Topology-Based Mobility Models
for
Wireless Networks

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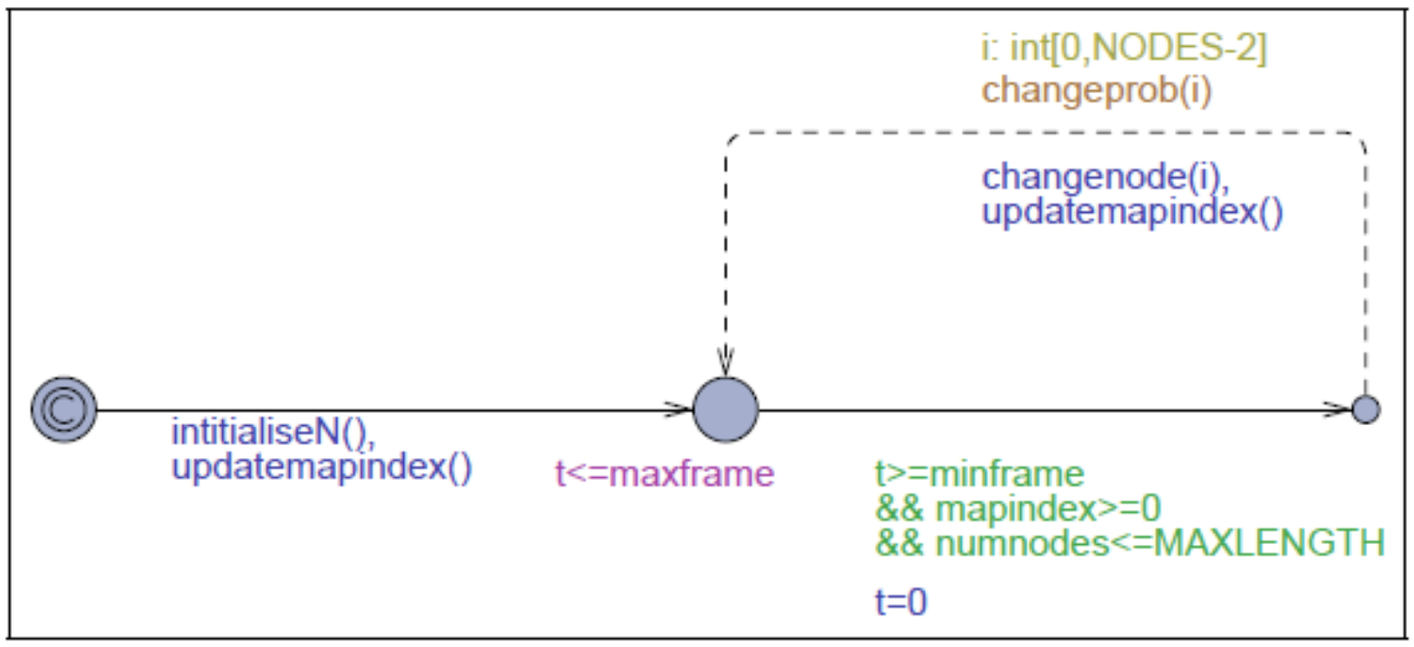
Mobility

- Protocols (Communication, Mesh, MANET, SDN,...) are designed to deal with dynamic topologies (mobile nodes)
- Protocols have to deal with nodes that join, disappear, or change neighbours
- Mobility is often source of problems (bugs, inefficiency,...)
- Analysis on formal models often
  - consider static topologies only, or
  - very few (arbitrary) topology changes, or
  - ignore topology (non-deterministic choices)

Aim

- Creation of mobility models
  - to be used for Model Checking
  - independent of the protocol (re-use)
  - simple (not adding too much complexity)



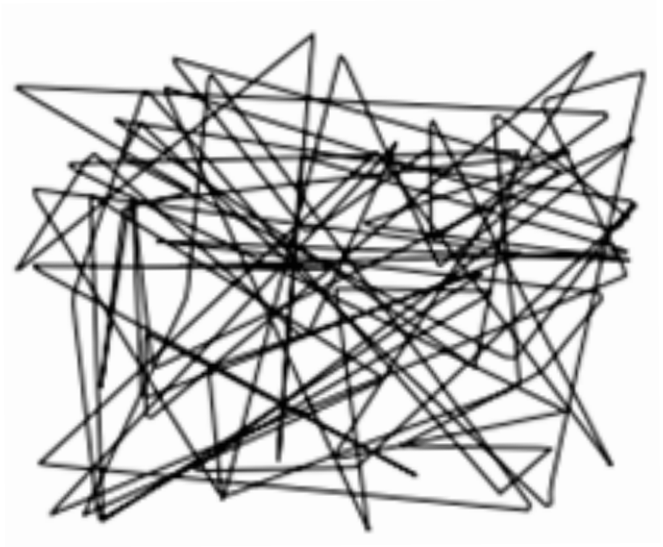
Mobility Models

- Realistic Mobility Models
  - replay traces obtained from real world

- Synthetic Models (non-realistic)
  - generate traces from mathematical model of motion
  - usually based on a physical model of a moving node
  - more than a dozen different models
    - random waypoint models
    - random walk models
    - Manhattan models
    - gravity mobility models
    - ...

Mobility Models

- Random Waypoint Model (RWP)
  1. select the next waypoint uniformly from abounded
  2. choose a speed with certain probability
  - choose a waiting time with a certain probability
  - may include additional probabilistic choices



Mobility Models

- Random Walk Models (RW)
  1. select a direction uniformly
  2. choose a speed, and distance with certain probability
  3. plus some rules what to do if the a boundary is hit
  - choose a waiting time with a certain probability
  - may include additional probabilistic choices.

Topology-Based Mobility

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- Idea
  - model mobility as changes of connectivity matrix
    - point of view of nodes
  - simplicity/compatibility
    - no speed, no time
      - compatible to all protocol models
  - transitions will be probabilistic

Topology-Based Mobility (Example)

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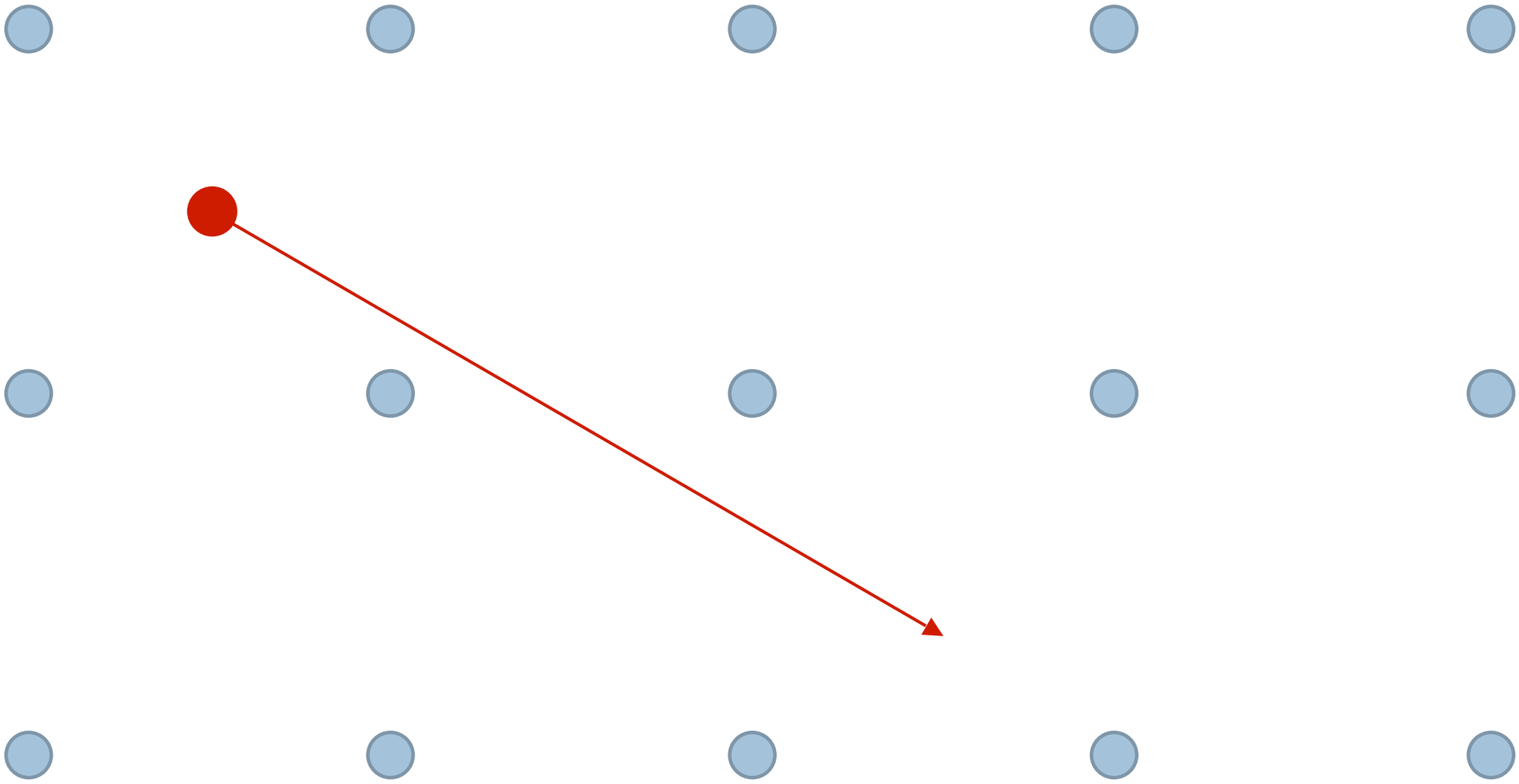
- Moving node along a grid



