A GRASP heuristic for the cooperative communication problem in ad hoc networks

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Joint work with C.W. Commander, C.A.S. Oliveira, and P.M. Pardalos

Summary of talk

- Mobile ad hoc networks
- Cooperative communication problem (CCPM)
- GRASP for CCPM
- Construction method
- Local search
- Experimental results

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- Set of mobile wireless units.
- Can communicate directly, without use of pre-established server infrastructure.
- Each client can access network nodes within its reach.
- Network has no predefined topology, which changes each time a node changes position.

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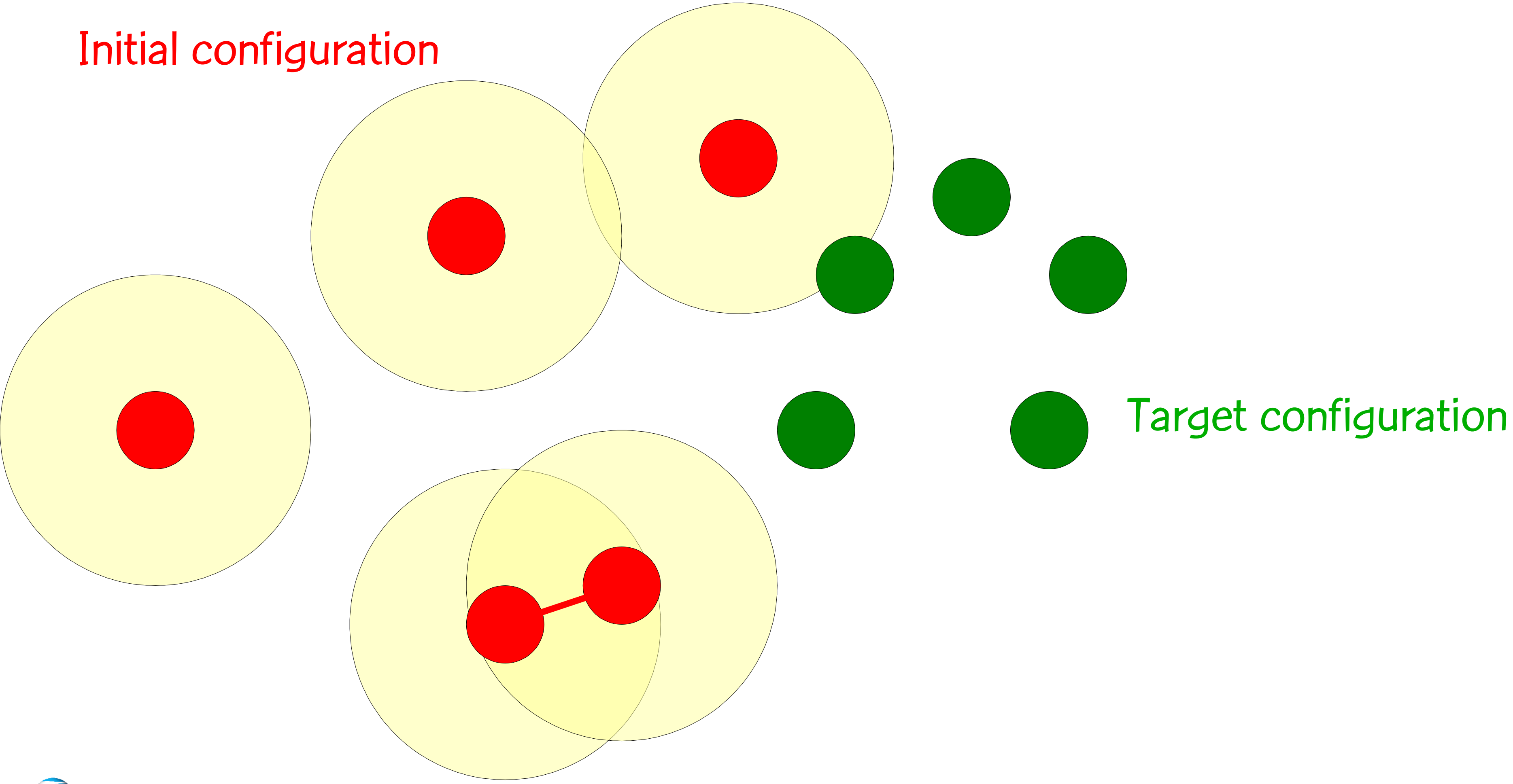

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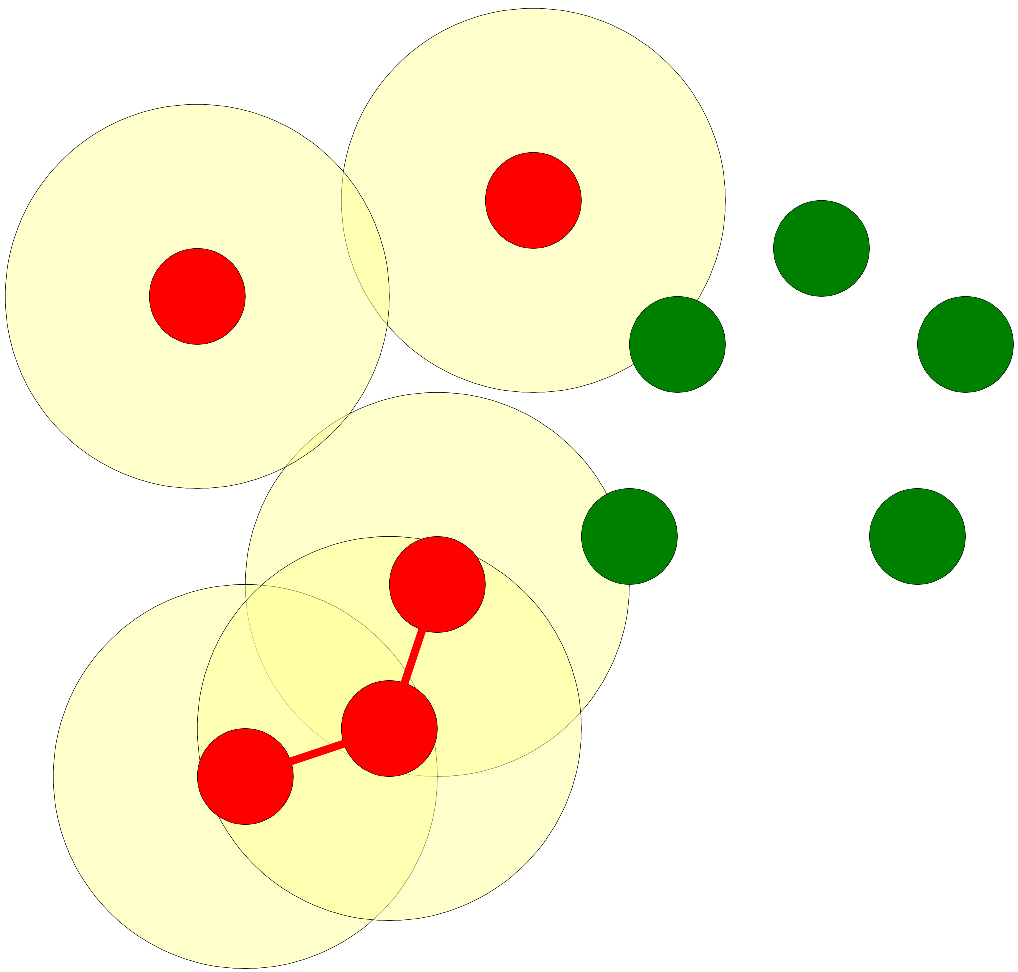

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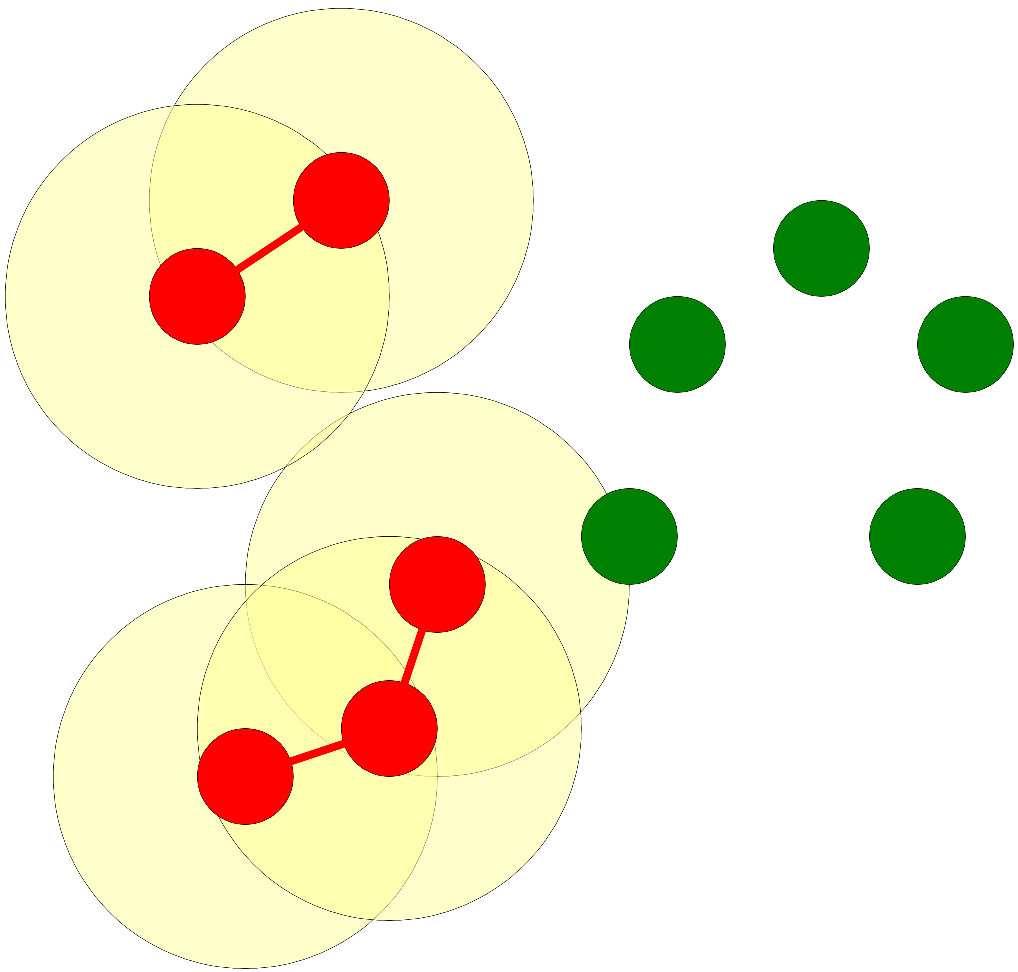

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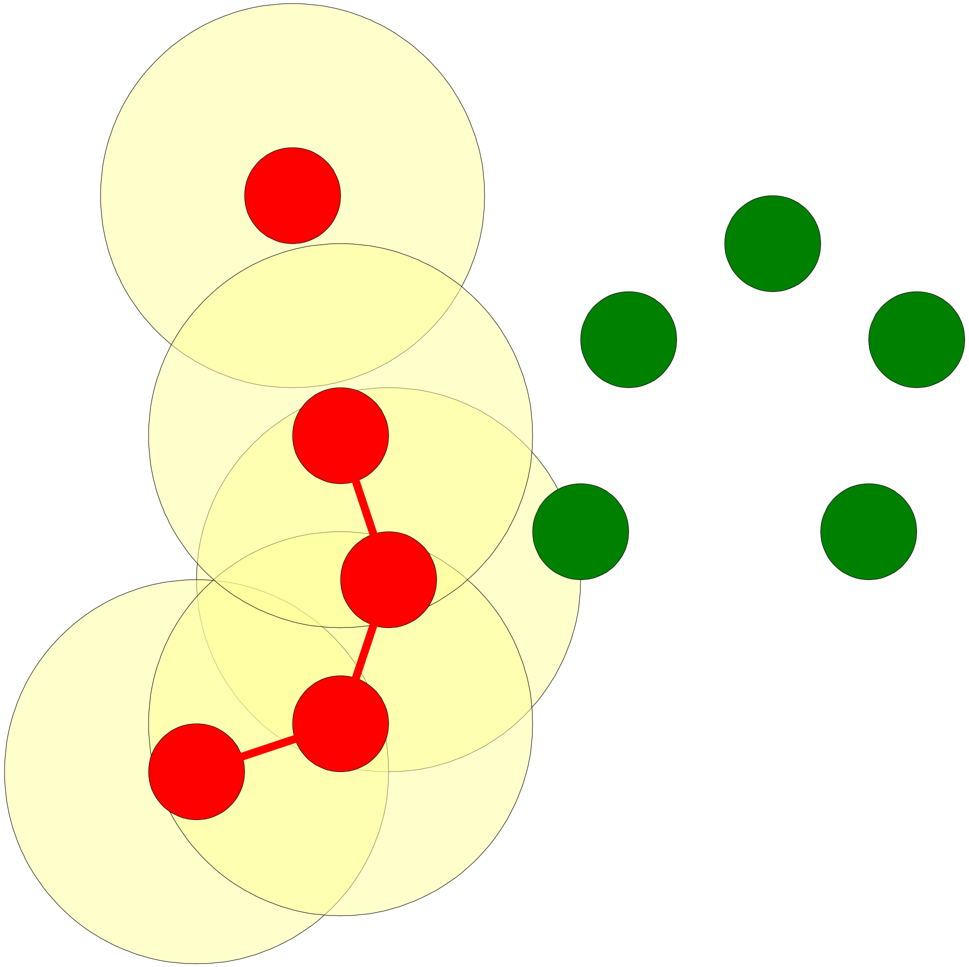

