Discrete Event Simulation

IN2045

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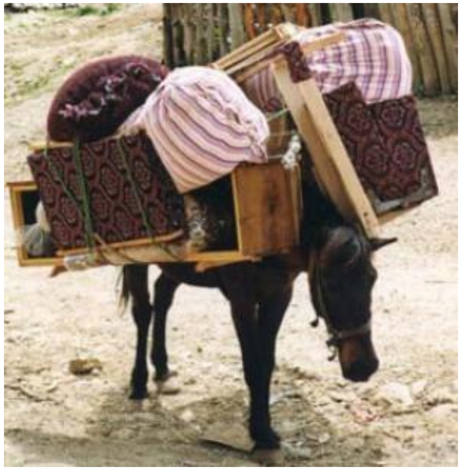
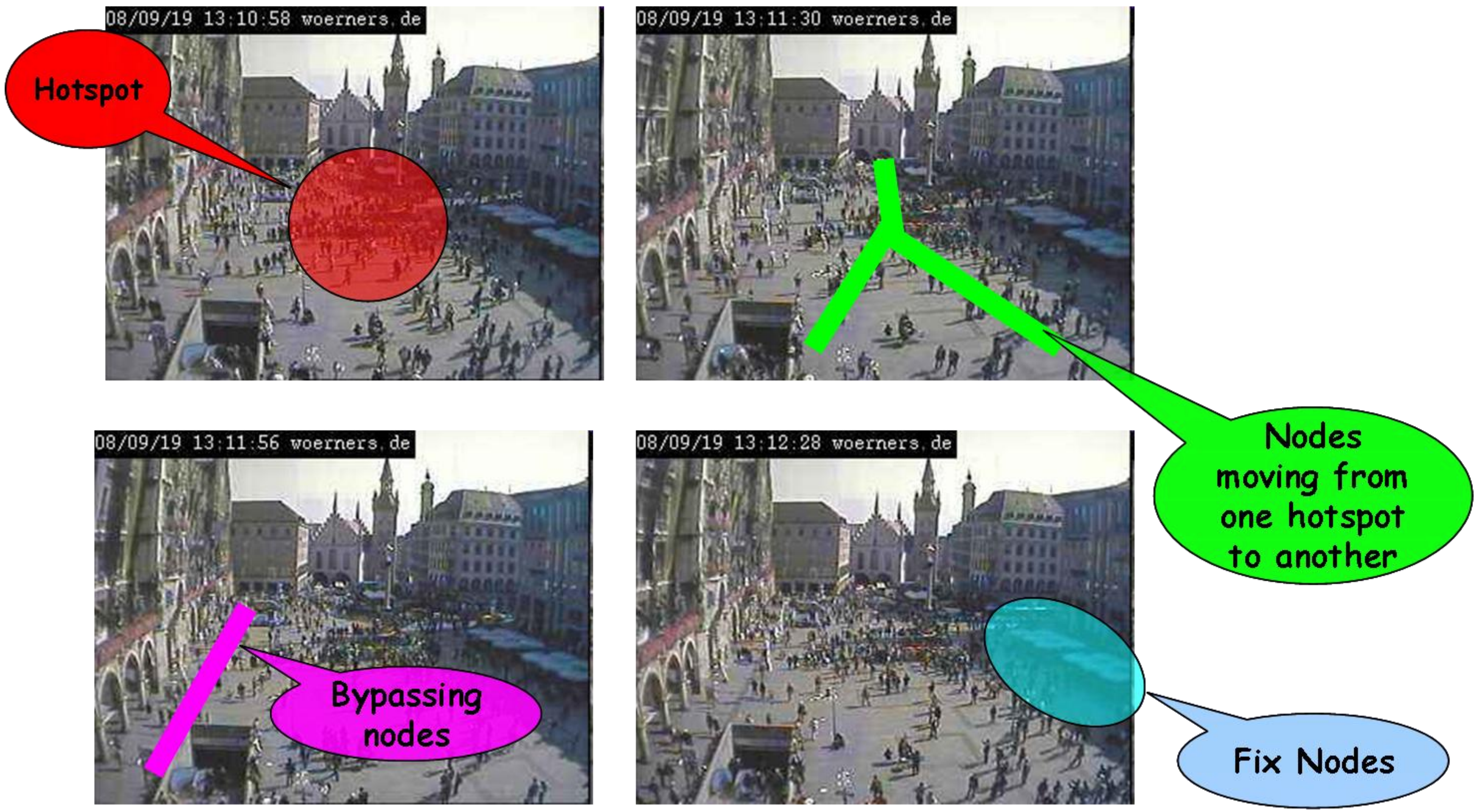
Topics

- Mobility in General
  - Realistic Movement
  - Human Mobility Pattern
- Visualization
  - Density
  - Speed Histograms
- Characteristics of Mobility Pattern
  - Link Duration, Transient Phase, Node Distribution, Speed Distribution, Correlated Movement
- Synthetic Mobility Models
  - Random Waypoint
  - Random Direction
  - Random Walk
  - Levi-Flight
  - Brownian Motion
  - Group Mobility



Mobility

- What is (random) mobility?



Mobility

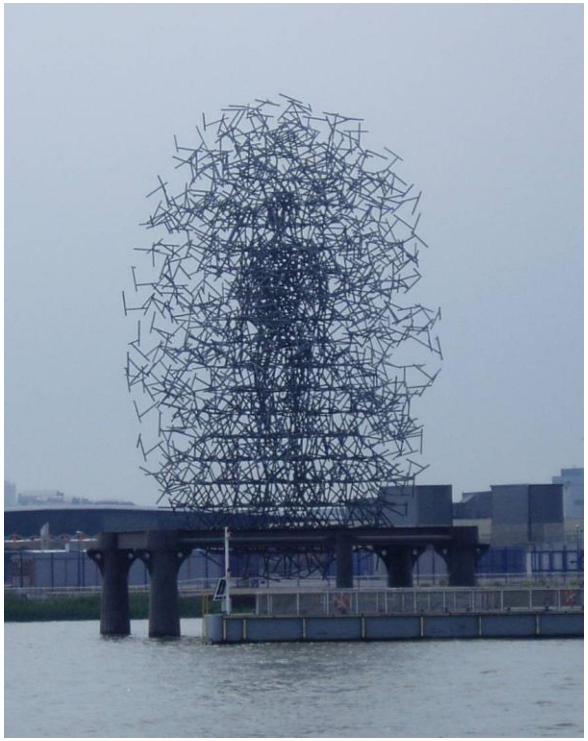
- Why simulate mobility?
  - Improvements in technology enable new technologies and result in cheaper hardware prices
  - Number of powerful mobile devices increases very quickly (Smartphones with high data rate interfaces)
  - Number of applications for mobile devices increases
  - Impact on the system performance can often not be predicted in advance

- Impact on wireless networks:
  - Topology depends on the user mobility
  - Routing protocols have to react on topology changes (link duration)
  - Frequent changes of the user density result in variation of the interference
  - May lead to a collapse of the network if the applied protocols are not optimized (overhead, dissemination of outdated information)
  - Enables new information dissemination strategies (Delay-Tolerant-Networking)

Mobility

- What is realistic movement?
  - Random movement?
  - Correlated movement?
  - Movement of humans?

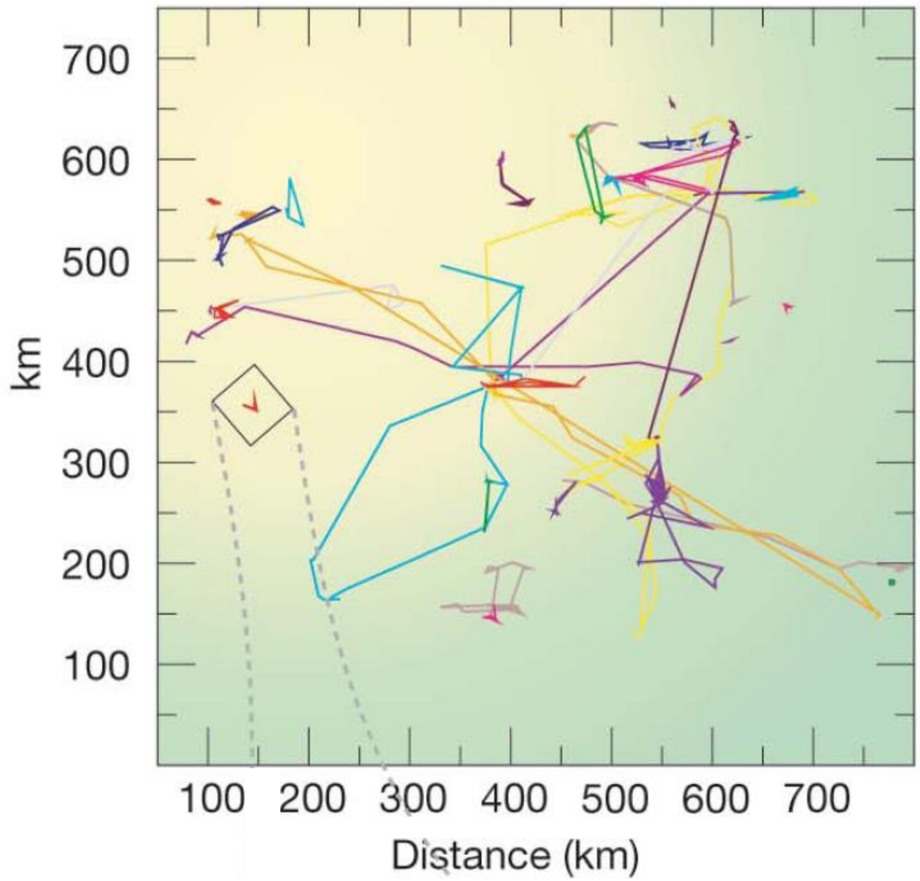
- Mobility Pattern
  - Pedestrians
  - Police patrol / avalanche rescue
  - Cars on the road
  - Trains
  - Air planes
  - Animals (hunter and prey)
  - Constraint by obstacles / infrastructure



Antony Gormley's *Quantum Cloud* sculpture in London (based on a random walk model)

Mobility

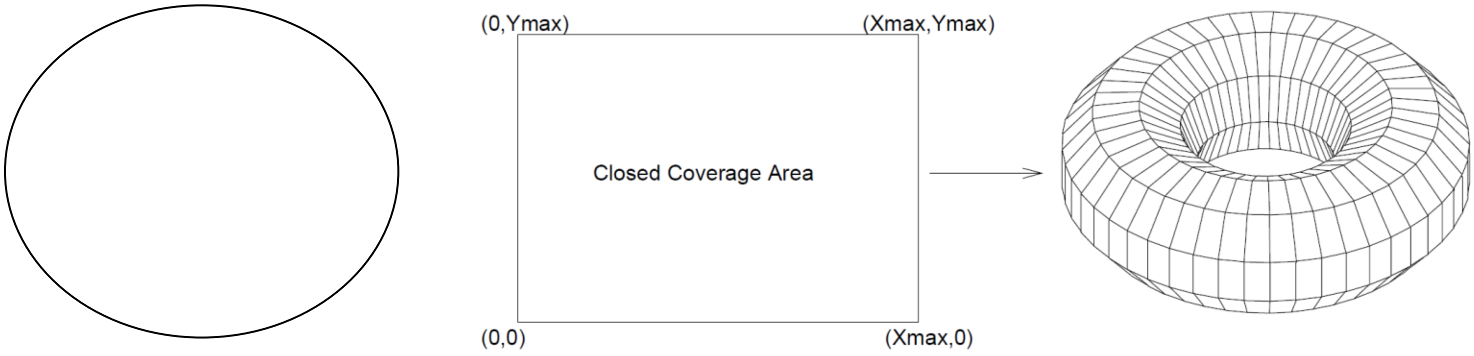
- Human mobility pattern:
  - Short-term and long-term characteristics
  - Often approximated by the levy-flight synthetic mobility model which is derived from the random walk model
  - High probability that the next position is close to the previous one
  - Low probability that the individual travels long distances
  - High variation between different individuals



González, M. C.; Hidalgo, C. A. & Barabási, A.
Understanding Individual Human Mobility Patterns
Nature, 2008, *453*, 779-782

Mobility

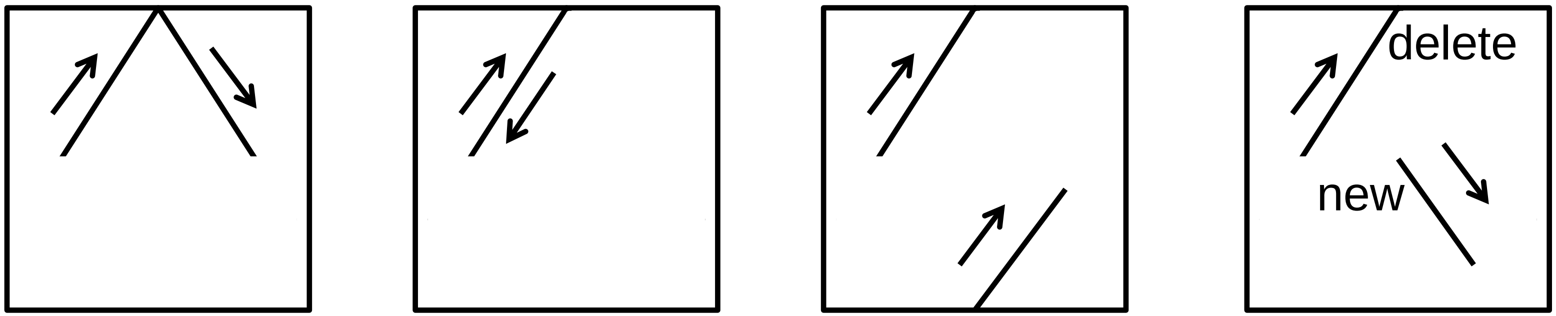
- Simulation
  - Area (circle, square, rectangle, sphere, torus, …)



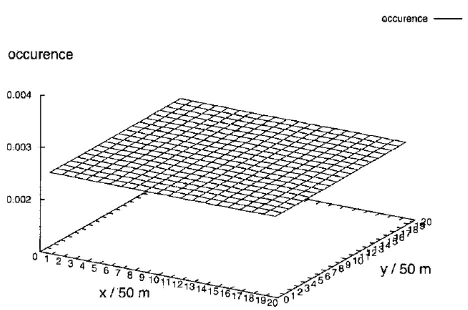
  - Long-term simulation
    - Transient phase of the model
    - Node distribution
    - Speed distribution
    - Partitioning of the network

Mobility

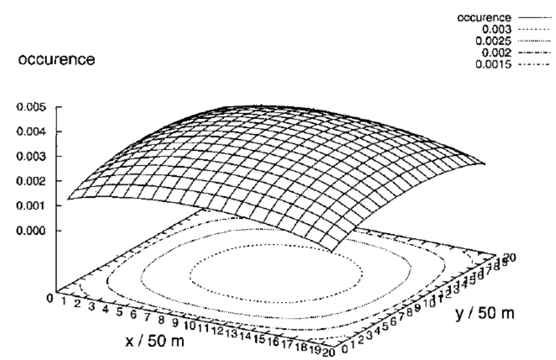
- Simulation
  - Bouncing rule:



bounce | reflect | wrap-around | delete & replace



f) Random direction model with “bounce” or “wrap–around”



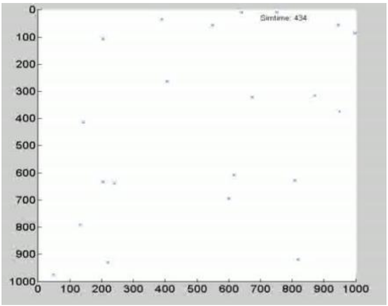
Random direction model with “delete and replace”

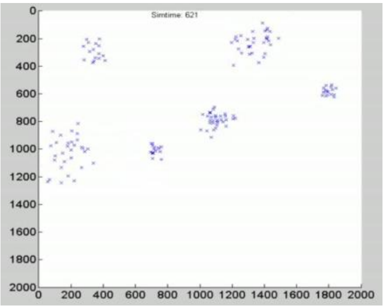
Article (Bettstetter2001)
Bettstetter, C.
Mobility Modeling in Wireless Networks: Categorization, Smooth Movement, and Border Effects
ACM SIGMOBILE Mobile Computing and Communications Review, ACM, 2001, *5*, 55-66

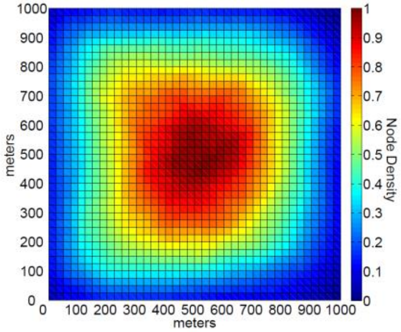
Node Distribution changes depending on the applied bouncing rule

