Mobile Agents Rendezvous in Mesh-Networks in spite of a Malicious Agent

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Rendezvous in a Hostile Network Environment

- Mobile agents need to gather at a node of a network.
- A malicious mobile agent tries to block the honest agents and to prevent them from gathering.

The malicious agent:

- is arbitrarily fast and has full knowledge of the network,
- cannot be exterminated by the honest agents.

The honest agents:

- are identical, asynchronous and anonymous and have only finite memory,
- have no prior knowledge of the network,
- can communicate only when they meet at a node.

Our Results [ALGOSENSORS 2015]

- Necessary conditions for solving rendezvous, in spite of the malicious agent, in arbitrary networks.
- Rendezvous is impossible for an even number of agents in unoriented rings.
- Distributed algorithms for all remaining cases in rings (i.e., for an odd number of agents in unoriented rings and for any number of agents in oriented rings).
- For oriented mesh networks, the problem can be solved when the honest agents initially form a connected configuration without holes if and only if they can detect the occupied nodes within a two-hops distance.

Related Work I

- Mobile Agent Rendezvous in Networks: S. Alpern and S. Gal. Searching for an agent who may or may not want to be found. Operations Research, 2002.
- Mobile Agent Rendezvous on the plane: R. Cohen and D. Peleg. Convergence of autonomous mobile robots with inaccurate sensors and movements. SIAM J. on Computing, 2008.
- Rendezvous of agents with unique identifiers: J. Czyzowicz, A. Labourel, and A. Pelc. How to meet asynchronously (almost) everywhere. SODA, 2010.
- Rendezvous of anonymous agents using tokens: J. Chalopin and S. Das. Rendezvous of mobile agents without agreement on local orientation. ICALP, 2010.

Related Work II

- Black-Holes: S. Dobrev, P. Flocchini, G. Prencipe, and N. Santoro. Mobile search for a black hole in an anonymous ring. Algorithmica, 2007.
- Rendezvous in spite of a black hole: S. Dobrev, P. Flocchini, G. Prencipe, and N. Santoro. Multiple agents rendezvous in a ring in spite of a black hole. OPODIS, 2003.
- Byzantine Agents: Y. Dieudonne, A. Pelc, and D. Peleg. Gathering despite mischief. ACM Transactions on Algorithms, 2014.
- Agents can be blocked for an arbitrary but finite time: J. Chalopin, Y. Dieudonne, A. Labourel, and A. Pelc. Fault-tolerant rendezvous in networks. ICALP 2014.

Related Work III

- Gray Holes: E. Bampas, N. Leonardos, E. Markou, A. Pagourtzis, and M. Petrolia. Improved periodic data retrieval in asynchronous rings with a faulty host. SIROCCO, 2014.
- Cops and Robbers: L. Barriere, P. Flocchini, F. V. Fomin, P. Fraigniaud, N. Nisse, N. Santoro, and D. Thilikos. Connected graph searching. Information and Computation, 2012.
- Rendezvous of faulty agents on the plane: N. Agmon and D. Peleg. Fault-tolerant gathering algorithms for autonomous mobile robots. SIAM J. on Computing, 2006.

Model Specifics I

Network

- Unoriented and oriented ring, oriented mesh.
- Asynchronous bidirectional FIFO links (i.e., an agent cannot overtake another agent moving in the same edge).
- The links incident to a host are distinctly labelled but this port labelling (unless explicitly mentioned), is not globally consistent.
- Agents at the same host are served by a mutual exclusion mechanism (i.e., an agent at a node u must finish its computation and move or decide to stay, before any other agent at u starts its computation or another agent visits u).

Model Specifics II

Honest Agents

- Identical DFAs with local communication capability.
- No prior knowledge of the network (apart from the topology) or of the number of the agents.
- Initially located at distinct nodes (selected by an adversary).
- Cannot leave or exchange messages.
- An agent arriving at a node u, learns the label of the incoming port, the degree of u and the labels of the outgoing ports.
- A honest agent located at a node u can see all other agents at u (if any), and can also read their states.
- Two agents travelling on the same edge in different directions do not notice each other, and cannot meet on the edge.