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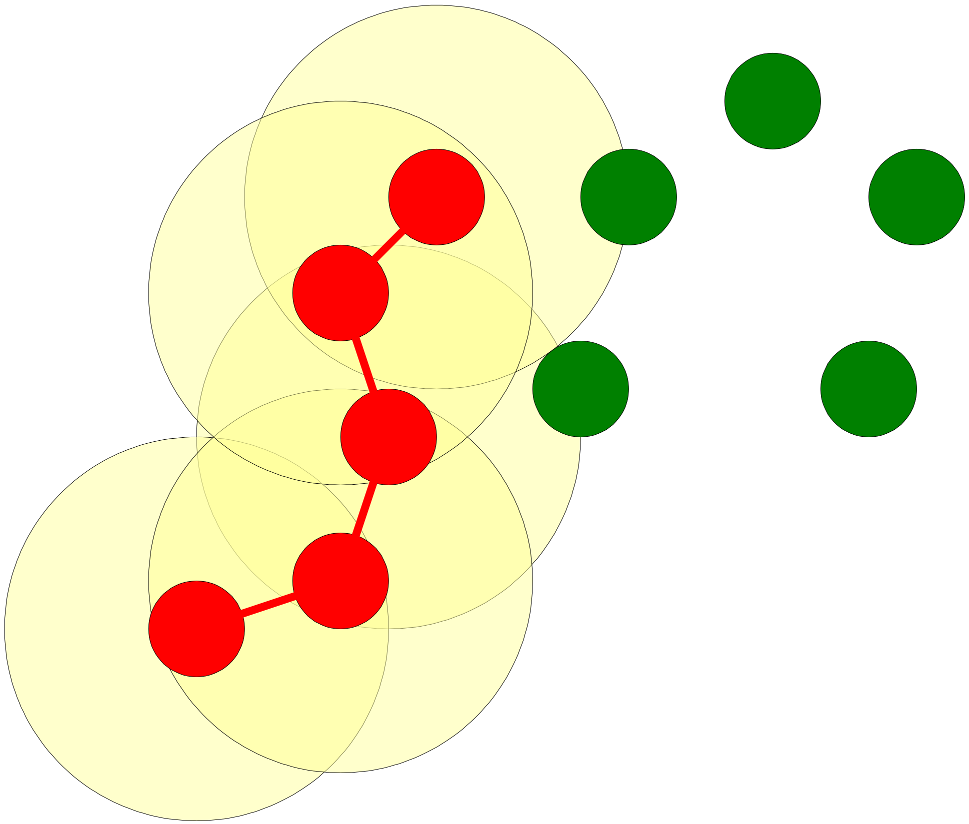

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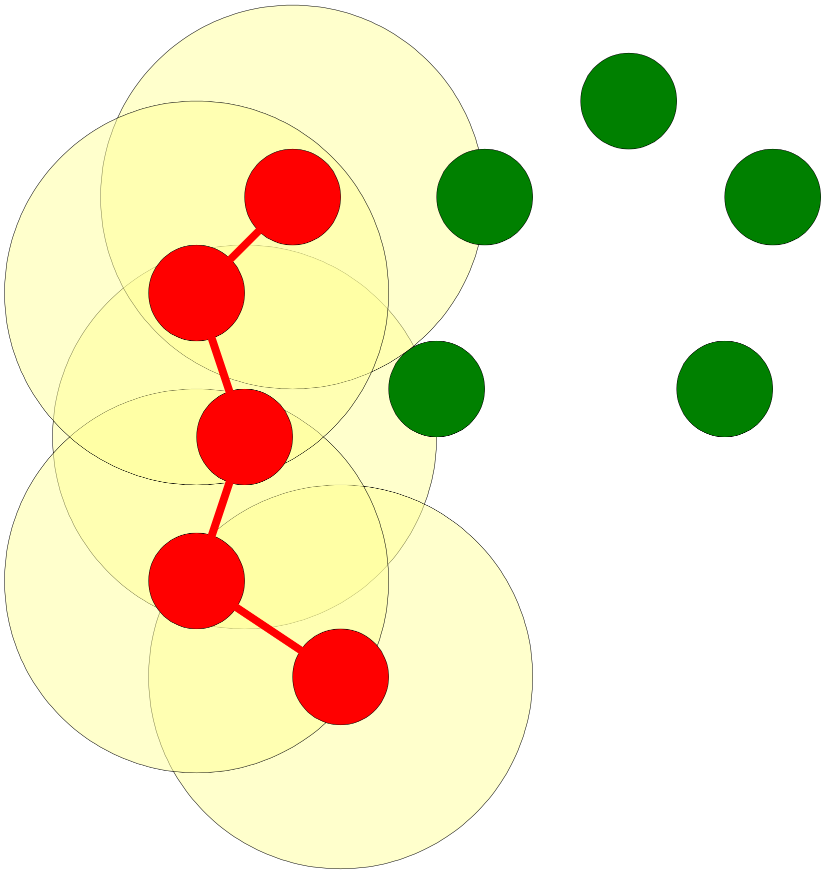

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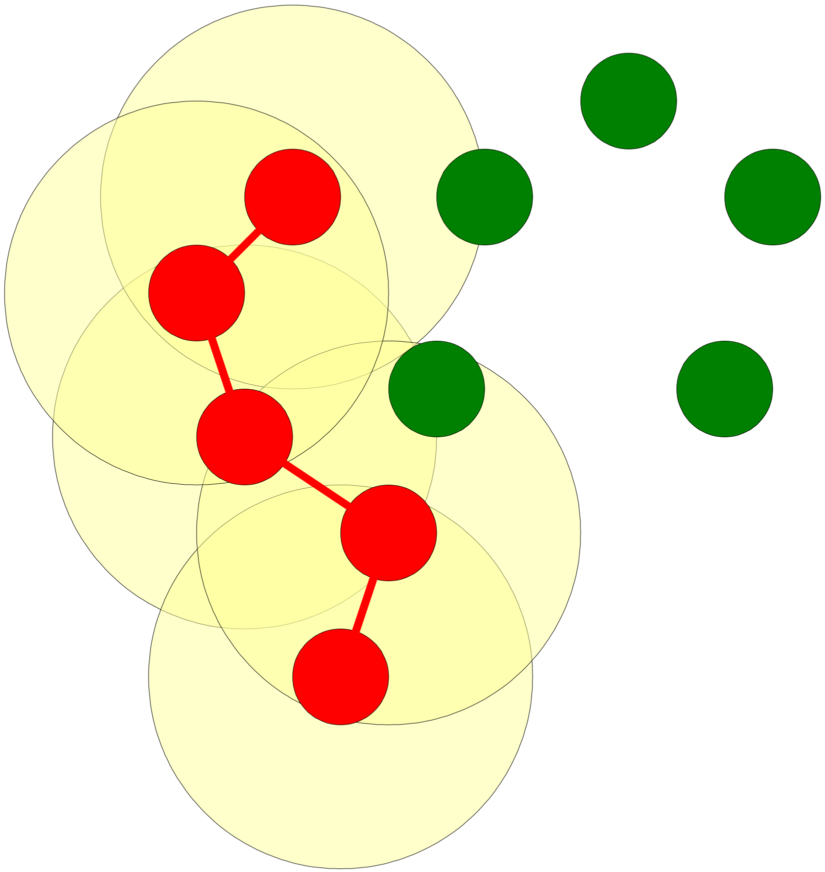

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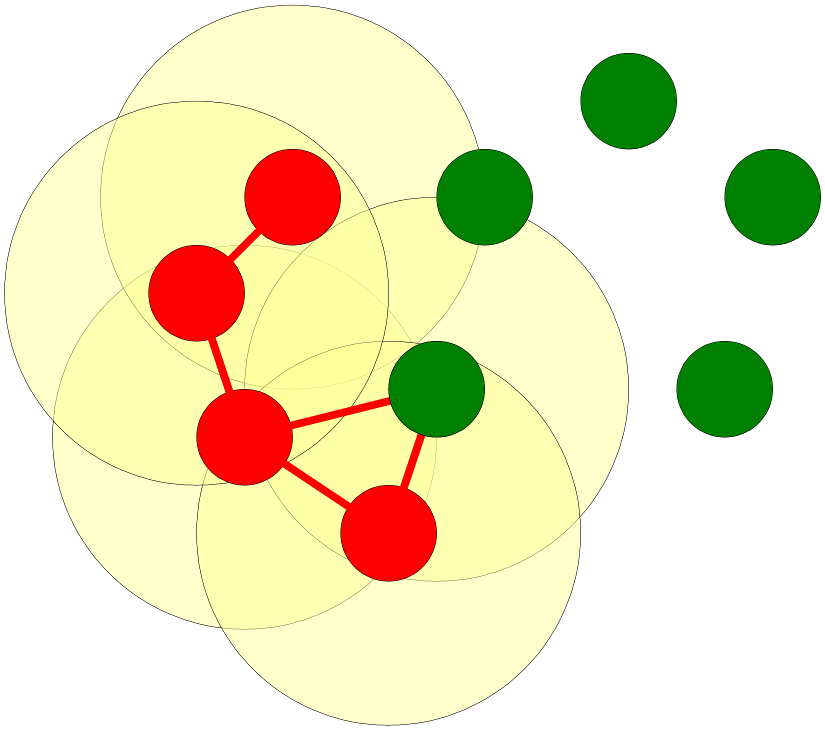

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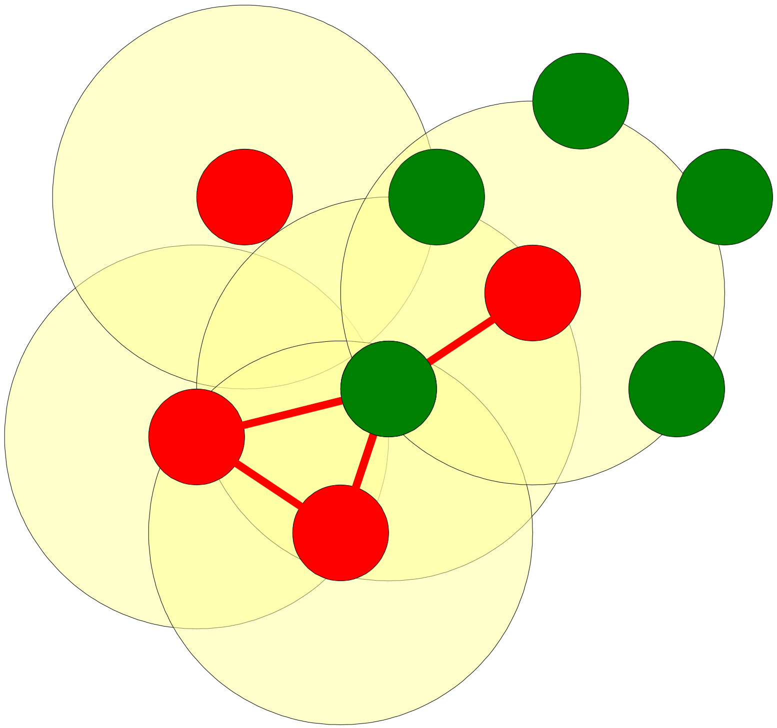
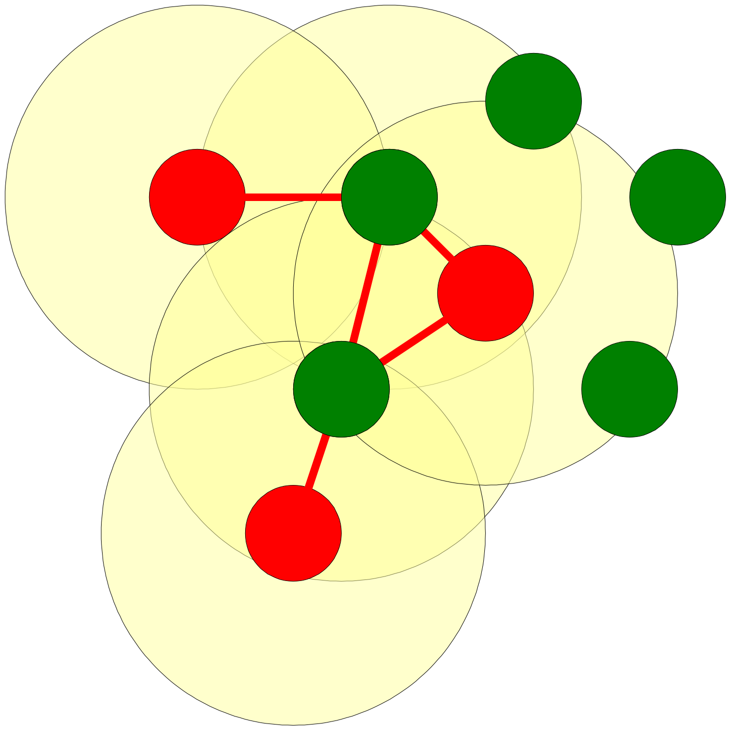


Mobile ad hoc network



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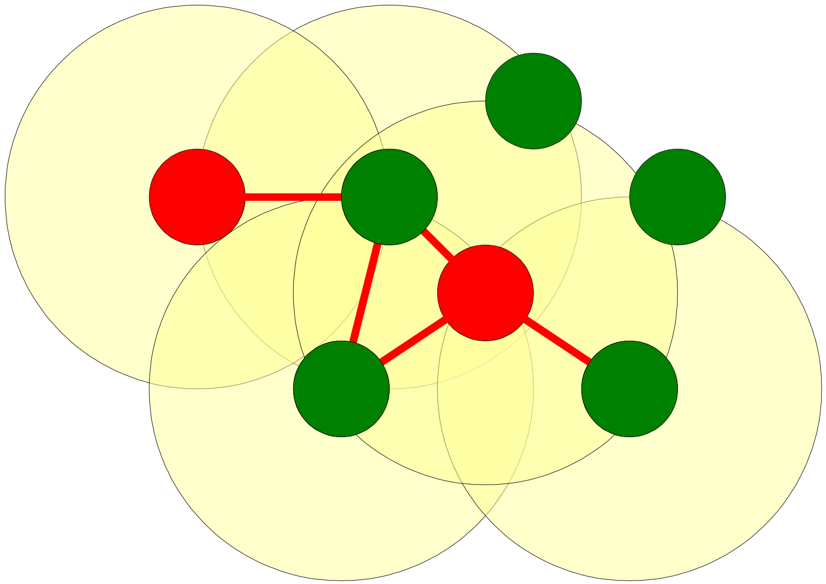