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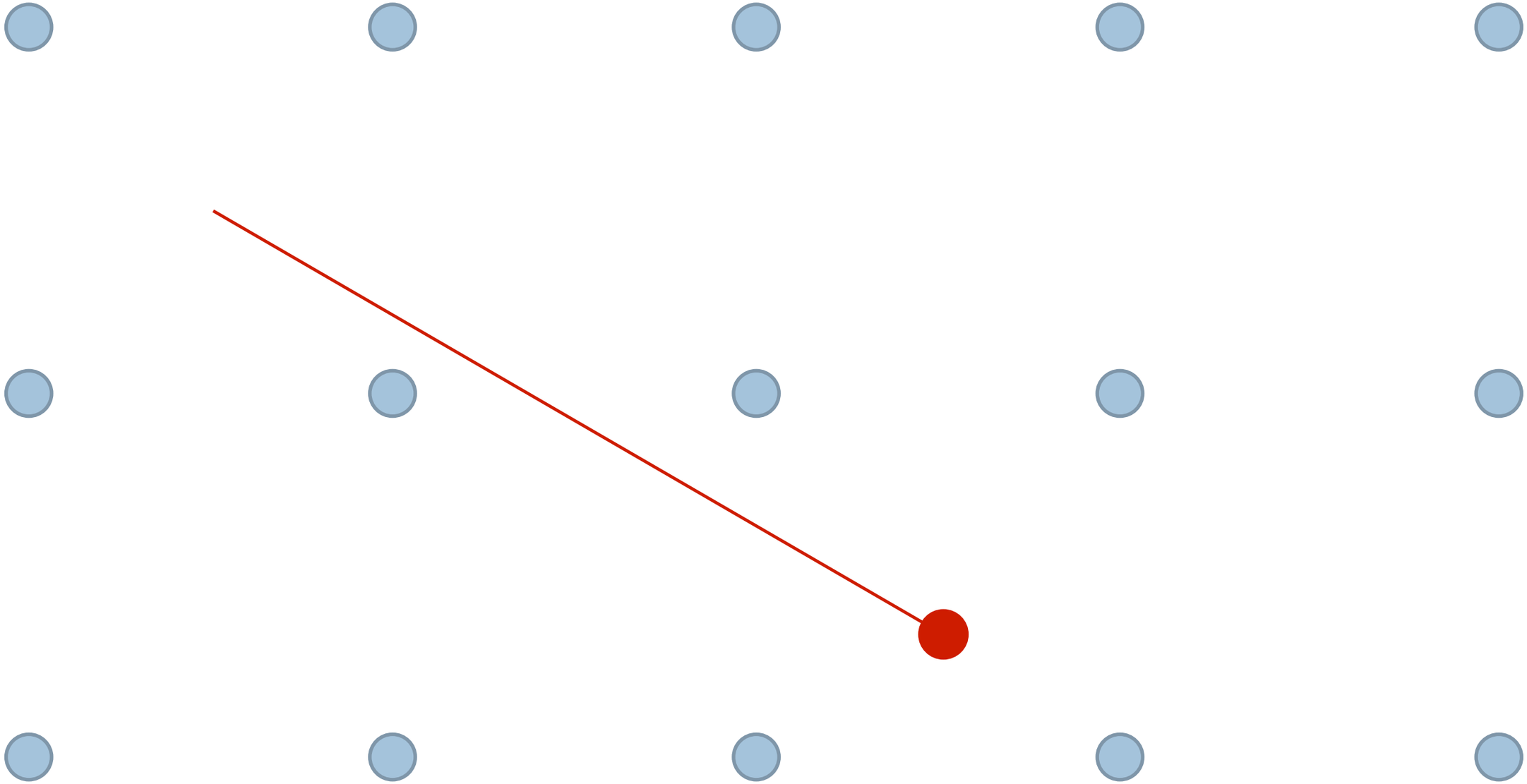

Topology-Based Mobility (Example)

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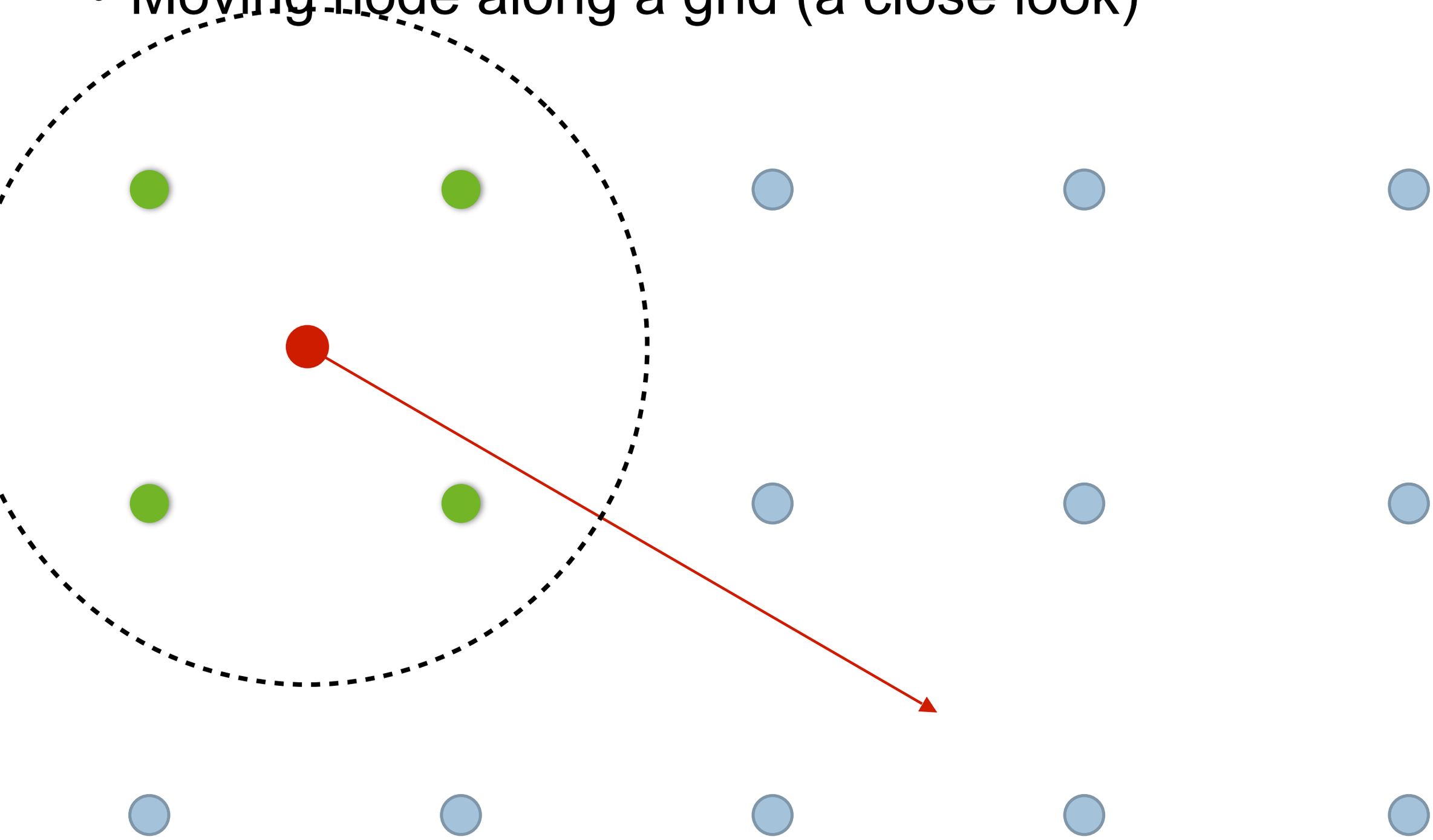
- Moving node along a grid (a close look)



