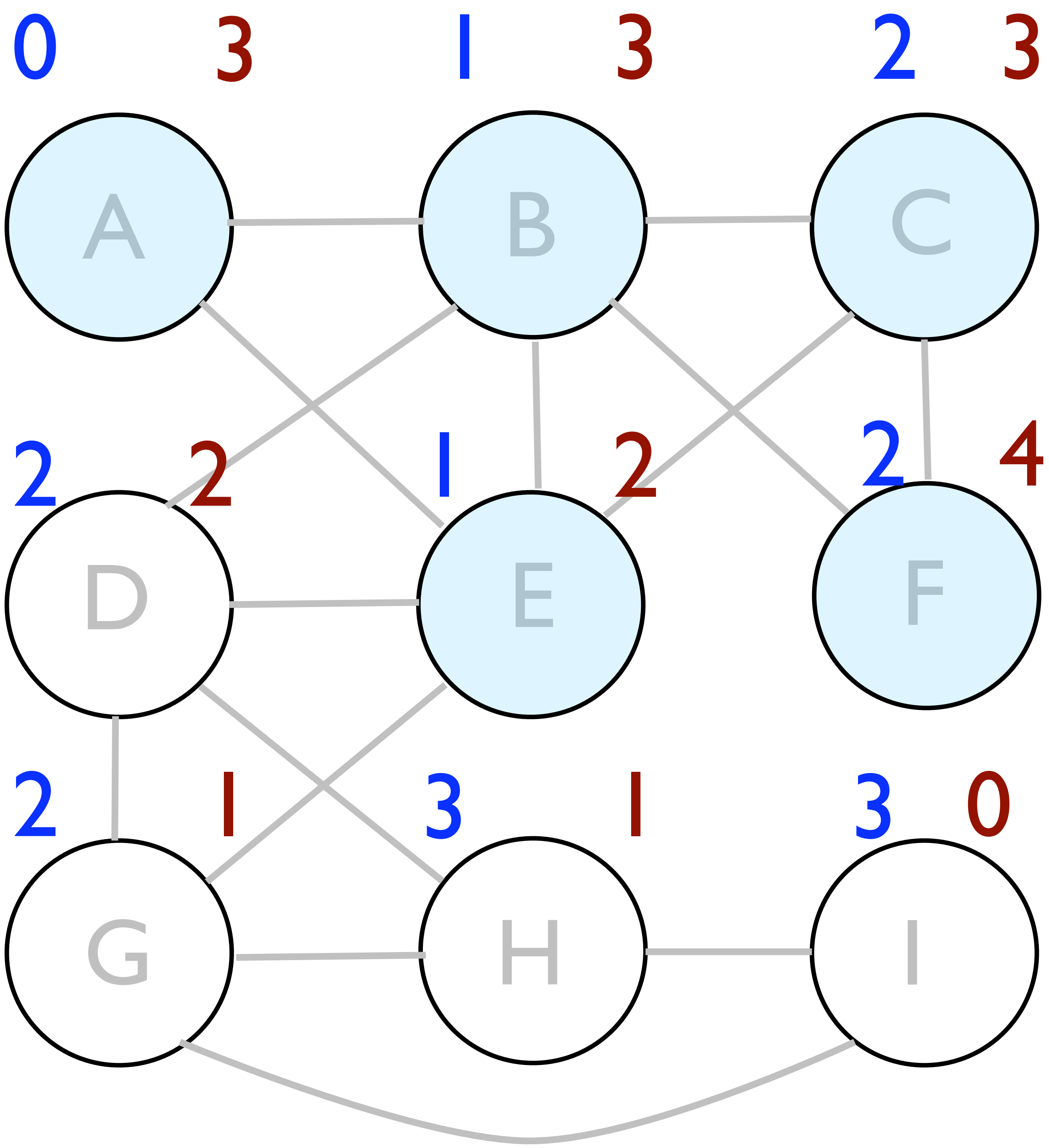
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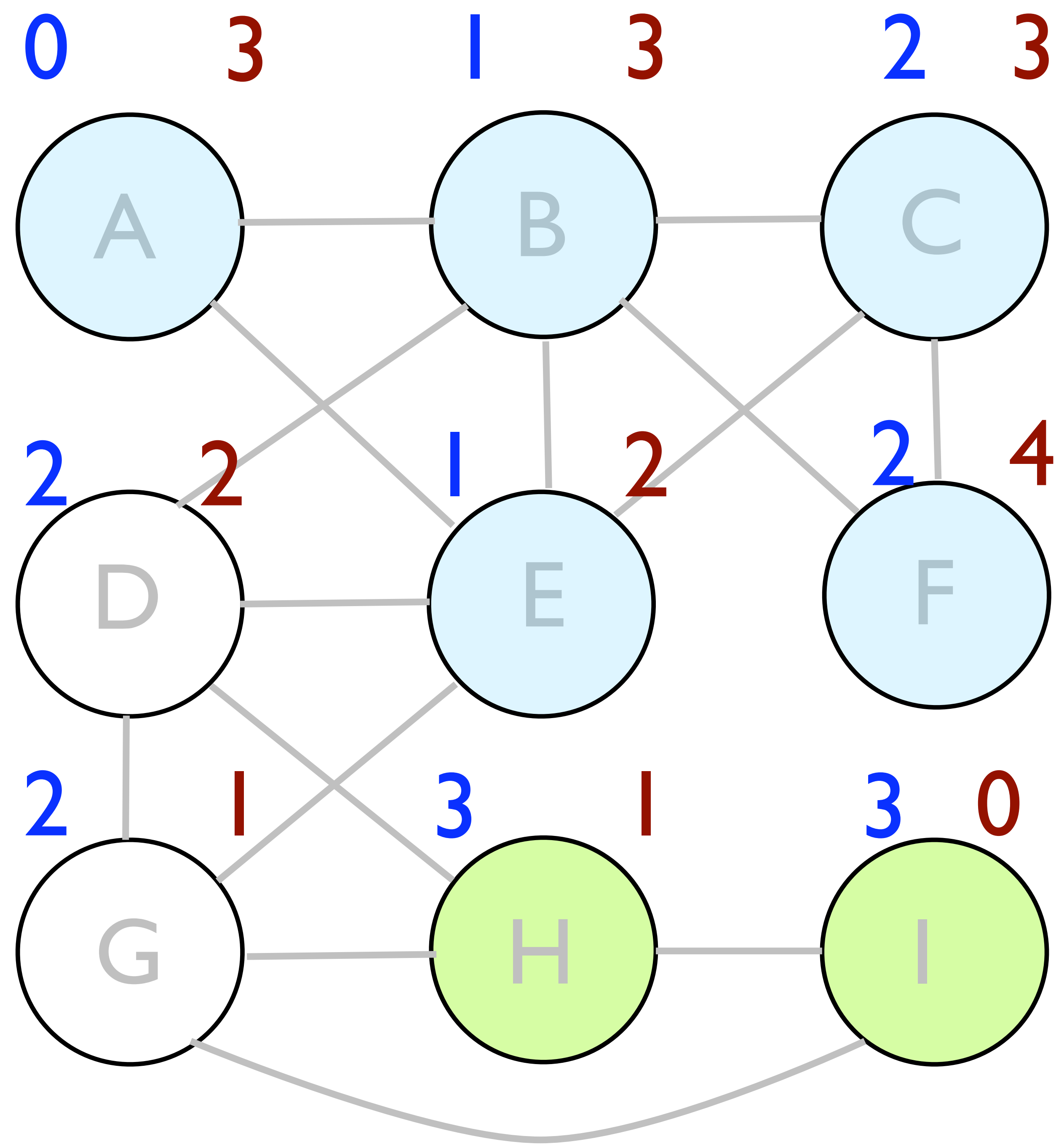
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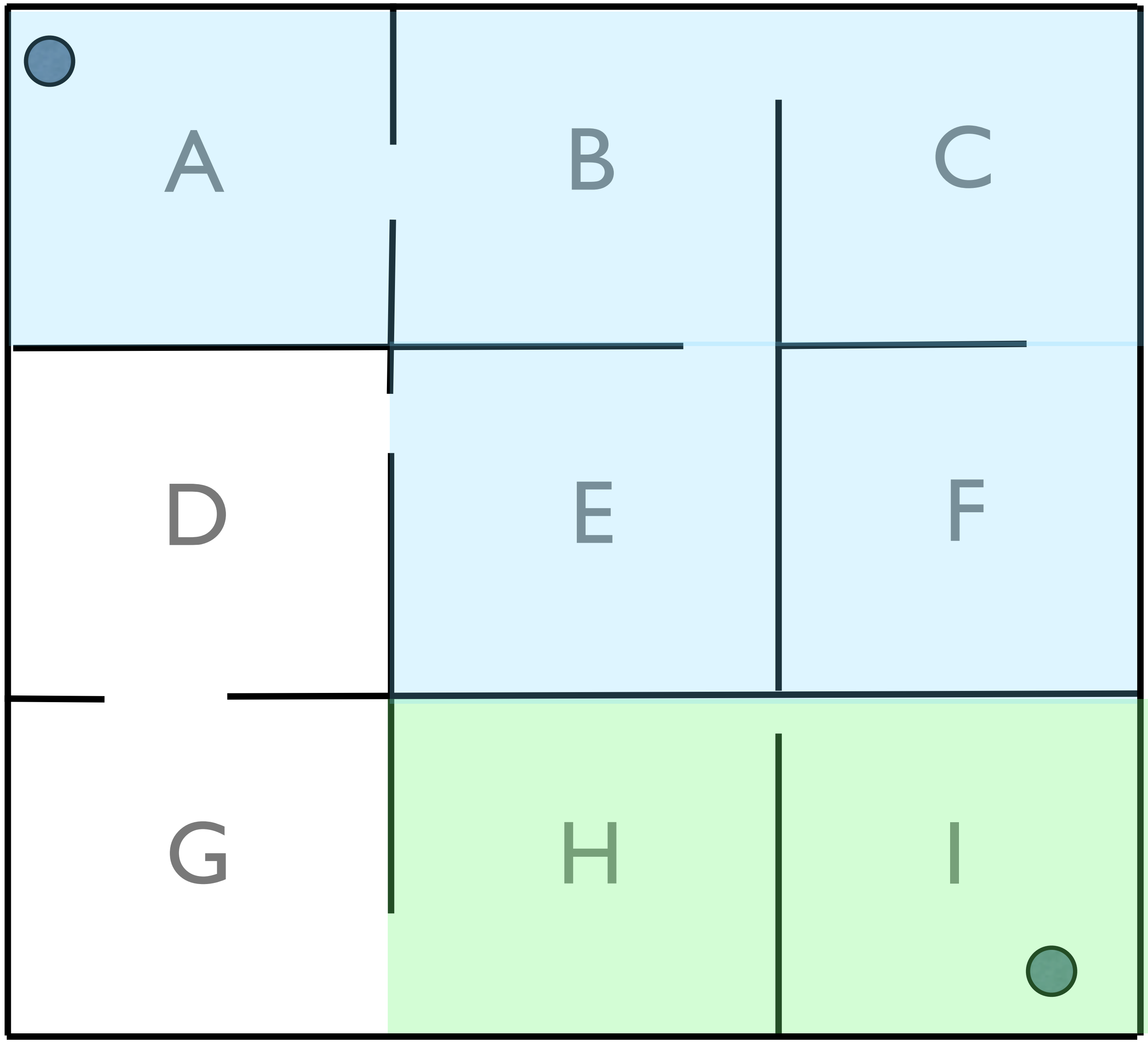
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Theorem

$F_{XY} = \{ i \mid \mathrm{dist}(X,i) <= \mathrm{dist}(Y,i) - 1 \}$

$F_{YX} = \{ j \mid \mathrm{dist}(Y,j) < \mathrm{dist}(X,j) - 1 \}$

are valid frontiers.

$F_{XY} = \{\, i \mid \mathrm{dist}(X,i) <= \mathrm{dist}(Y,i) - 1 \,\}$
$F_{YX} = \{\, j \mid \mathrm{dist}(Y,j) < \mathrm{dist}(X,j) - 1 \,\}$

Proof (by contradiction)
Suppose there are two cells, C in F_{XY} and D in F_{YX}, that can see each other.

$F_{XY} = \{ i \mid \mathrm{dist}(X,i) <= \mathrm{dist}(Y,i) - 1 \}$

$F_{YX} = \{ j \mid \mathrm{dist}(Y,j) < \mathrm{dist}(X,j) - 1 \}$

$\mathrm{dist}(X,C) <= \mathrm{dist}(Y,C) - 1$

$\mathrm{dist}(Y,D) < \mathrm{dist}(X,D) - 1$

$\mathrm{dist}(C,D) = \mathrm{dist}(D,C) = 1$

dist(X,C) <= dist(Y,C) - 1
dist(Y,D) < dist(X,D) - 1
dist(C,D) = dist(D,C) = 1

We also know that
dist(X,D) <= dist(X,C) + dist(C,D)
dist(Y,C) <= dist(Y,D) + dist(D,C)

1. dist(X,C) <= dist(Y,C) - 1
2. dist(Y,D) < dist(X,D) - 1
3. dist(C,D) = 1
4. dist(X,D) <= dist(X,C) + dist(C,D)
5. dist(Y,C) <= dist(Y,D) + dist(D,C)

From 4, 1, and 3:

dist(X,D) <= dist(Y,C) - 1 + 1

From 5:

dist(X,D) <= dist(Y,D) + 1

1. dist(X,C) <= dist(Y,C) - 1
2. dist(Y,D) < dist(X,D) - 1
3. dist(C,D) = 1
4. dist(X,D) <= dist(X,C) + dist(C,D)
5. dist(Y,C) <= dist(Y,D) + dist(D,C)

We have

dist(X,D) <= dist(Y,D) + 1

Which contradict 2

dist(X,D) > dist(Y,D) + 1

How good is the idea?