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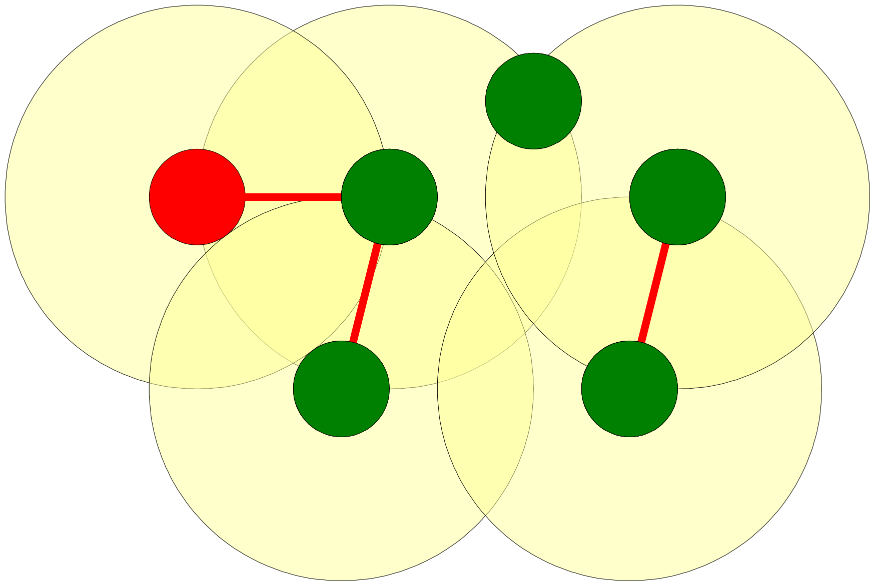

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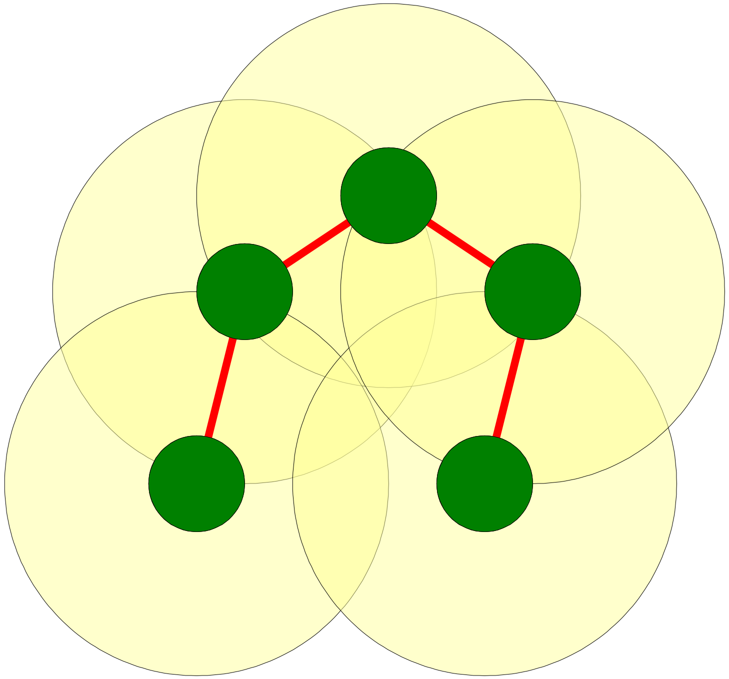

Mobile ad hoc networks

- Any situation where:
  - Communication in a region is required;
  - No fixed communication system exists;
  - Users are supposed to be in reach of each other.
- Examples:
  - Emergency / rescue operations;
  - Disaster relief;
  - Battlefield operations.
- National Institute of Standards & Technology
  - Advanced network technologies division webpage: `http://w3.antd.nist.gov/wahn_home.shtml`

Cooperative communication

- We study the problem of coordinating wireless users in a task that requires going from an initial location to a target location.
- We want to maximize network connectivity.
- Subject to:
  - Initial and final configurations;
  - Maximum distance a user can move;
  - Types of movements user can make.

Cooperative communication

- The problem is too difficult to solve in general:
  - Movement decisions (e.g. types of movement);
  - Physical decisions (e.g. velocities, autonomy, ...);
  - Strategic decisions (e.g. low detection probabability).
- We propose a model for a simpler case:
  - Speeds of agents are equal and constant;
  - Agents can only be at fixed locations (space discretization);
  - Adjacent locations are equidistant from each other;
  - Two agents can occupy same location at same time;
  - Agents can only move in limited directions.

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Cooperative communication

- Let $G = (V,E)$ represent the set of valid positions and moves.
- Each node in G is connected only to nodes that can be reached in one unit of time.
- A possible user trajectory can be represented as a path $P = \{v_1, v_2, \ldots, v_k\}$ in G, where:
  - $v_1 \in V(G)$ is the starting node
  - $v_k \in V(G)$ is the target node

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Cooperative communication

- We are also given:
  - A set U of users;
  - A set S of initial positions, with $|S|=|U|$ and $S \subseteq V(G)$;
  - A set D of destinations, with $|D|=|U|$ and $D \subseteq V(G)$;
  - A vector L of maximum distances users can move.
- To perform its task, user $u_i \in U$
  - starts from position $s_i \in S$ and moves to position $d_i \in D$
  - not moving more that a distance L_i
- Users must reach destination in at most T time units.

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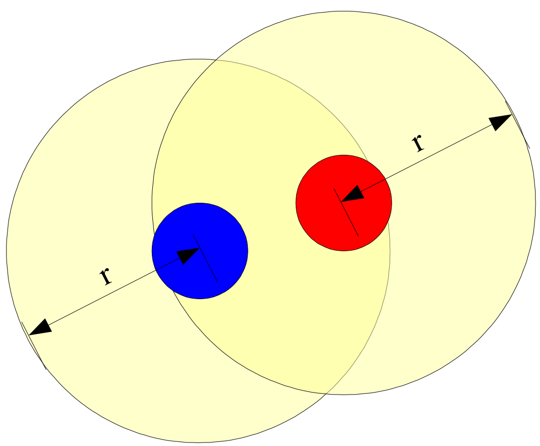
Cooperative communication

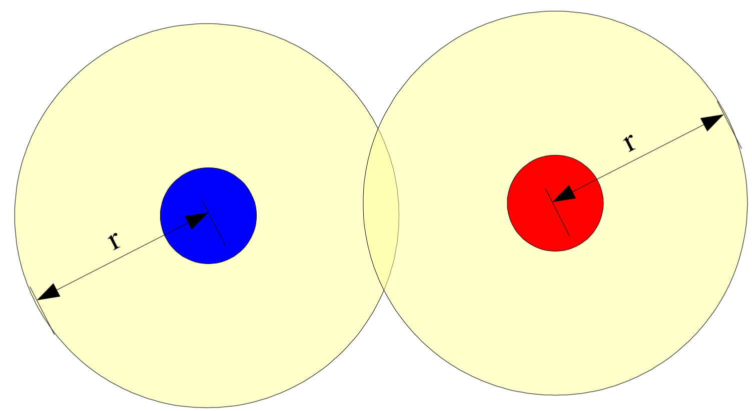
- Trajectory of users occurs as follows:
  - Let $N(v) \subseteq V(G)$ be the set of nodes in the neighborhood of node v, i.e. the set of nodes $w \in V(G)$ s.t. $(v,w) \in E(G)$.
  - Let $p_t: U \rightarrow V(G)$ be a function that returns the position of a user at time t.
  - At each time t, a user u can either stay still (at $p_{t-1}(u)$) or move to one of its neighbors $v \in N(p_{t-1}(u))$.

Cooperative communication

- Objective is to maximize connectivity of users in U.
- Let $c: V^2 \rightarrow \{0,1\}$ be a function that returns 1 iff $d(p(u),p(v)) \leq r$.



$c[p(u), p(v)] = 1$



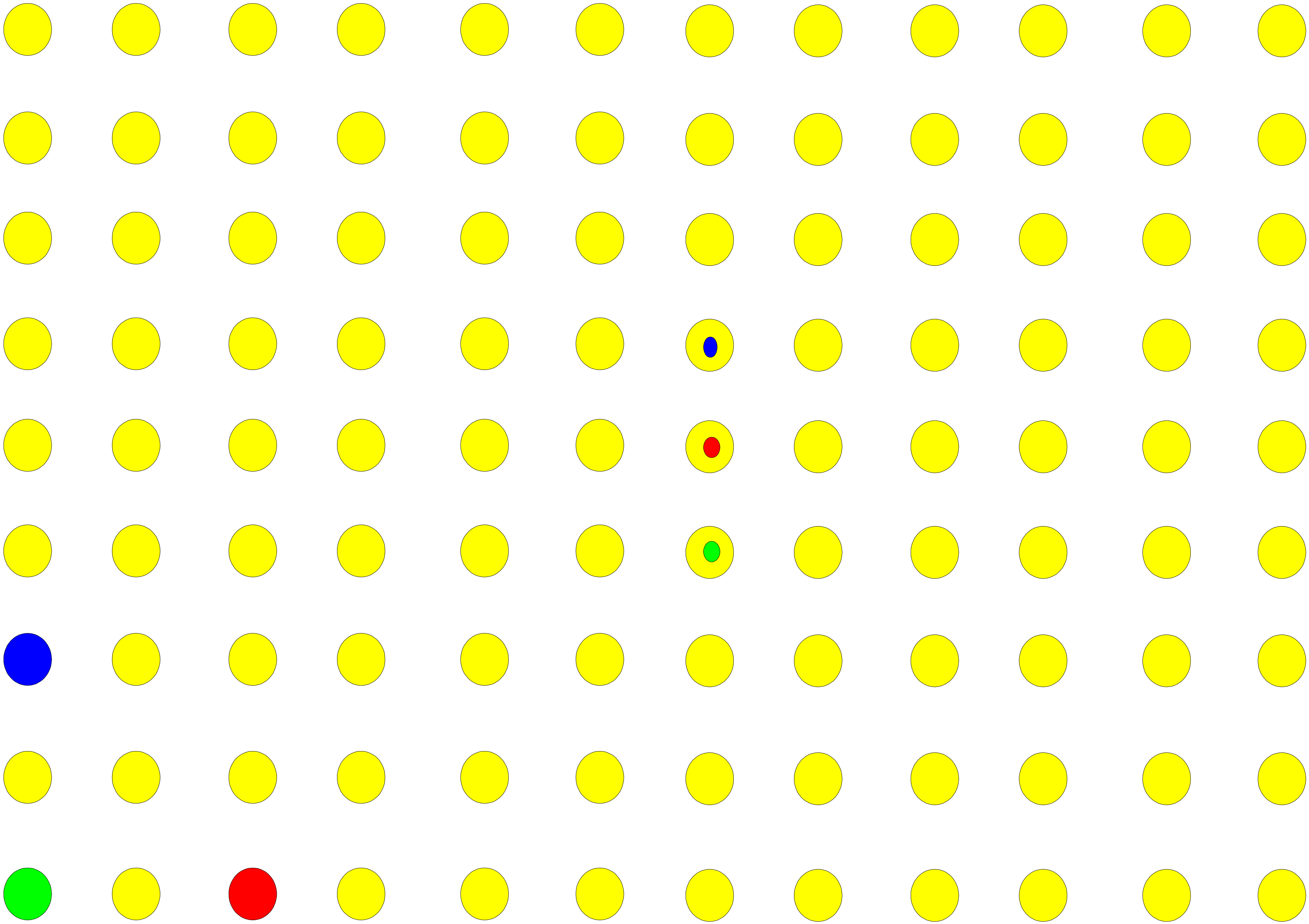
$c[p(u), p(v)] = 0$

Cooperative communication

- The objective function is

$$\text{maximize} \ \sum_{t=1,T} \sum_{u,v \in U} c[p_t(u), p_t(v)]$$

- Cooperative communication problem in mobile ad hoc networks (CCPM) is NP-hard (Oliveira & Pardalos, 2005)