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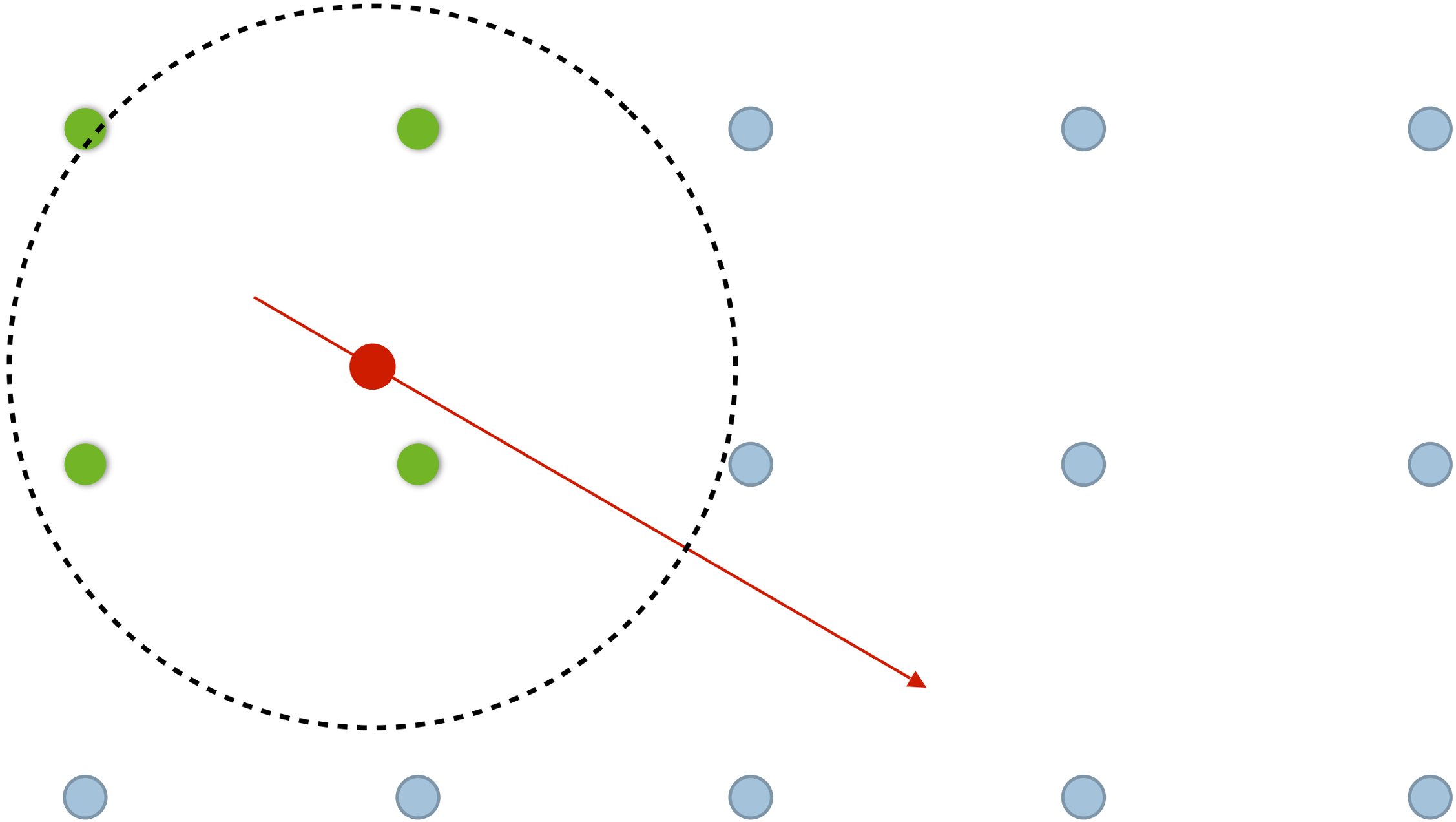

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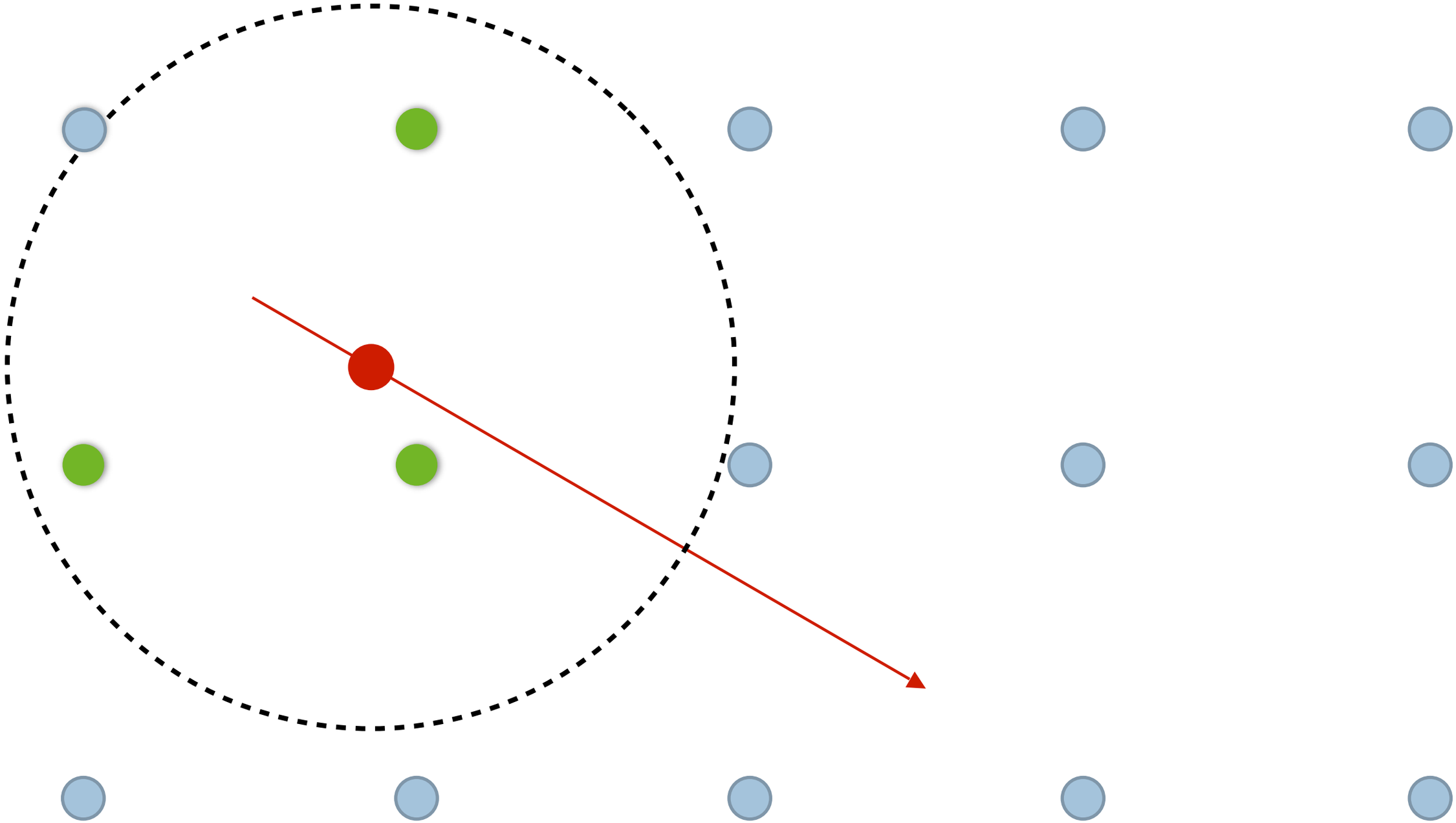

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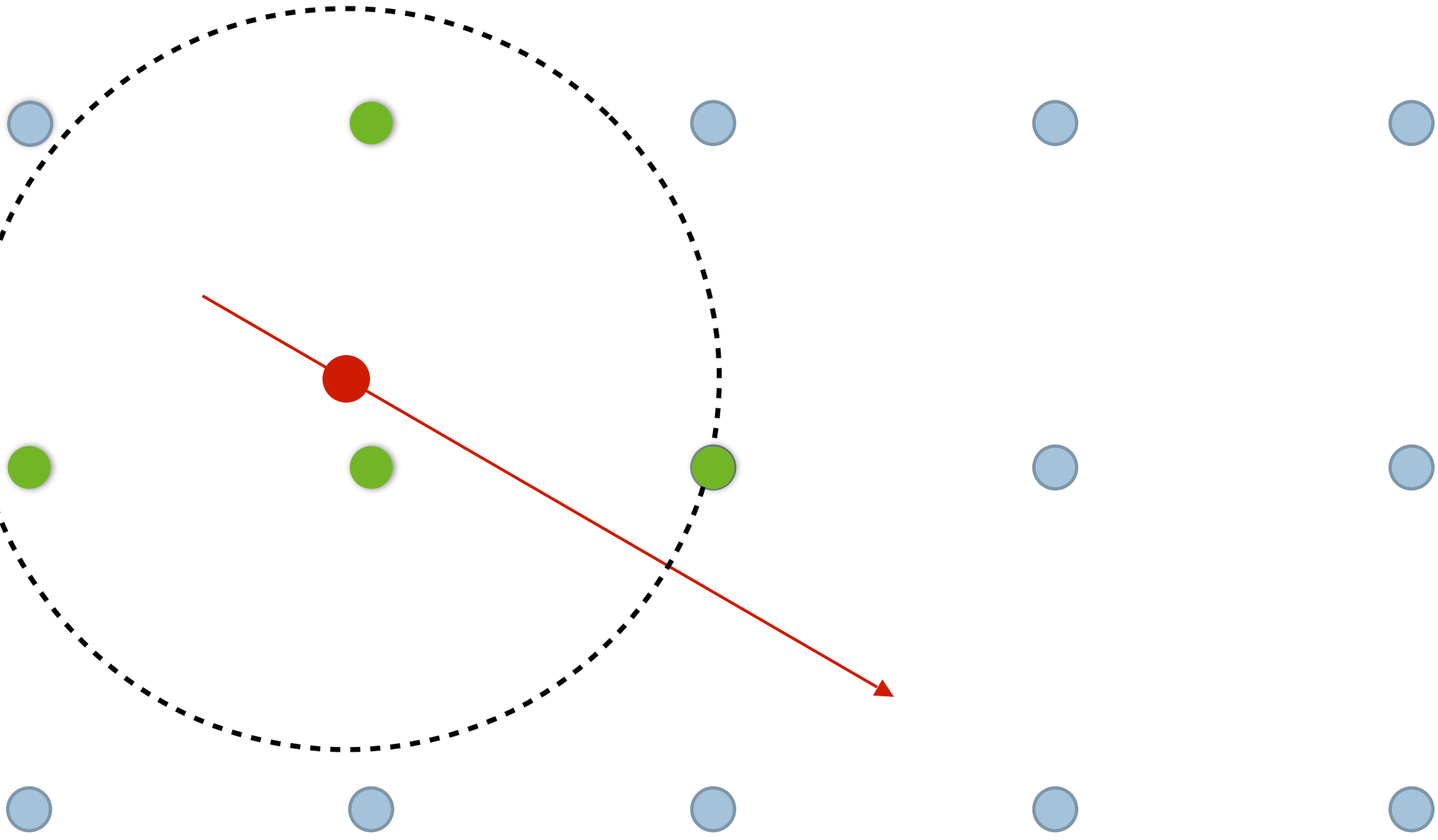