(How many messages can we save by using Frontier Sets?)

	q2dm3	q2dm4	q2dm8
Max dist()	4	5	8
Num of cells	666	1902	966

Frontier Density: % of player-pairs with non-empty frontiers.

	q2dm3	q2dm4	q2dm8
Frontier Density	83.9	93.0	84.2

Frontier Size:

% of cells in the frontier on average

	q2dm3	q2dm4	q2dm8
Frontier Size	38.3%	67.3%	68.2%

Compare with

1. Naive P2P
2. Perfect P2P

Naive P2P

Always send update to 15 other players.

Perfect P2P

Hypothetical protocol that sends messages only to visible players.

Number of messages per frame per player.

	q2dm3	q2dm4	q2dm8
NPP	15	15.7	14.4
PPP	3.7	1.9	4.2
Frontier	5.4	2.6	5.9

Space Complexity

Let N be the number of cells. If we precompute Frontier for every pair of cells, we need

$$O(N^3)$$

space.

If we store visibility graph and compute frontier as needed, we only need

$$O(N^2)$$

space.

Frontier Sets

cell-based, visibility-based IM

Limitations

Works badly if there’s little occlusion in the virtual world.

Still need to exchange locations with every other players occasionally.

Frontier Sets

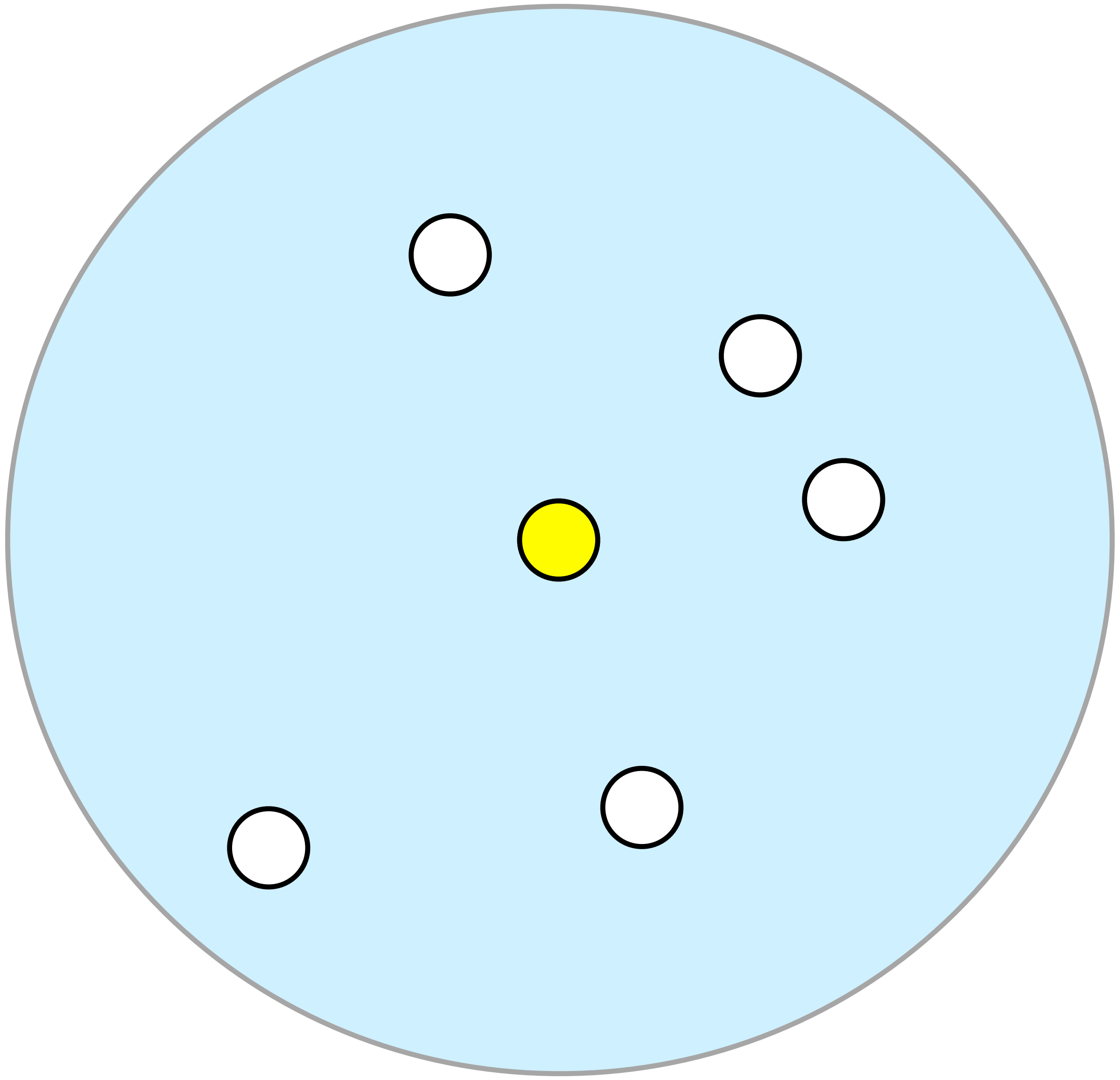
cell-based, visibility-based IM

Voronoi Overlay Network:

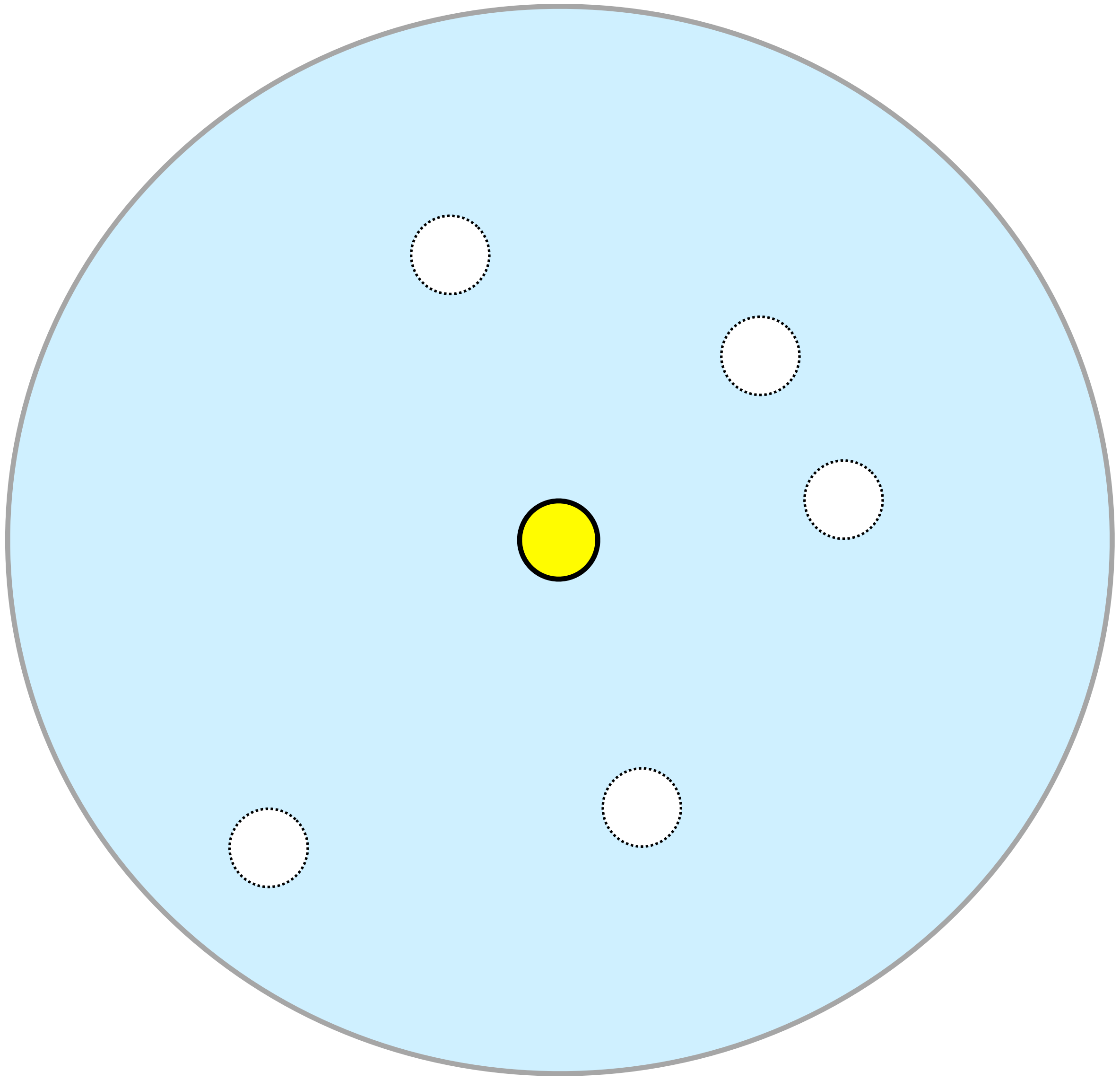
Aura-based Interest Management

Diagrams and plots in the sections are taken from presentation slides by Shun-yun Hu, available on http://vast.sf.net

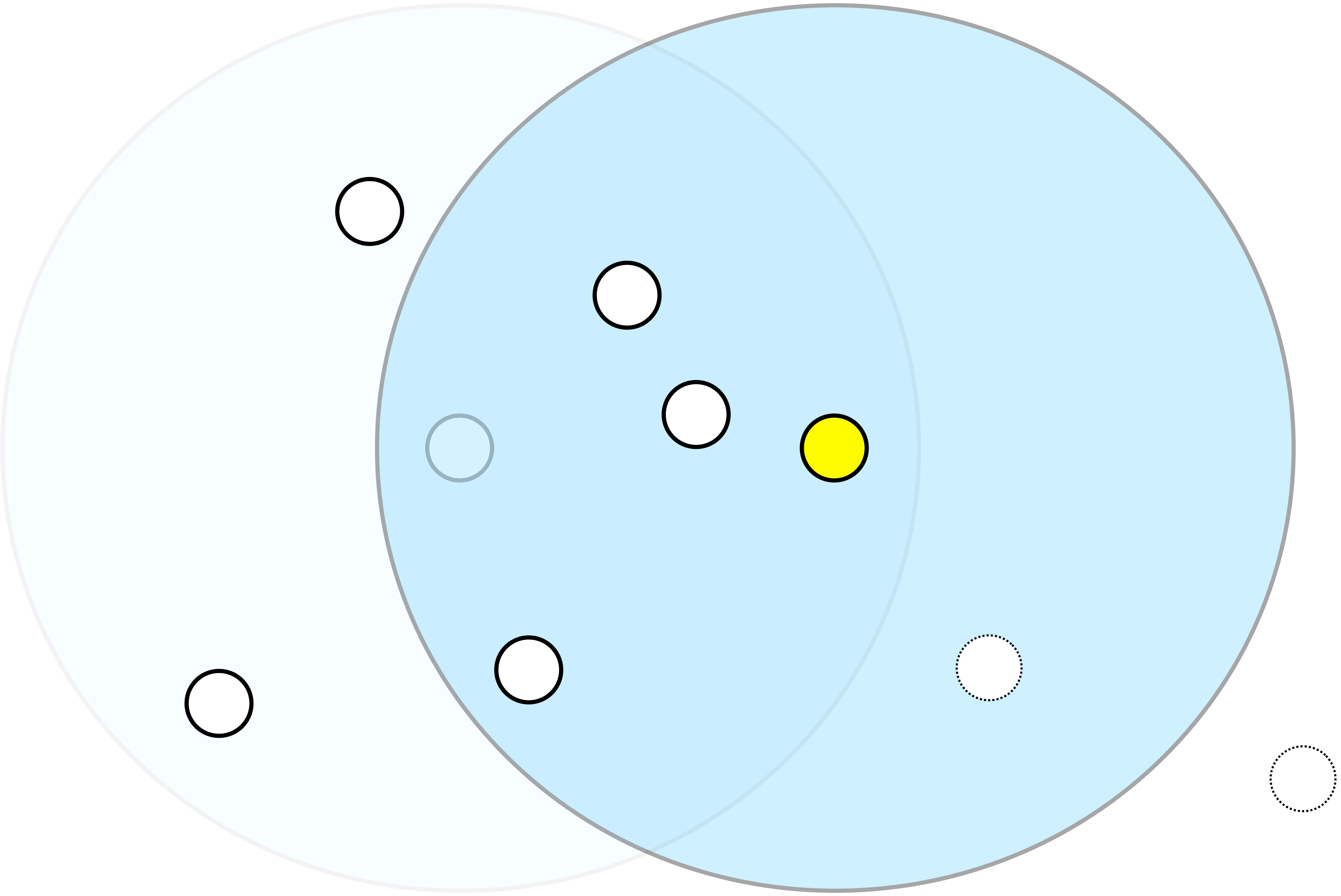
Keep a list of AOI-neighbors and exchange messages with AOI-neighbors.



Q: How to initialize AOI-neighbors?