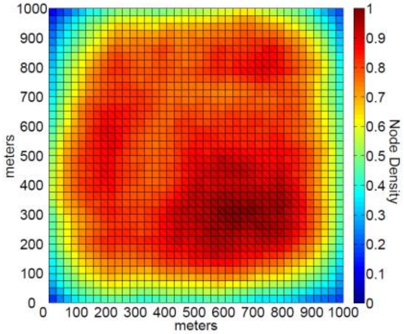
Mobility

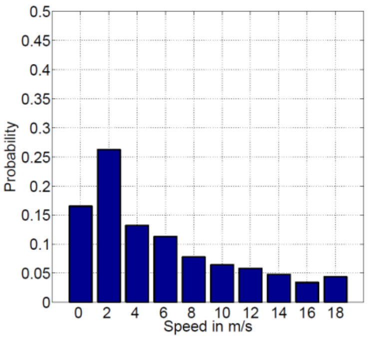
- Visualization
  - Movement (Debugging)
    - Debugging
    - Detect correlated movement
    - Evaluation
  - Density
    - Spatial node distribution
    - Border effects
    - Estimation of transient phase
  - Histograms
    - Node speed distribution
    - Link duration
    - Estimation of transient phase

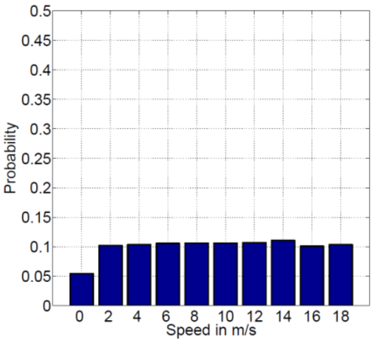












Mobility

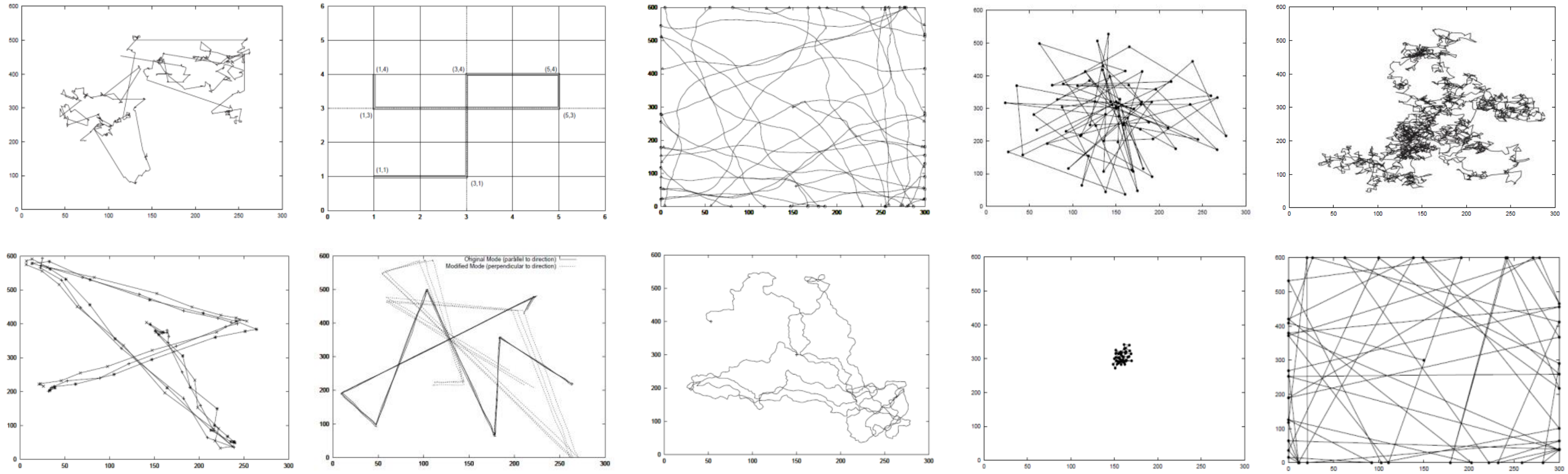
- Characteristics:
  - Link duration
    - Important wireless communication parameter
    - Represents the time interval during which two nodes are able to communicate with each other
  - Transient phase
    - One or more parameters change significantly during this phase
    - Duration of the transient phase varies between different synthetic mobility models
  - Spatial node distribution
    - Depends on the mobility model
    - Often affected by the shape of the simulation plane
    - Influenced by the applied bouncing rule

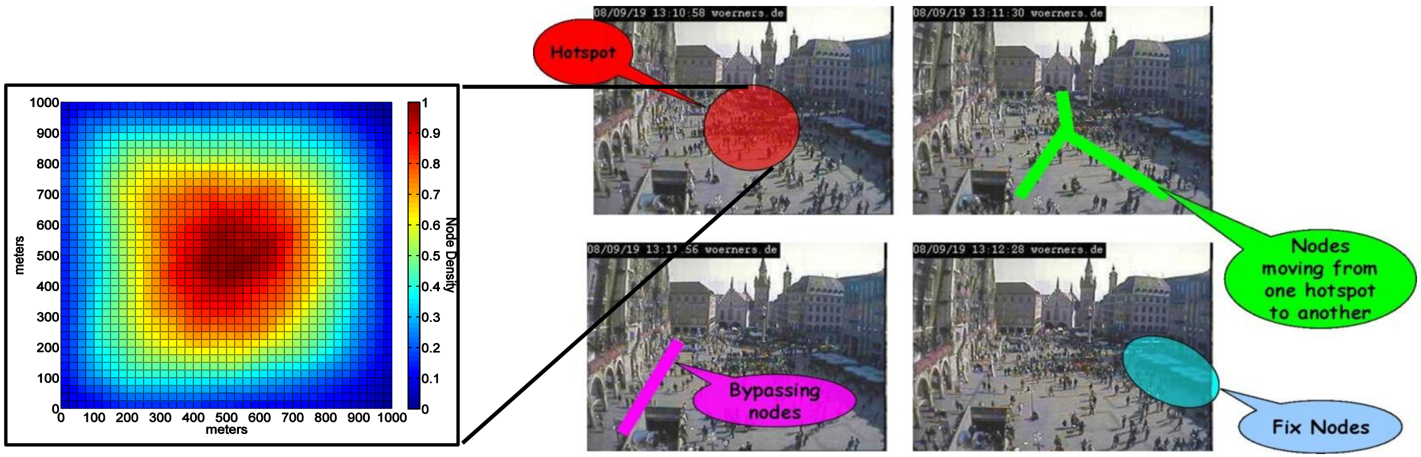
Mobility

- Characteristics:
  - Speed distribution
    - Good indicator for the duration of the transient phase
    - Mainly influenced by the following parameters:
      - Time-based or distance-based movement decision
      - Pause time
      - Shape of the simulation plane
  - Correlated / Constraint movement
    - Each move is affected by the previous one
    - Objects may interact with each other
  - Group mobility
    - The movement of objects is a composition of the movement of the individual and a common (group leader) object

Mobility

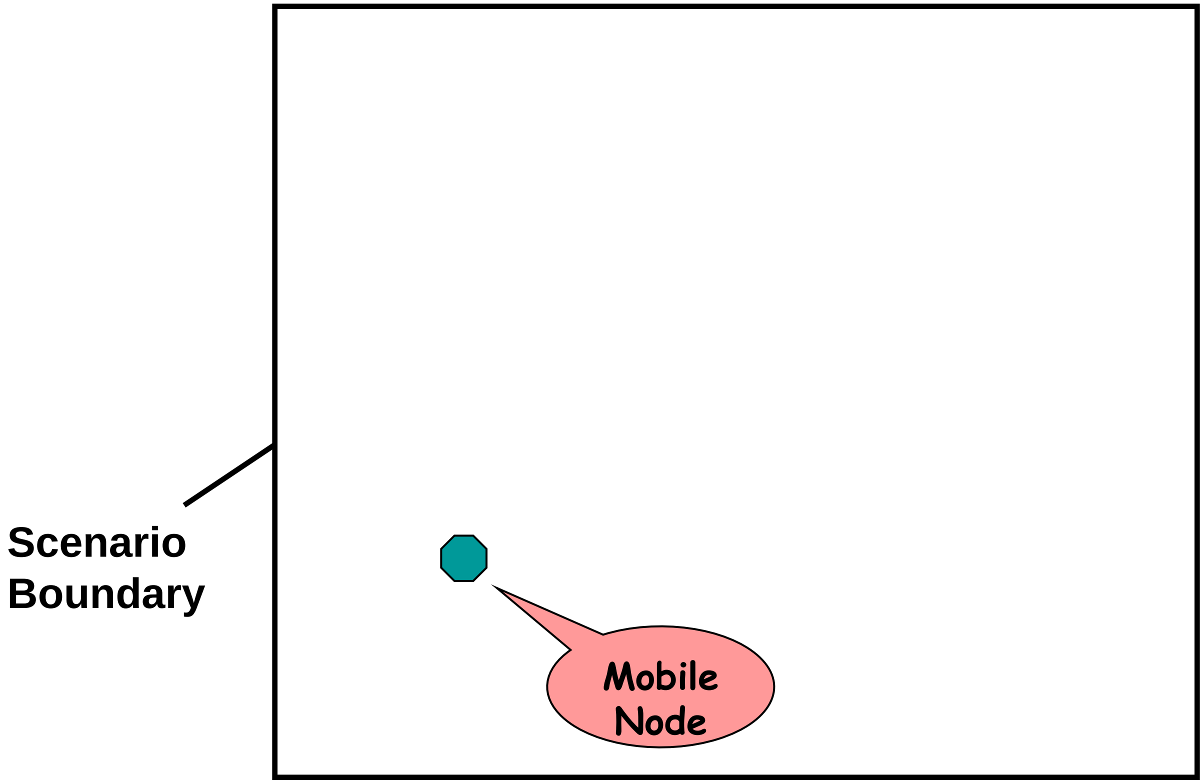
- Synthetic Mobility Models





- Random Waypoint

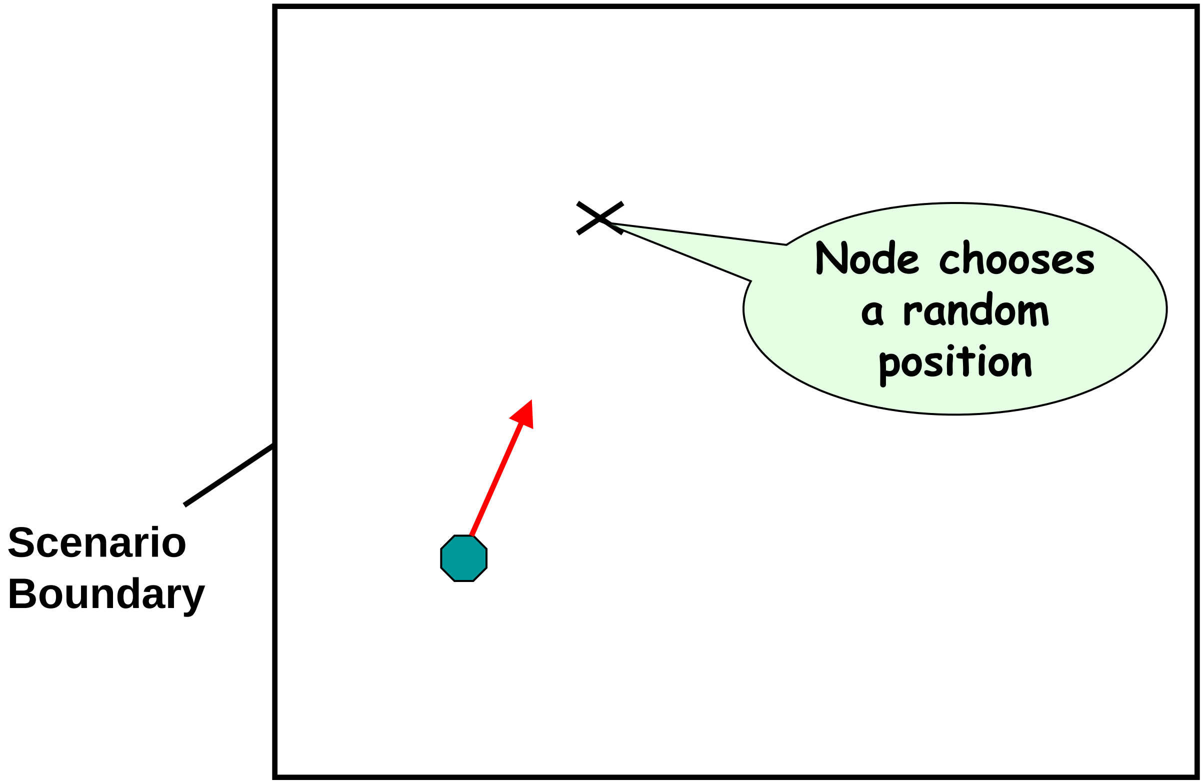
Algorithm:



Mobility

- Random Waypoint

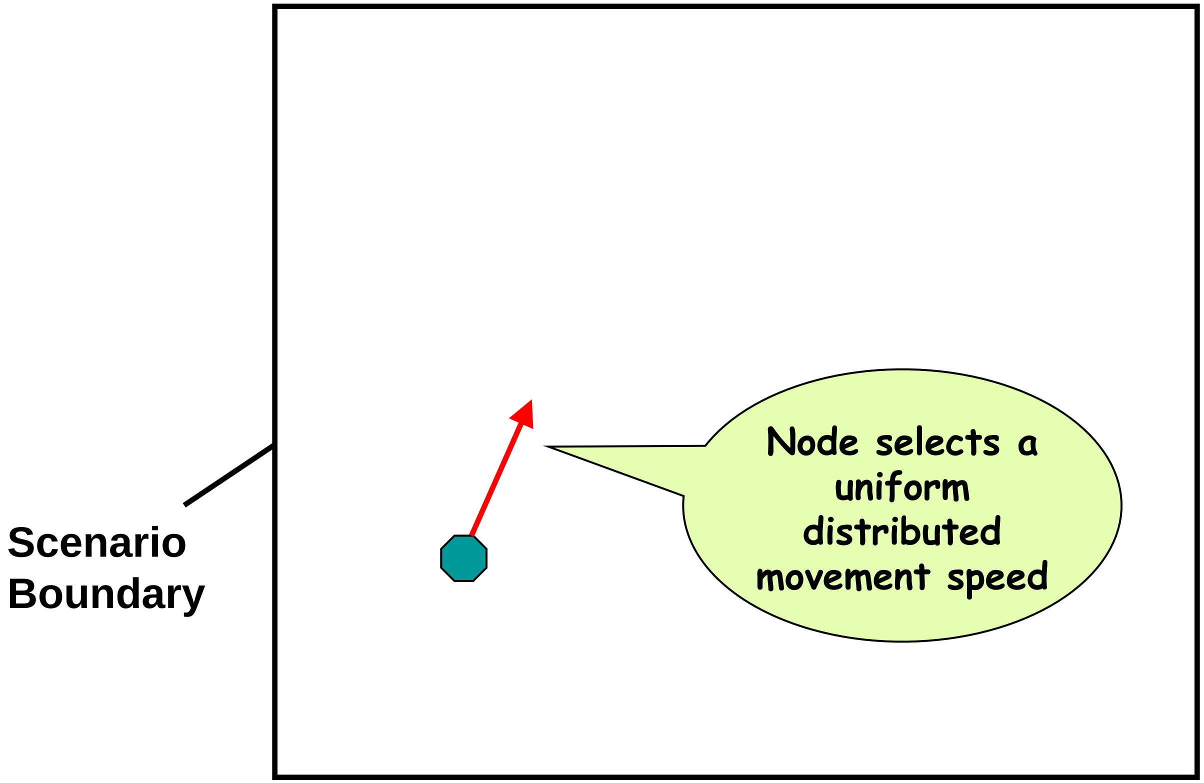
Algorithm:



Mobility

- Random Waypoint

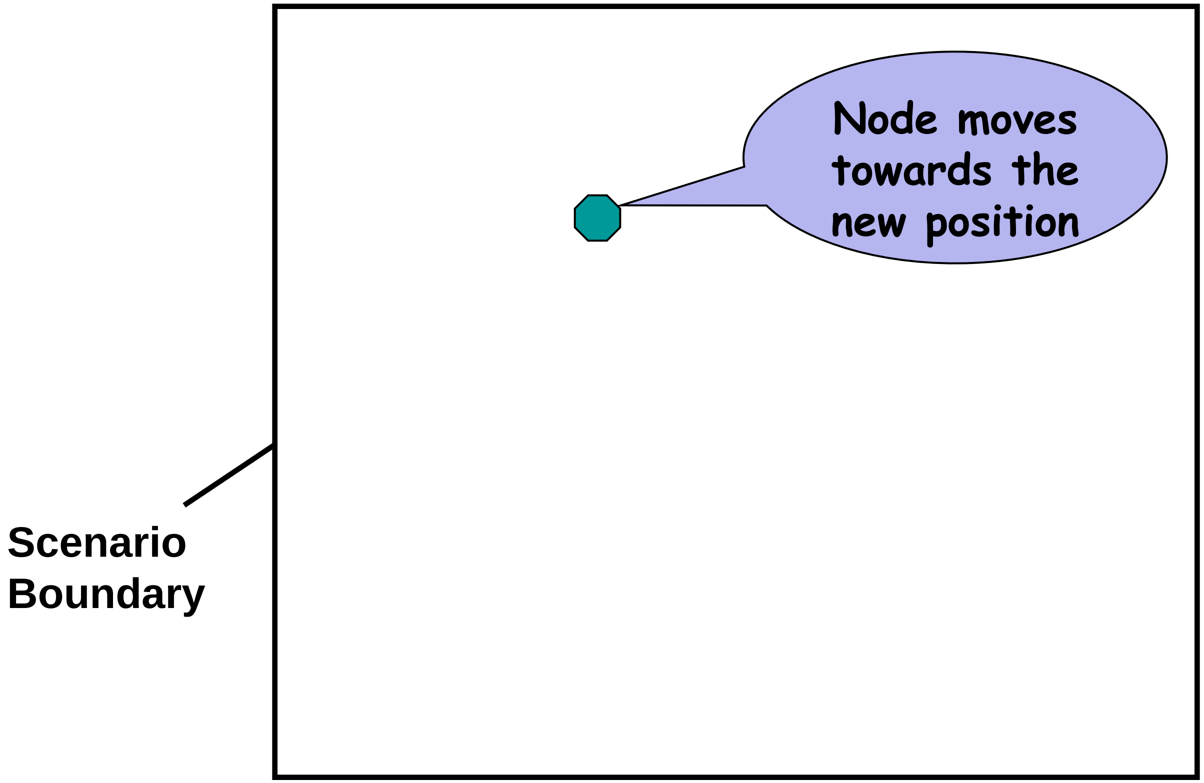
Algorithm:



Mobility

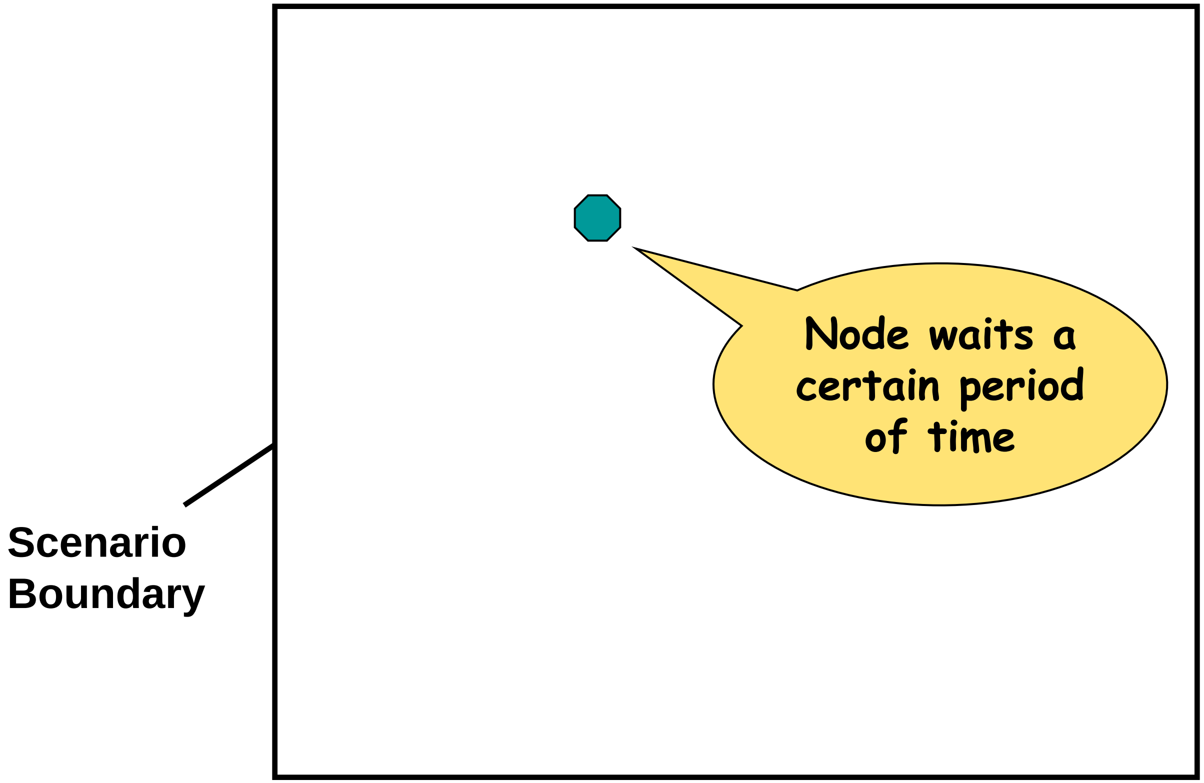
- Random Waypoint

Algorithm:



- Random Waypoint

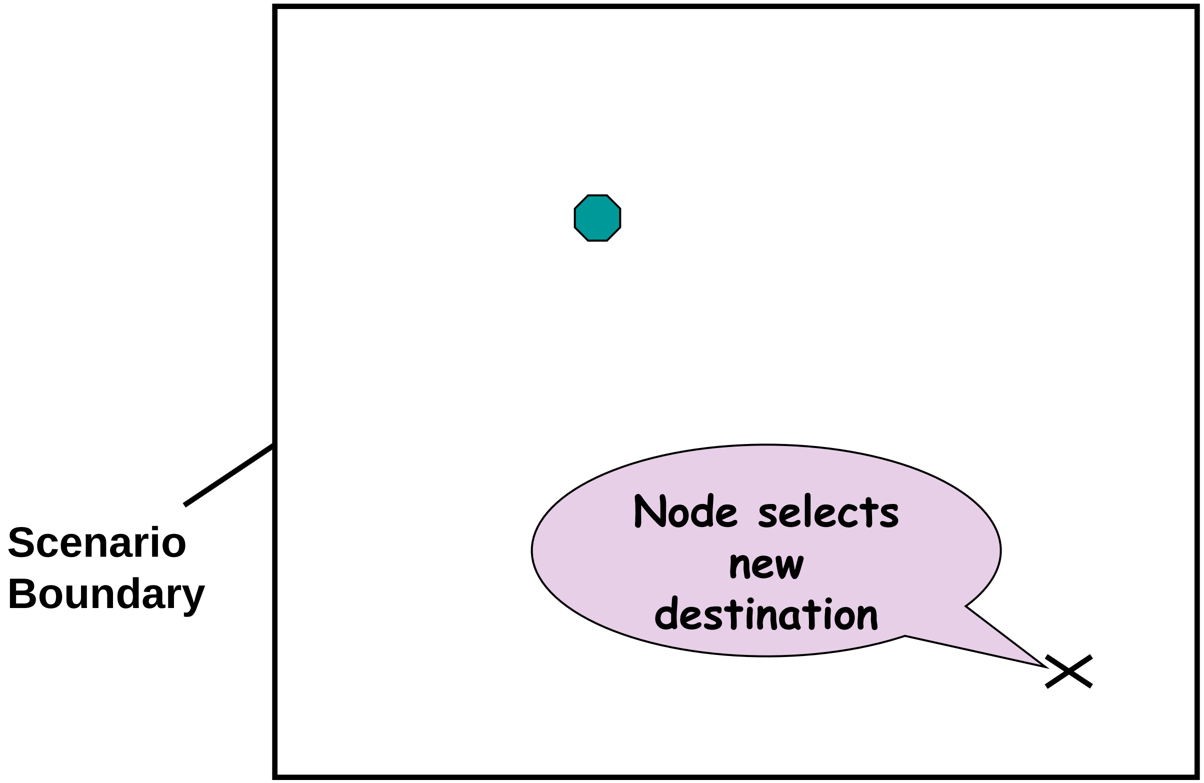
Algorithm:



Mobility

- Random Waypoint

Algorithm:



Mobility

- Random Waypoint

Algorithm:

Step 1: Select a random destination within the scenario

Step 2: Select a random speed $speed \in [speed_{Min}; speed_{Max}]$

Step 3: Move until the destination is reached

Step 4: Wait a random period of time $pause \in [0; pause_{Max}]$

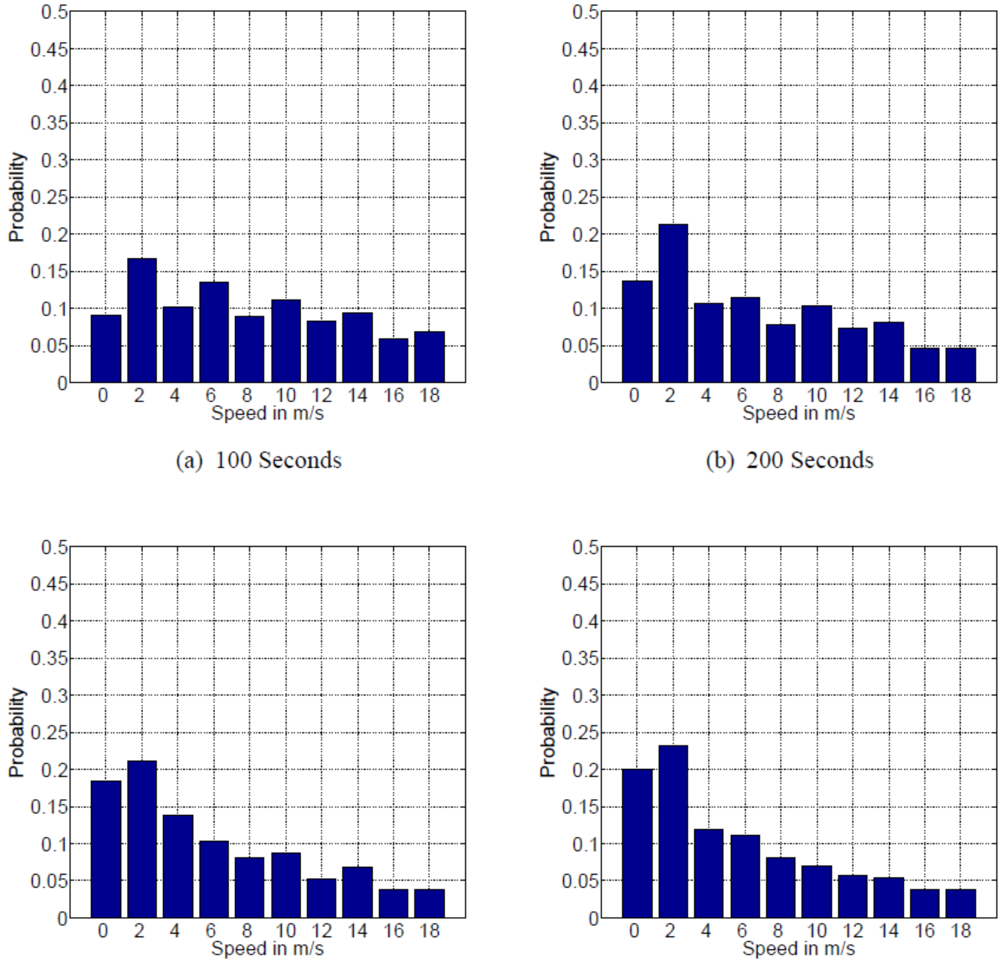
Step 5: Go to step 1

Mobility

- Random Waypoint
  - Characteristics:
    - Node density decreases towards the border
    - Highest node density in the center
    - The fraction of slow moving nodes increases over time
    - Long transient phase
    - Individual nodes recognize density waves while moving through the center
    - Average node speed decreases over time ⇒ speed decay problem
  - Advantage:
    - Simple to implement
    - Challenging mobility due to changing node density
  - Disadvantage:
    - Has to be configured carefully (Minimum speed and pause duration)
    - Movement affected by the shape of the simulation plane

Mobility

- Random Waypoint
  - Node speed distribution:



(a) 100 Seconds

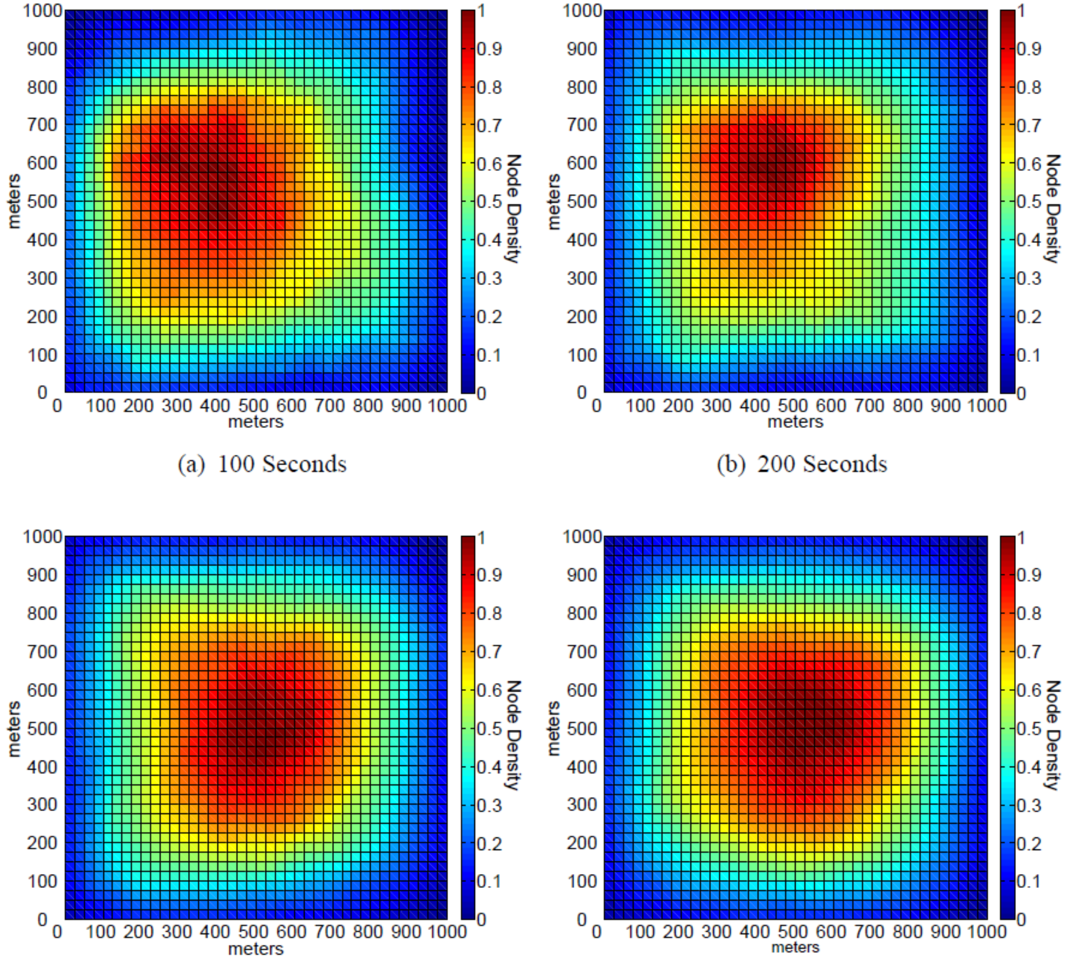
(b) 200 Seconds

(c) 400 Seconds

(d) 800 Seconds

Mobility

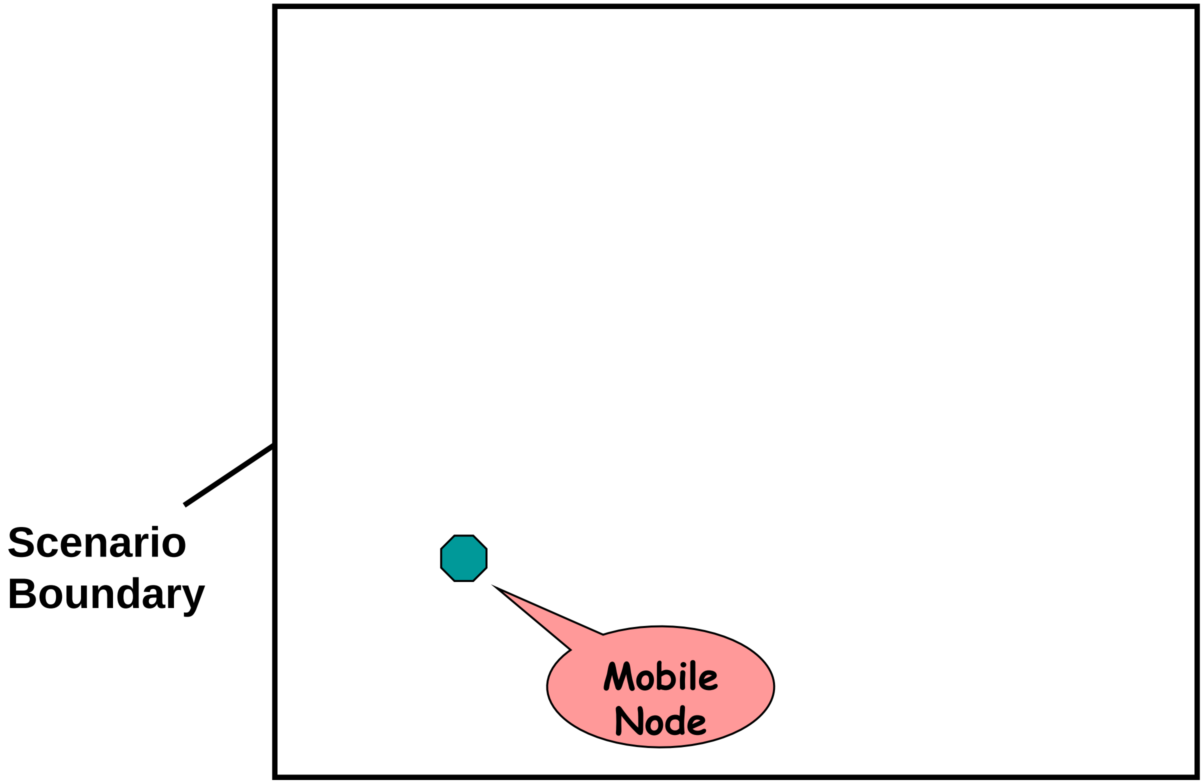
- Random Waypoint
  - Node density:



(a) 100 Seconds (b) 200 Seconds (c) 400 Seconds (d) 800 Seconds

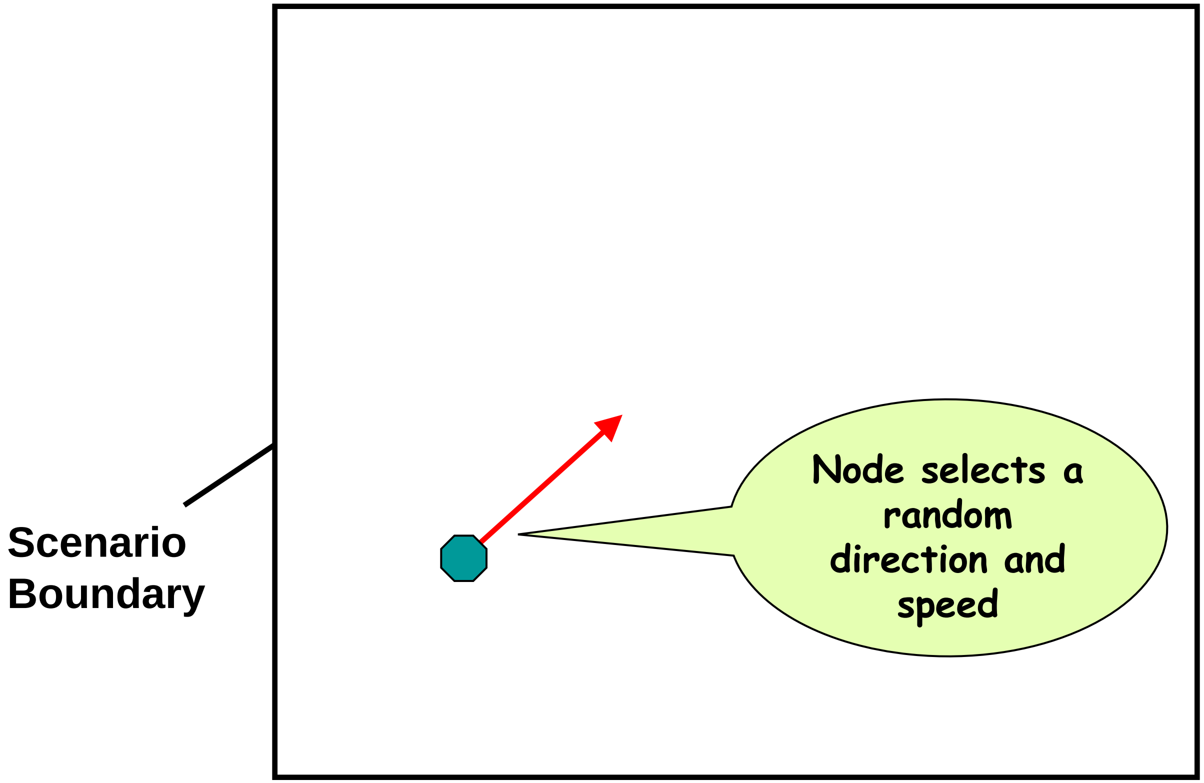
- Random Direction

Algorithm:



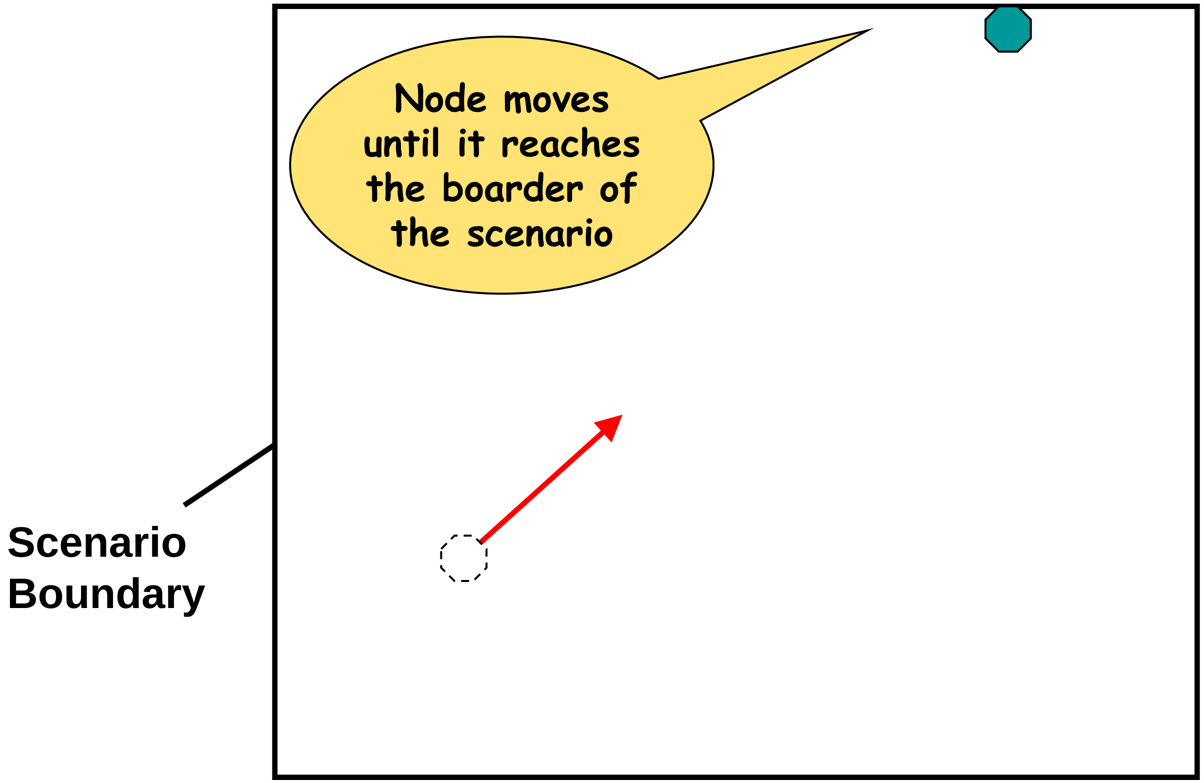
- Random Direction

Algorithm:



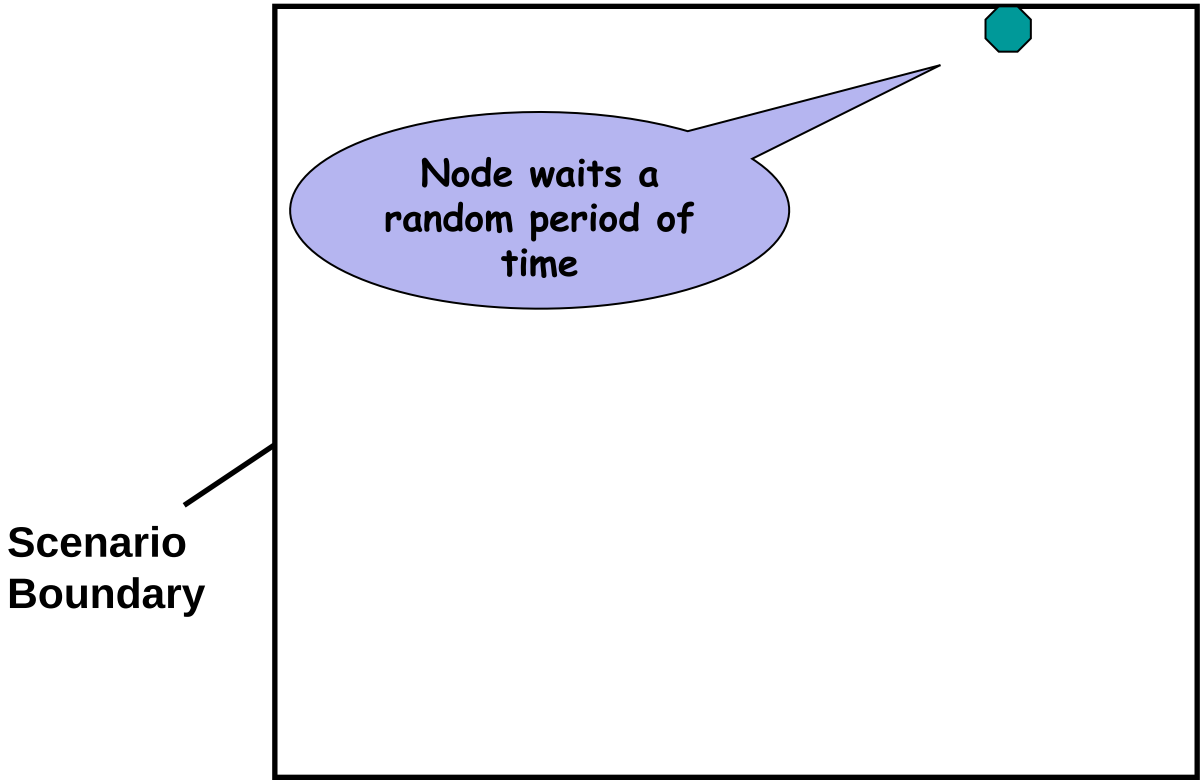
- Random Direction

Algorithm:



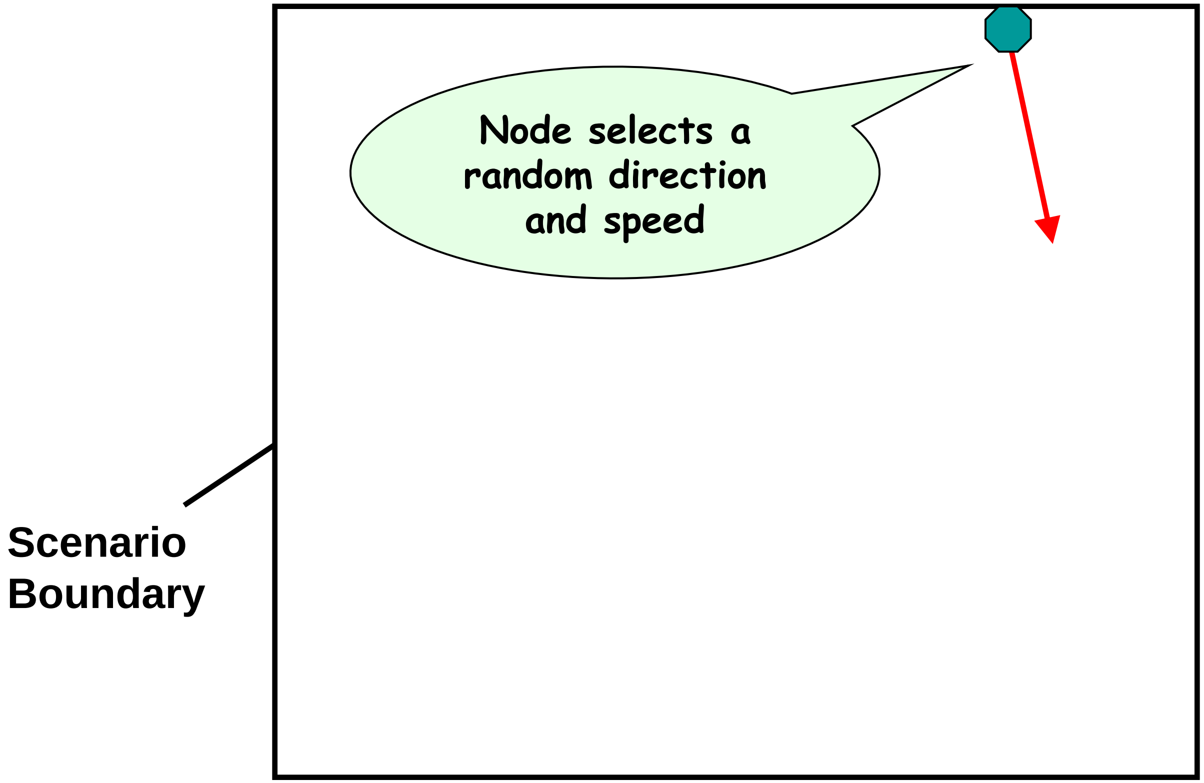
- Random Direction

Algorithm:



Random Direction

Algorithm:



Random Direction

Algorithm:

Step 1: Select a random direction $direction \in [0;2\pi]$
(such that the node does not leave the scenario)

Step 2: Select a random speed $speed \in [speed_{Min}; speed_{Max}]$

Step 3: Move until the border of the scenario is reached

Step 4: Bouncing rule:
a. Wait a random period of time $pause \in [0; pause_{Max}]$
b. Delete the node and replace it with a new node in the center or at a random position
c. Place the node at the opposite side of the simulation plane

Step 5: Go to step 1

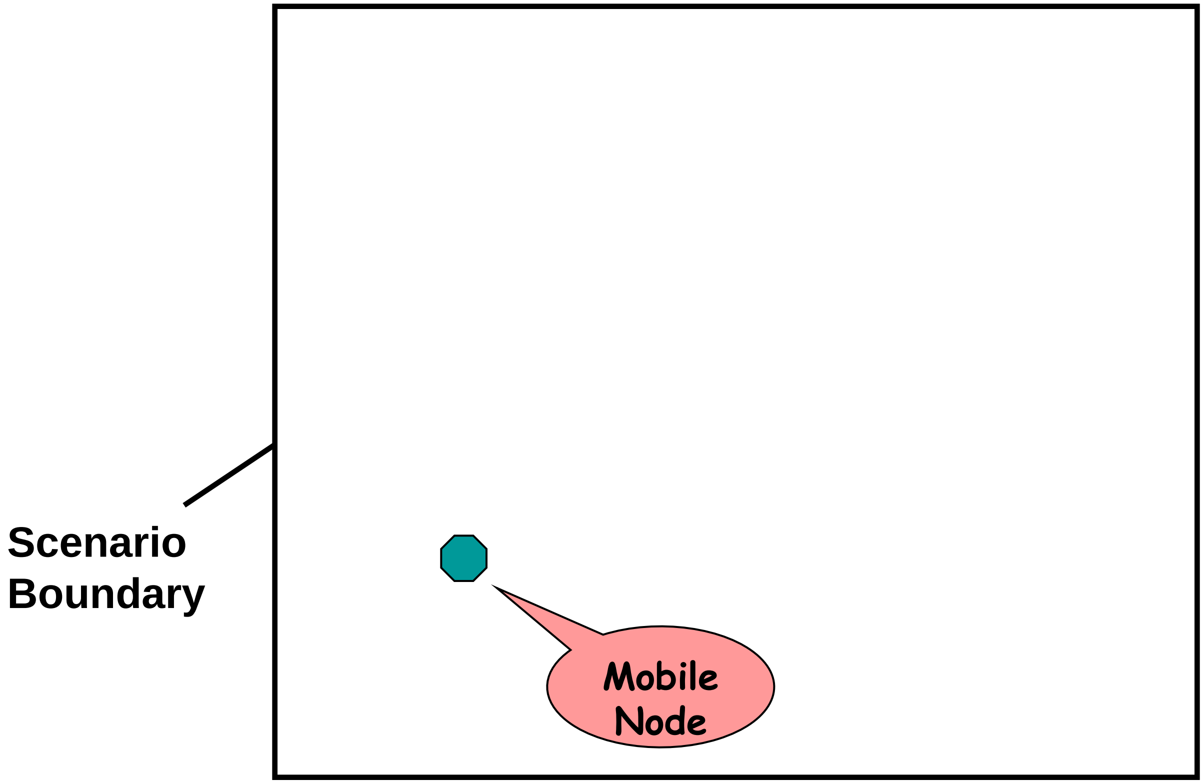
Mobility

- Random Direction
  - Characteristics:
    - Node density increases towards the border
    - Highest node density at the border and in the corners
    - The fraction of slow moving nodes increases over time
    - Short transient phase
    - Nodes in the corner are strongly affected by the applied bouncing rule
  - Advantage:
    - Simple to implement
    - Uniform distributed node density (depends on the bouncing rule)
  - Disadvantage:
    - Has to be configured carefully (Minimum speed and pause duration)
    - Movement affected by the shape of the simulation plane
    - Large impact of the bouncing rule