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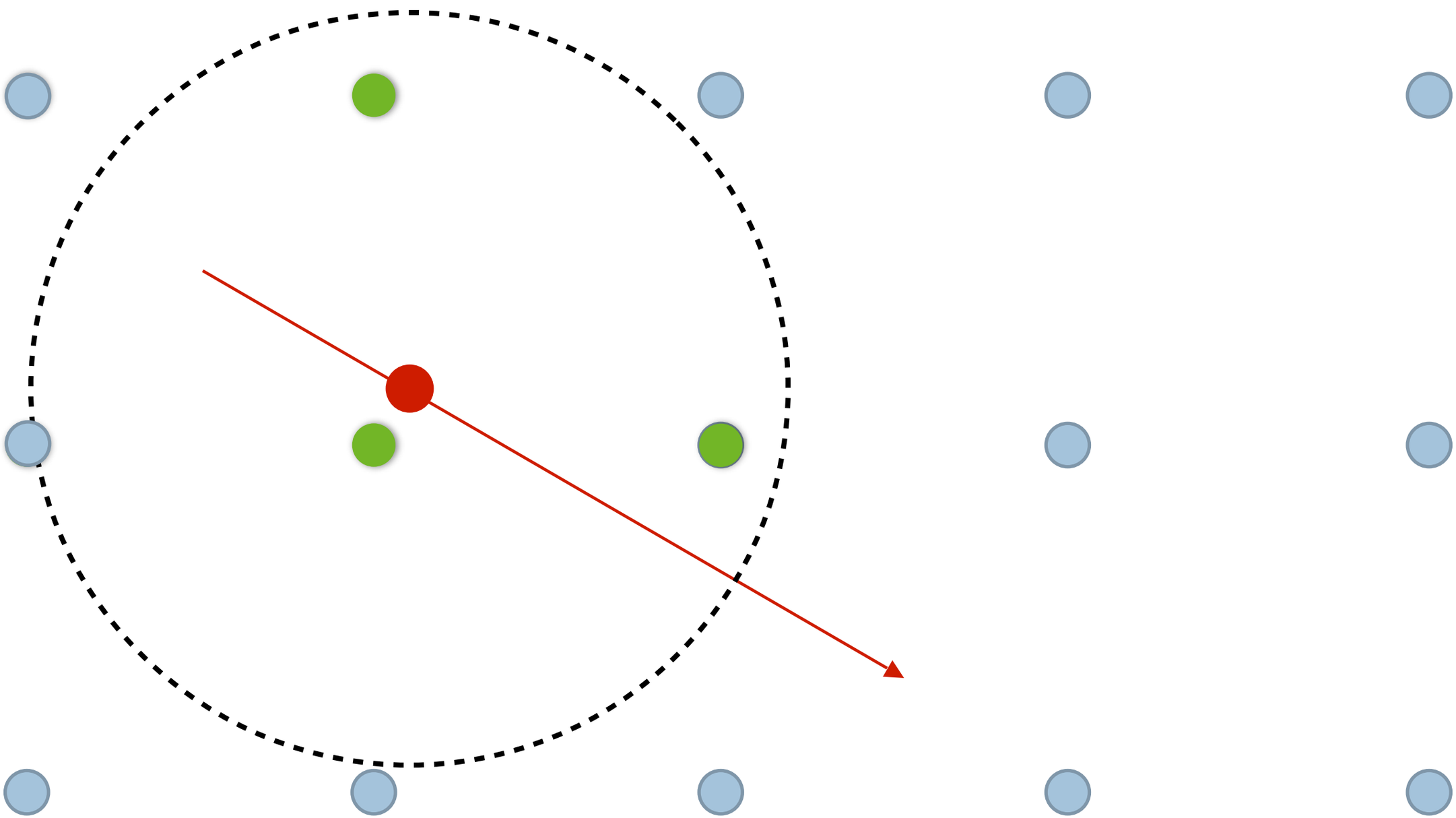