Model Specifics III

Malicious Agent

- Has a complete map of the network.
- Can move arbitrarily fast and it can permanently ‘see’ the positions of all the other agents.
- It has unlimited memory and knows the transition function of the honest agents.
- Prevents any honest agent from visiting the node it occupies.
- Cannot visit a node occupied by a honest agent, nor cross some honest agent in a link.
- It also obeys the FIFO property of the links (i.e., it cannot overpass a honest agent which is moving on a link).

Terminology

- Let n be the number of nodes of the network and k be the number of honest agents.
- We denote with M the malicious agent.
- If the malicious agent M resides at a node u and a honest agent A attempts to visit u it receives a signal that M is in u and in that case we say that A *bumps* into M.
- We call a node u *occupied* when one or more *honest* agents are in u, otherwise we call u *free* or *unoccupied*.

Basic Properties in Arbitrary Networks I

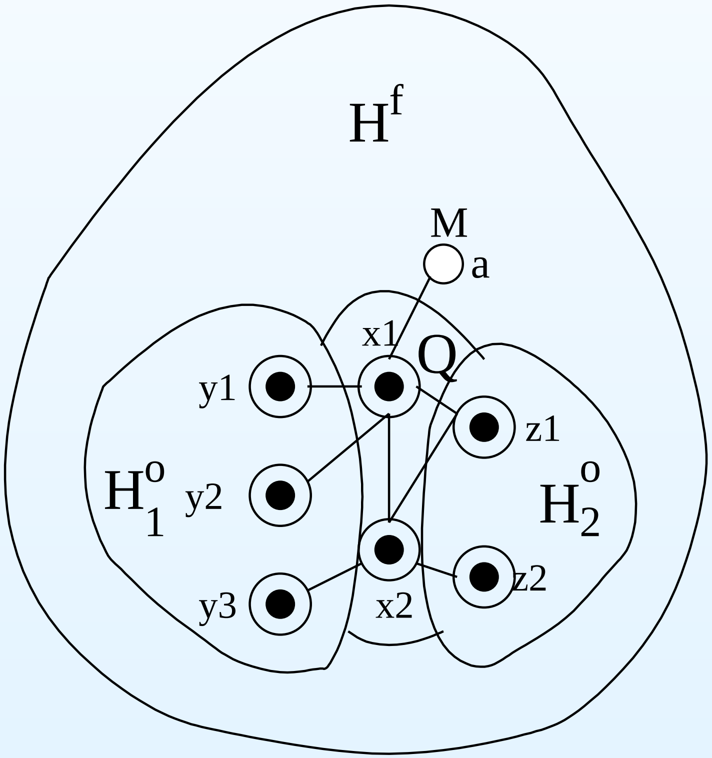
Def. Let C be a configuration of a number of agents in a graph G with a malicious agent. The configuration C is called **separable** if there is a connected vertex cut-set F composed of free nodes which, when removed, disconnects G so that not all occupied nodes are in the same connected component.

Lemma. Rendezvous is impossible for any initial configuration in a graph G which is separable, even if the agents have unlimited memory, distinct identities and can always see their current configuration.

Basic Properties in Arbitrary Networks II

There are even non-separable initial configurations for which the problem is unsolvable.

A connected initial configuration.