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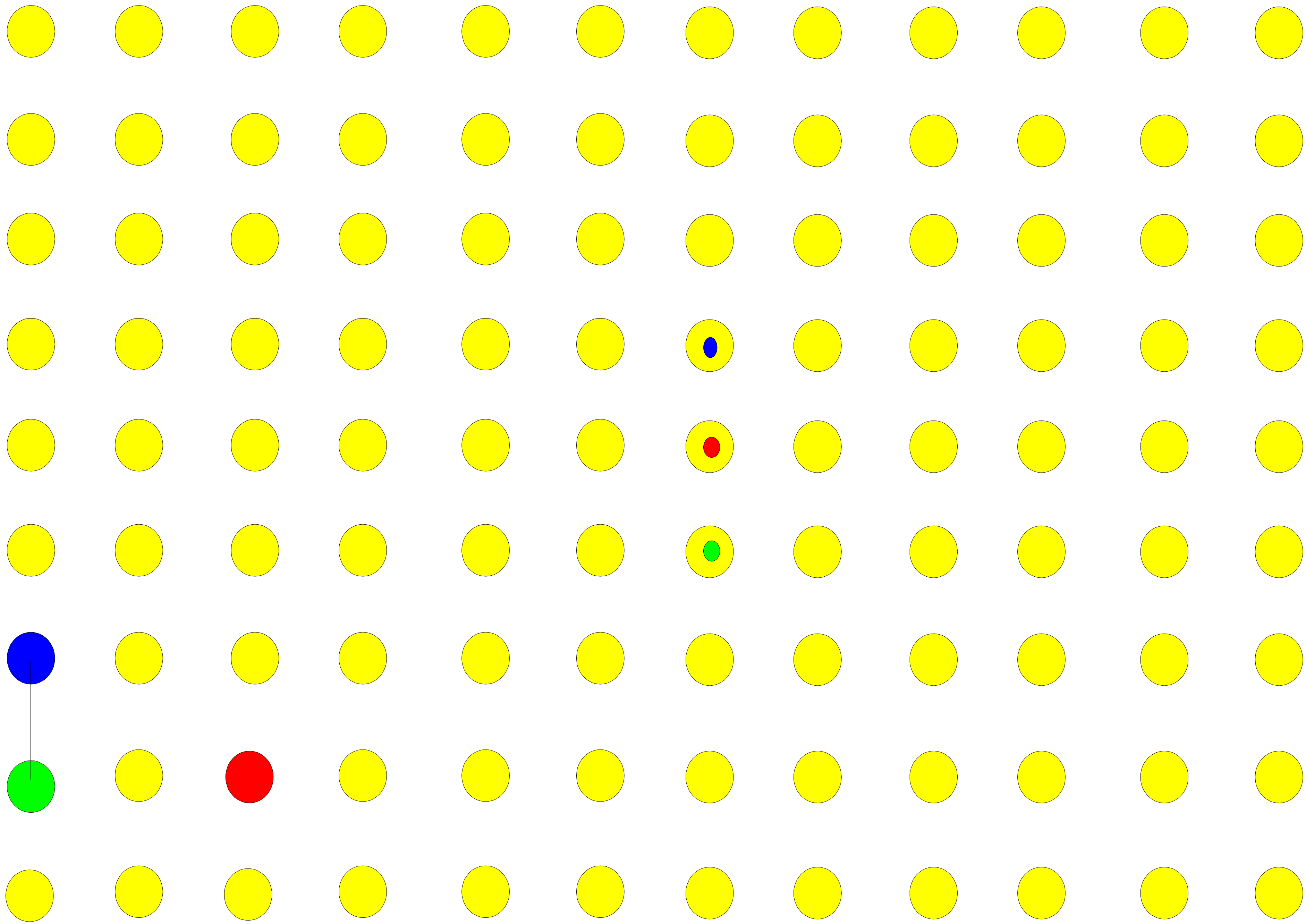

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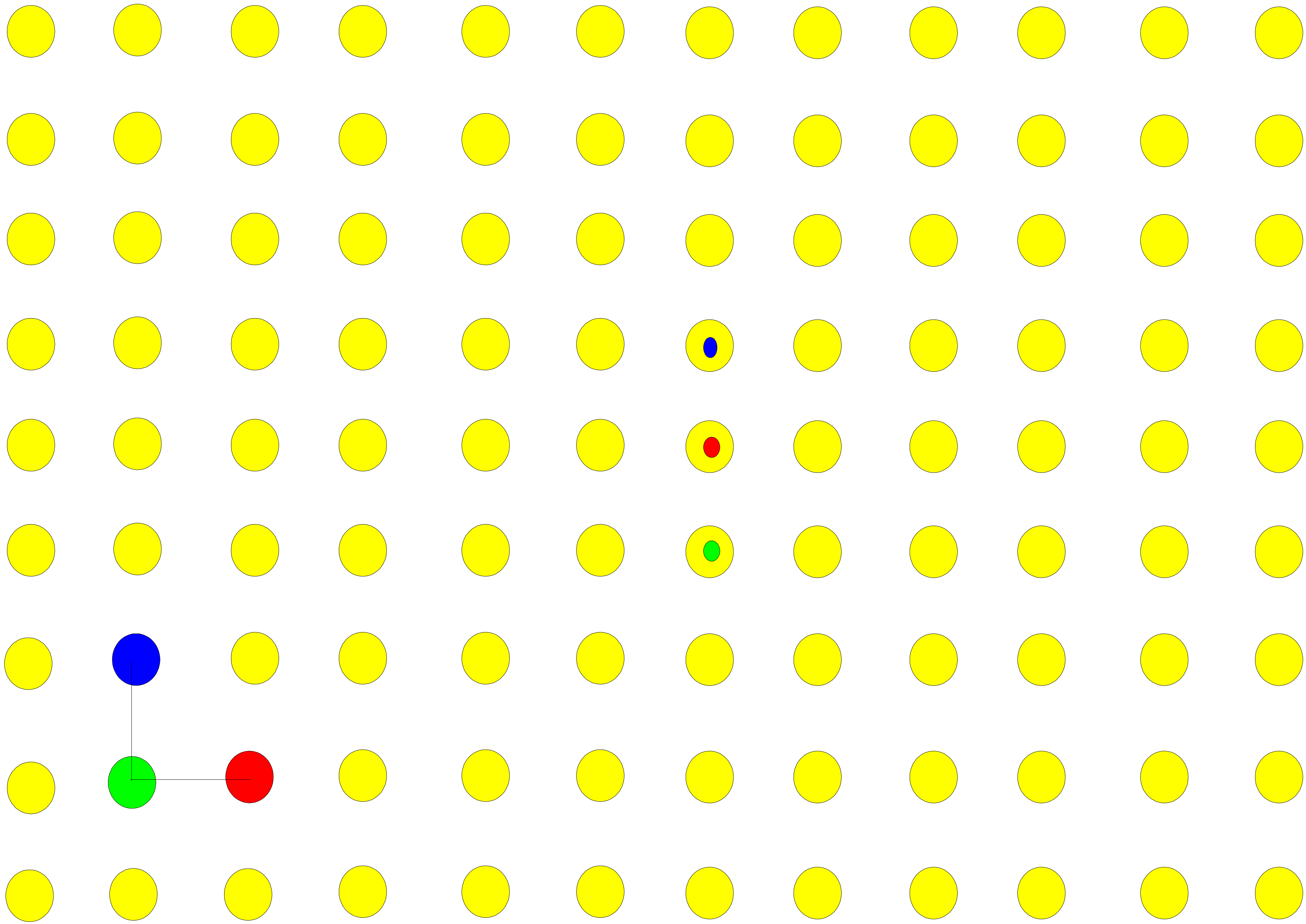