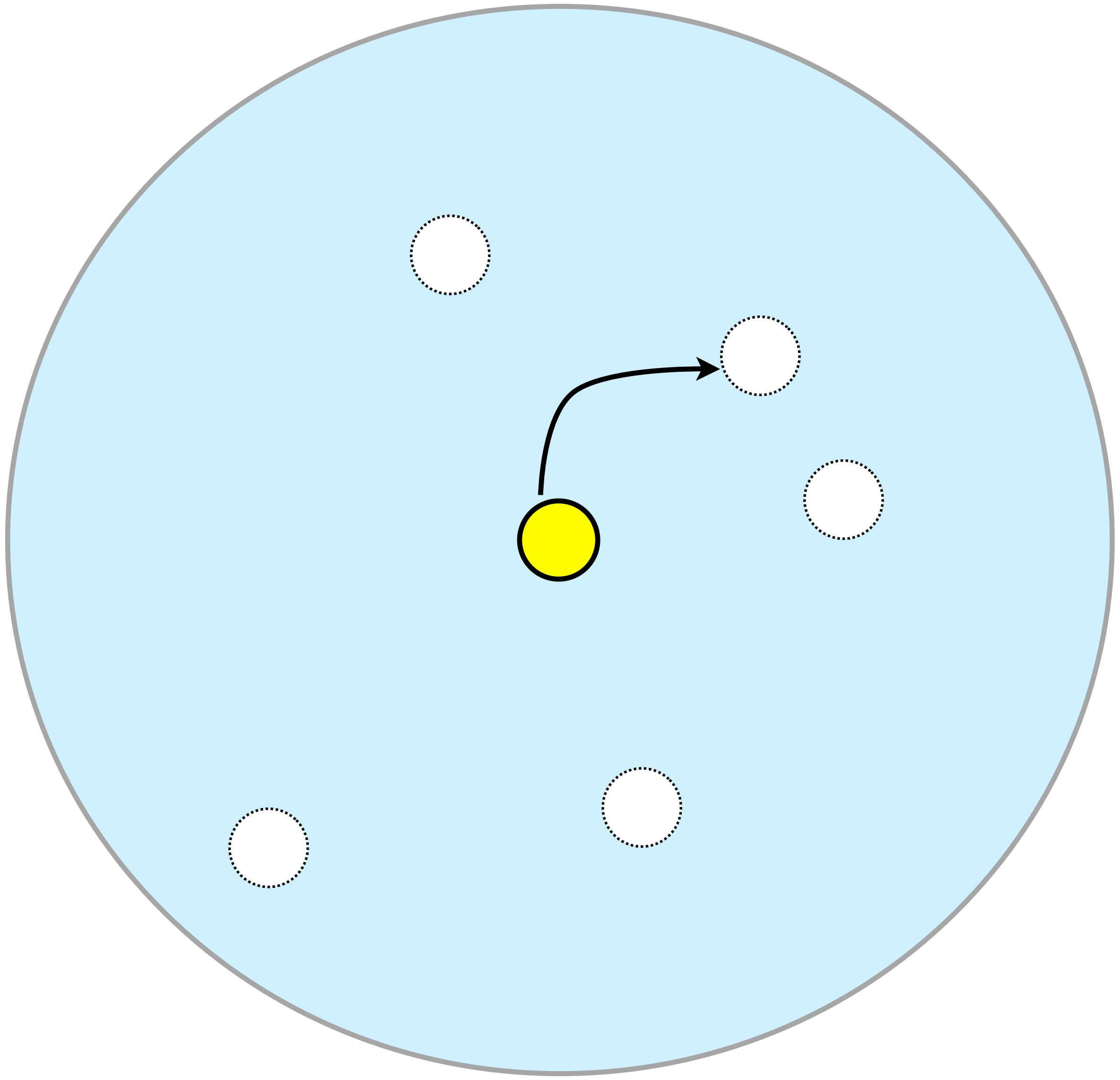


Q: How to update AOI-neighbors?

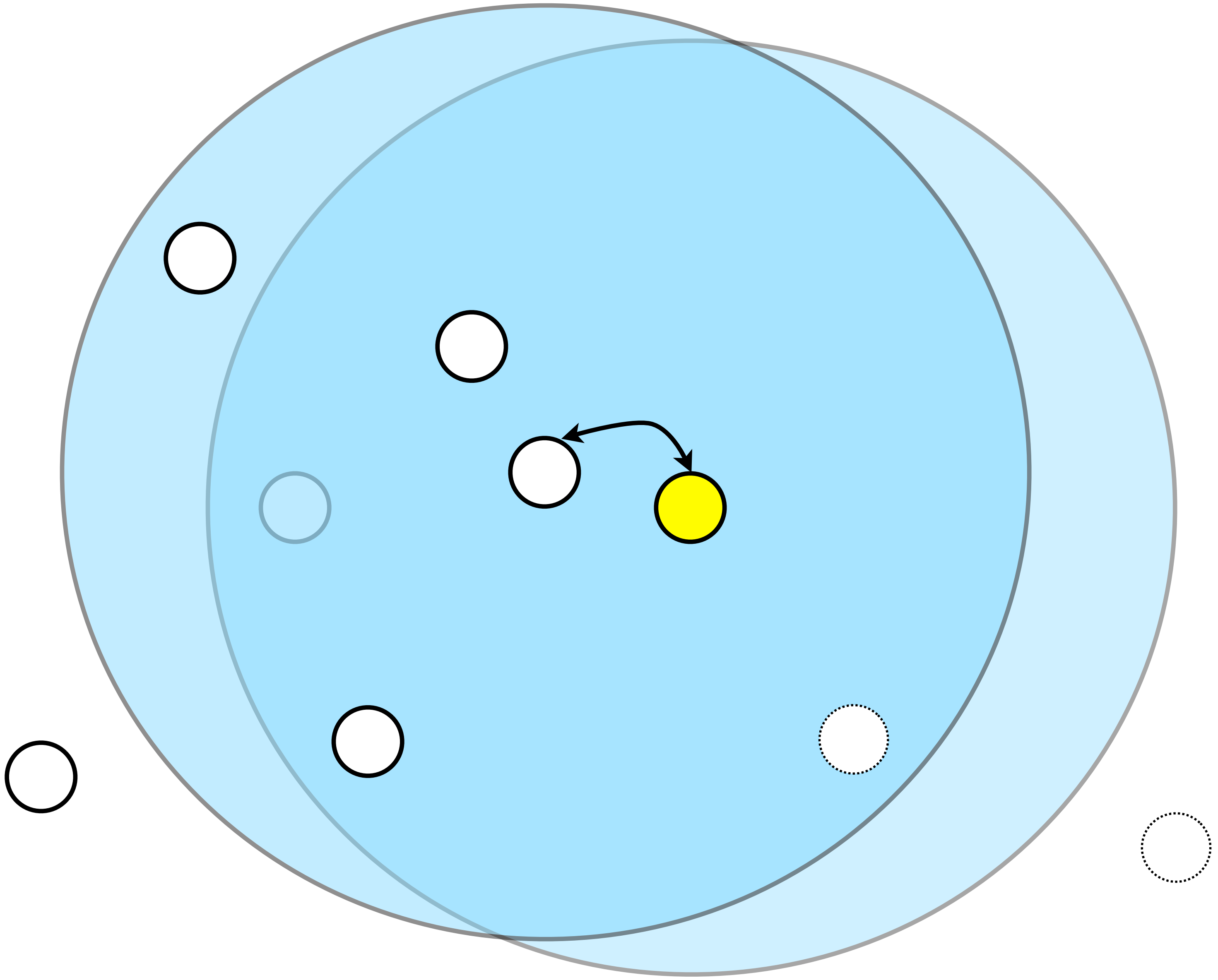


Problem: No global information in P2P architecture.

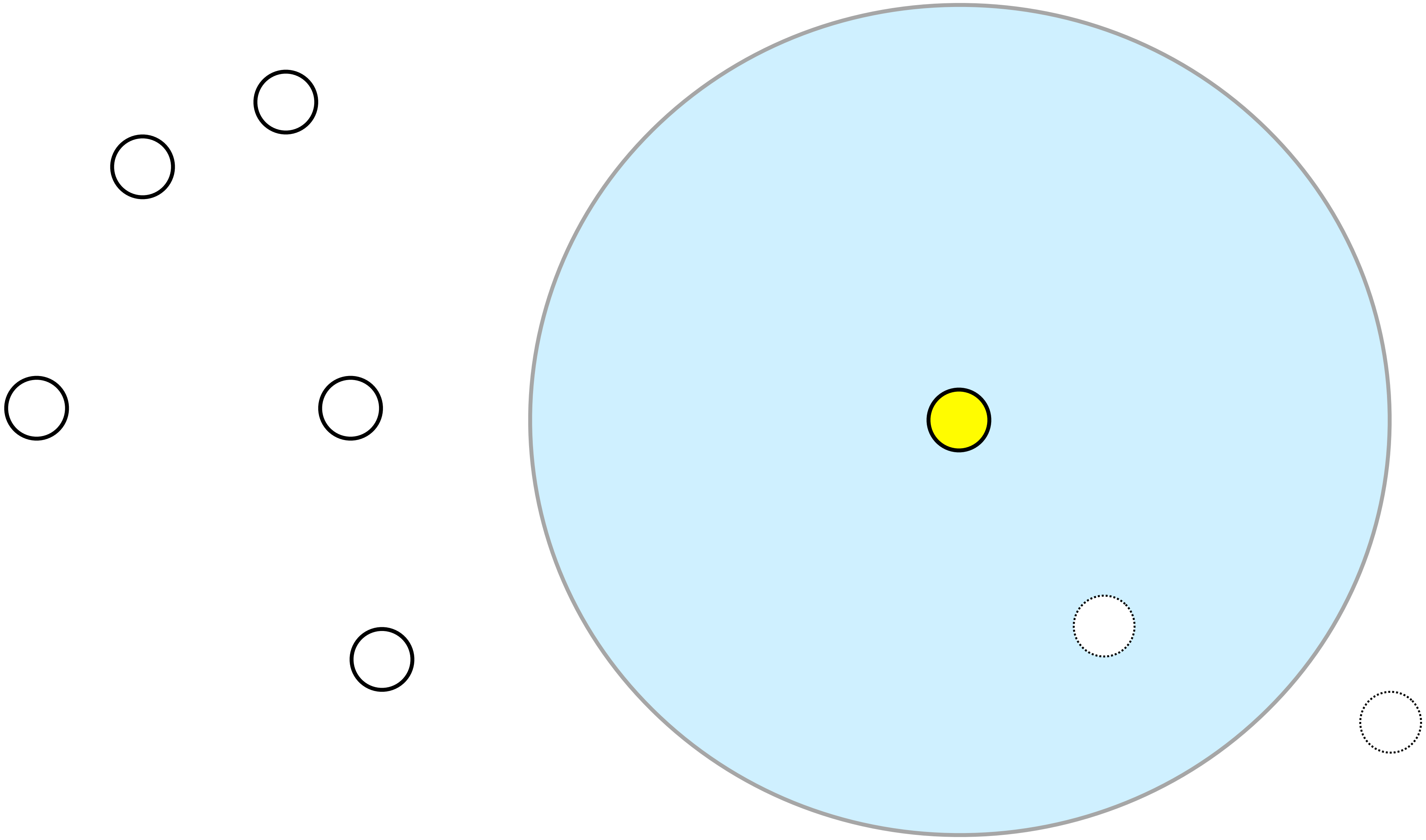
Idea: Find closest node and ask for introductions



Idea: New AOI-neighbors will likely be neighbors of my existing AOI-neighbors.