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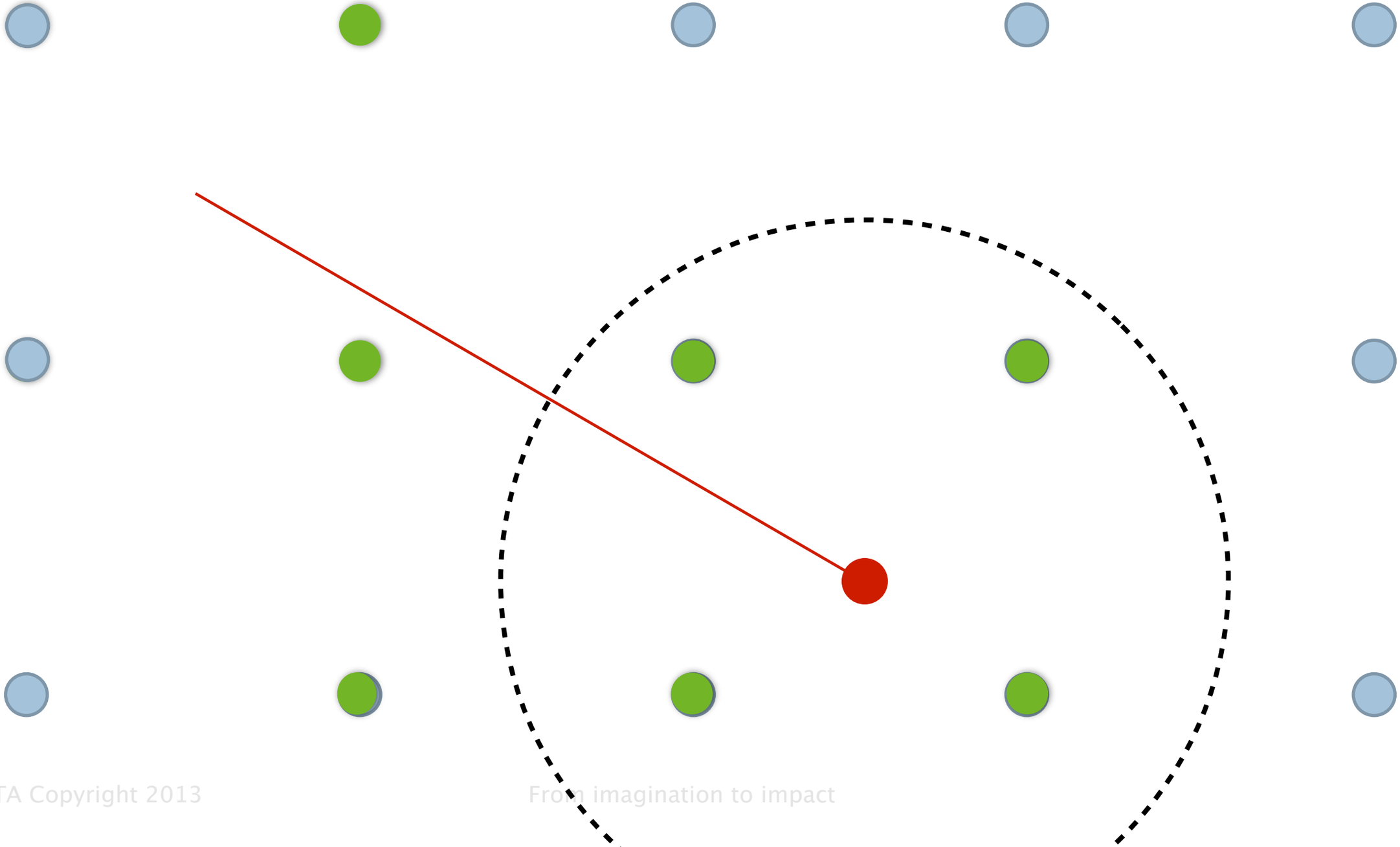
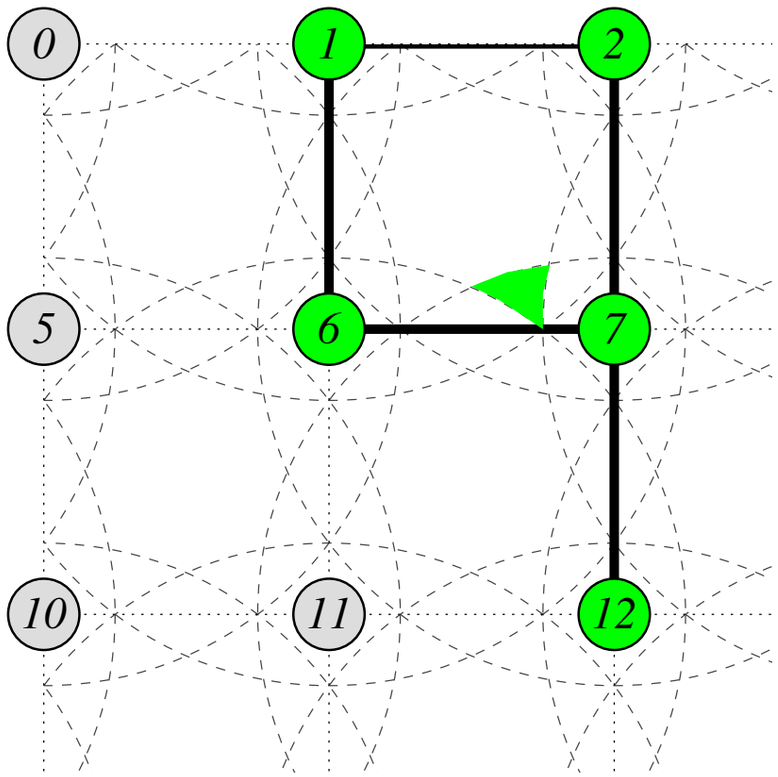
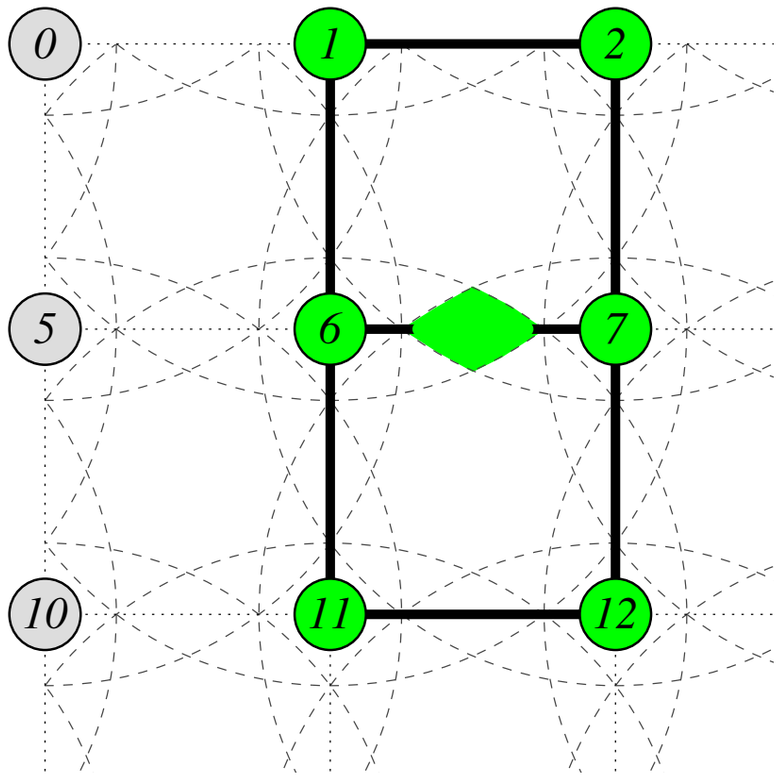


Topology-Based Mobility

- The mobile node is characterised by its neighbours (nodes within transmission range)
- Space can be partitioned into regions with the same topology
- Mobility is expressed as probability of moving from one region/topology to the next





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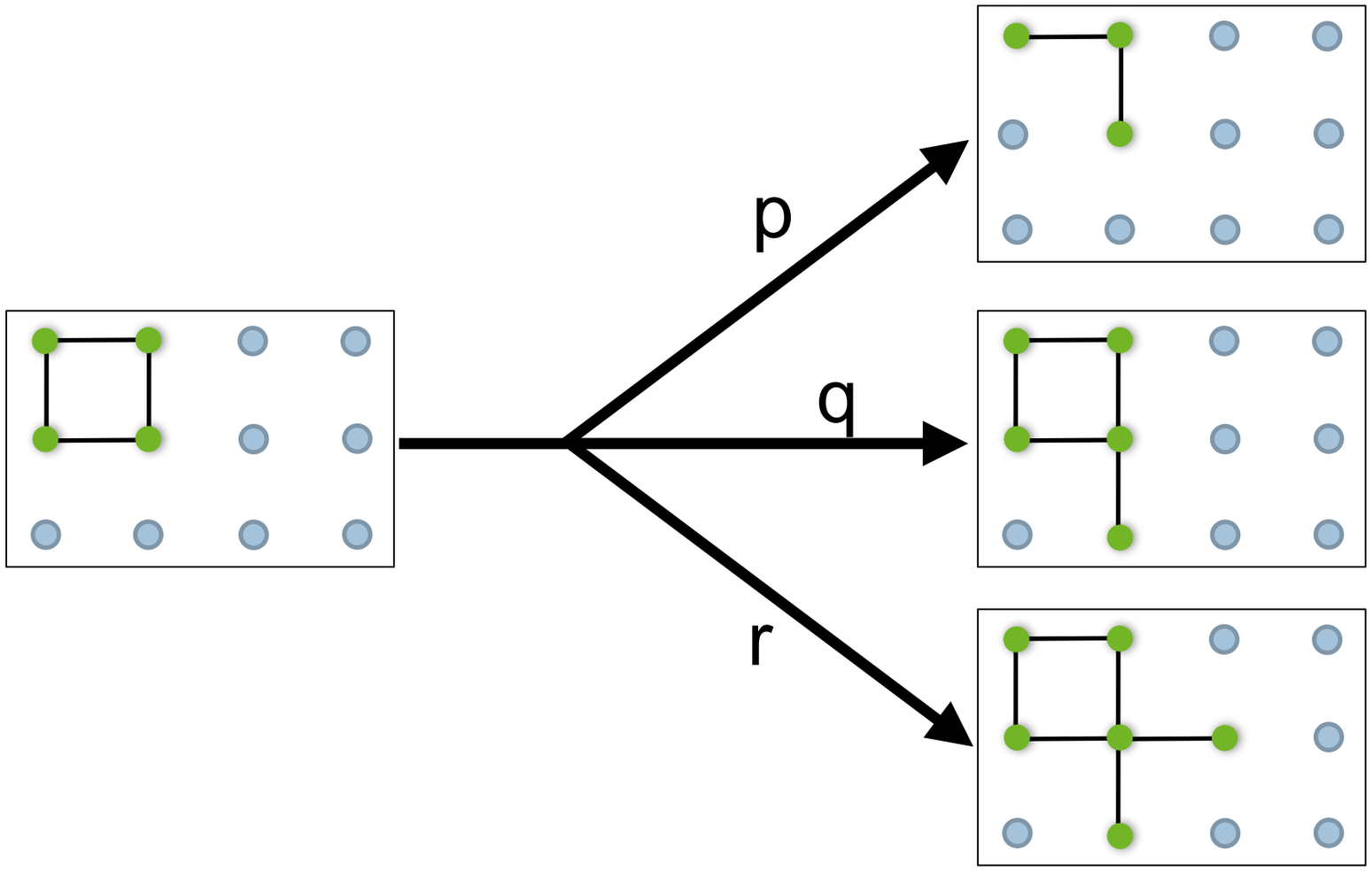