Basic Properties in Arbitrary Networks II

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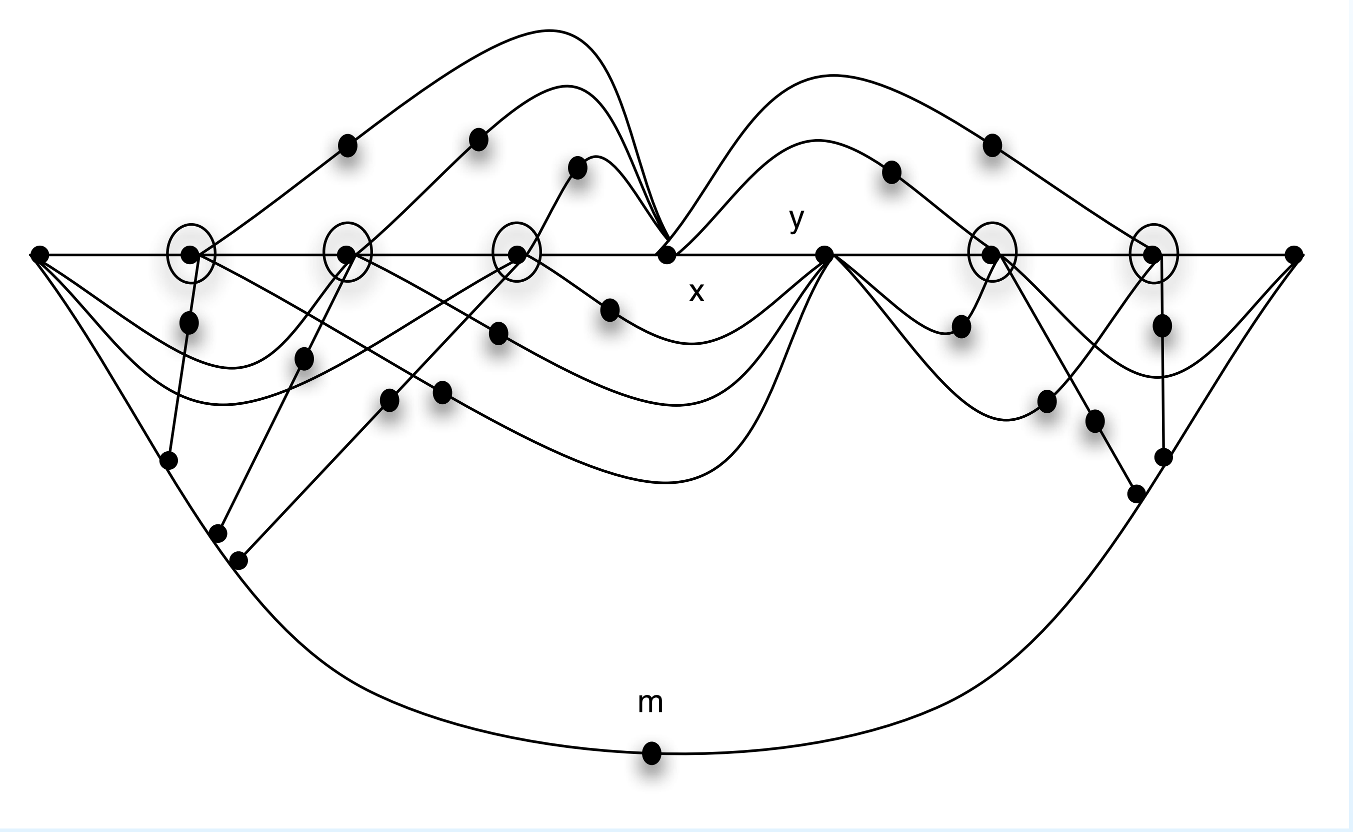


Basic Properties in Arbitrary Networks III

Def. If C_t is a separable configuration, and in C_t there is a free node x so that either: i) x has been always free or, ii) there are paths of nodes which eventually become free and they form a connection between a free node at C_0 and x, then the configuration C_t is called **separating**.

Lemma. Rendezvous is impossible for any *separating* configuration in a graph G, even if the agents have unlimited memory, distinct identities and can always see their current configuration.

Rendezvous in an Oriented Ring

- Rendezvous is impossible even if the agents have unlimited memory and have full knowledge of the configuration.
- A natural step is to assume that there is a special node labeled o^* in the ring which can be recognized by the agents.