Mobility

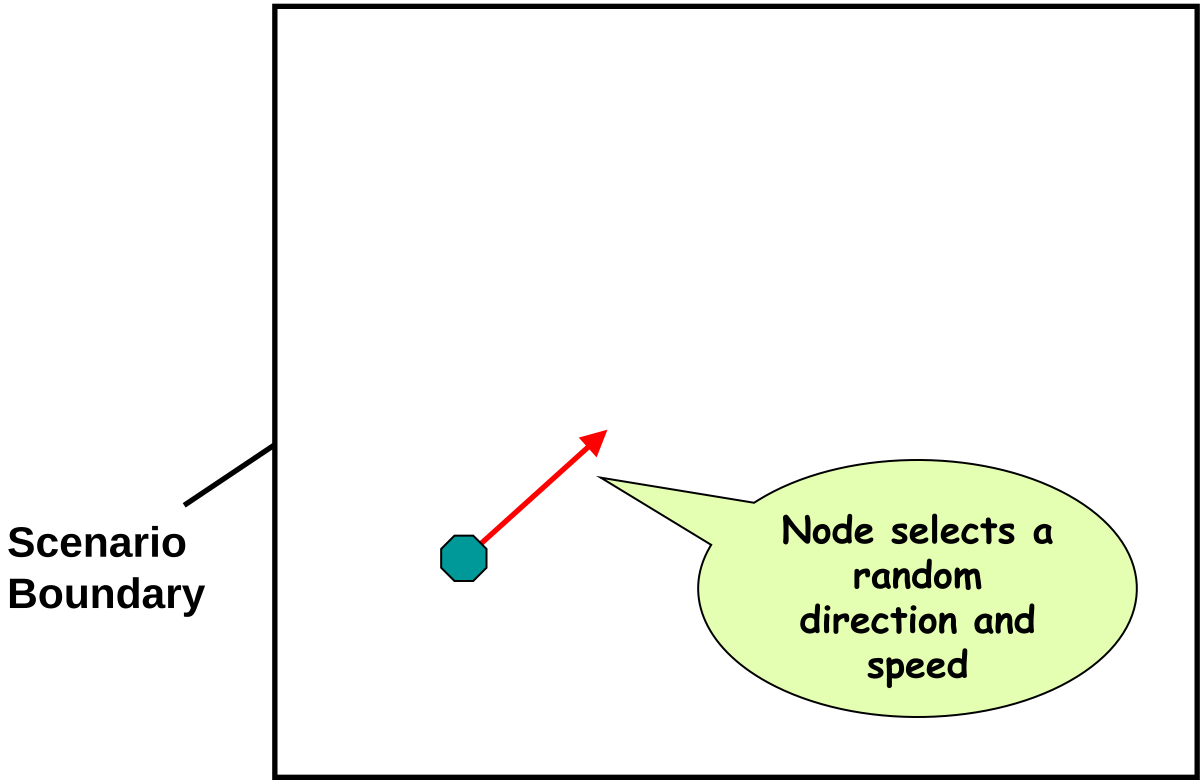
- Random Walk (time-based / distance-based)

Algorithm:



- Random Walk (time-based / distance-based)

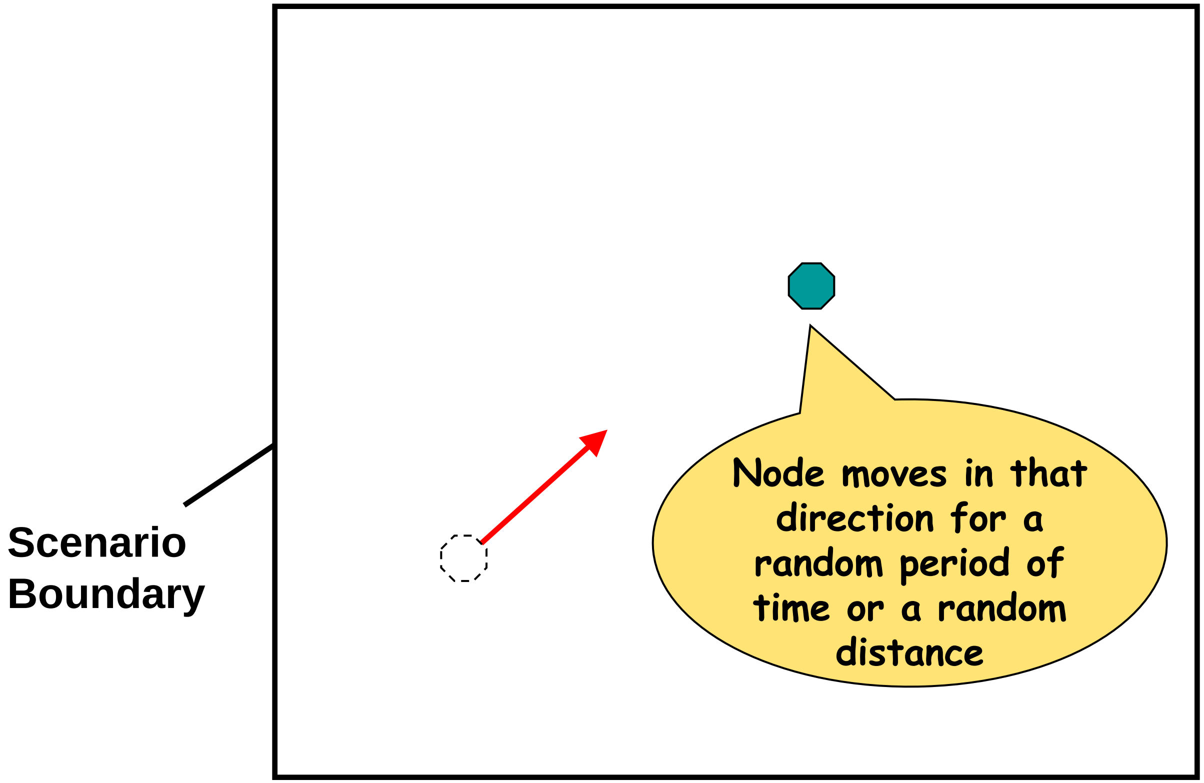
Algorithm:



Mobility

- Random Walk (time-based / distance-based)

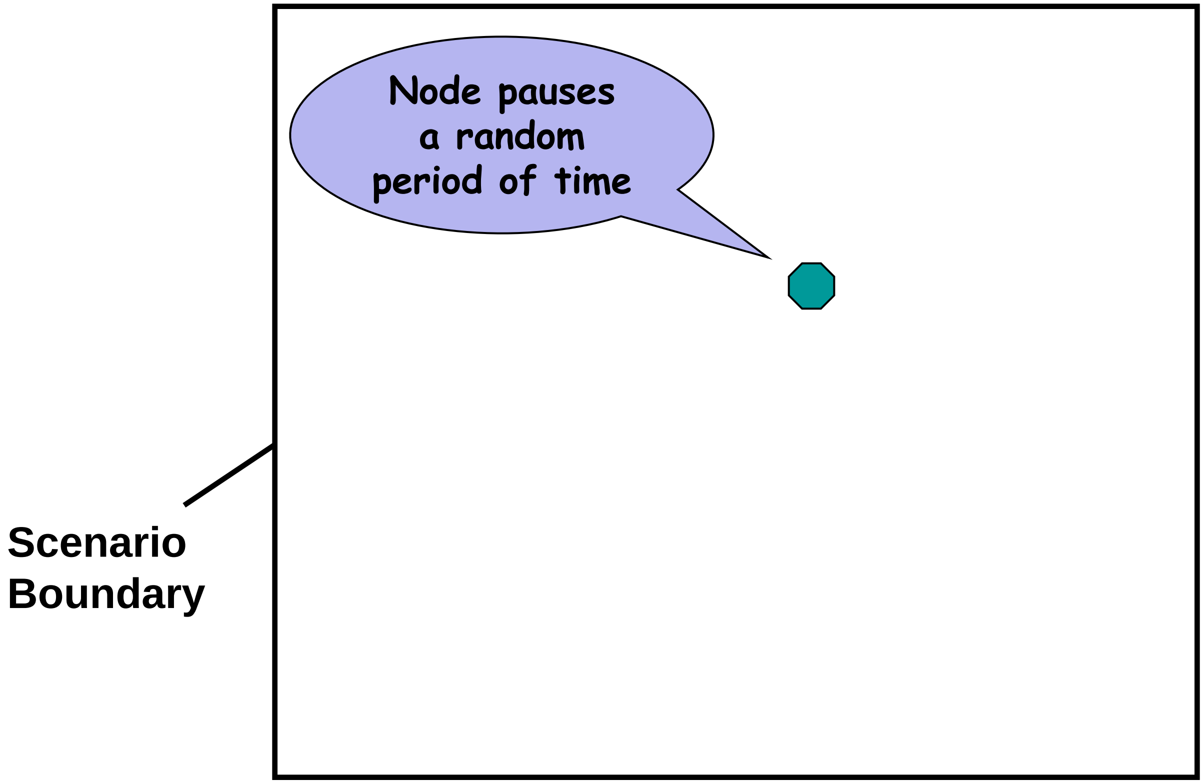
Algorithm:



Mobility

- Random Walk (time-based / distance-based)

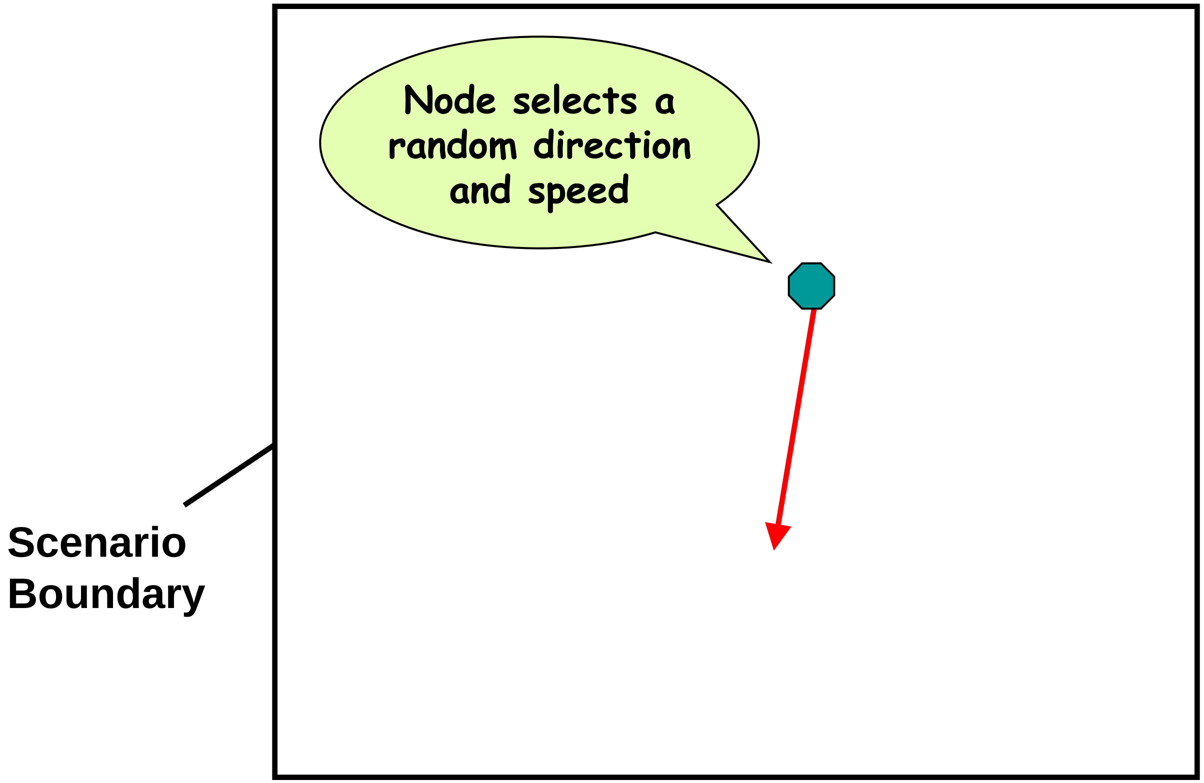
Algorithm:



Mobility

- Random Walk (time-based / distance-based)

Algorithm:



Mobility

- Random Walk (time-based / distance-based)

Algorithm:

Step 1: Select a random speed $speed \in [speed_{Min}; speed_{Max}]$

Step 2: Select a random direction $direction \in [0;2\pi]$

Step 3: Move into that direction
a. for a pre-defined period of time
b. for a certain distance
c. if the border of the scenario is reached, select a new direction (bouncing rule)

Step 4: Wait a random period of time $pause \in [0; pause_{Max}]$

Step 5: Go to step 1

Mobility

- Random Walk (time-based)
  - Characteristics (time-based):
    - Node density (almost) uniform distributed
    - Nodes in are affected by the applied bouncing rule
    - Node speed uniform distributed
  - Advantage:
    - Simple to implement
    - Uniform distributed node density (depends on the bouncing rule)
  - Disadvantage:
    - Has to be configured carefully
      - Minimum speed
      - Pause duration
      - Travel duration
    - Affected by the bouncing rule
    - Required computational power depends on the movement duration

Mobility

- Random Walk (distance-based)
  - Characteristics (distance-based):
    - Node density (almost) uniform distributed
    - Nodes in the corner are affected by the applied bouncing rule
    - Node speed decreases over time (similar to RWP)

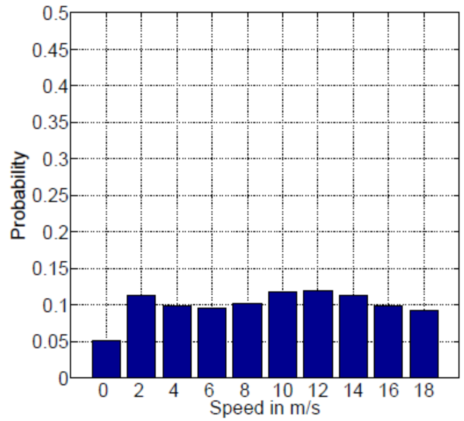
    ⇨ Speed decay problem

  - Advantage:
    - Simple to implement
    - Uniform distributed node density (depends on the bouncing rule)
  - Disadvantage:
    - Has to be configured carefully
      - Minimum speed
      - Pause duration
      - Travel distance
    - Movement affected by the shape of the simulation plane
    - Required computational power depends on the travel distance

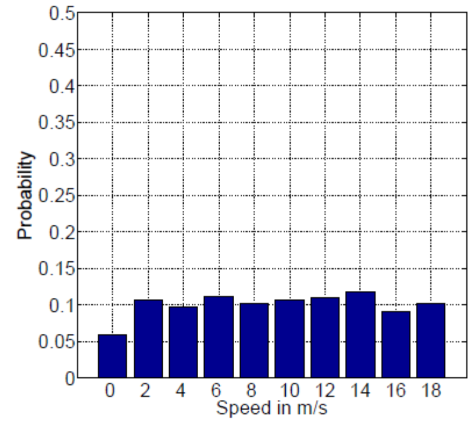
Mobility

- Random Walk (time-based)
  - Node speed distribution:

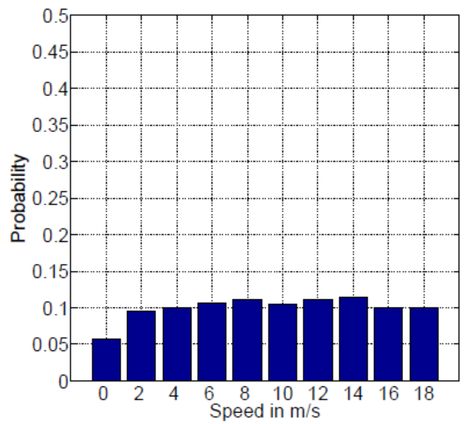
speed_{Min}	1 m/s
speed_{Max}	20 m/s
pause_{Min}	0 s
pause_{Max}	0 s
Movement	time-based
Movement Duration	10 s