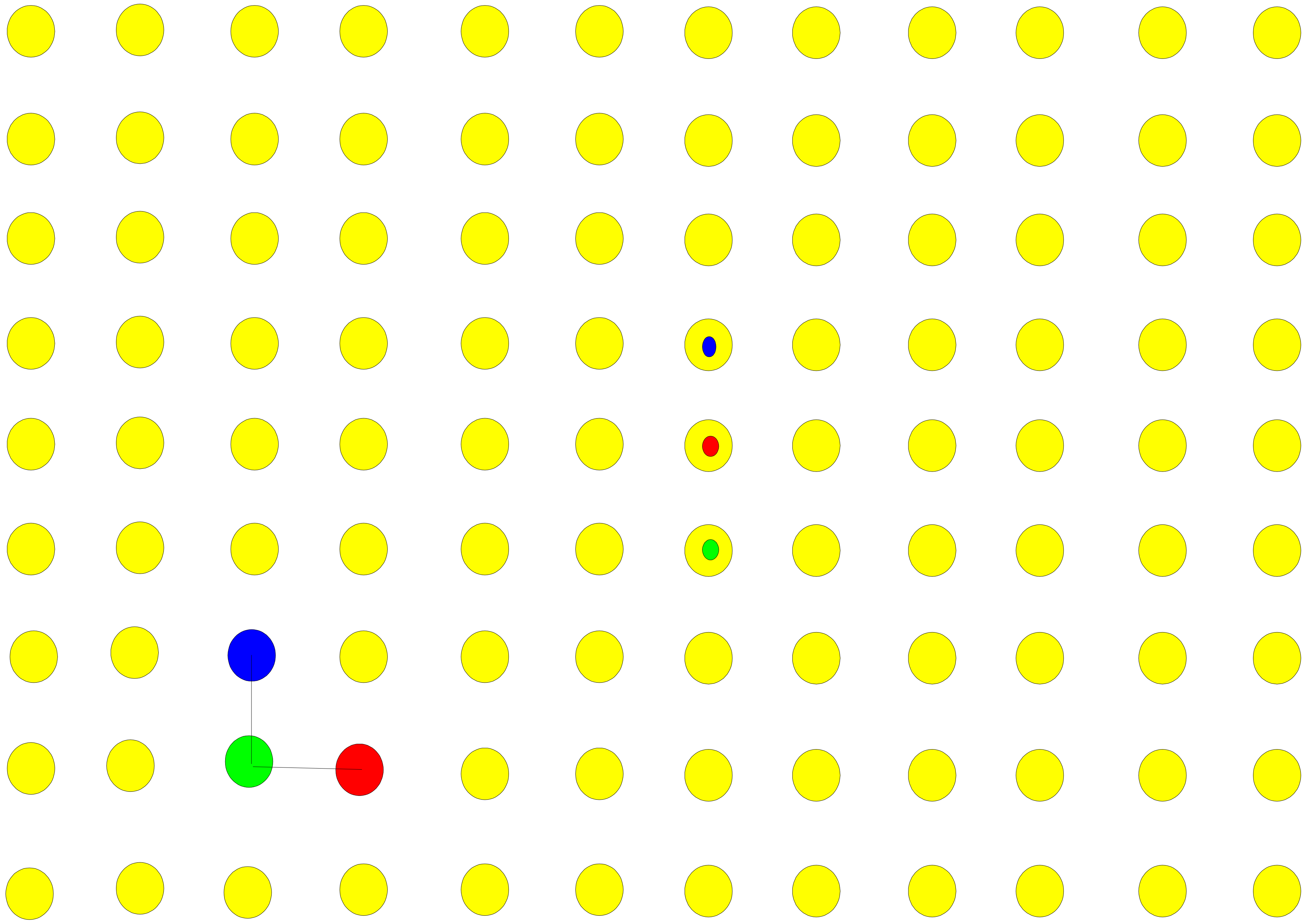

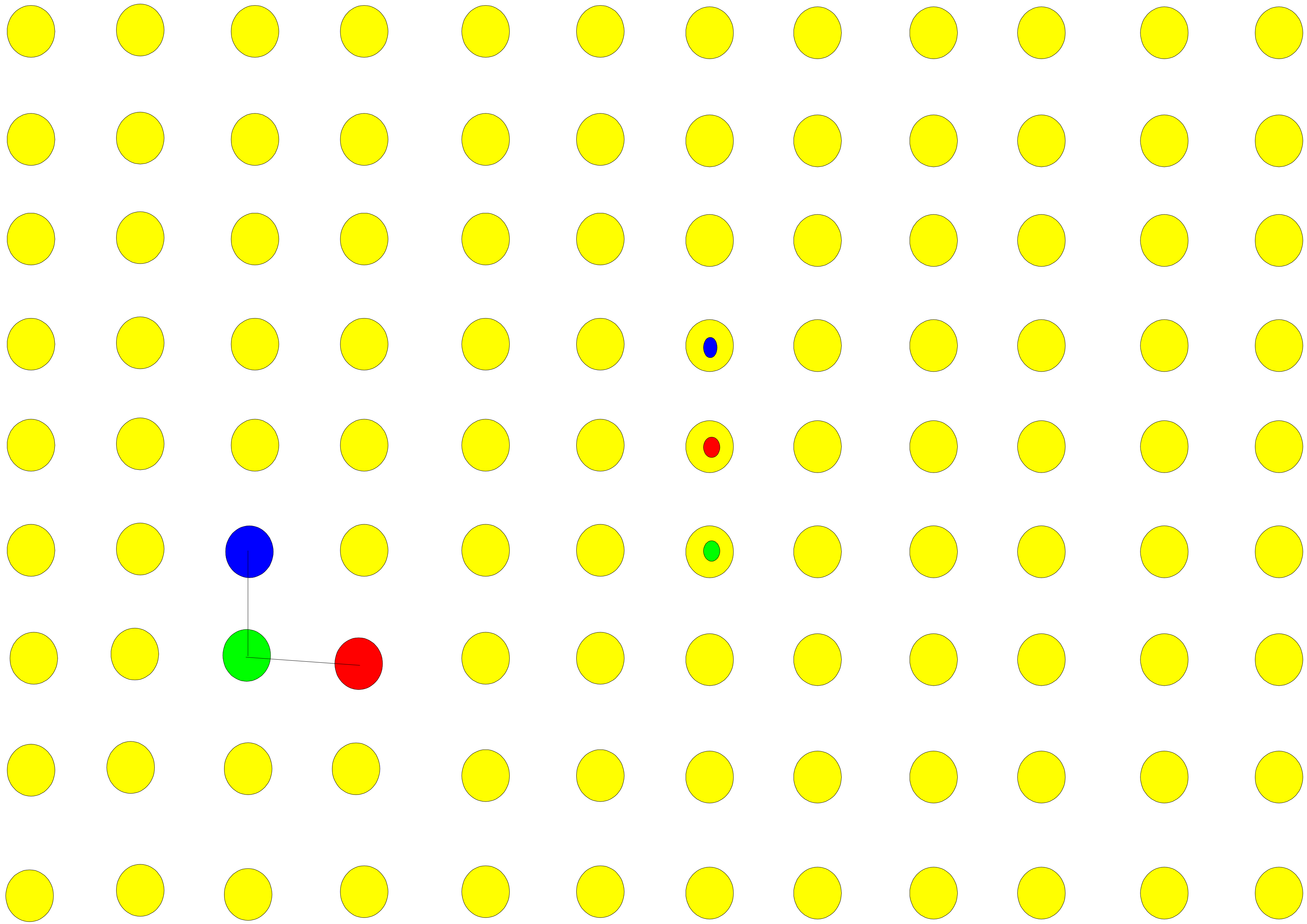

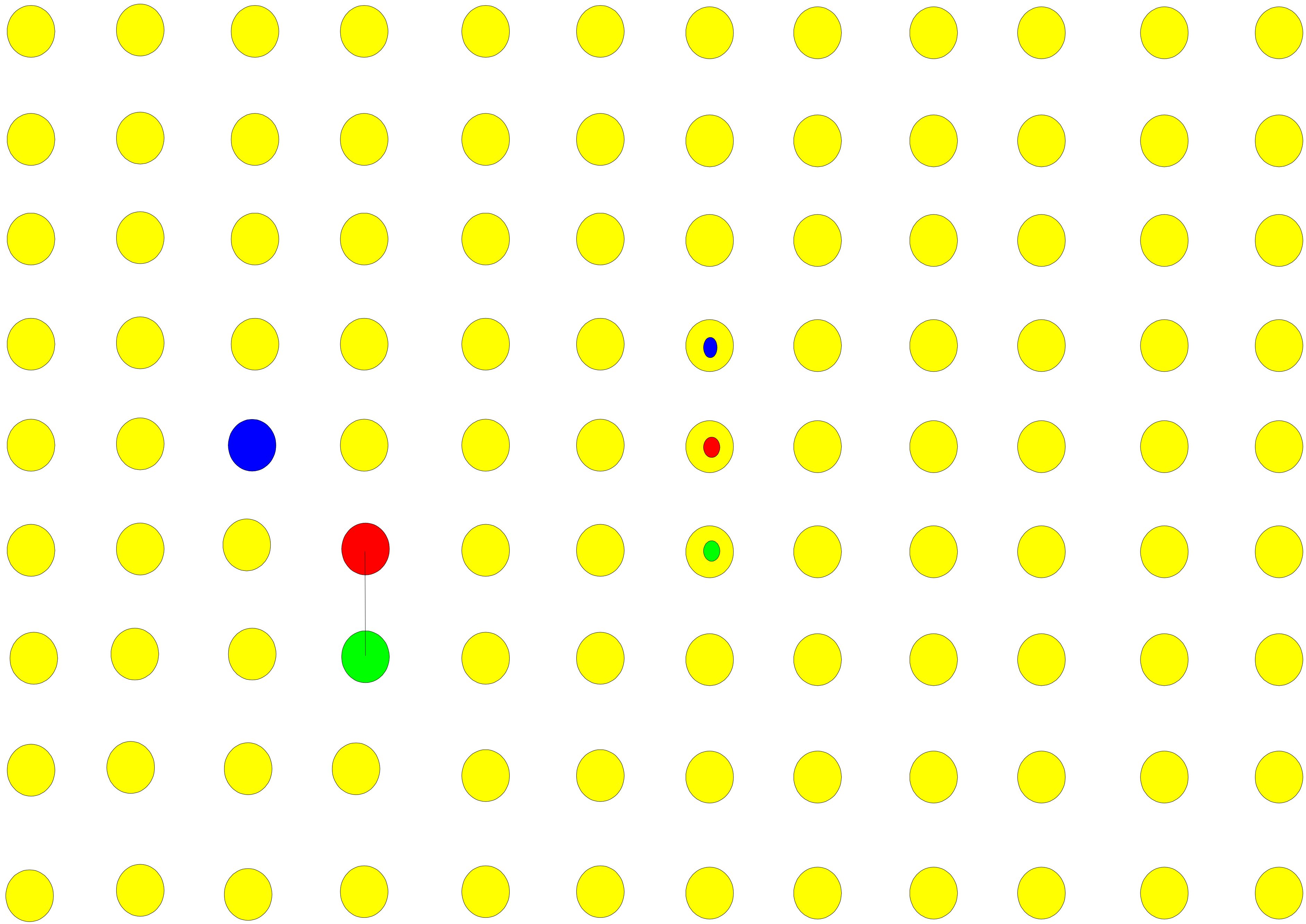

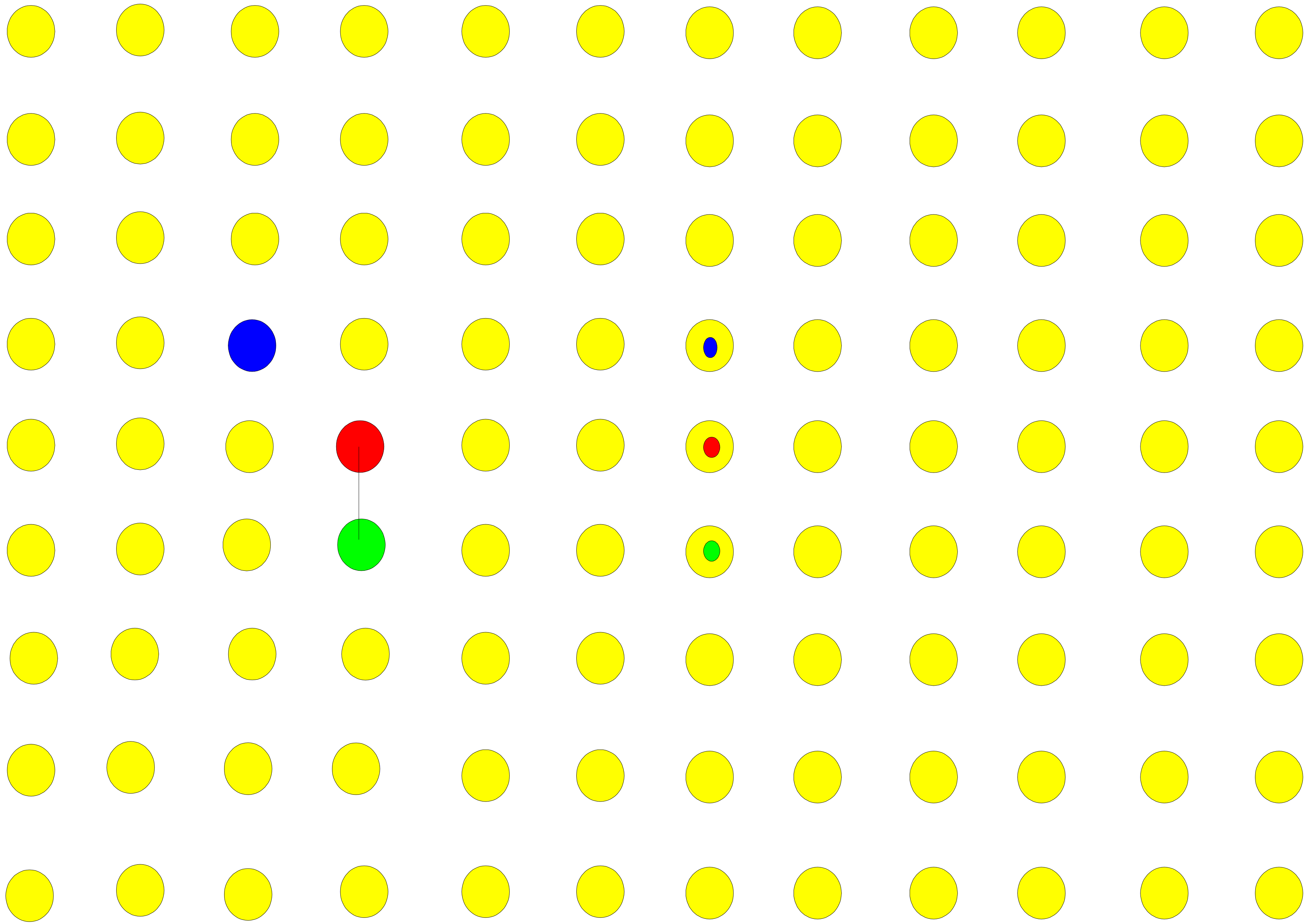

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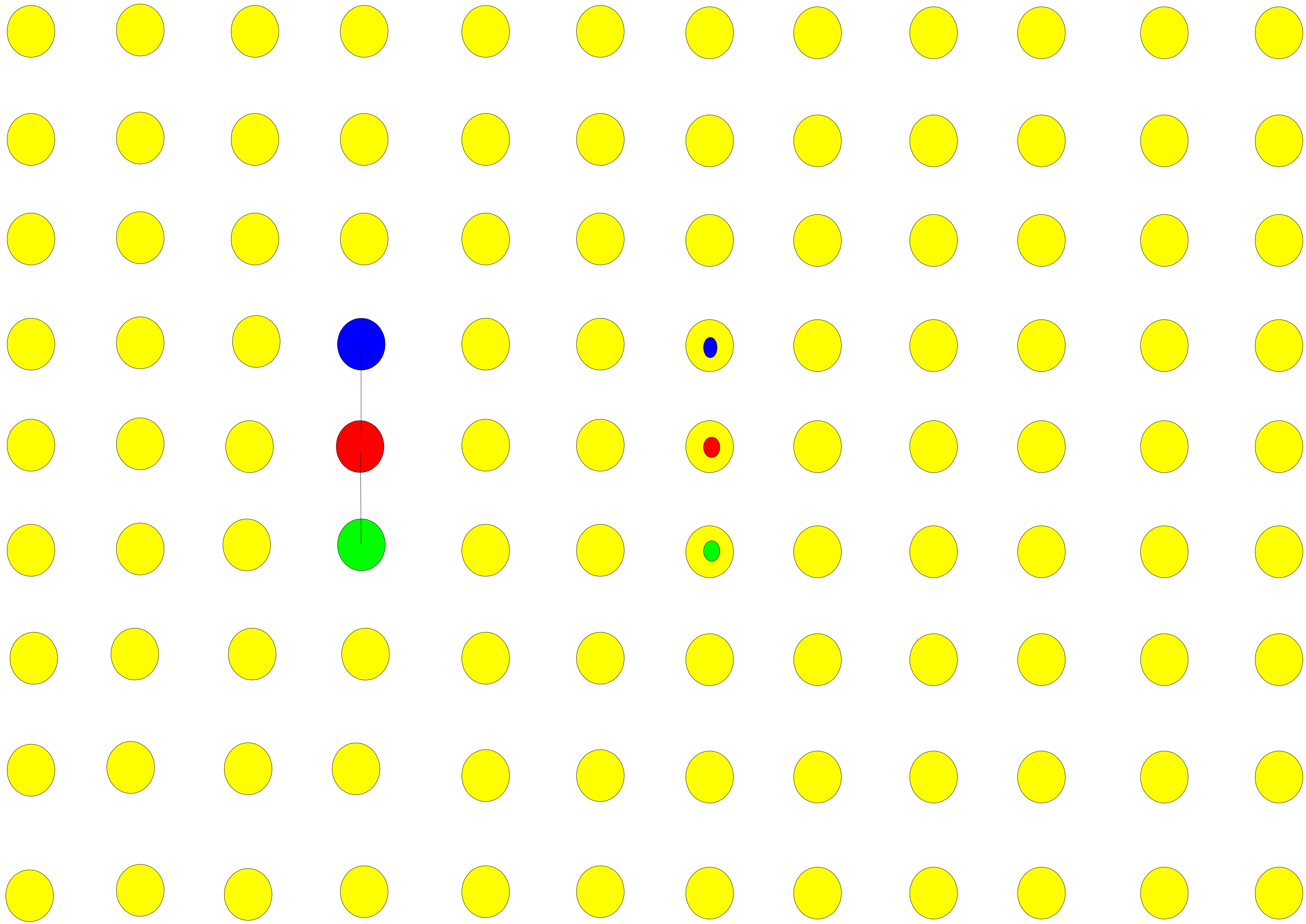