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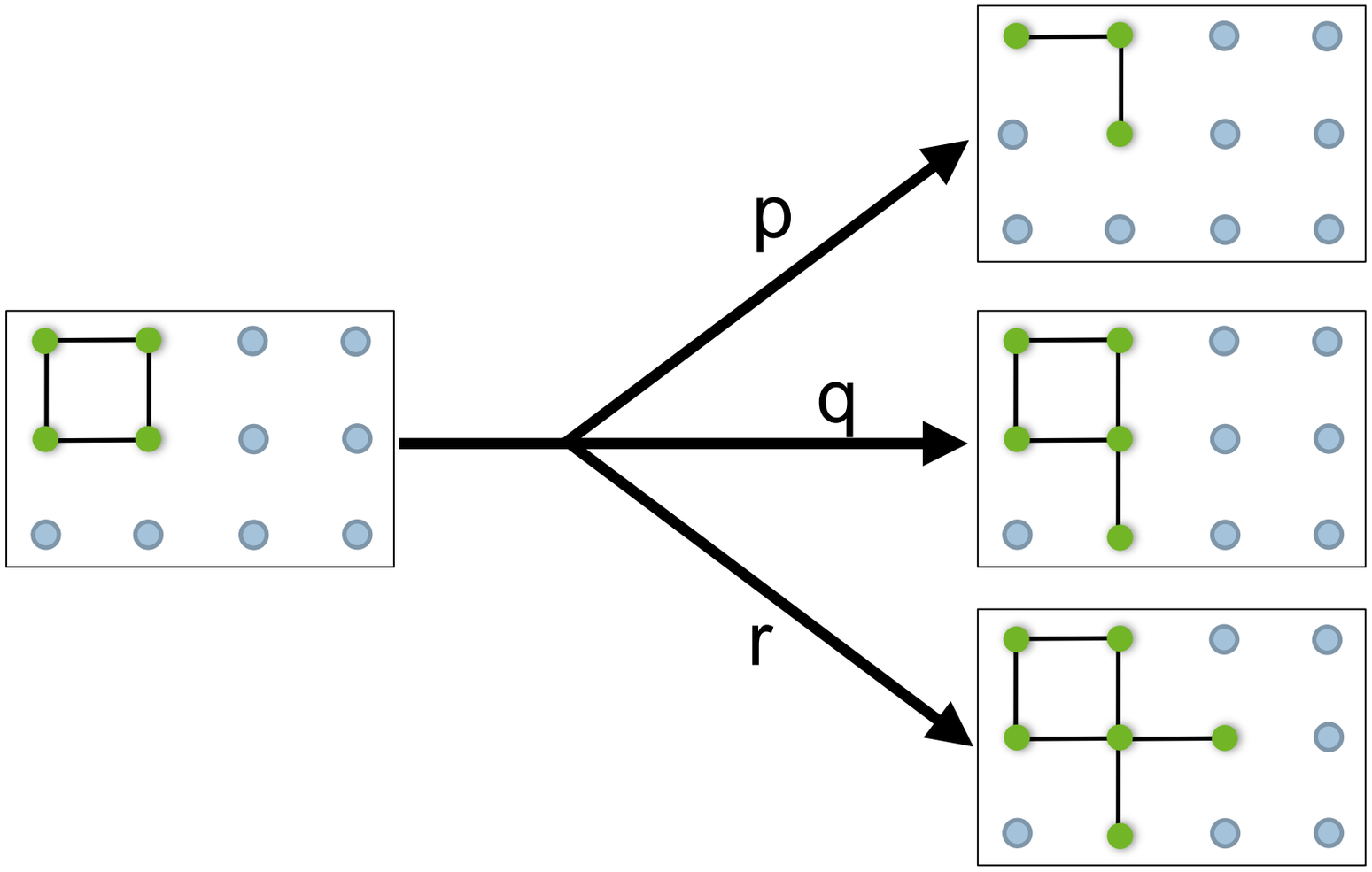

What are the probabilities?

Two Step Approach

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1. Mobility simulation
   - using a “traditional” simulator to estimate the transition probabilities
2. Probabilistic mobility model
   - instantiate a probabilistic automaton model of mobility with obtained probabilities

- Combination with (probabilistic) model of a protocol
  - use a (statistical) model checker to analyse the impact of mobility on performance of the protocol.

Mobility Simulation

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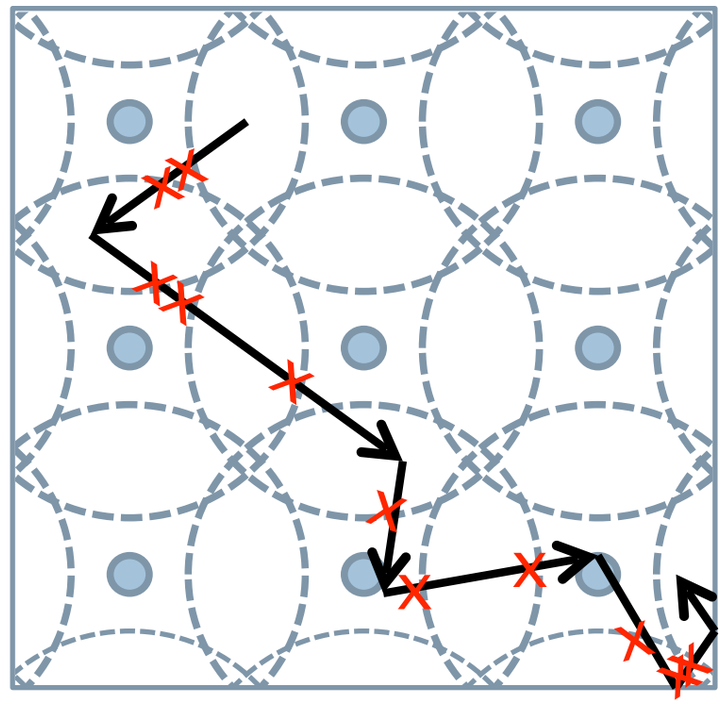
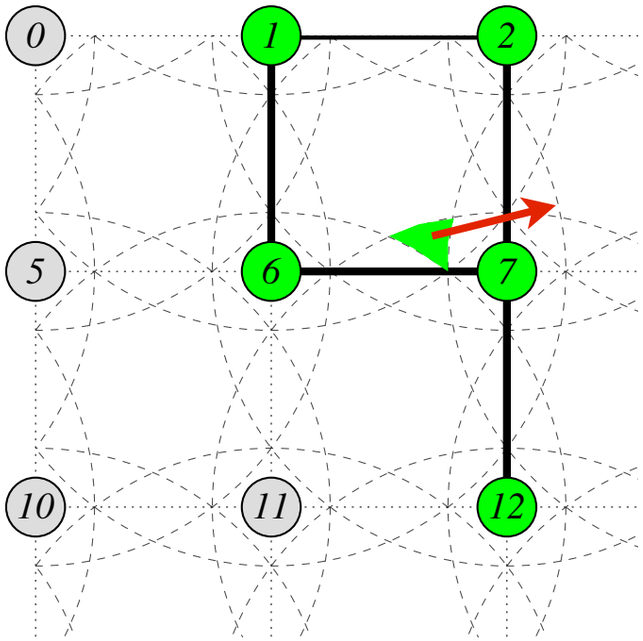
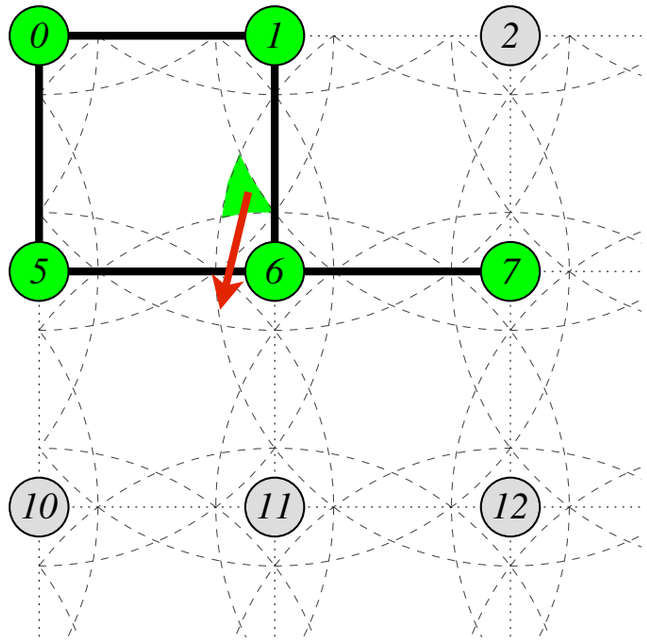
- Simulator
  - computes a series of waypoints;
    each successive pair defines a line segment
    - RWP: Next waypoint selected uniformly from area
    - RW: Next waypoint is old plus value from 2-D normal distribution
  - computes intersection of line with transmission ranges
  - each intersection corresponds to a transition
  - count transitions
  - estimate probabilities
  - implementation
    - C++
    - 100.000 waypoints



Simulation Results I

- Random Walk Model
  - transition probabilities are independent of grid size
  - number of transitions per path grows linear with range
  - same transition probabilities of congruent regions
  - probabilities depend only locally on the set of nodes within range