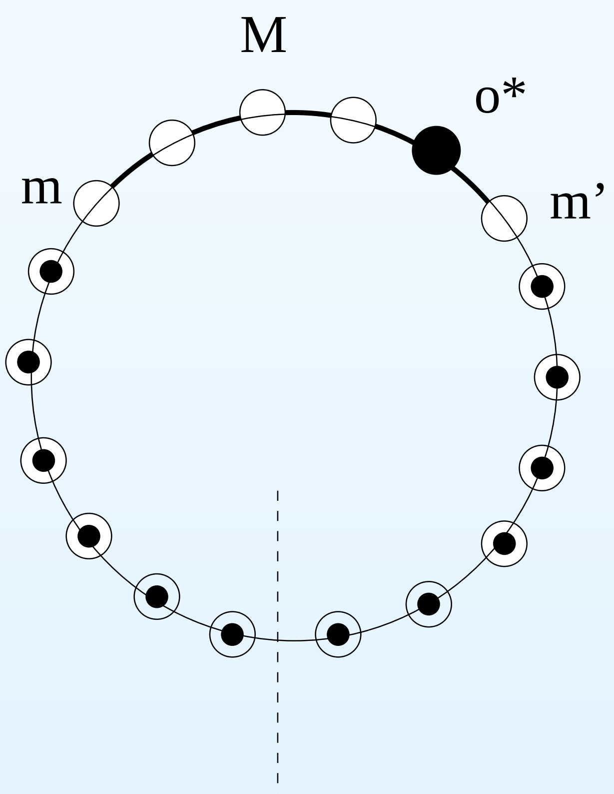
Rendezvous in an Oriented Ring

The idea of the algorithm is the following.

- Each agent moves in the clockwise direction until it meets o^* or bumps into M.
- First and second meeting (or bumping):
  - o^*? stop;
  - M? reverse direction and continue moving.
- Third meeting (or bumping):
  o^* or M? reverse direction and continue moving.
- Forth meeting (or bumping):
  o^* or M? stop.

Rendezvous in an Unoriented Ring

Lemma. For any even number $k \geq 2$, the rendezvous problem for k honest agents and one malicious agent cannot be solved in any bidirectional unoriented anonymous ring with a special node o^*, even if the agents know k.

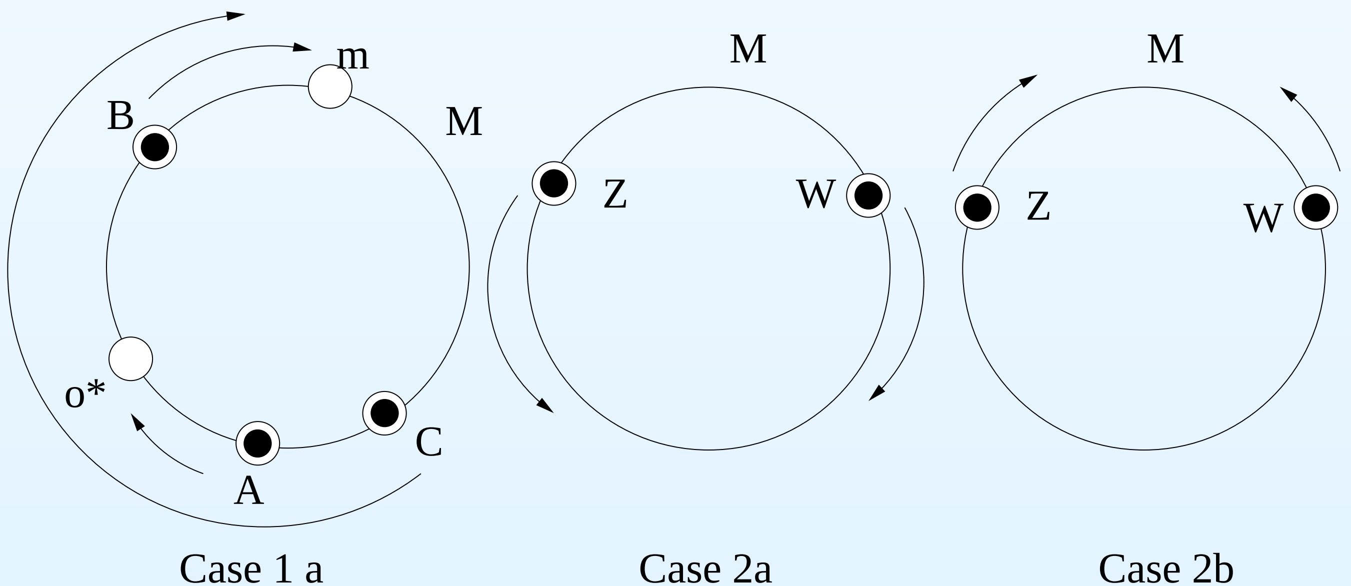


Rendezvous in an Unoriented Ring

An algorithm for an odd number of agents

(Idea of the algorithm)

- The agents form exactly two distinct groups that gather at two distinct nodes.
- One of the agents of the group with an even number of agents moves to collect all the other agents.