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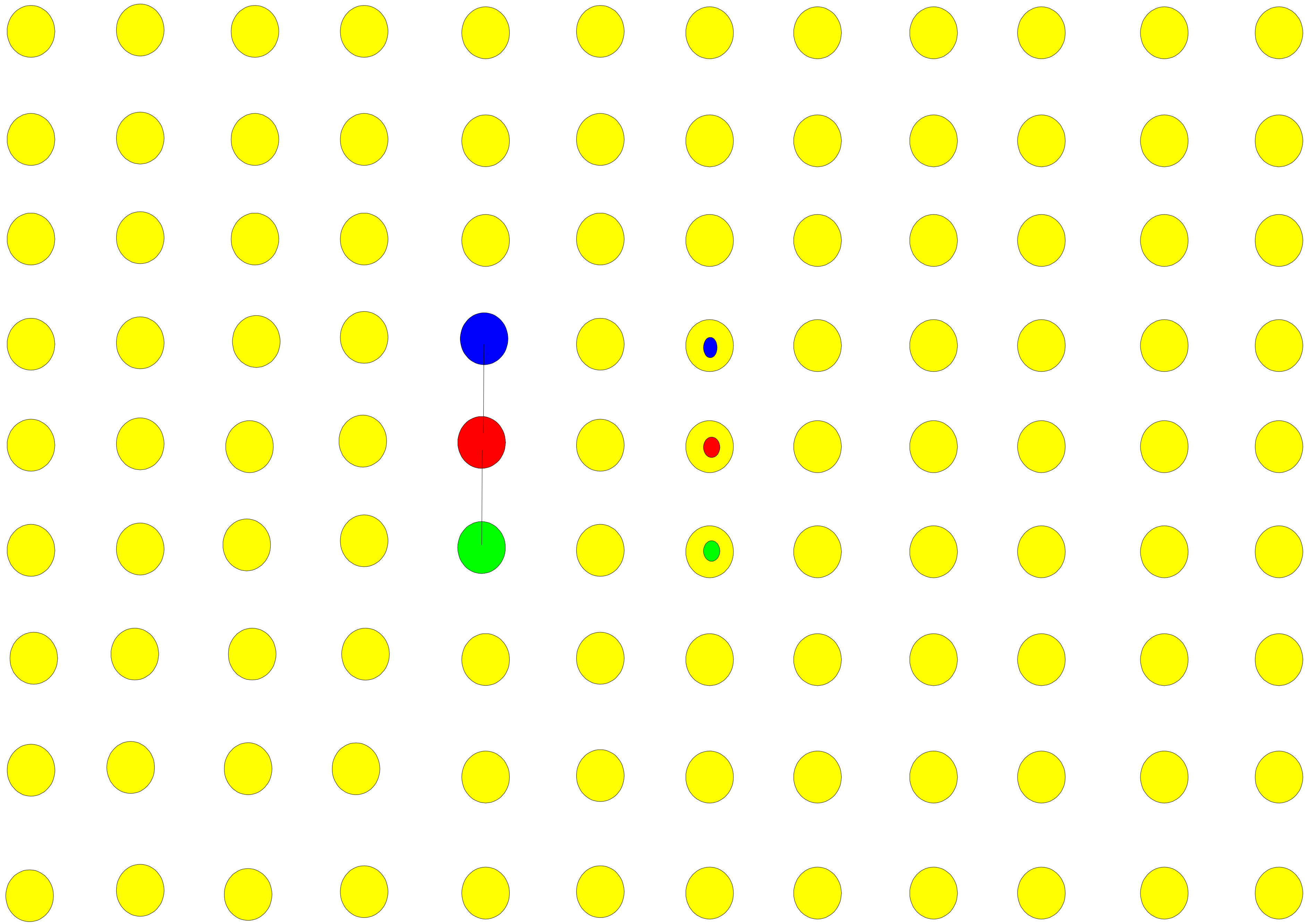
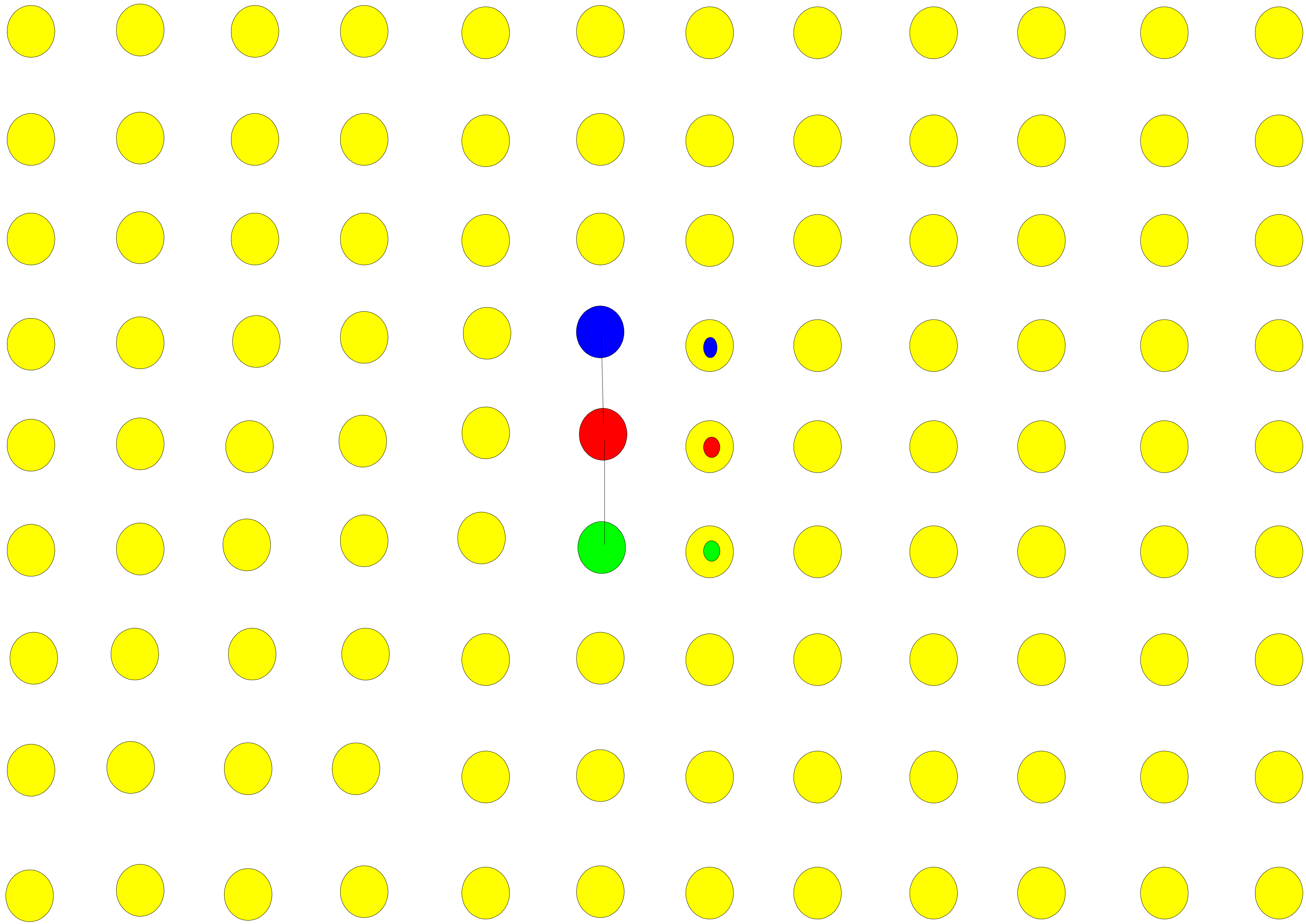
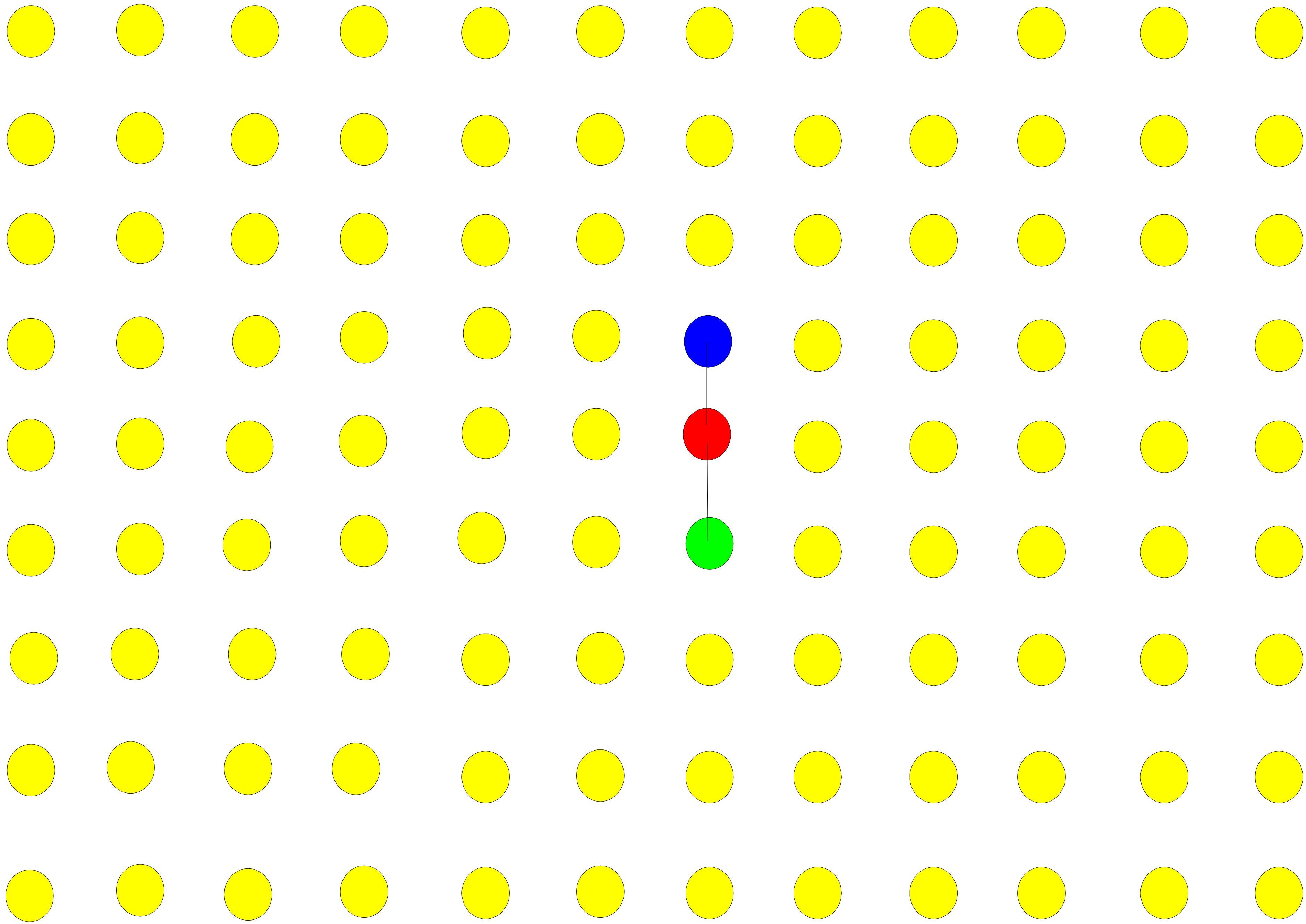




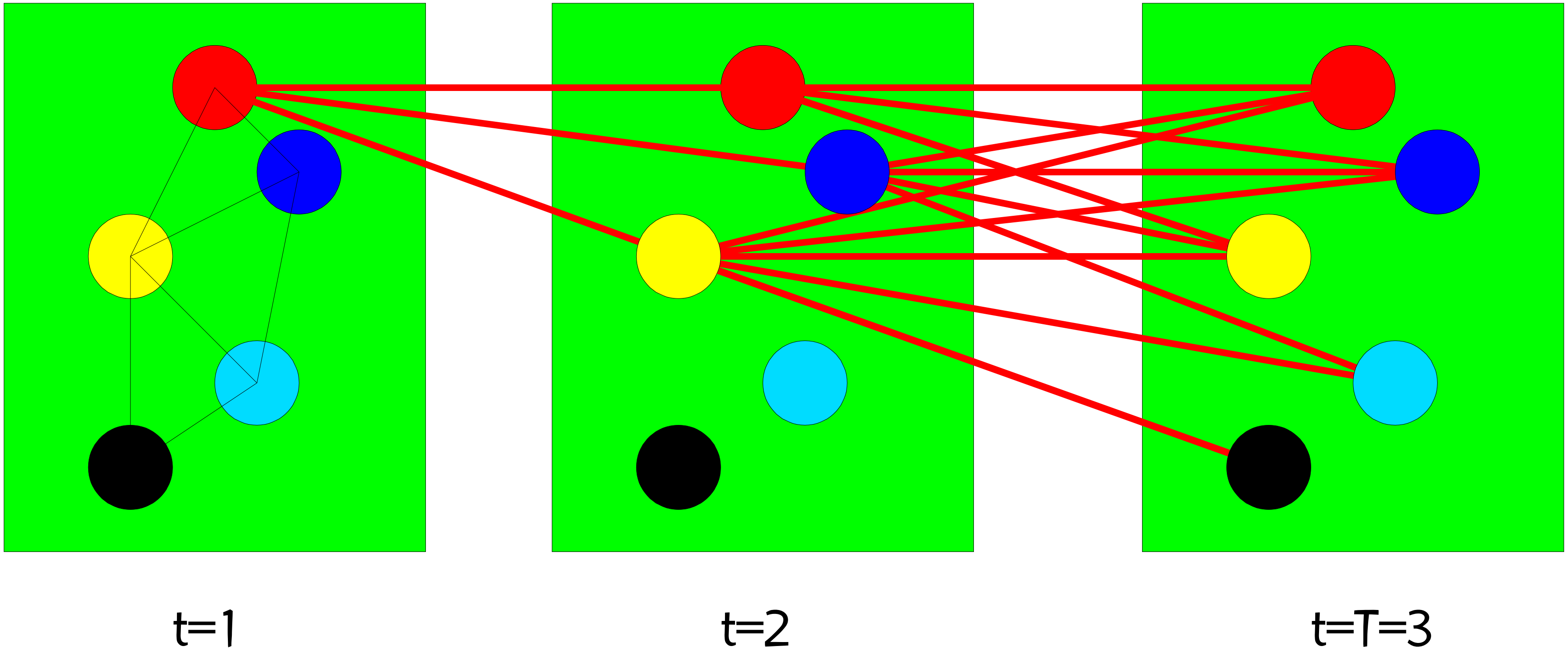


GRASP for CCPM

- Initialize ConnectivityBestSolution $\leftarrow -\infty$;
- Repeat MaxIterations cycles:
  - solution $\leftarrow$ GreedyRandomizedSolution();
  - solution $\leftarrow$ LocalSearch(solution);
  - if (connectivity(solution) $>$ ConnectivityBestSolution) then
    - BestSolution $\leftarrow$ solution;
    - ConnectivityBestSolution $\leftarrow$ connectivity(solution);
- Return BestSolution;

Construction phase

T-layered graph (each layer is a time period)



Construction phase

- Select one agent at random and route it on shortest path from initial position in layer 1 to destination in layer T.
- For other agents, move one agent one time period per iteration. There will be $(T-1)\times(|U|-1)$ iterations.