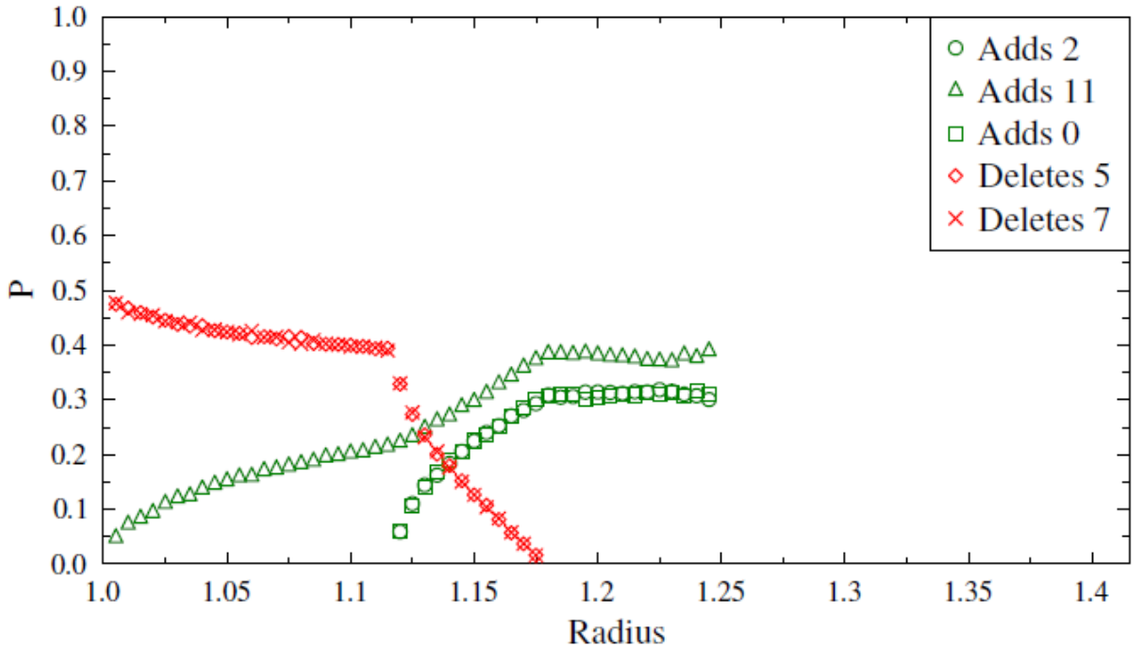


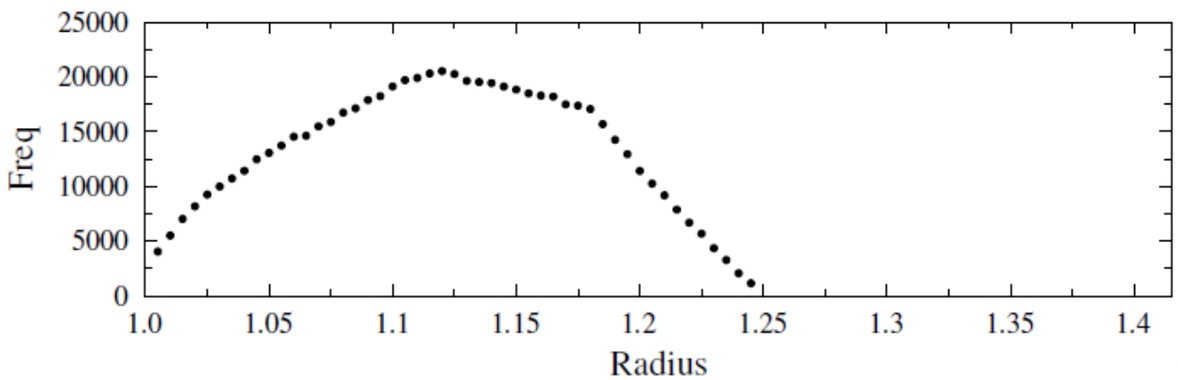


Simulation Results II

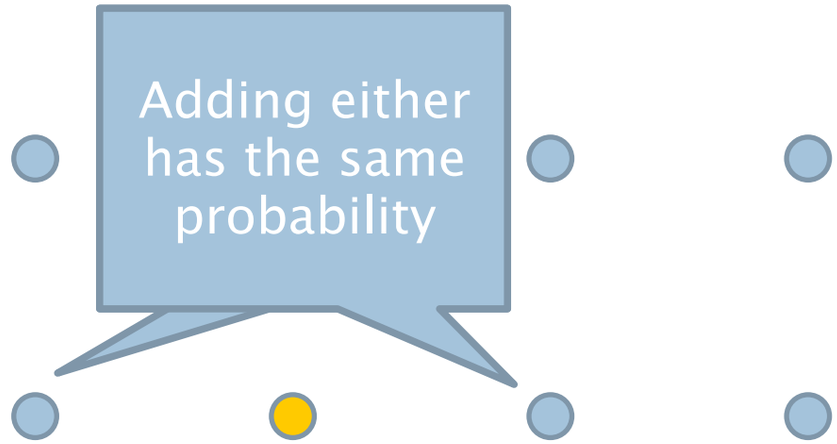
- Random Walk Model

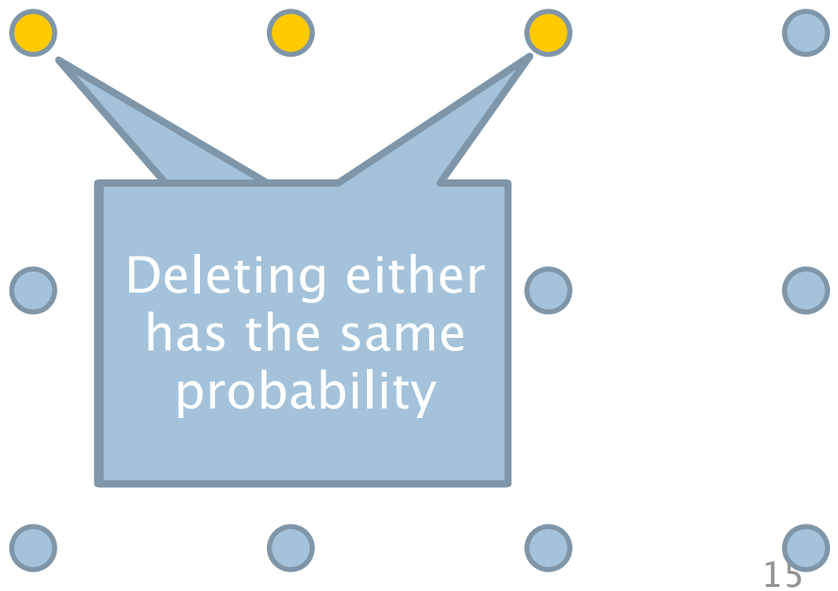
transitions may become possible or impossible at certain ranges





entire set may become possible or impossible at certain ranges.





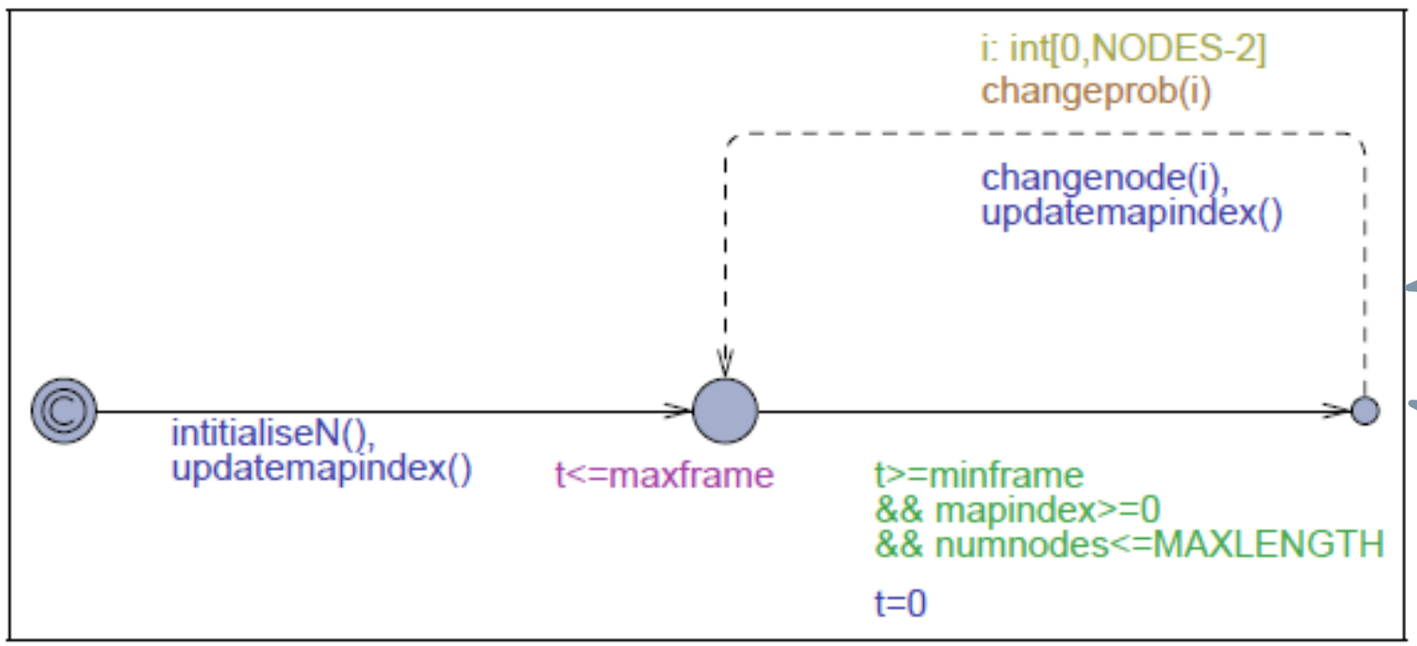
Simulation Results III

- Random Walk Model
  - transition probabilities are independent of grid size
  - number of transitions per path grows linear with range
  - same transition probabilities of congruent regions
  - probabilities depend only locally on the set of nodes within range