Challenge: Need to discover new neighbors even if current node has no neighbor

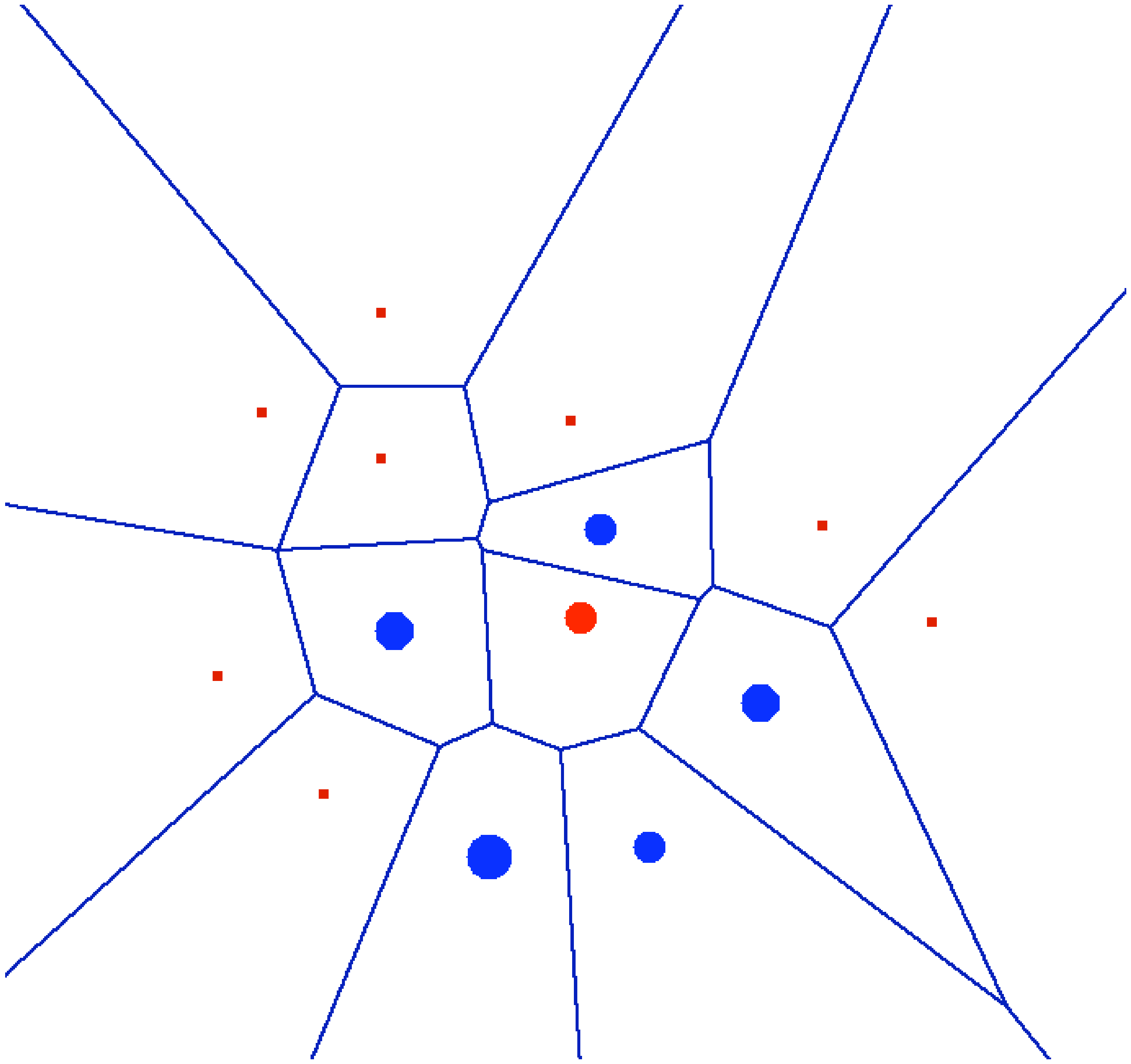


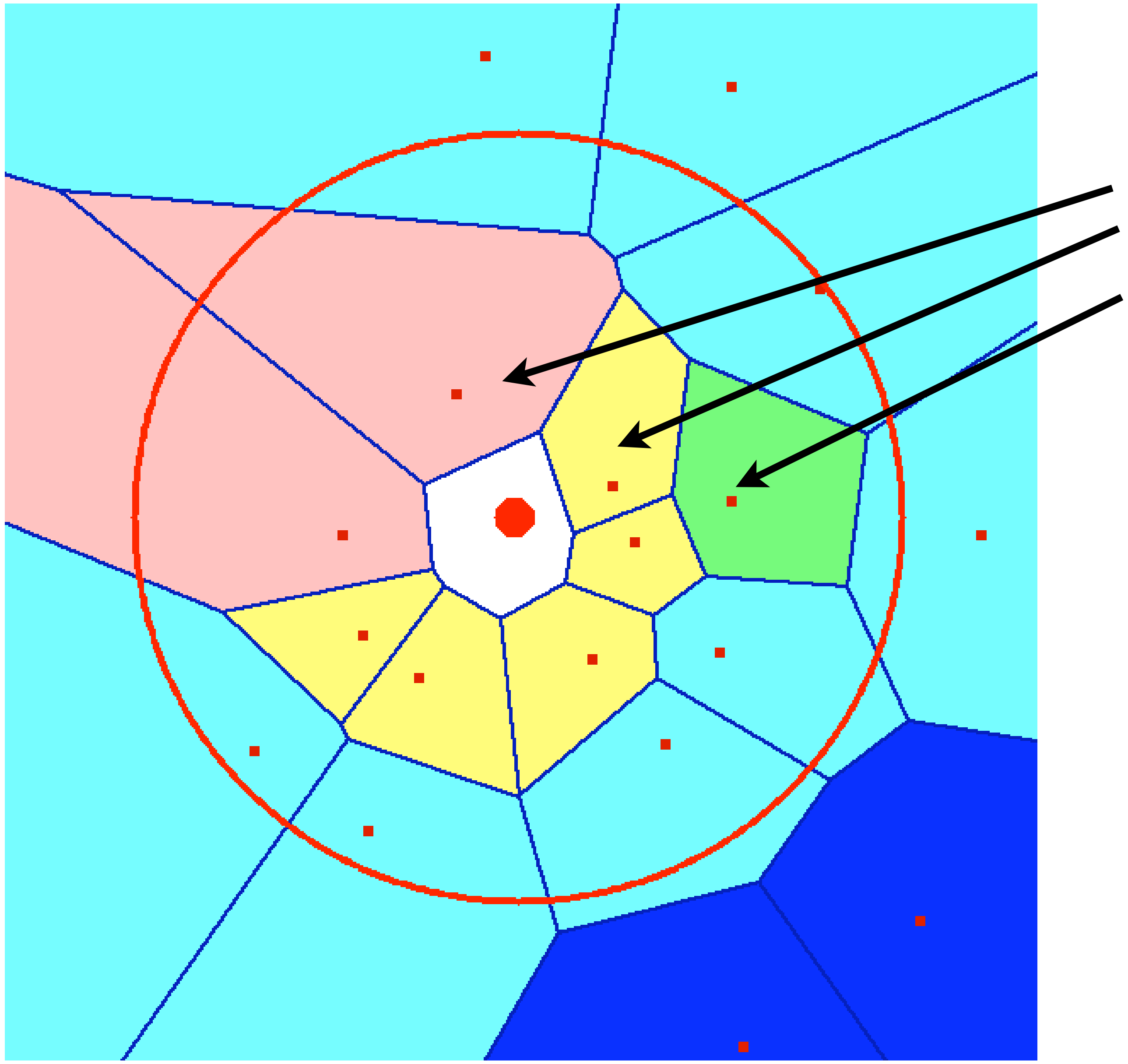
Question: How to find closest node?

Every node is in charge of a region in the virtual world.

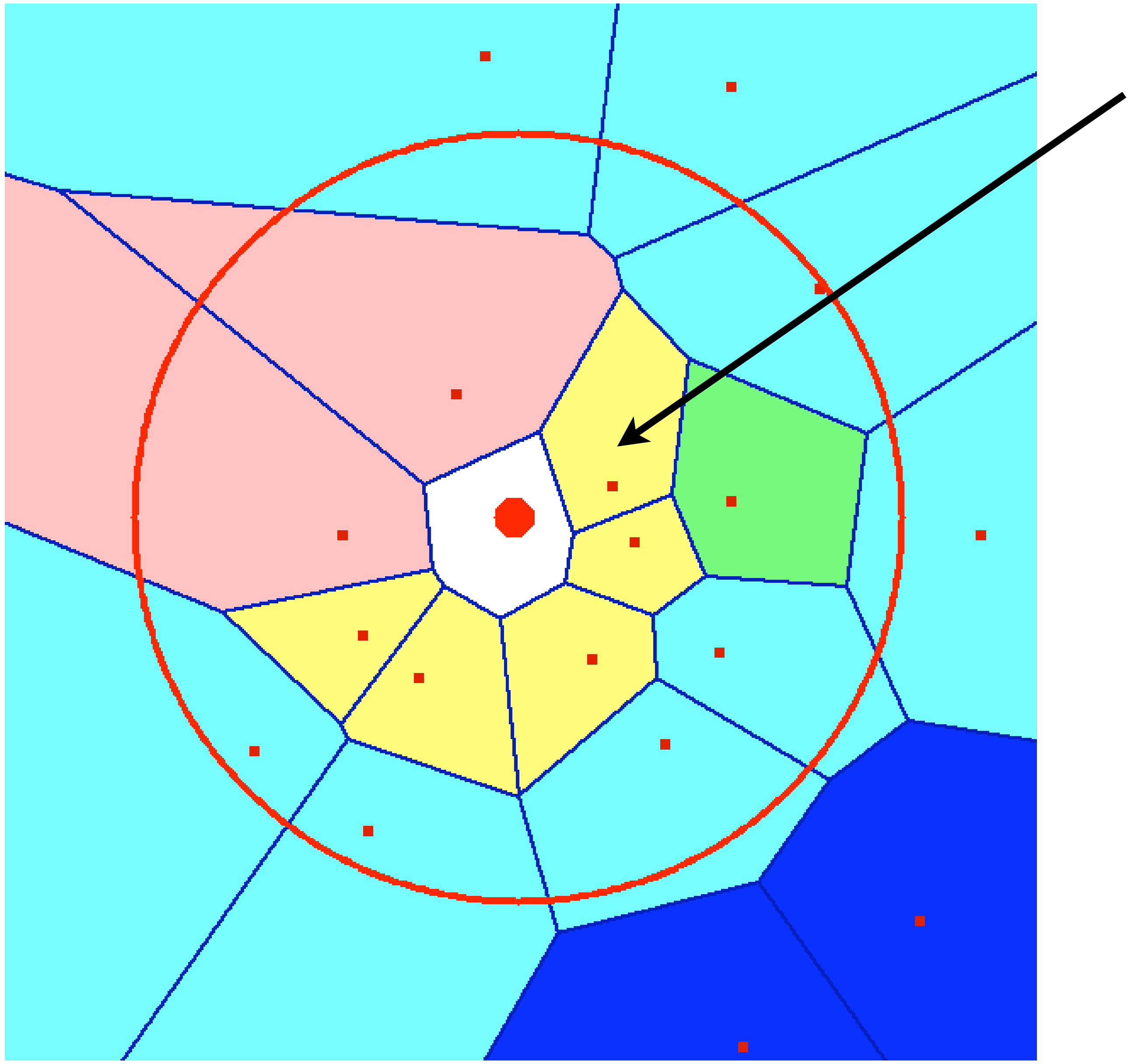
The region contains points closest to the node.