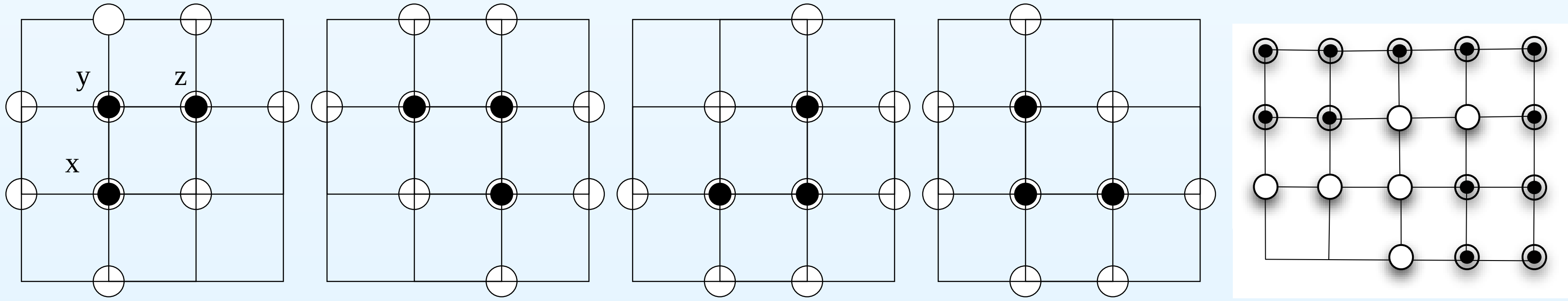


Rendezvous in an Oriented Mesh: Infeasibility

We study initially connected without holes configurations.

- The agents need to be able to gain some knowledge about their current configuration before they move.
- We enhance our model by giving the agents, the capability to discover all occupied nodes within a distance of d-hops.

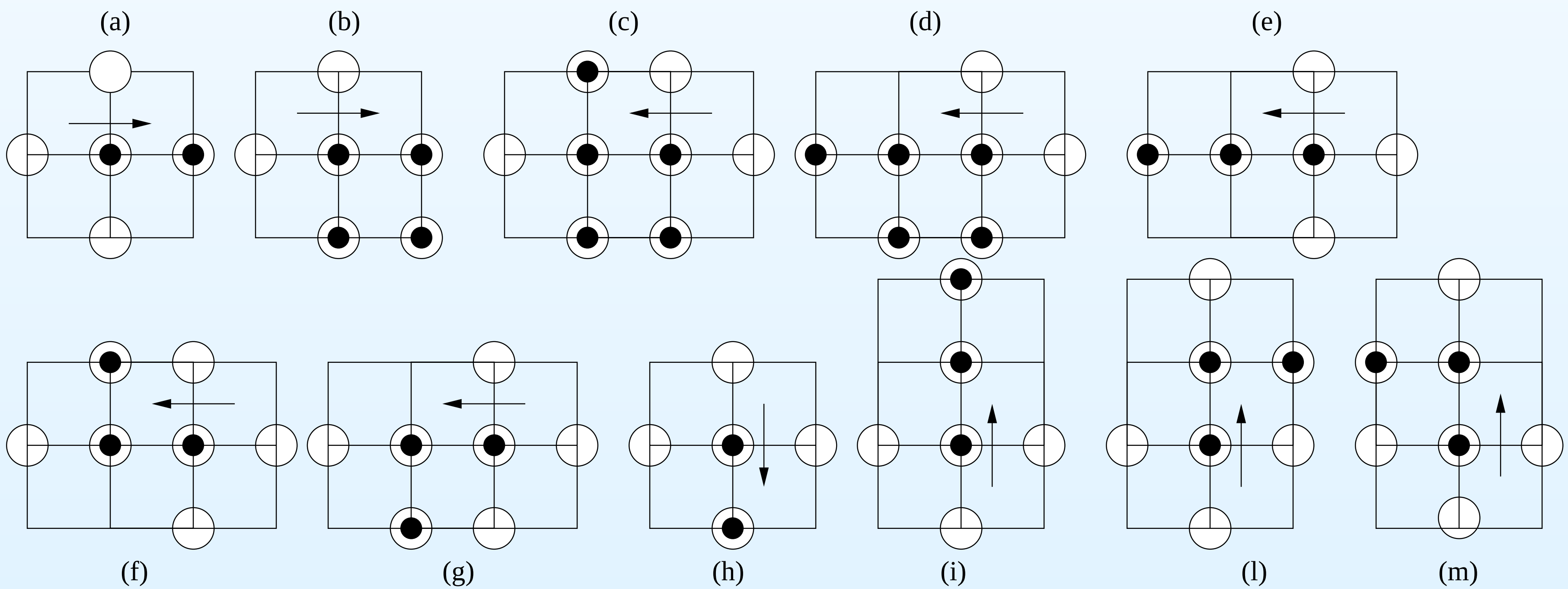
Lemma. The rendezvous problem is unsolvable even when the agents are capable of scanning their adjacent nodes.