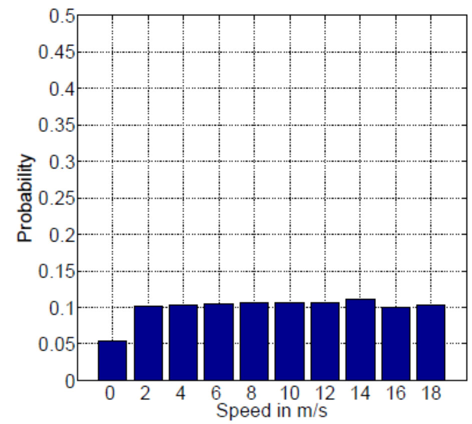
(a) 100 Seconds



(b) 200 Seconds



(c) 400 Seconds

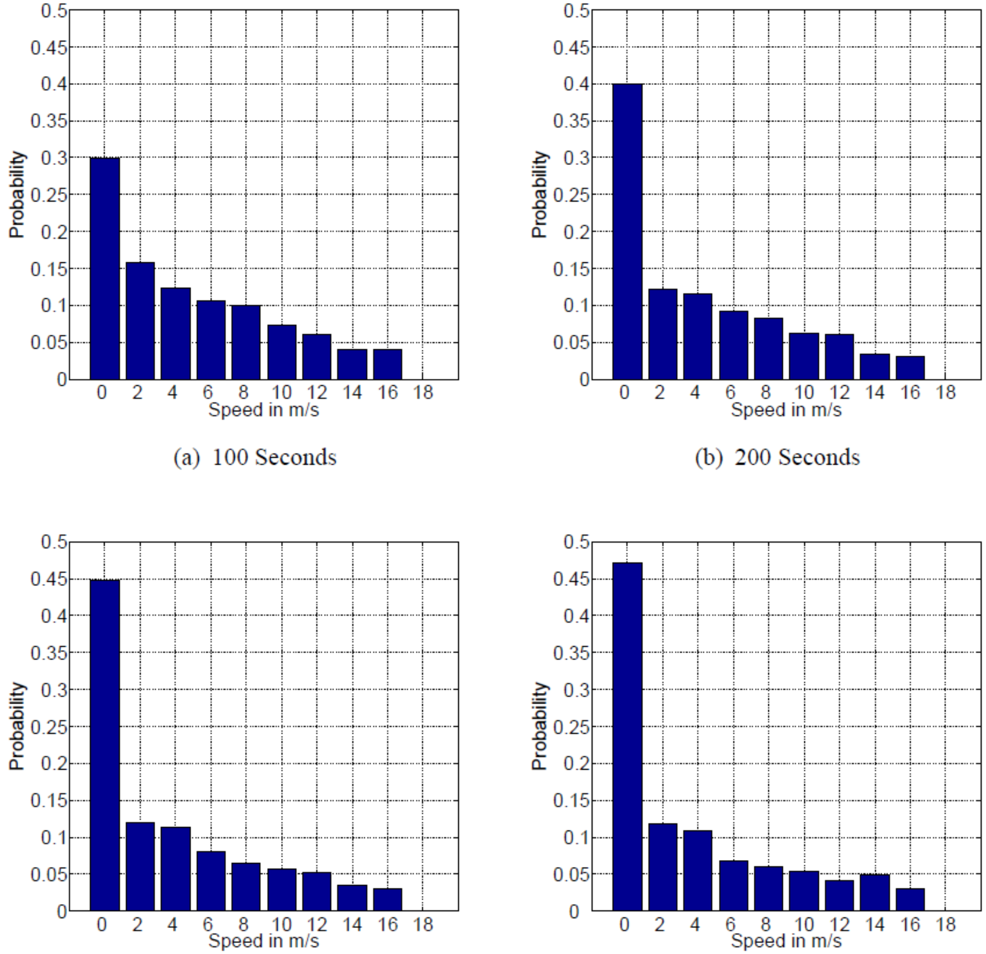


(d) 800 Seconds

Mobility

- Random Walk (distance-based)
  - Node speed distribution:

speed_{Min}	1 m/s
speed_{Max}	20 m/s
pause_{Min}	0 s
pause_{Max}	0 s
Movement	distance-based
Travel Distance	200 m

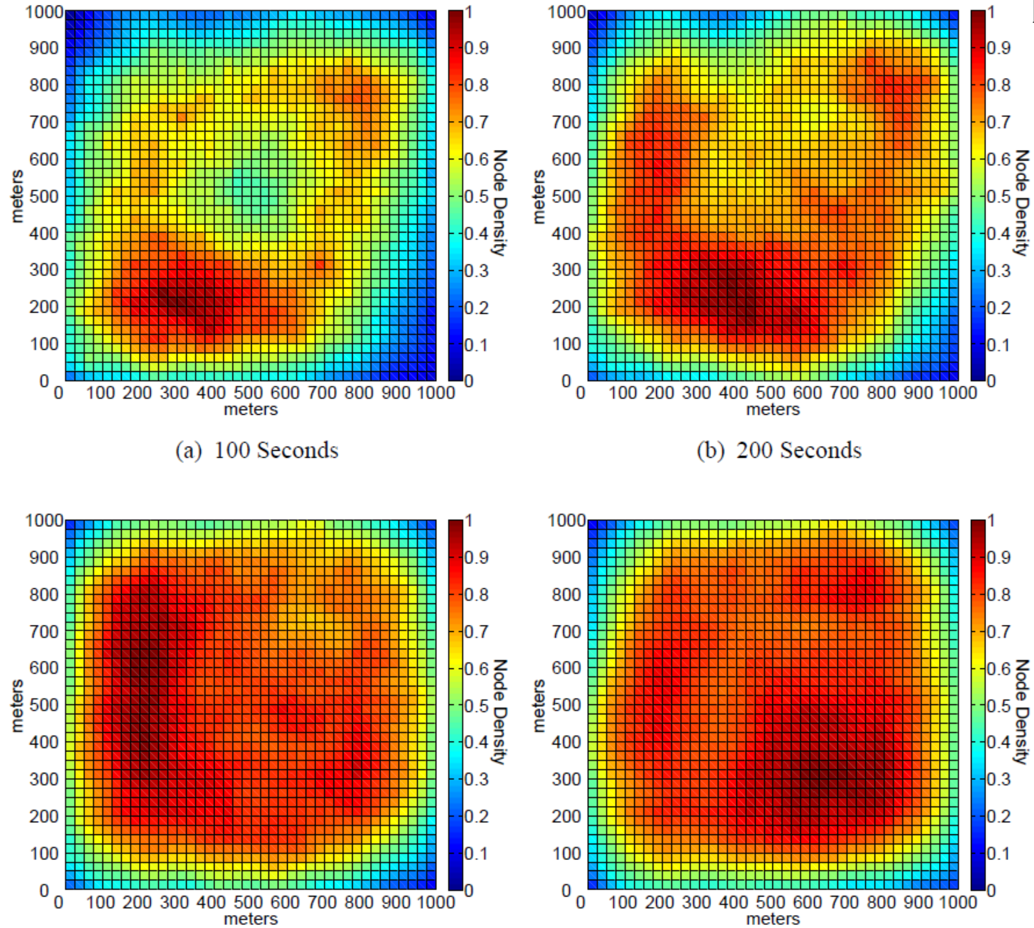


(a) 100 Seconds (b) 200 Seconds

(c) 400 Seconds (d) 800 Seconds

- Random Walk (time-based)
  - Node density:

$speed_{Min}$	1 m/s
$speed_{Max}$	20 m/s
$pause_{Min}$	0 s
$pause_{Max}$	0 s
Movement	time-based
Movement Duration	10 s

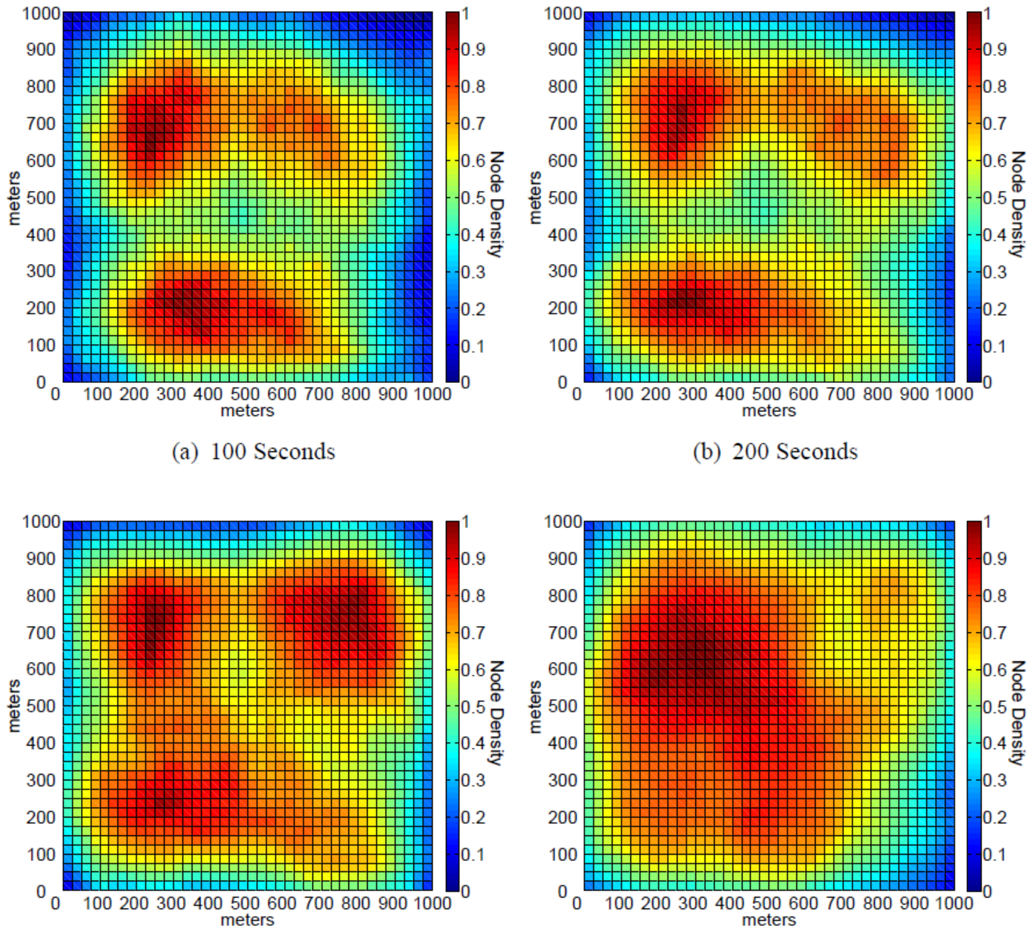


(a) 100 Seconds
(b) 200 Seconds
(c) 400 Seconds
(d) 800 Seconds

Mobility

- Random Walk (distance-based)
  - Node density:

speed$_{Min}$	1 m/s
speed$_{Max}$	20 m/s
pause$_{Min}$	0 s
pause$_{Max}$	0 s
Movement	distance-based
Travel Distance	200 m

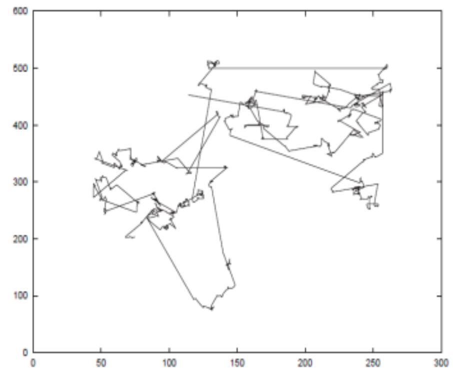


(a) 100 Seconds (b) 200 Seconds

(c) 400 Seconds (d) 800 Seconds

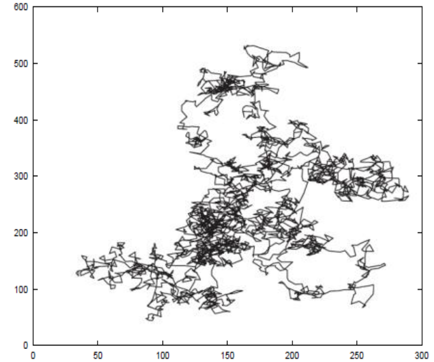
Mobility

- Random Walk
  - Lévy flight
    - Distance-based random walk
    - Distance is chosen according to a heavy-tailed distribution
    - Probability is high that the object only moves a short distance
    - Probability is low that the object moves straight over a long distance
    - Often used to simulate the movement of humans and animals



Example: Lévy flight

  - Brownian Motion
    - Distance-based random walk
    - Travel distance between subsequent points is close to zero
    - Describes the movement of small particles in liquids



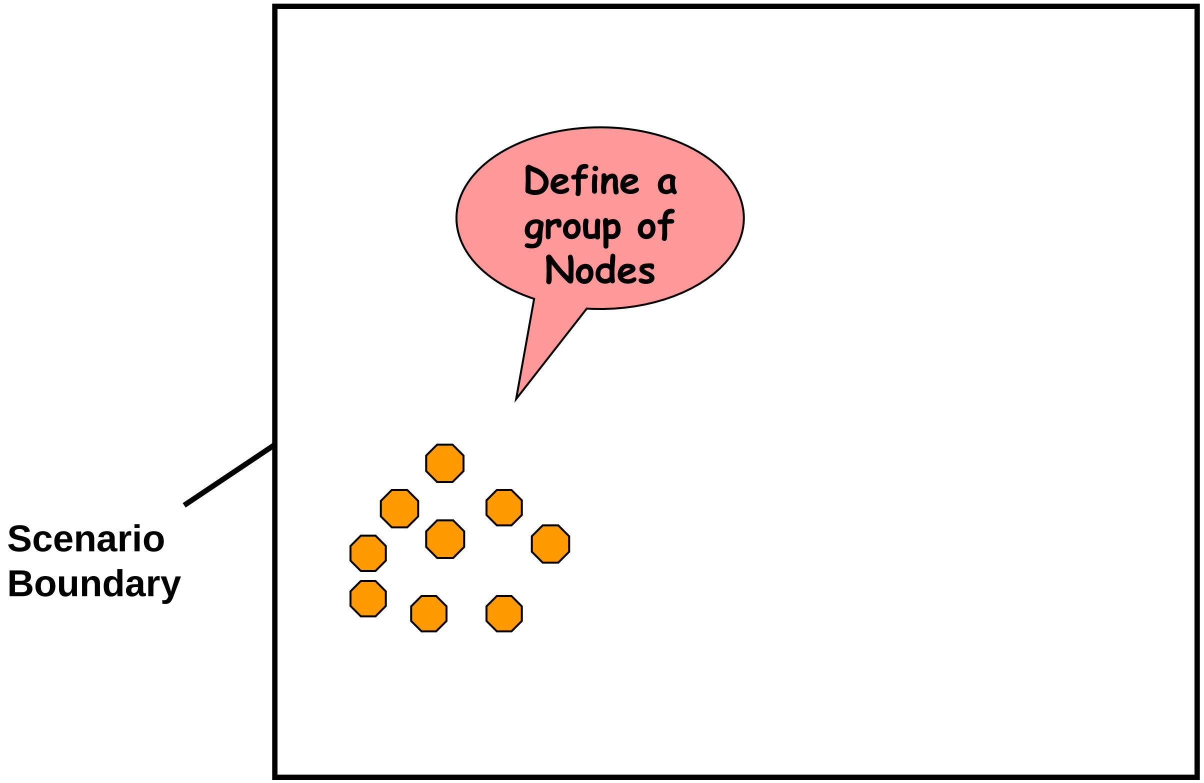
Example: Brownian Motion

Mobility

- Random Walk (according to Turchin)
  - Uncorrelated random walk:
    - Previous move does not affect the following move
    - Each move is independent from the previous one
  - Correlated random walk:
    - Previous move affects the following move
      - High probability of moving into the same direction
      - Long travels are followed by short travels with high probability
  - Biased random walk:
    - The probability of moving in a certain direction is higher than moving into other directions (non-uniform selection of the direction)
  - Biased correlated random walk:
    - Each move is affected by the previous one and an absolute direction
  - Constrained random walk:
    - Measured parameters and estimated distributions are used as input for the synthetic mobility model
    - The direction and speed are chosen with respect to the measurements