Voronoi Diagram



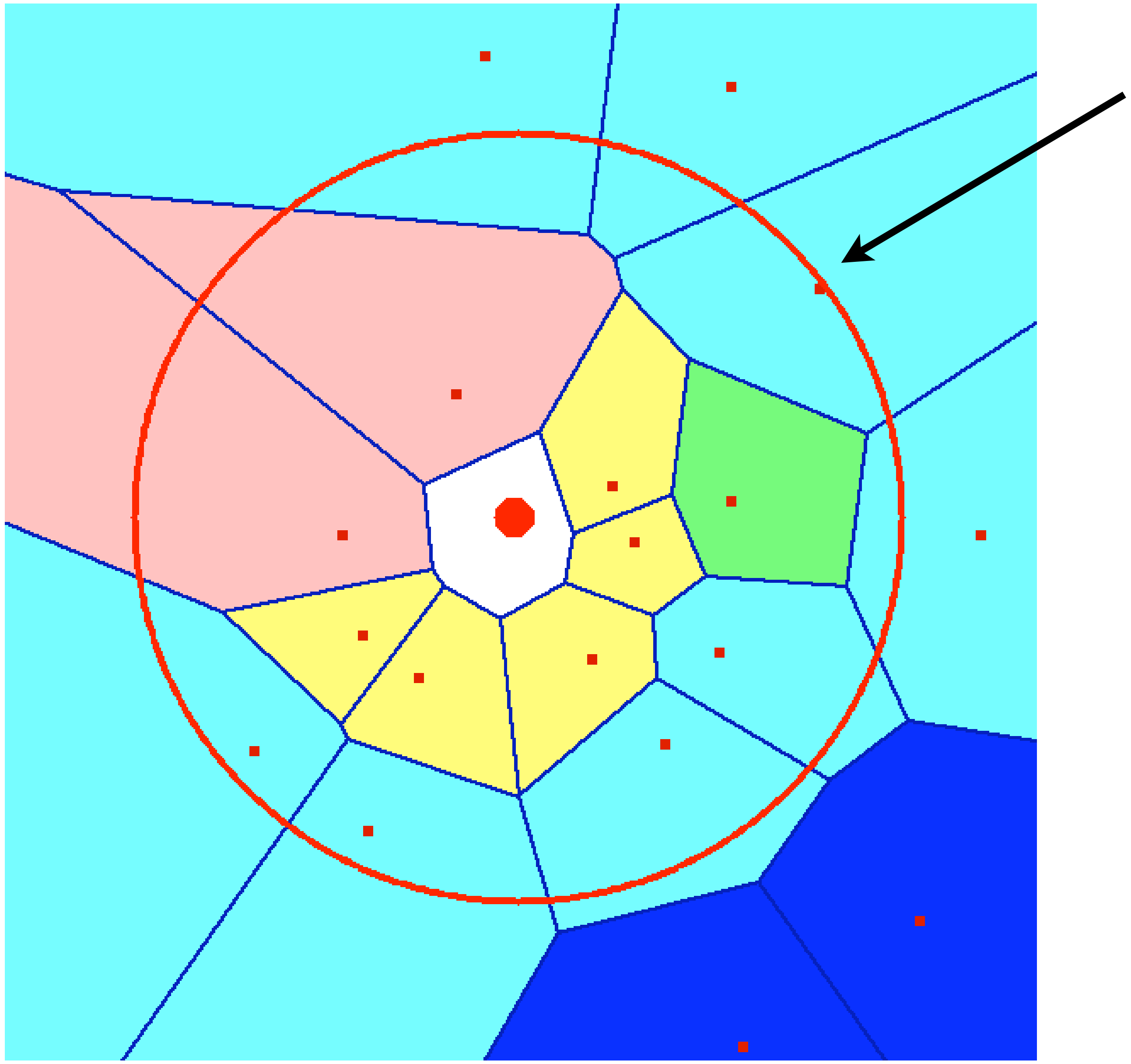


AOI Neighbors:
Neighbors in AOI



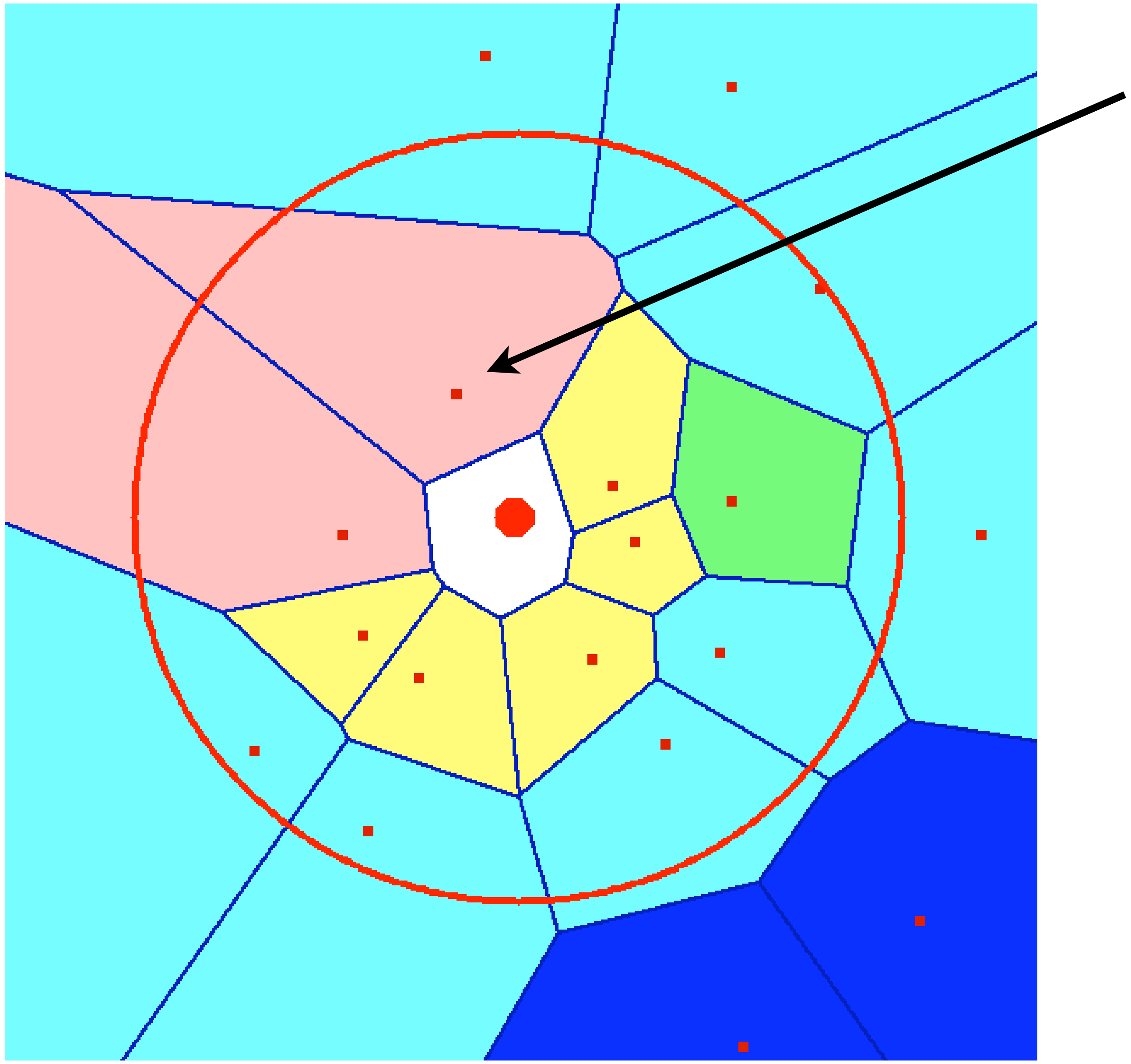
Enclosing Neighbors:
Neighbors in adjacent region.

(may or may not be in AOI)

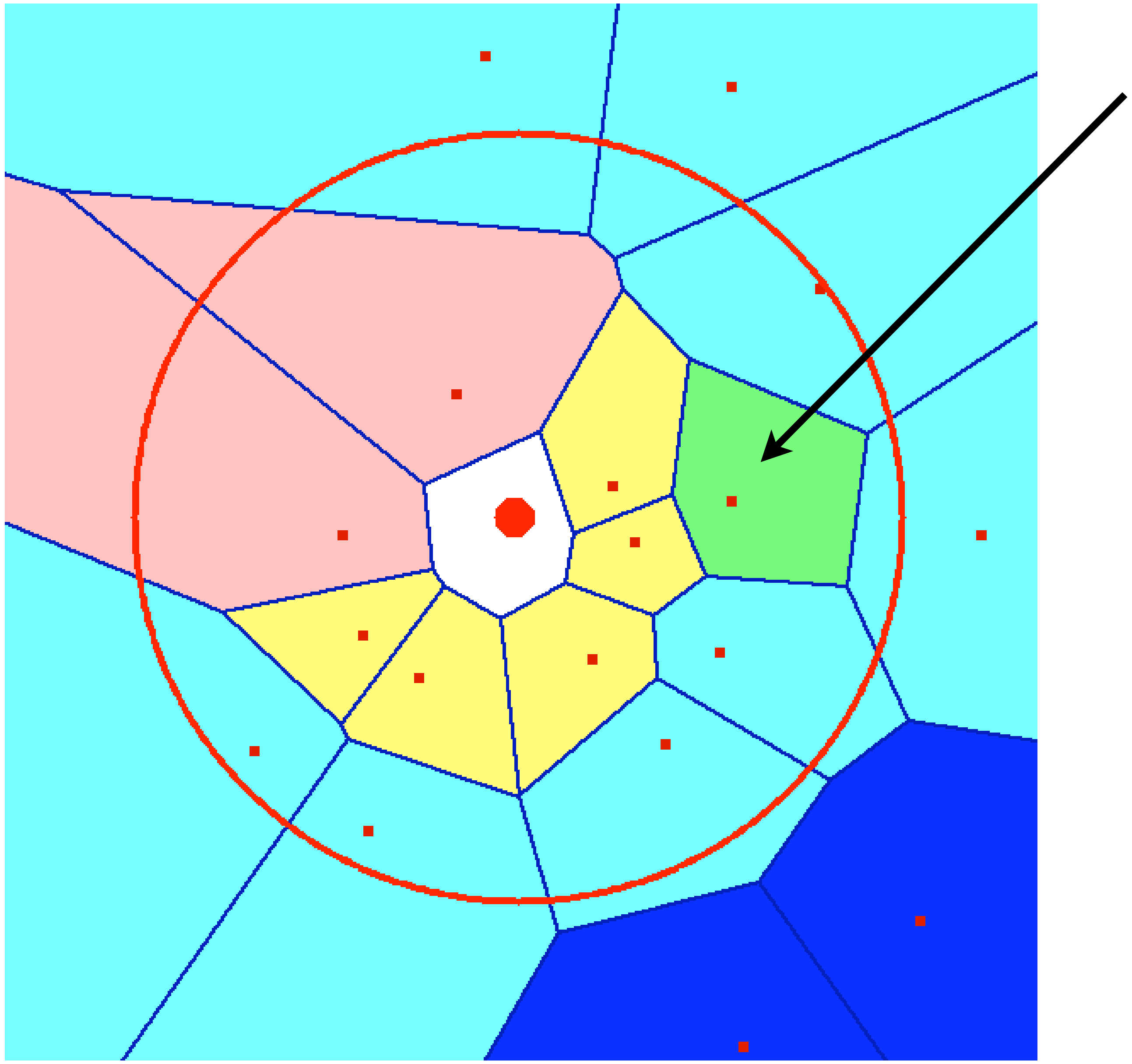


Boundary Neighbors: Neighbors whose region intersect with AOI.

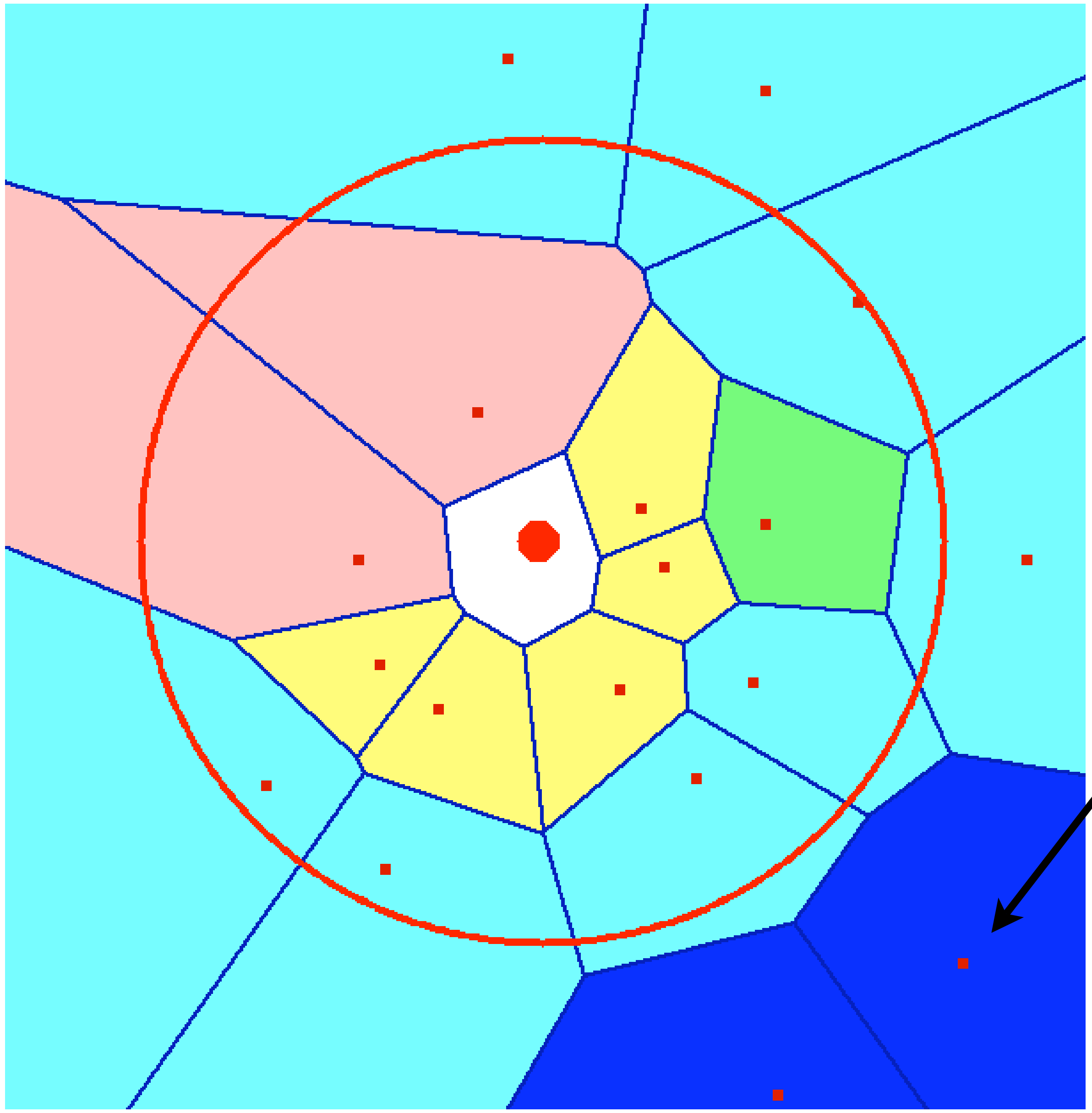
(may or may not be in AOI)



Boundary and Enclosing Neighbor

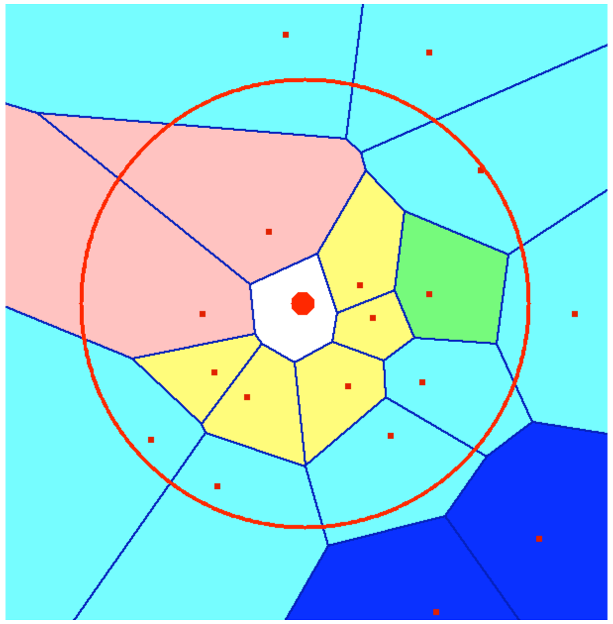


Regular AOI Neighbor: Non-boundary and non-enclosing neighbor in AOI

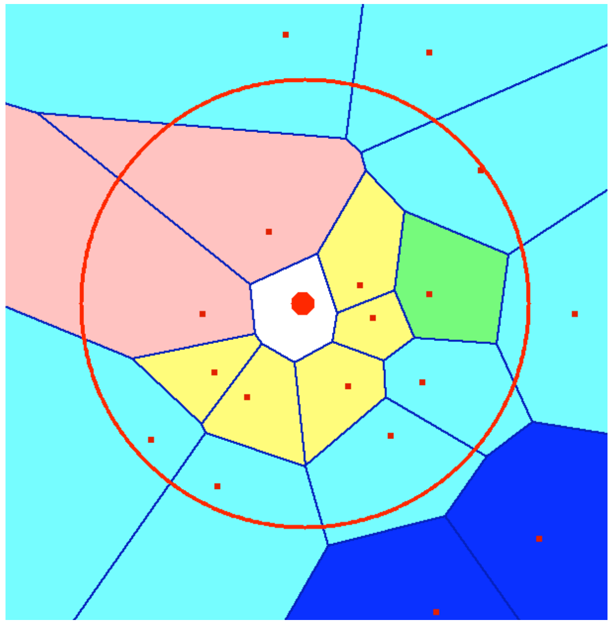


Unknown nodes
(not neighbors!)