Rendezvous in an Oriented Mesh: An algorithm

We further equip the agents with the capability of discovering the occupied nodes within a two-hops distance.

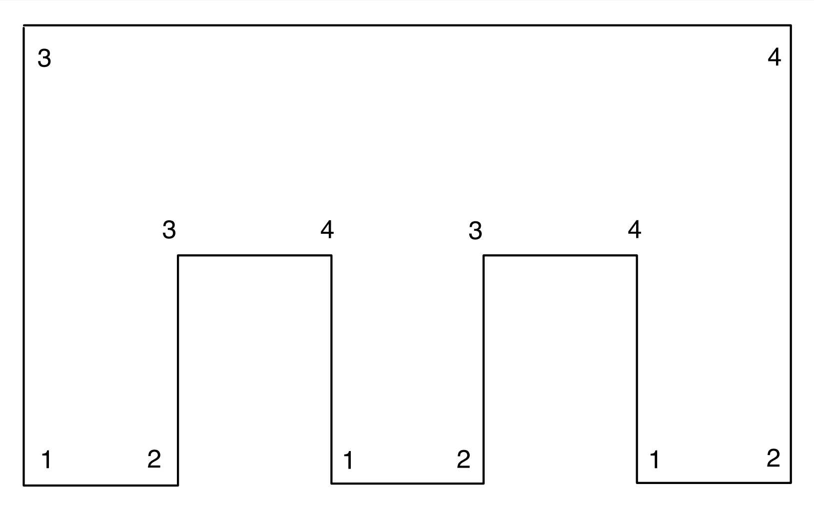
Algorithm: If an agent has a view (within two hops) like the one of the agent under or left of the arrow in the figures below, then this agent moves towards the direction shown by the corresponding arrow; otherwise the agent does not move.



Oriented=mesh configurations with holes

If the initial non separable configuration is different from the one considered before, then even the 2-visibility capability is not sufficient anymore to solve rendezvous.

For example, as the figure below demonstrates, the problem remains unsolvable for connected configurations with holes even when the agents are able to discover the occupied nodes within any constant distance.



Conclusion and Open Problems

We have presented algorithms for ring and oriented mesh networks which gather the honest agents within $O(kn)$ and $O(k^2)$ edge traversals respectively.

- Randomized protocols for some of the unsolvable cases.
- Study this problem in synchronous networks with unit-speed cooperating agents and unit-speed/infinite-speed malicious agents.
- $(m+1)$-connected graphs in the presence of m malicious agents.
- Study this problem with malicious agents that demonstrate a more severe behaviour.

Thank you!!