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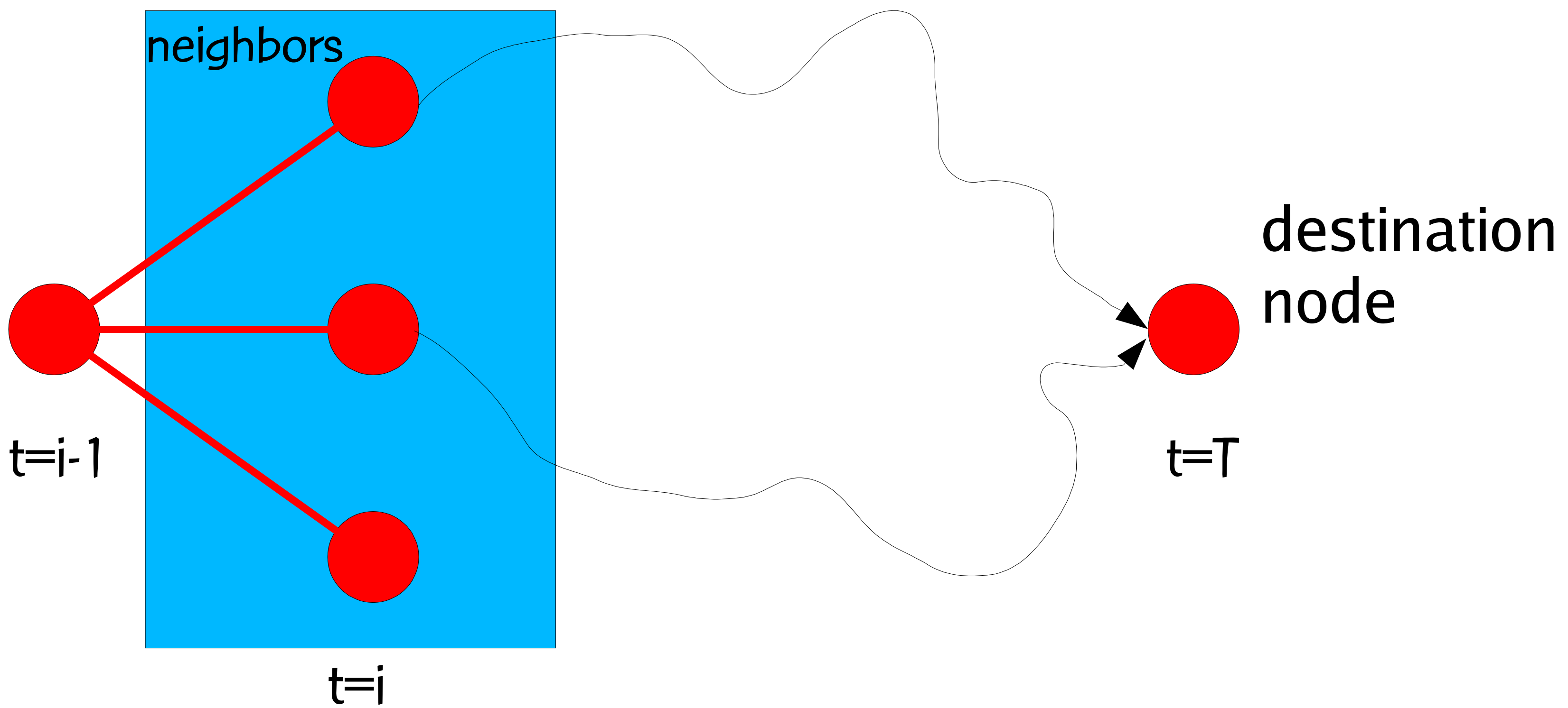

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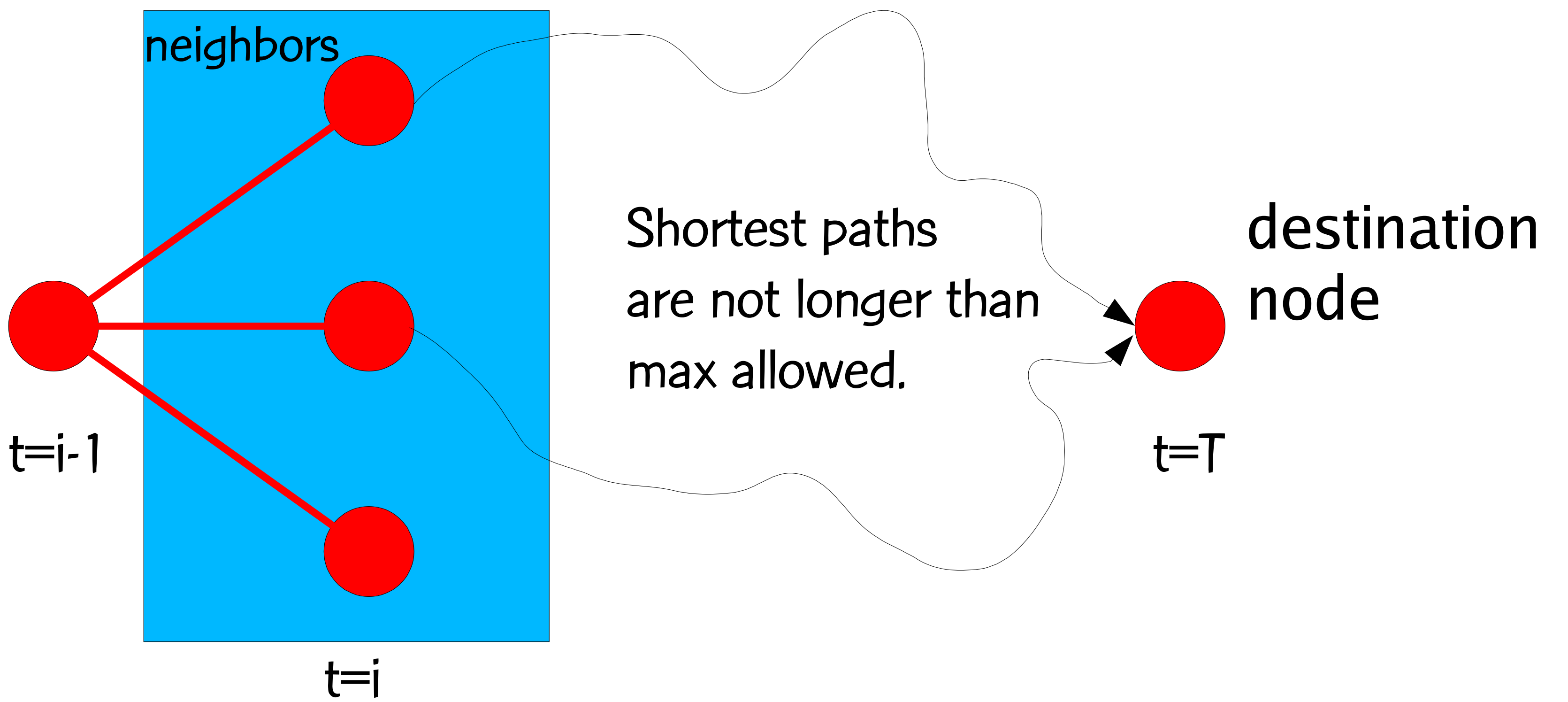

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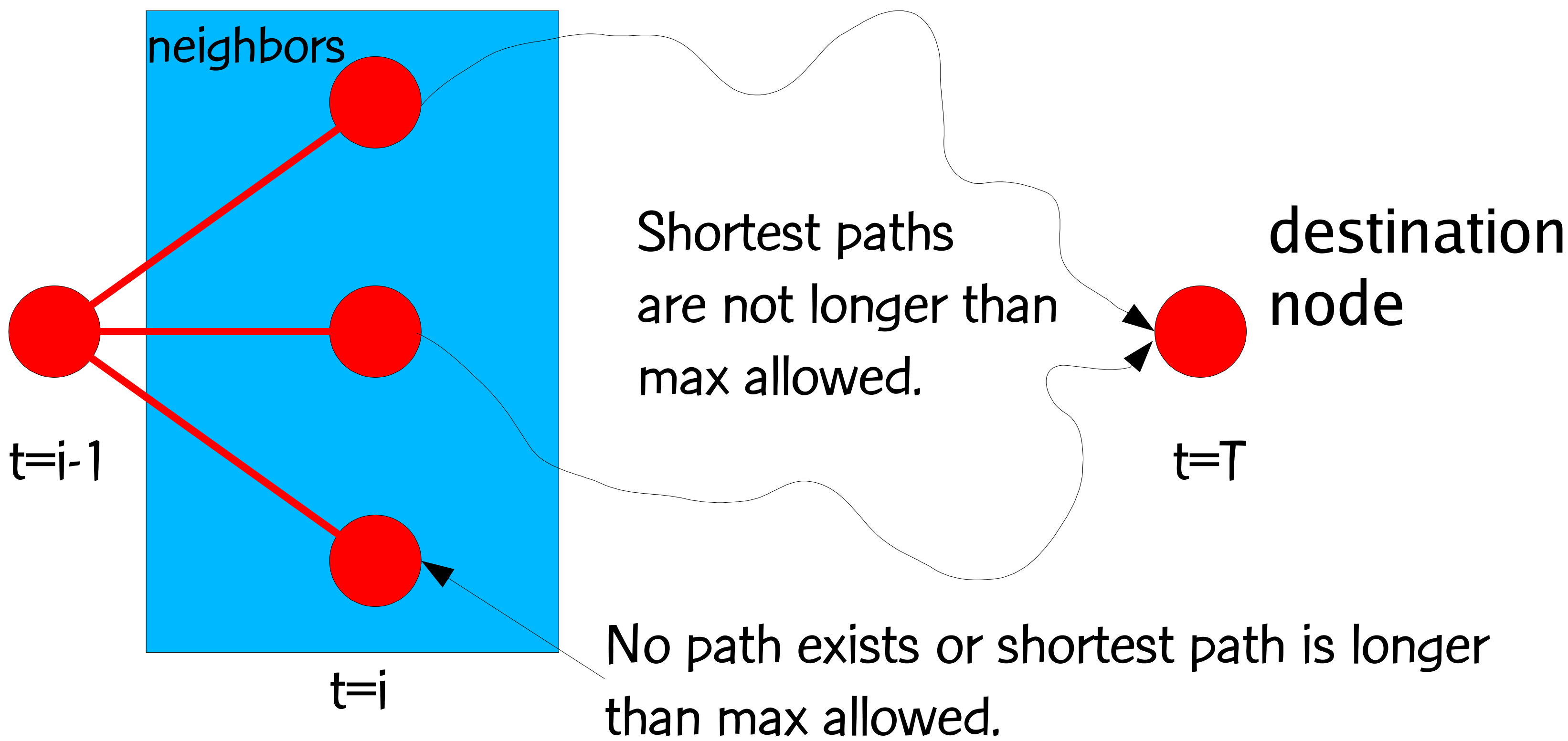

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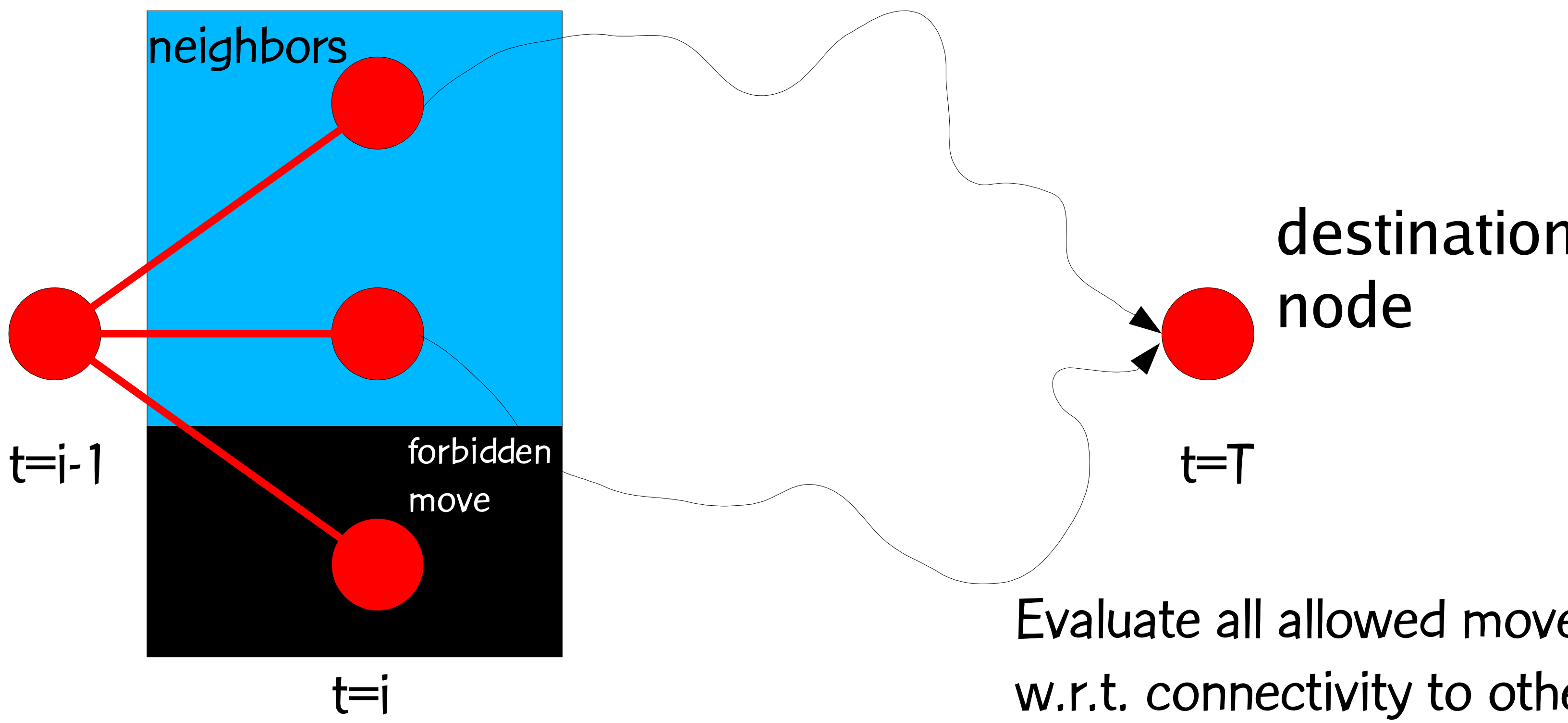


Evaluate all allowed moves w.r.t. connectivity to other agents in partial solution.

Construction phase

1: Compute contribution to connectivity of each allowed move and place best moves in restricted candidate list (RCL).