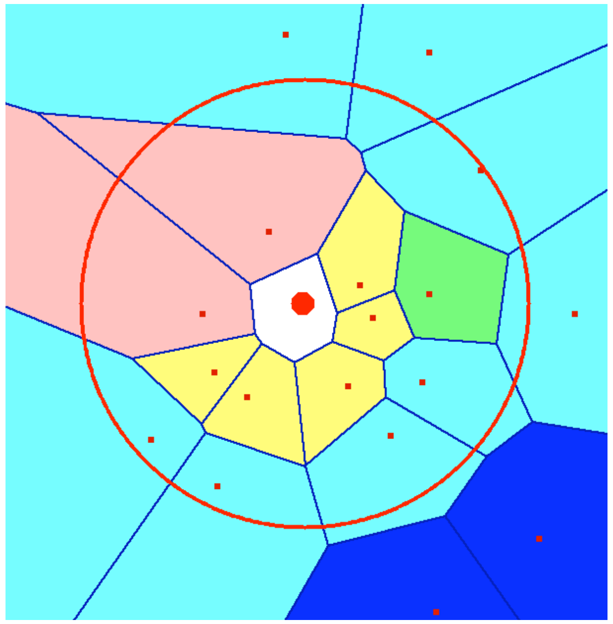
Type	in AOI?	intersect?	adjacent?
Regular	yes	no	no
Enclosing	maybe	no	yes
Boundary	maybe	yes	no
Enclosing +Boundary	maybe	yes	yes



A node always connect to its enclosing neigbours, regardless of whether they are in the AOI.



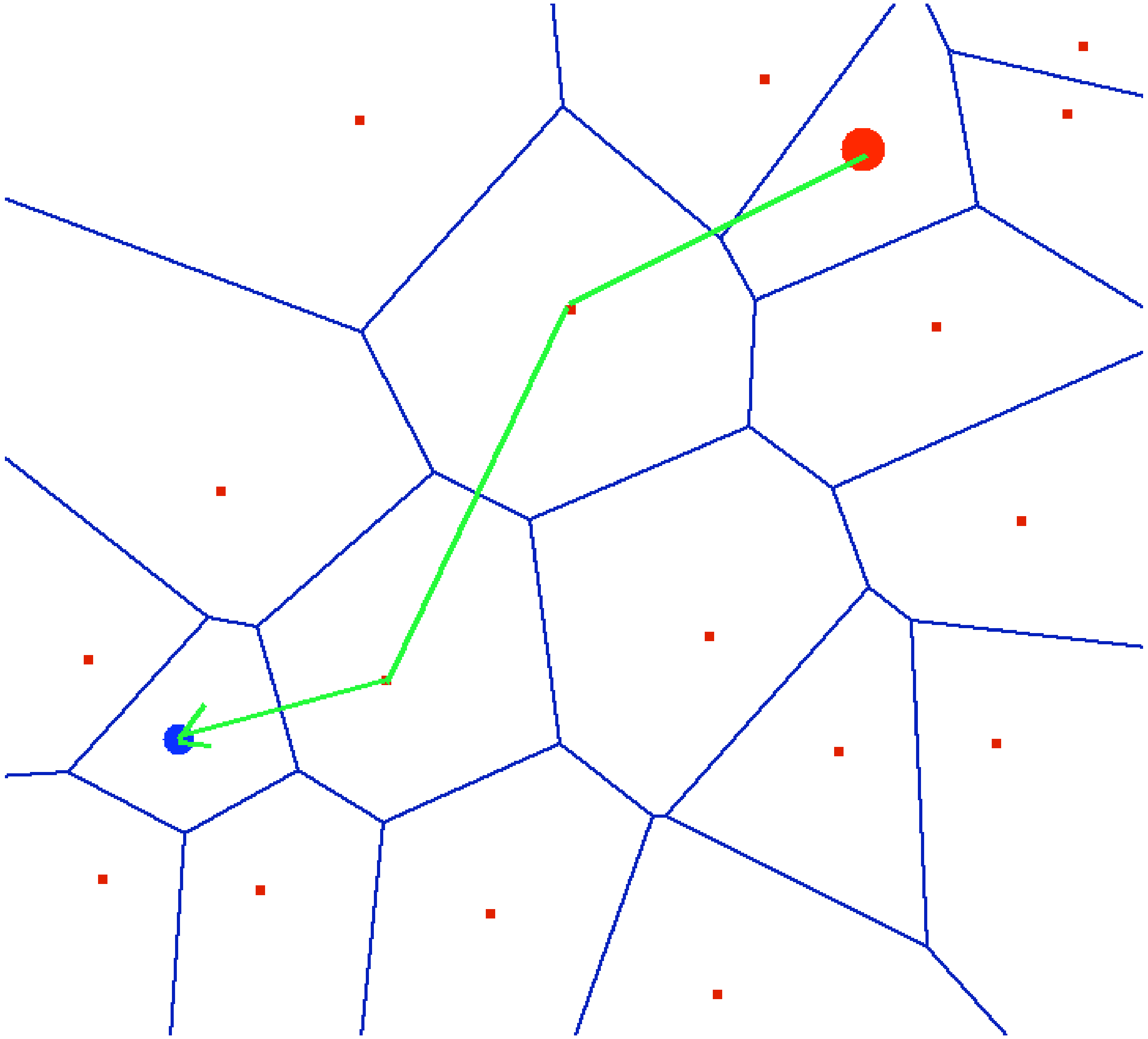
A node connects to exchanges updates with all neighbors.



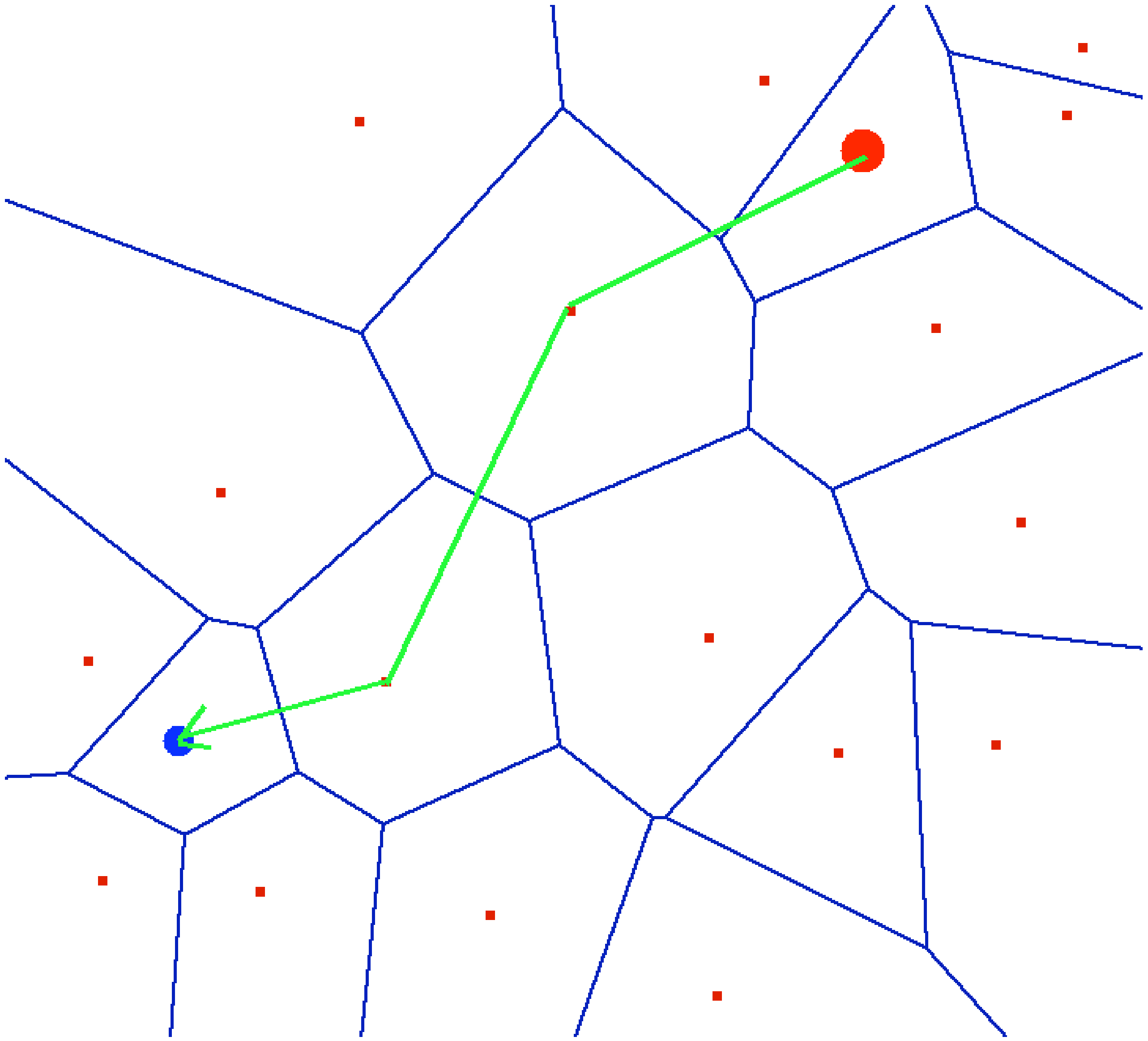
A node maintains Voronoi of all neighbors (regardless of inside AOI or not)

Suppose a player X wants to join. X sends its location to any node in the system.

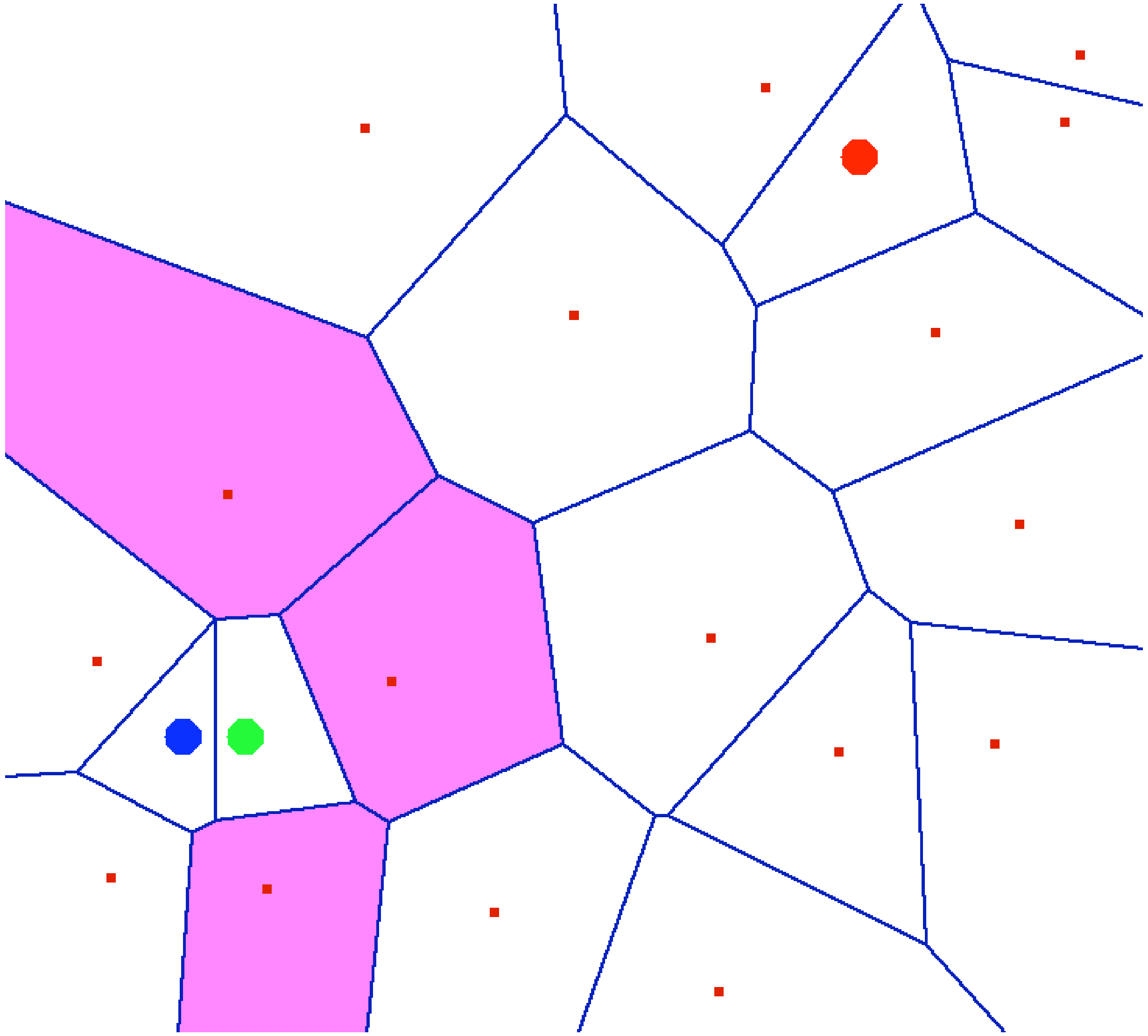
X join request is forwarded to the node in charge of the region (i.e., closest node to X), called acceptor.