- Random Waypoint Model
  - none of the above holds
  - (still we determined probabilities)

Model Checking --- Uppaal Model

- (statistical) Uppaal
  - topology is modelled as a connectivity matrix
  - changes in topology are changes to the matrix
  - probabilities are obtained from a lookup table (obtained from simulator, as discussed)
  - (properties checked with 0.95 confidence)



"One" probabilistic transition to change the topology

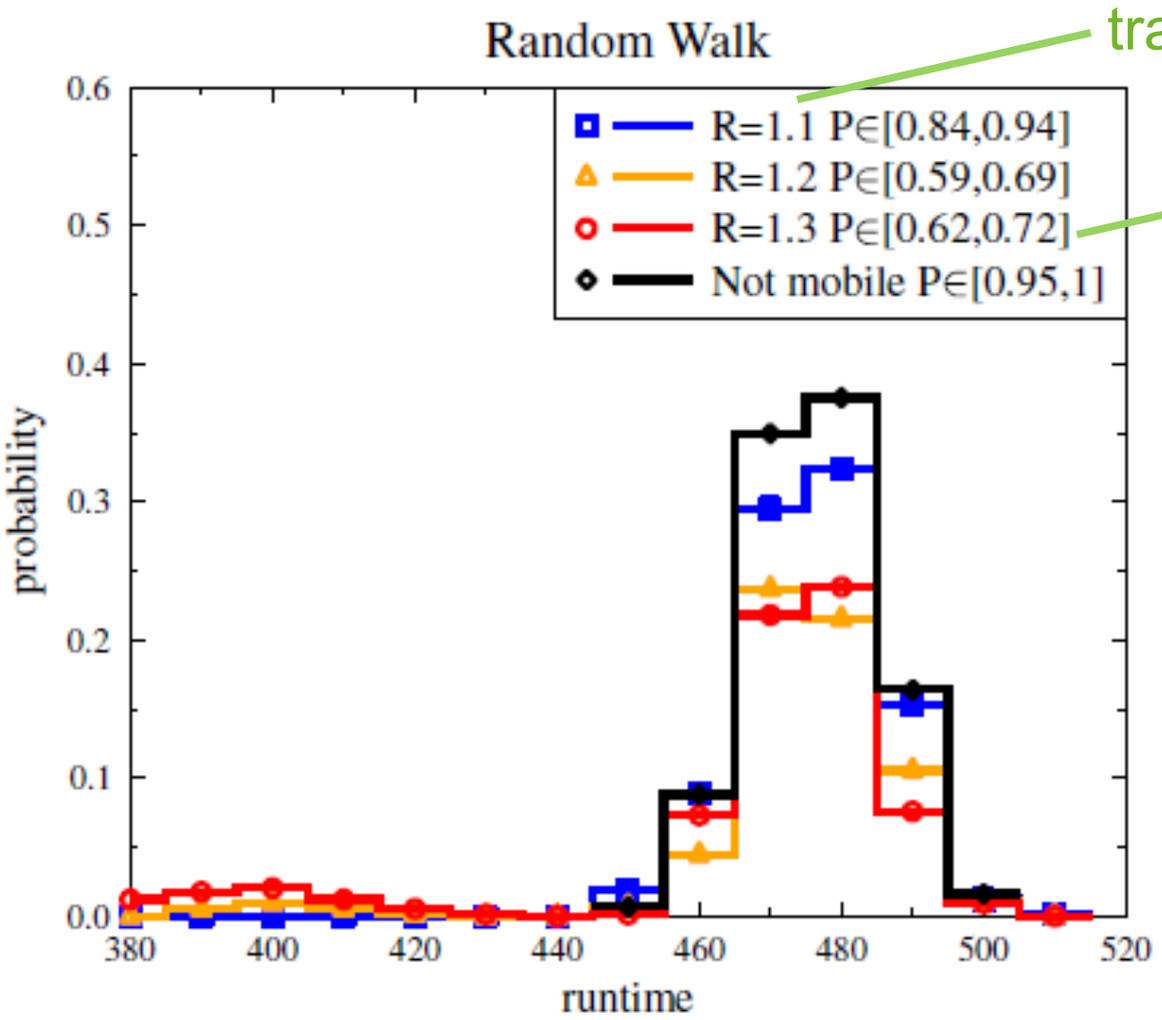
Changes topology once in a given timeframe

Case Studies

- Combination of mobility model with existing protocol models
  - AODV
    - an on-demand routing protocol
    - a routing request is flooding the network, a routing reply to initiator will report the route
  - LMAC
    - time synchronisation (time division) protocol
    - all neighbouring nodes and their neighbours need to select different slot in a time frame; if not, collisions occur

Case Study I

- AODV
  (time needed for successful route establishment)



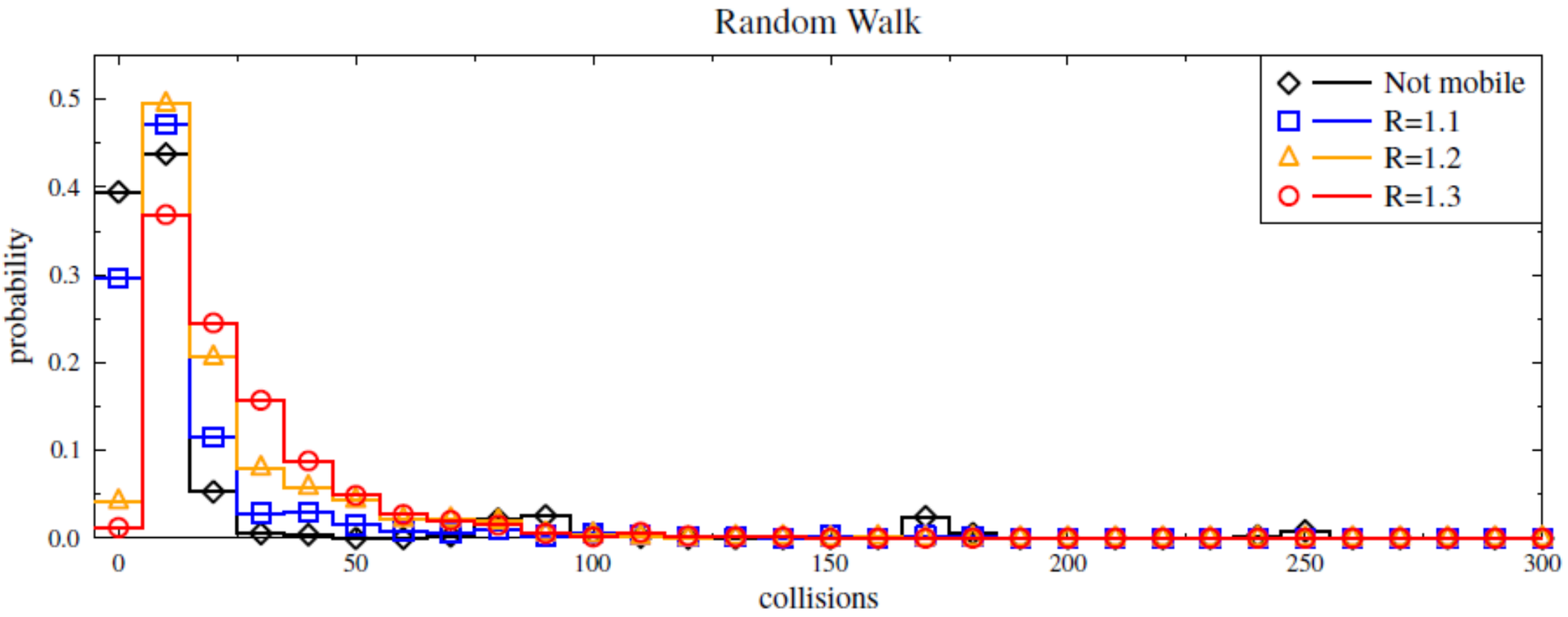
transmission range

probability that route is established
(confidence level 95%)

Introducing mobility makes it possible to establish routes faster/slower

Case Study I

- LMAC
  (probability of collisions for a 4 by 4 network within 2000 time units after fresh start)



  - mobility decreases probability that no or few collisions will occur
  - mobility decreases probability that perpetual collisions will occur
  - mobility increases probability that all nodes will choose time slot, from 80-90% to 95-100% (not in picture)

Conclusion

- Topology-Based model for mobility
  - generic
  - allows adaptation on mobility model
- Demonstrated how this model can be instantiated with probabilities obtained from a simulator
  - random way point and random walk model in a grid
  - other models could be used as well
- Demonstrated how the instantiated mobility model can be combined with existing protocol models
  - AODV and LMAC are only examples
- Future work:
  - other protocols
  - increase efficiency (make more use of symmetries)