Select α at random from interval [0,1]

$$RCL = \{ \text{ move } \mid \text{ contrib(move)} \geq \text{maxcontrib} - \alpha \text{ (maxcontrib } - \text{ mincontrib)} \}$$

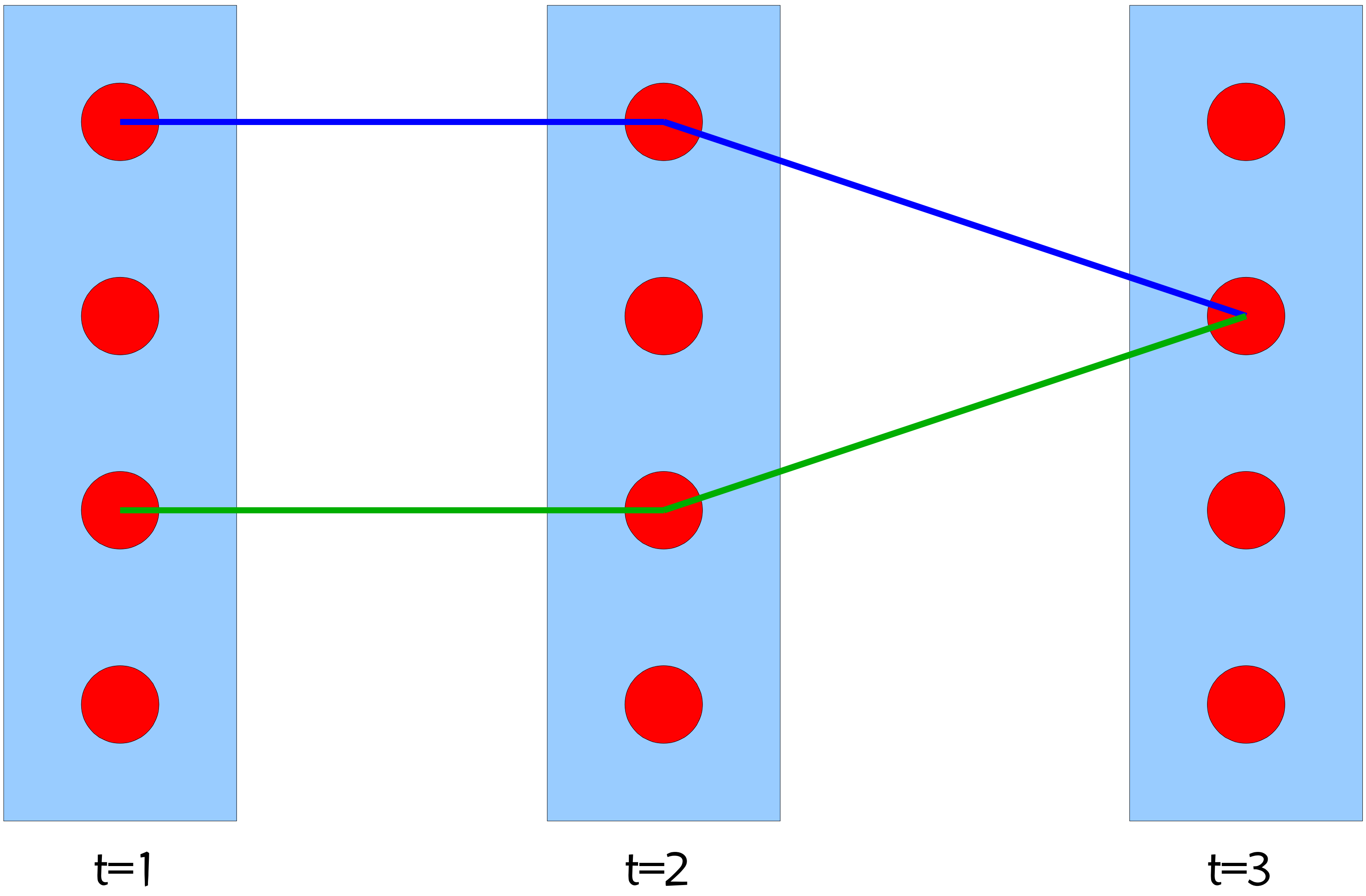
2: Select move at random from RCL and add move to partial solution.

Repeat (1–2) until all agents reach their destinations.

Local search

- A solution is said to be locally optimal if no agent can be rerouted greedily to improve connectivity of the solution.
- Solution $\leftarrow$ GreedyRandomizedSolution;
- While (there exists an agent that can be rerouted to improve Solution) do
  - Greedily reroute agent
  - Solution $\leftarrow$ updated Solution with rerouted agent

Local search



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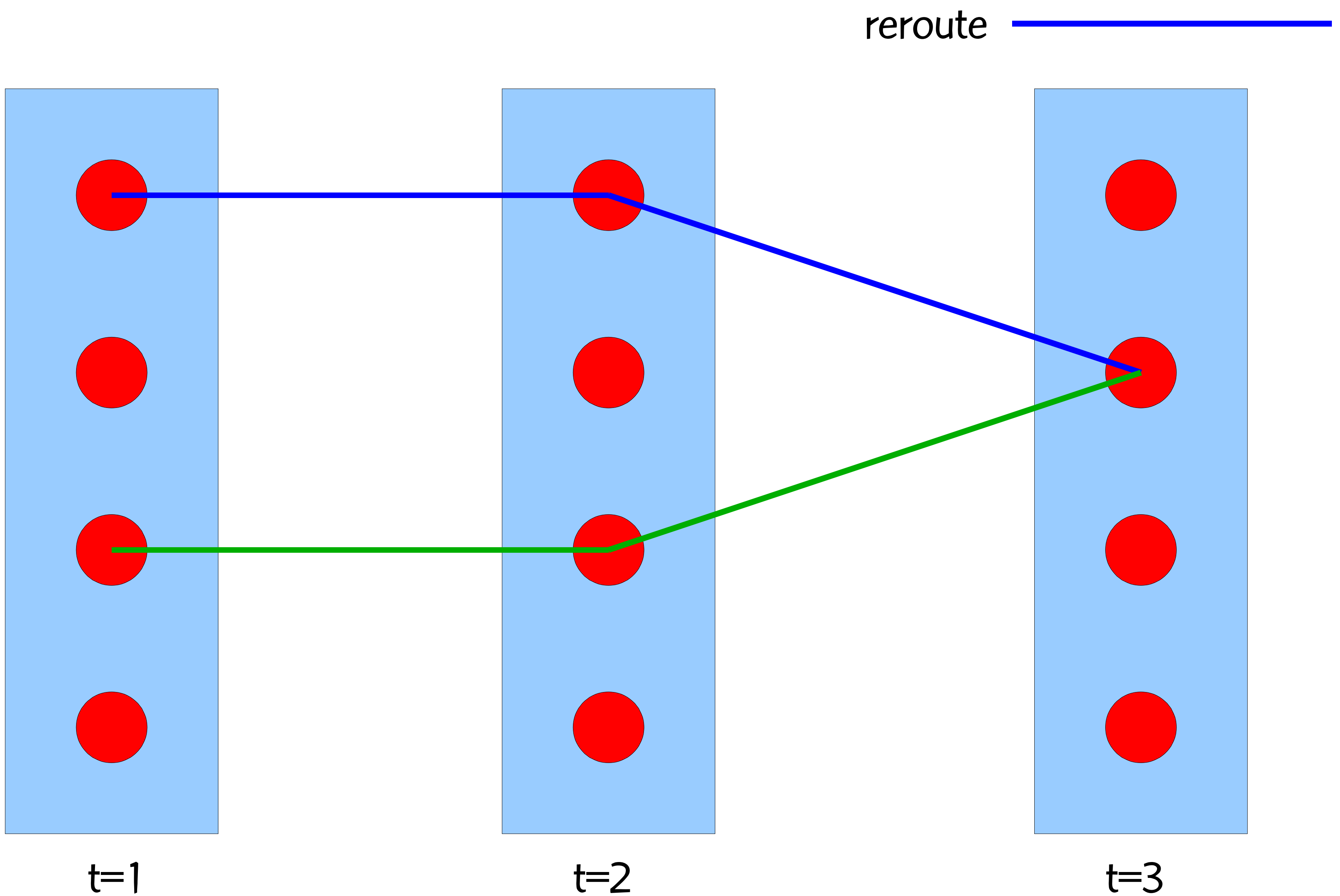
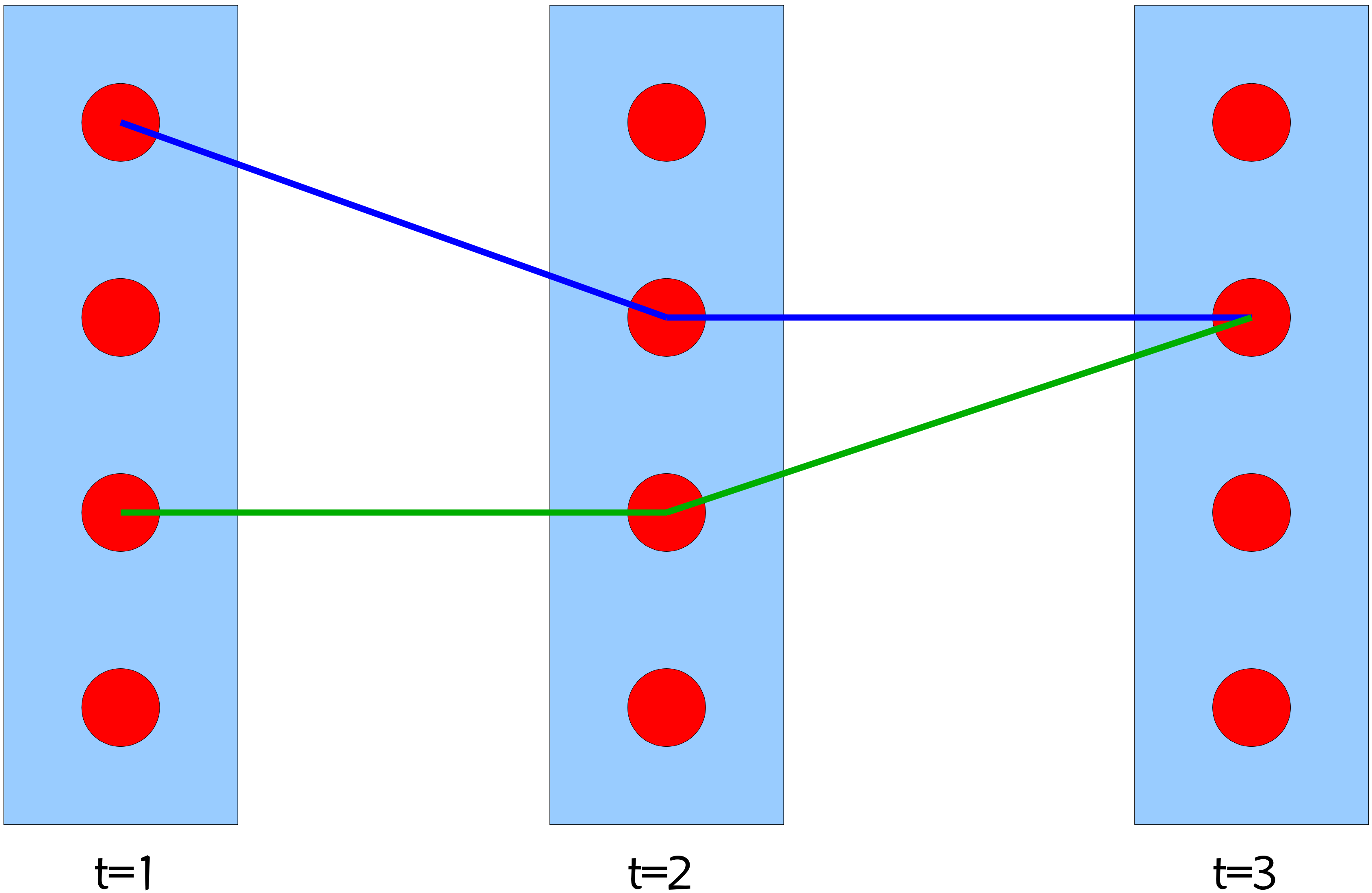


Local search

Rerouting improved connectivity.



Computational results

- 10 instances created with generator for minimum connected dominating set problem (Butenko et al., 2003)
- 20 to 120 nodes
- 5 agents
- Integer programming formulation implemented on Xpress Mosel
- Run for max 2 hours on 2.8 GHz (512 Mb) PC
- 3 of 10 instances not solved by IP solver
- Compared with local search starting from shortest path solutions

Computational results

Instance	nodes	IP solution	time (secs)	LS solution	time (secs)
1	20	517	12	517	1
2	30	721	71	721	4
3	40	769	59	758	5
4	60	811	129	806	12
5	70	876	178	875	16
6	80	974	291	969	19
7	90	992	482	990	23
8	100	1184.7	7200	1153	34
9	110	1523.4	7200	1432	39
10	120	1589.6	7200	1496	46

Computational results

- Instances generated with generator for Broadcast Scheduling Problem (Commander, Butenko, & Pardalos, 2004)
- 50 to 100 nodes
- 10 to 50 agents
- 5 instances per category
- Compare a previous GRASP implementation with shortest path solutions.

Computational results (50 nodes)

radius	agents	GRASP	SP solution	GRASP/SP ratio
20	15	152.0	120.8	1.26
20	25	414.7	353.6	1.17
30	15	182.2	124.4	1.46
30	25	516.2	415.6	1.24
40	15	228.6	171.8	1.33
40	25	695.0	474.8	1.46
50	15	275.8	167.4	1.65
50	25	797.4	485.4	1.64

Computational results (75 nodes)

radius	agents	GRASP	SP solution	GRASP/SP ratio
20	20	270.2	228.6	1.18
20	30	575.2	464.0	1.24
30	20	299.6	241.2	1.24
30	30	725.4	554.0	1.32
40	20	386.0	261.0	1.48
40	30	862.6	595.4	1.45
50	20	403.2	246.8	1.63
50	30	1082.4	670.8	1.61

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Computational results (100 nodes)

radius	agents	GRASP	SP solution	GRASP/SP ratio
20	25	333.4	269.4	1.24
20	50	1523.2	1258.8	1.21
30	25	511.2	365.0	1.40
30	50	1901.4	1515.8	1.25
40	25	600.6	389.8	1.54
40	50	2539.2	1749.4	1.45
50	25	756.8	479.6	1.58
50	50	3271.2	2050.6	1.60

Concluding remarks

- We have introduced a GRASP for the cooperative communication problem in mobile ad hoc networks.
- Computational experiments with simple local search and a simple GRASP implementation show promising results.
- We will now implement and test the GRASP described in this talk together with the path-relinking described in the GRASP with PR for private virtual circuit routing of Resende and Ribeiro (2003).

My coauthors

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