Forwarding is done greedily
(at every step, forward to neighbor closest to X)



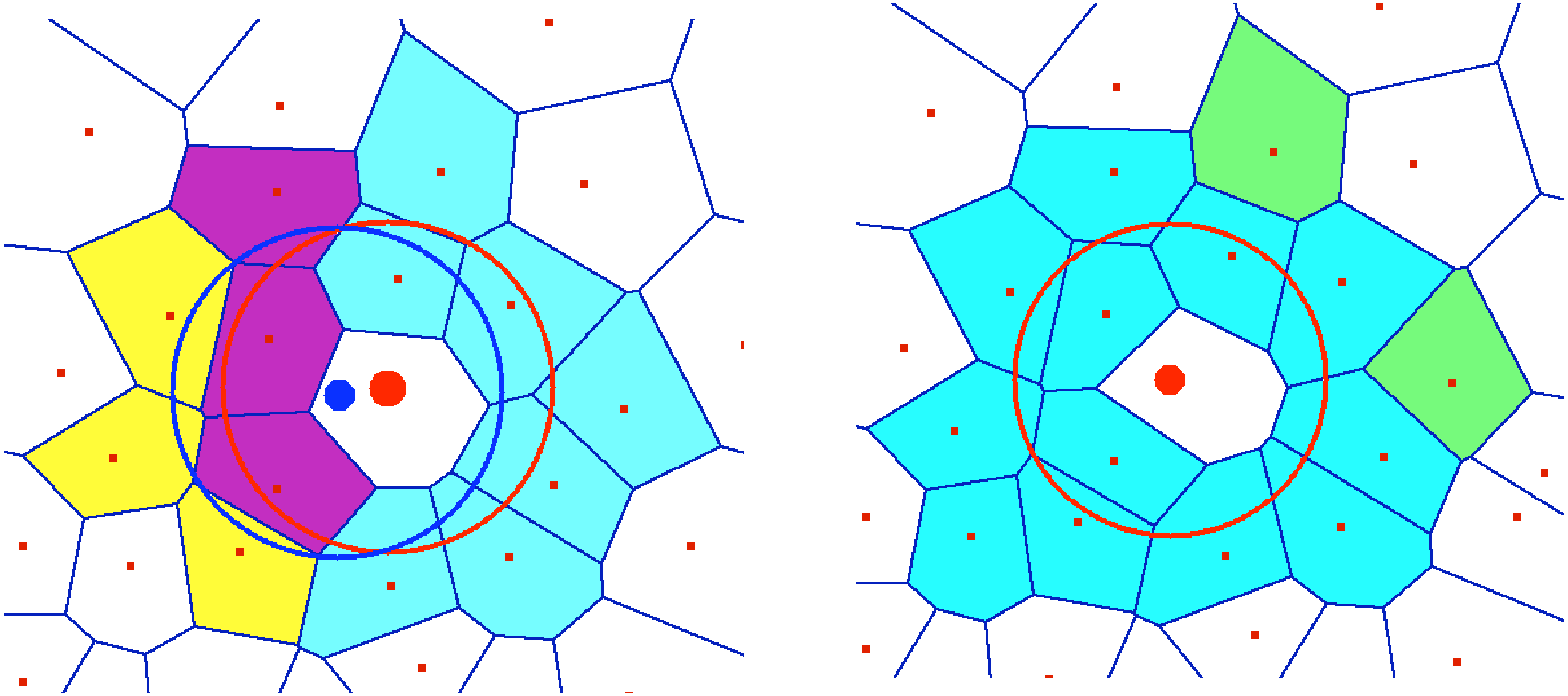
Acceptor informs the joining node X of its neighbors. Acceptor, X, and the neighbors update their Voronoi diagram to include the new node.



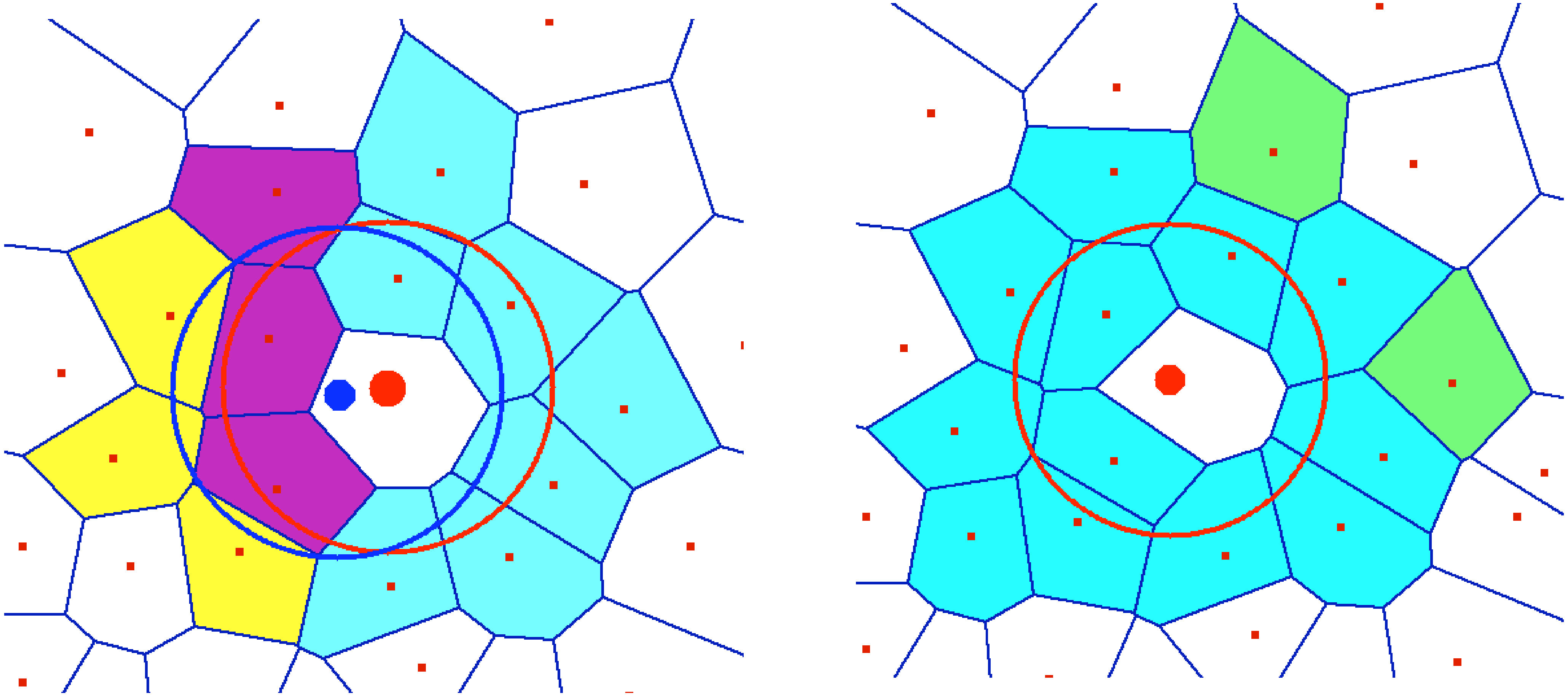
True or false:

Enclosing neighbors of X are also enclosing neighbors of acceptor.

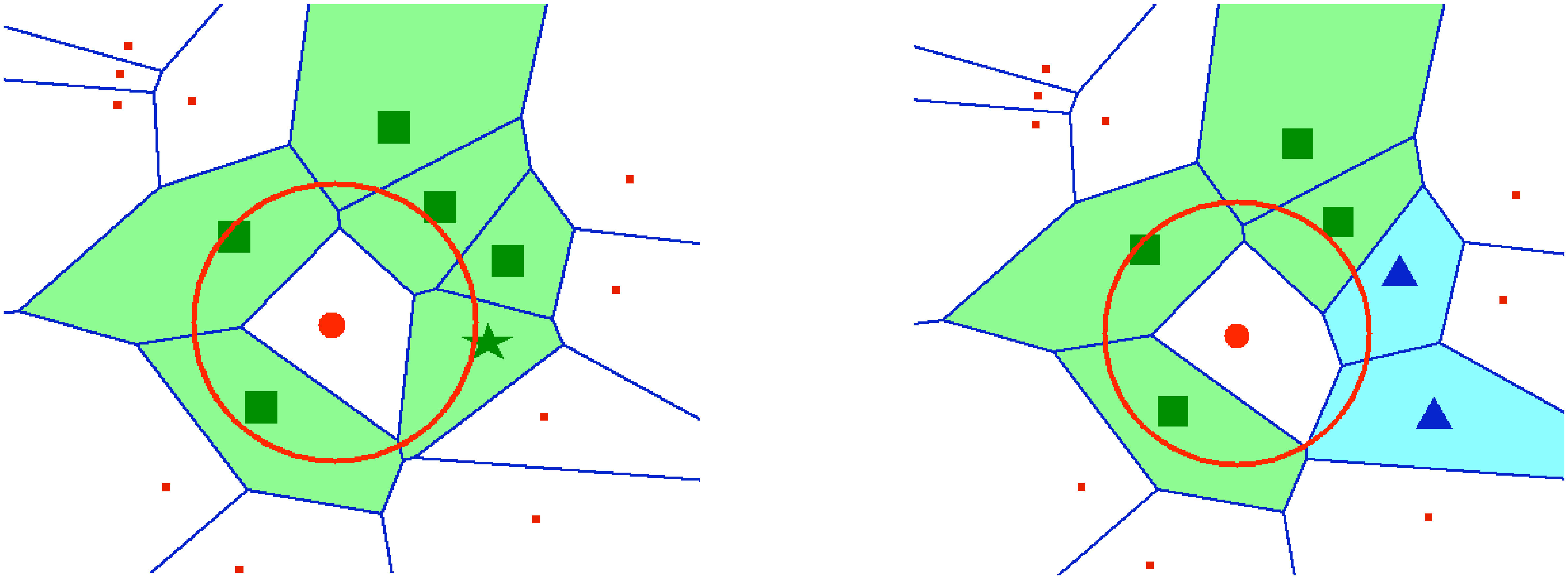
When X moves, X learns about new neighbors from the boundary neighbors.



Boundary neighbors' enclosing neighbors may become new neighbors of X.



When a node disconnects, Voronoi diagrams are updated by the affected nodes. New boundary neighbors may be discovered.



Advantages of VON:

Number of connections depends on size of AOI, not size of virtual world

We can bound number of connections by adjusting AOI radius (smaller AOI is crowded area).

Advantages of VON:

Maintain a minimal number of enclosing neighbors when the world is sparse to ensure connectivity.

Advantages of VON:

Boundary neighbors ensure that new neighbors are discovered.

Problems with VON:

Inconsistency may occur (e.g. with fast moving nodes)