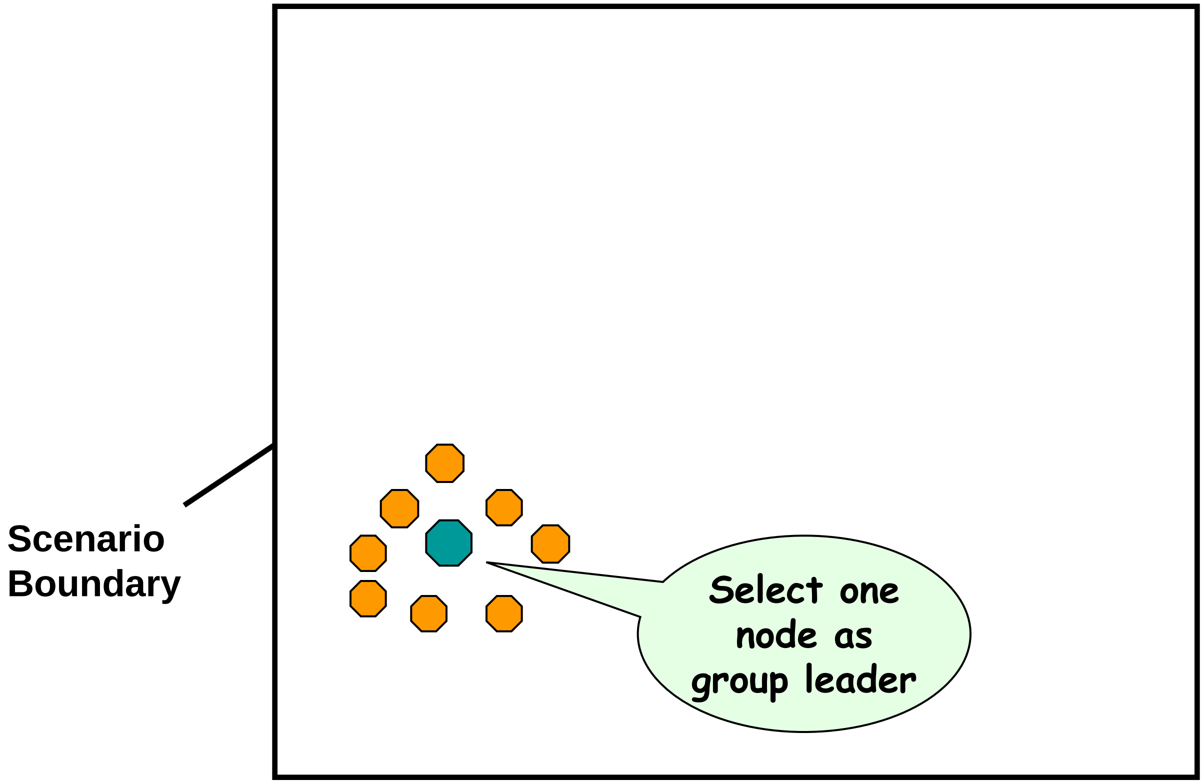
- Random Group Mobility

Algorithm:



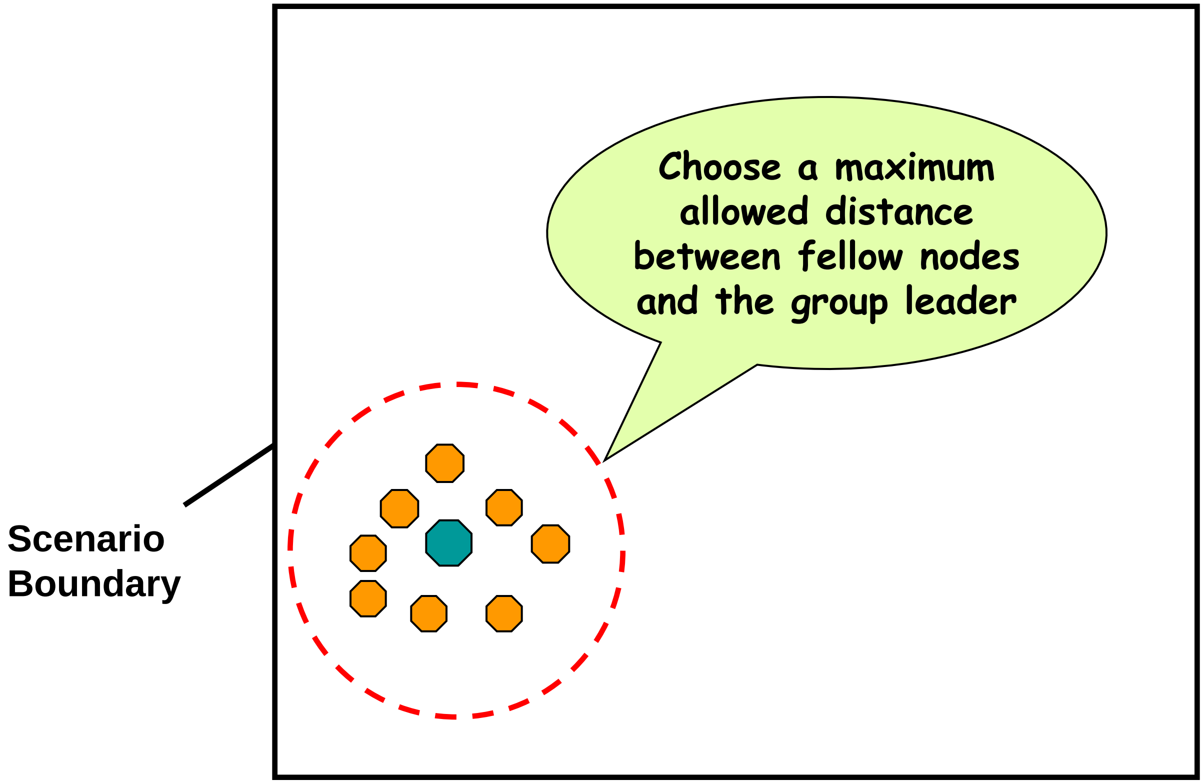
- Random Group Mobility

Algorithm:



❑ Random Group Mobility

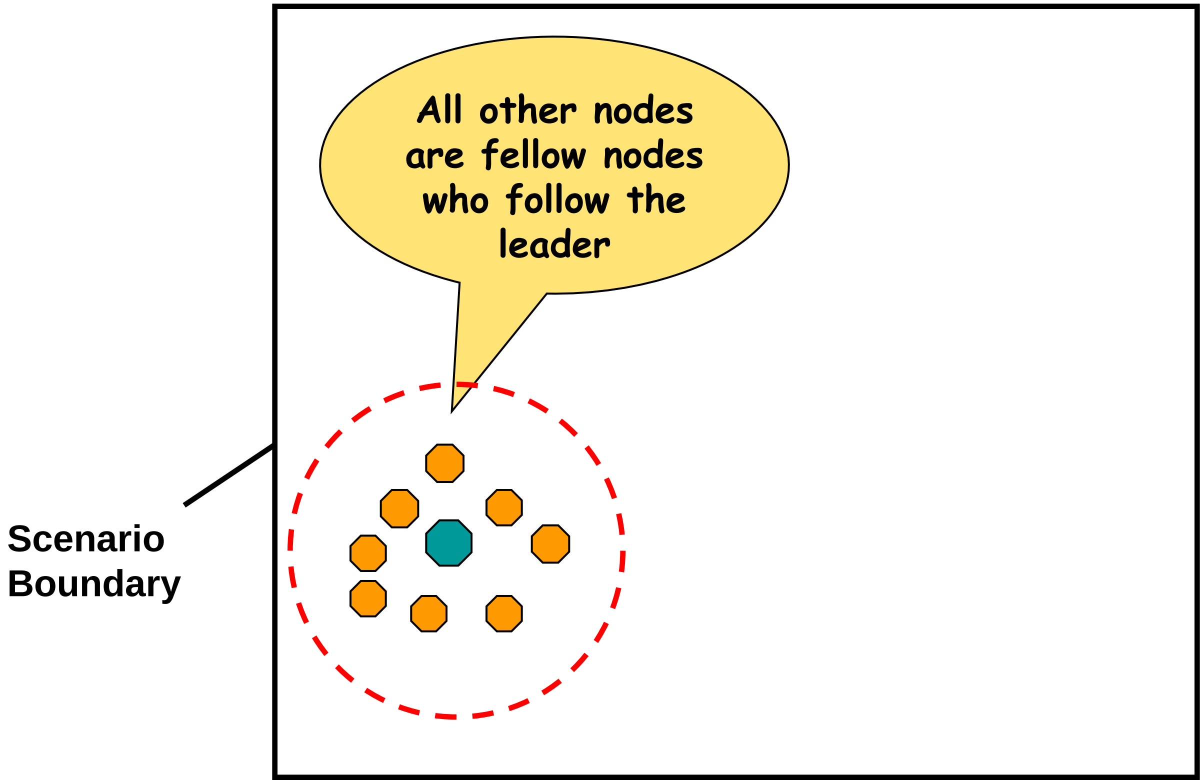
Algorithm:



Mobility

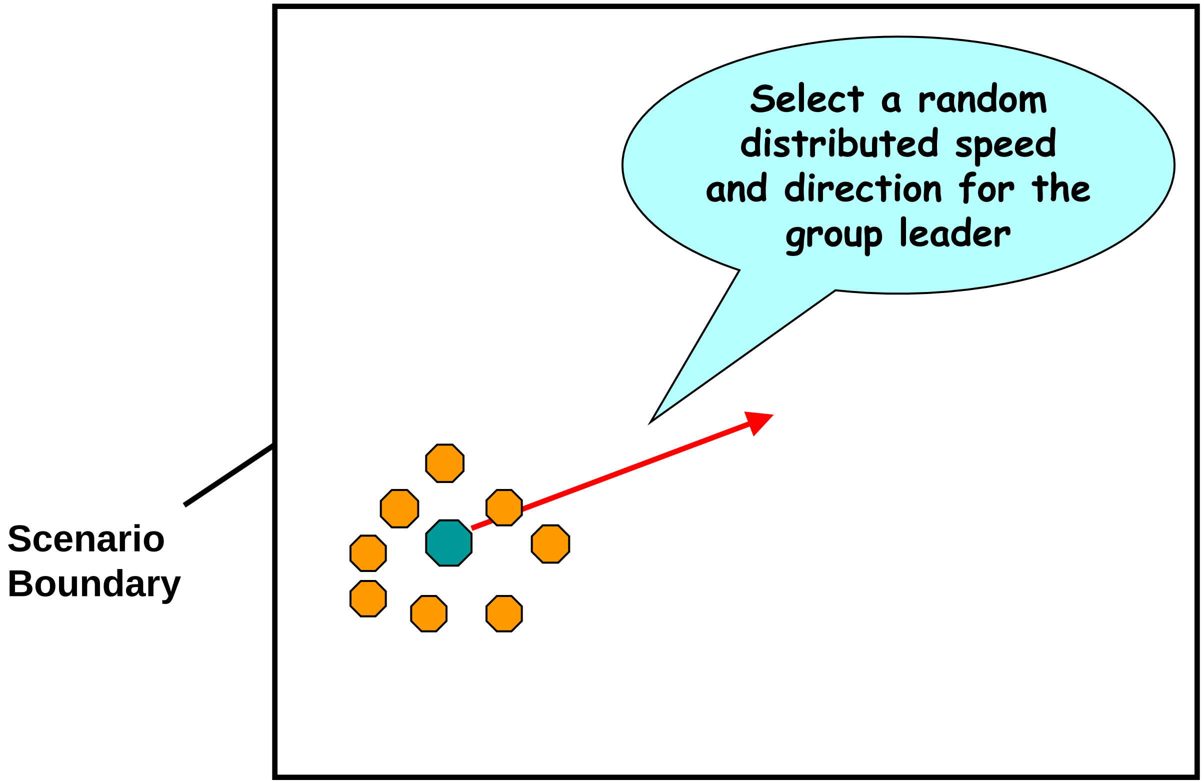
- Random Group Mobility

Algorithm:



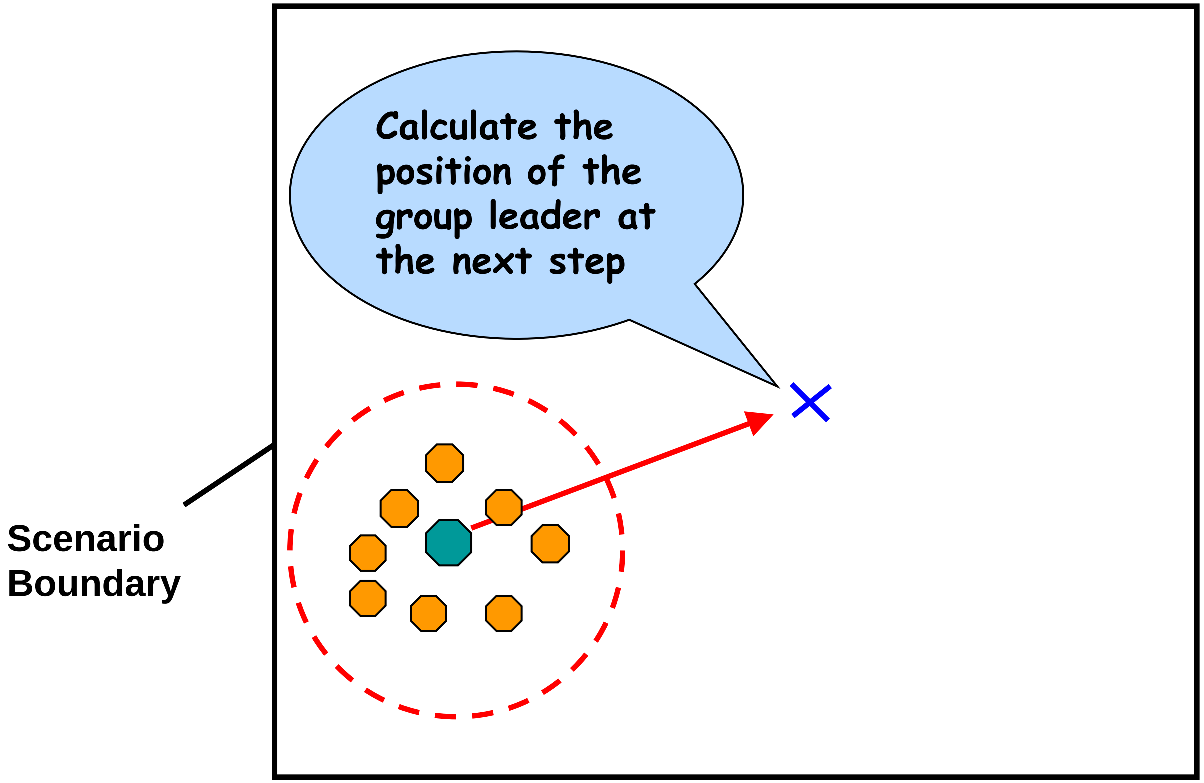
- Random Group Mobility

Algorithm:



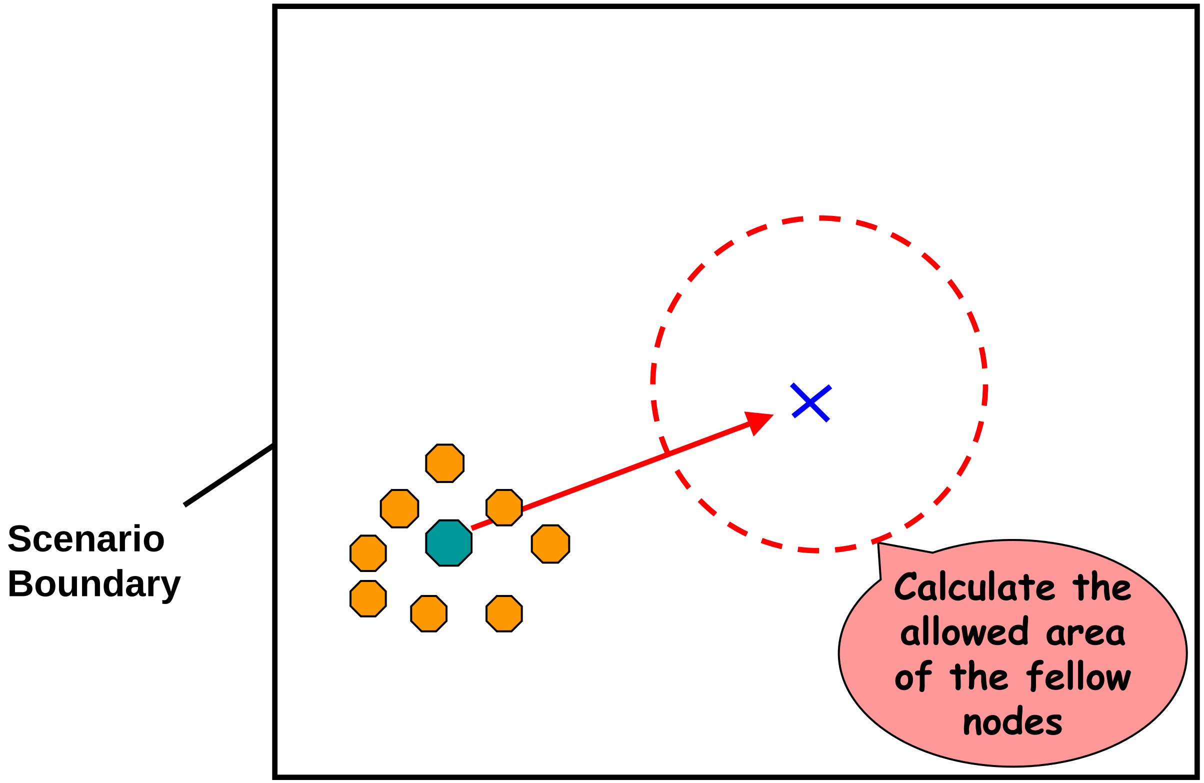
- Random Group Mobility

Algorithm:



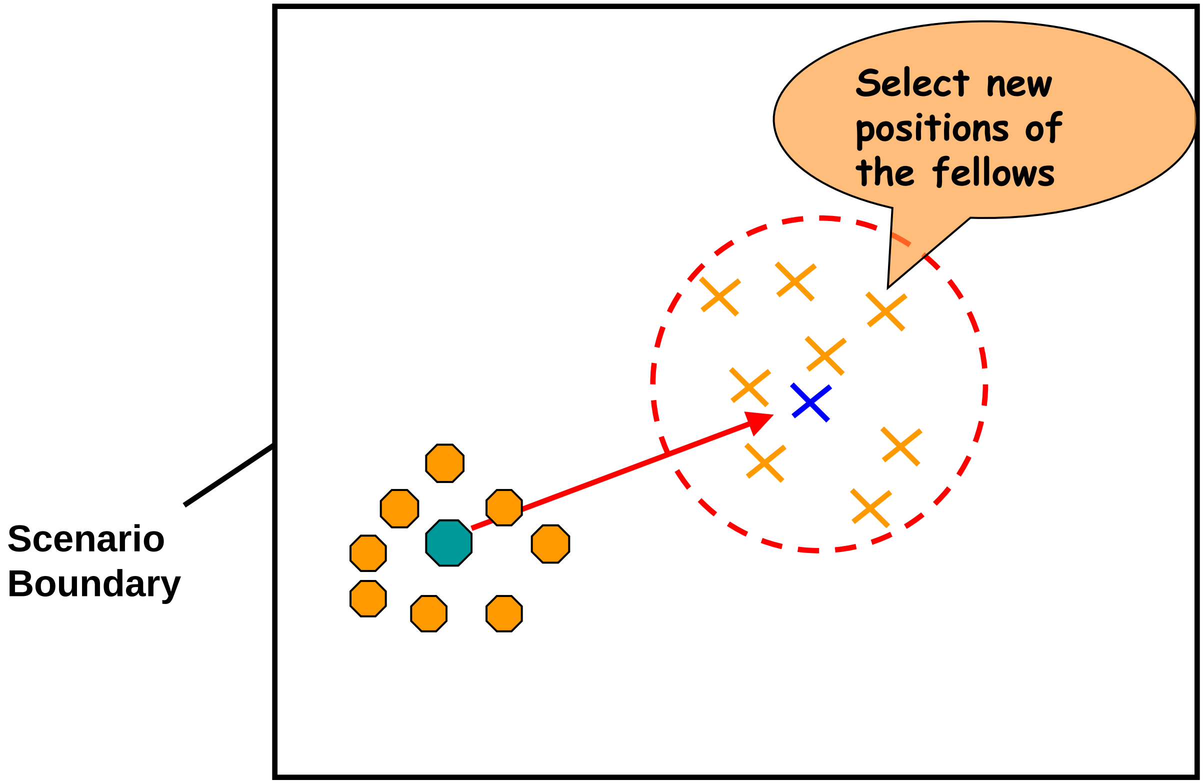
- Random Group Mobility

Algorithm:



- Random Group Mobility

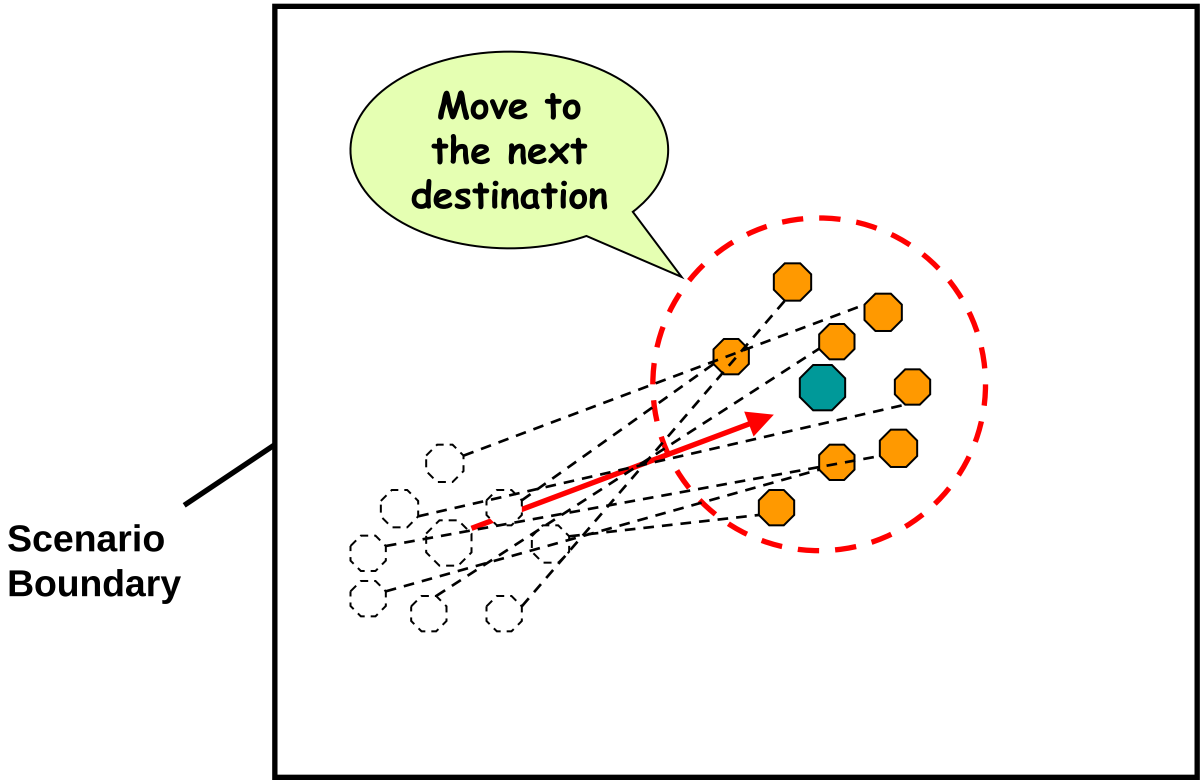
Algorithm:



Mobility

- Random Group Mobility

Algorithm:



- Random Group Mobility

Algorithm (1/2):

Preliminary steps

Step 1: Define a group of nodes
Step 2: Select one node as group leader and mark the others as fellows
Step 3: Choose the maximum allowed distance between a fellow node and the group leader

Group leader

Step 4: Select a random speed $speed \in [speed_{Min}; speed_{Max}]$
Step 5: Select a random direction $direction \in [0; 2\pi]$
Step 6: Go to step 10
Step 7: Move into that direction
  a. for a pre-defined period of time / remaining movement duration
  b. for a pre-defined distance
  c. Go to step 15 if the border of the scenario is reached before the movement is complete
Step 8: Wait a random period of time $pause \in [0; pause_{Max}]$
Step 9: Go to step 4

- Random Group Mobility

  Algorithm (2/2):

  Fellow nodes

Step 10:	Calculate the position of the group leader at the next movement / bouncing position
Step 11:	Calculate the allowed area around the group leader at the next movement / bouncing position
Step 12:	Choose a random position within the allowed area
Step 13:	Calculate speed and direction such that the new position is reached at the same time the group leader reaches its next movement / bouncing position
Step 14:	Go to step 7

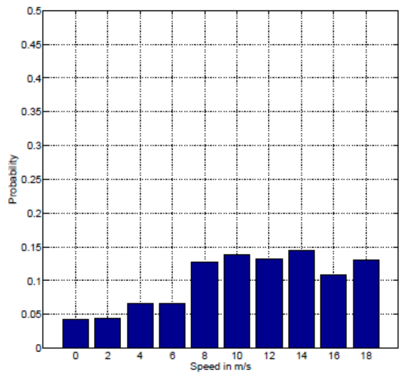
  Group leader

Step 15:	Select a new direction of the group leader
Step 16:	Go to step 10

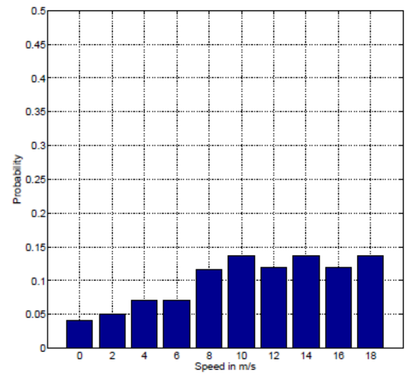
Mobility

- Random Group Mobility
  - Node speed distribution:

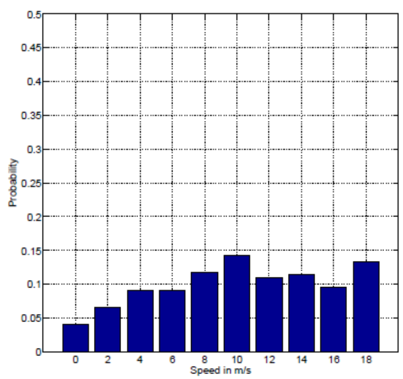
Leader Mobility	Random Walk(time-based)
Leader-Fellow Distance	< 200m
Fellow Area	circle
$speed_{Min}$	5 m/s
$speed_{Max}$	20 m/s
$pause_{Max}$	0 s
Movement Duration	20 s



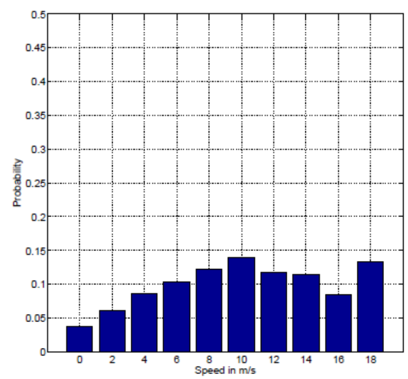
(a) 100 Seconds



(b) 200 Seconds



(c) 400 Seconds

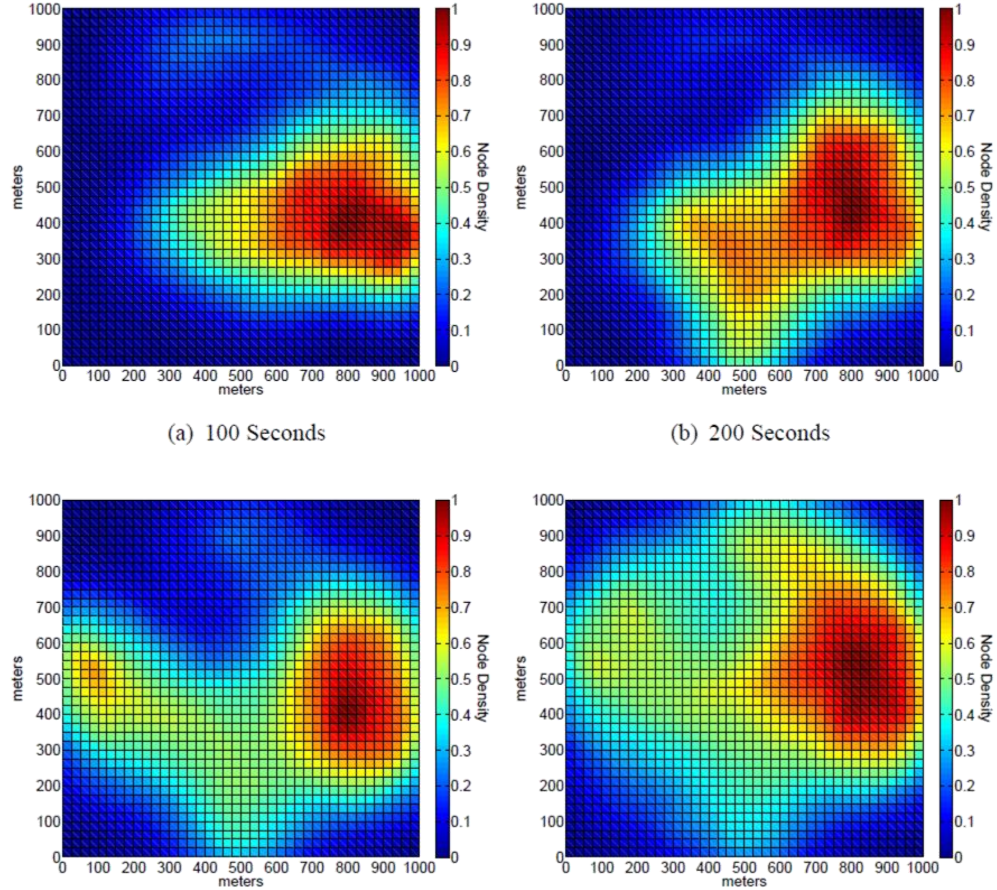


(d) 800 Seconds

Mobility

- Random Group Mobility
  - Node density:

Leader Mobility	Random Walk(time-based)
Leader-Fellow Distance	< 200m
Fellow Area	circle
$speed_{Min}$	5 m/s
$speed_{Max}$	20 m/s
$pause_{Max}$	0 s
Movement Duration	20 s

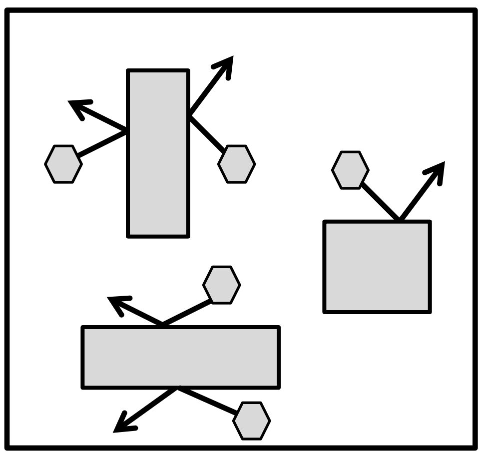


(a) 100 Seconds (b) 200 Seconds

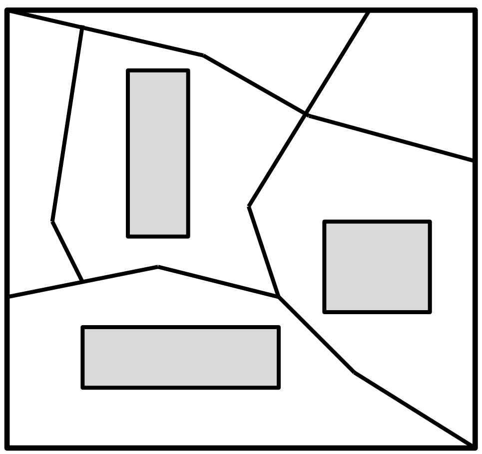
(c) 400 Seconds (d) 800 Seconds

Mobility

- Obstacles:
  - Movement of objects is usually constraint by
    - obstacles
    - pre-defined pathways
  - Bouncing rule becomes more import with an increasing number of obstacles
  - Obstacles block movement but do not necessarily affect the signal propagation (e.g. river or lake)
  - Some models use Voronoi diagrams as predefined paths



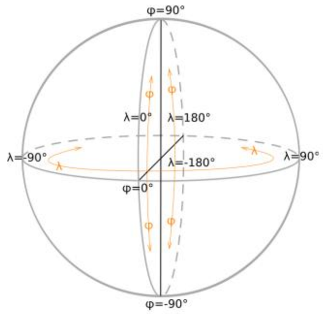
Movement with obstacles



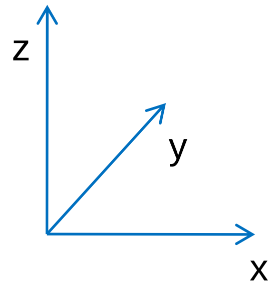
Movement with obstacles and predefined paths

Mobility

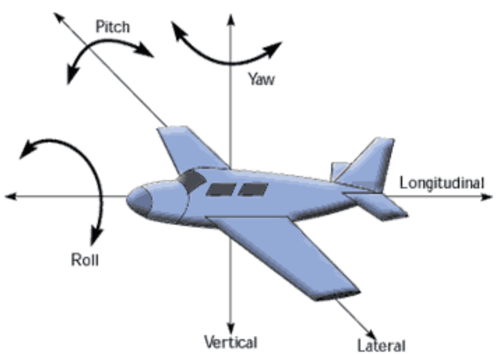
- How to describe position and orientation?
  - Position:
    - Geographic
      Latitude φ, Longitude λ, Altitude



    - Cartesian
      X, Y, Z



  - Orientation:
    - Yaw
    - Pitch
    - Roll



Picture taken from nasa.gov

Mobility

- Implementation:
  - Types of mobility
    - Direct
      - Change the position and orientation of objects directly at a given simulation time
    - Trajectory
      - Sequence of triples [position, orientation, simulation time] which describe the position and orientation at a given simulation time
      - The movement is usually interpolated between subsequent triples
    - Vector
      - Bearing, ground speed, ascent rate
      - Trajectories can be described by [bearing, ground speed, simulation time] triples
    - External modification
      - Co-simulation
      - Hardware-In-The-Loop
      - Can use any type of mobility