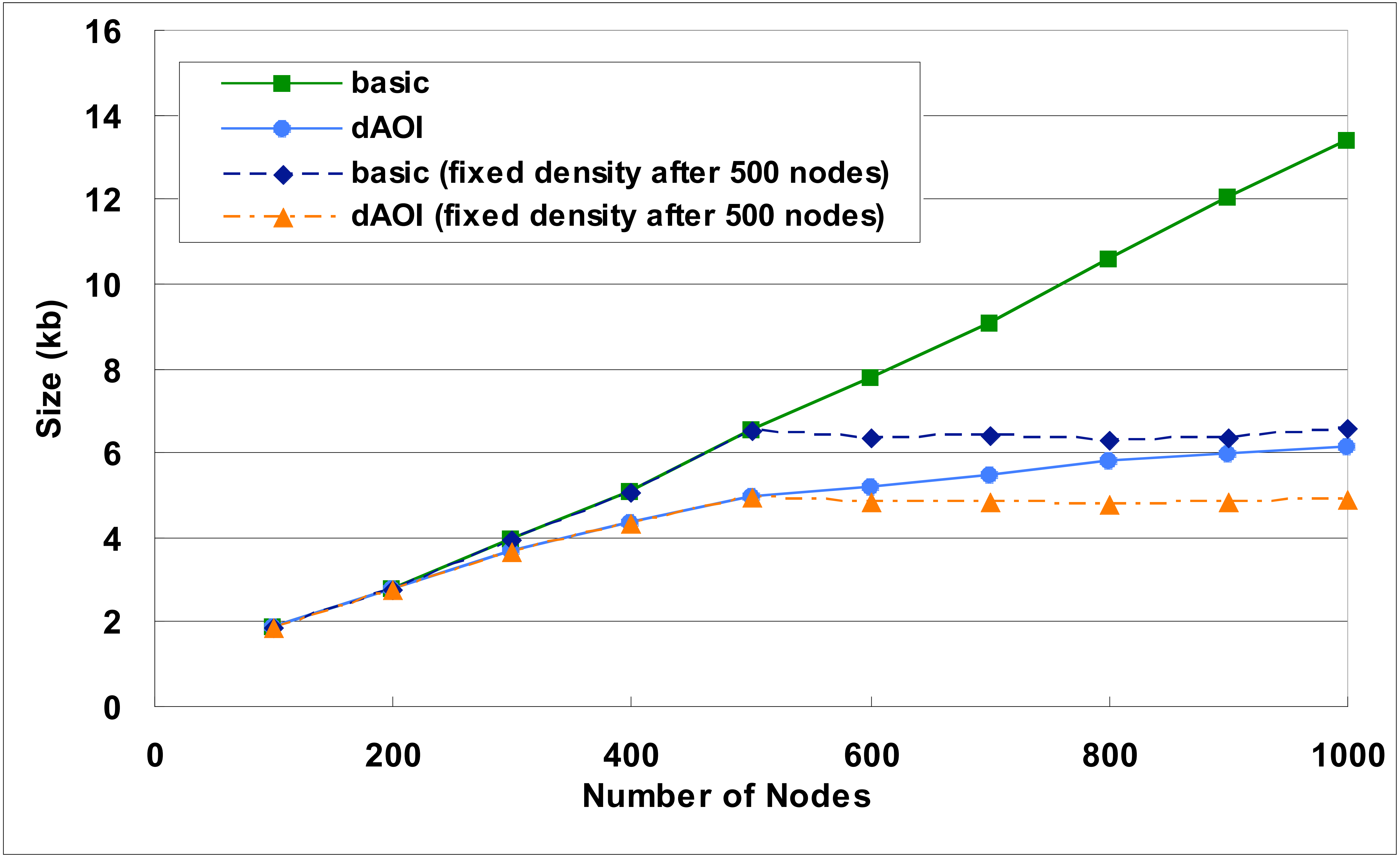
No rigorous proof

Working on evaluation with realistic traces

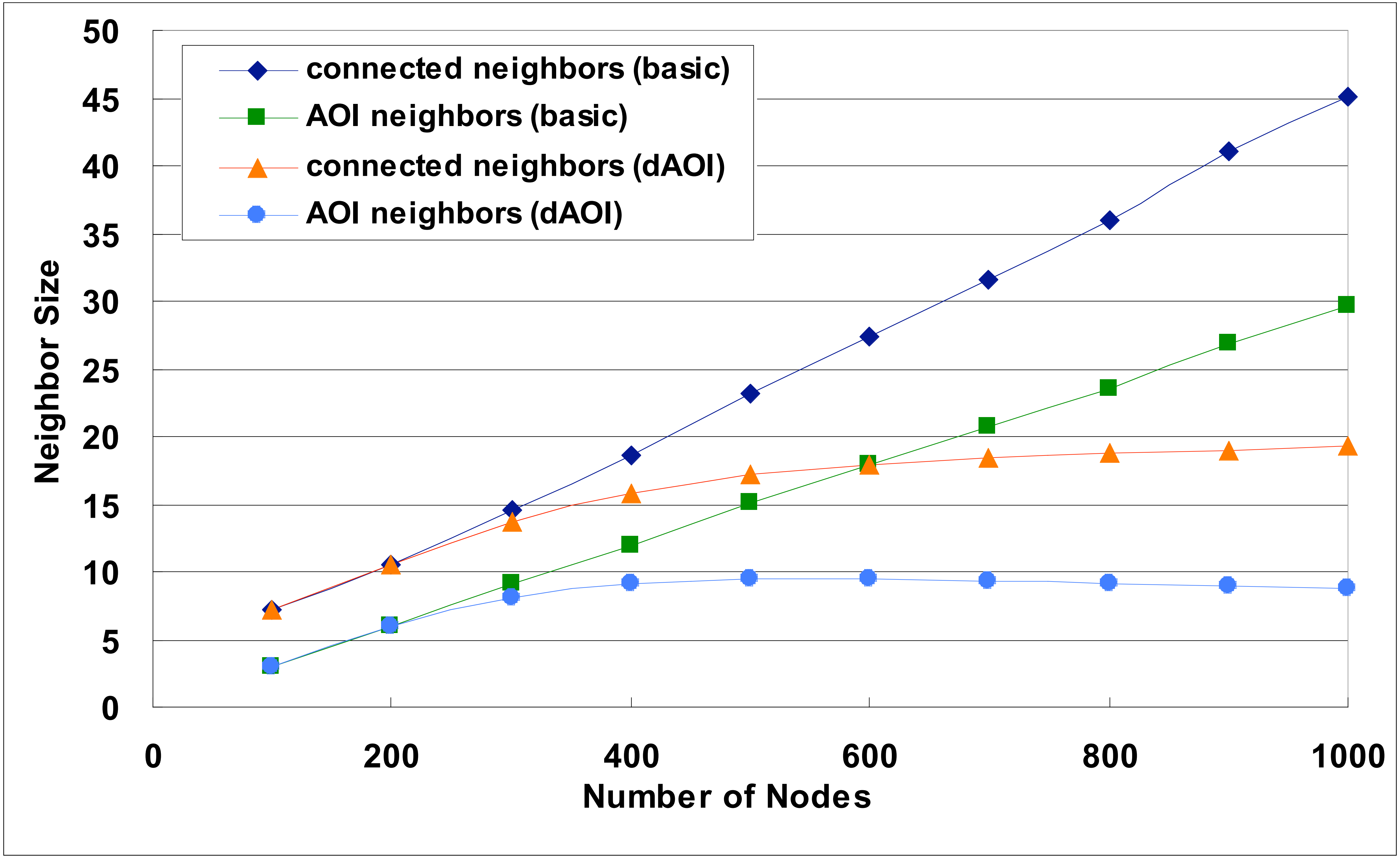
For now, simulation only

World Size	1200x1200
Players	100 to 1000
AOI	100
Connection Limit	20
Movement	Random Waypoint
Velocity	Constant 5 units /step

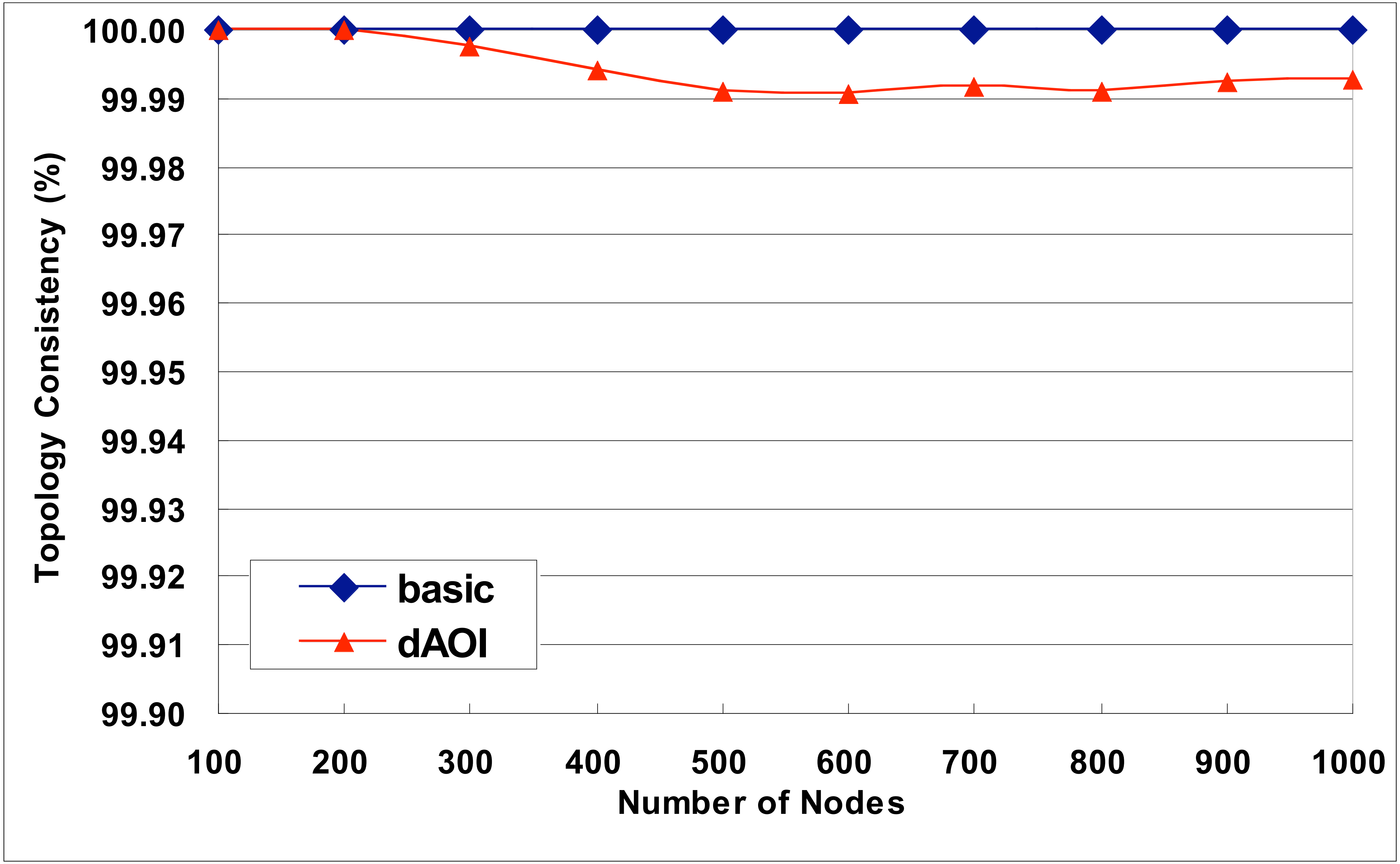
Average Transmission per Second



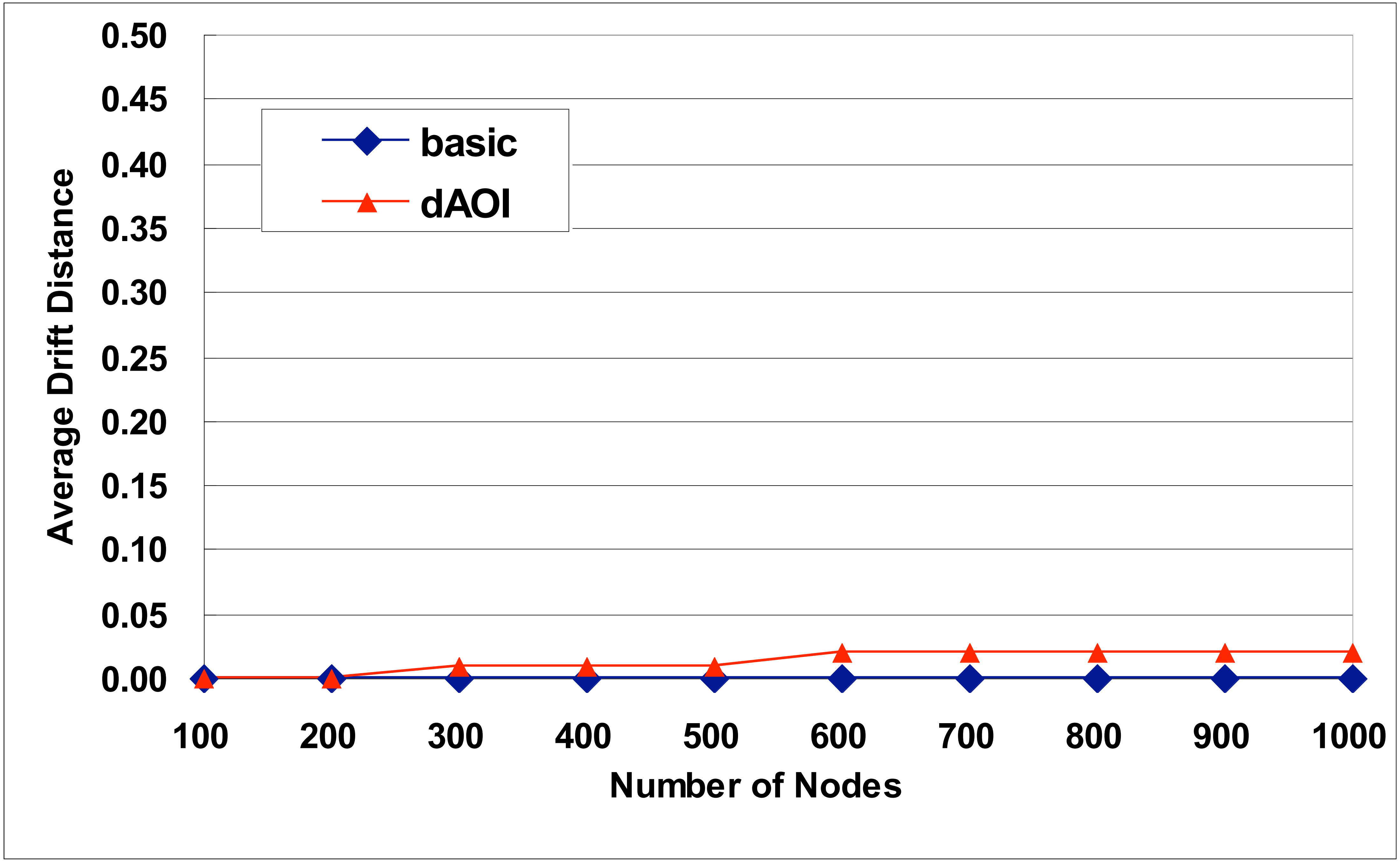
Average Neighbor Size



Observed/Actual AOI Neighbors



actual - observed position (average over all nodes)



Responsive

Consistent

Cheat-Free

Fair

Scalable

Efficient

Robust

Simple