Connecting Moving Objects: Managing the Complexity of Movement in Modern Communication Networks

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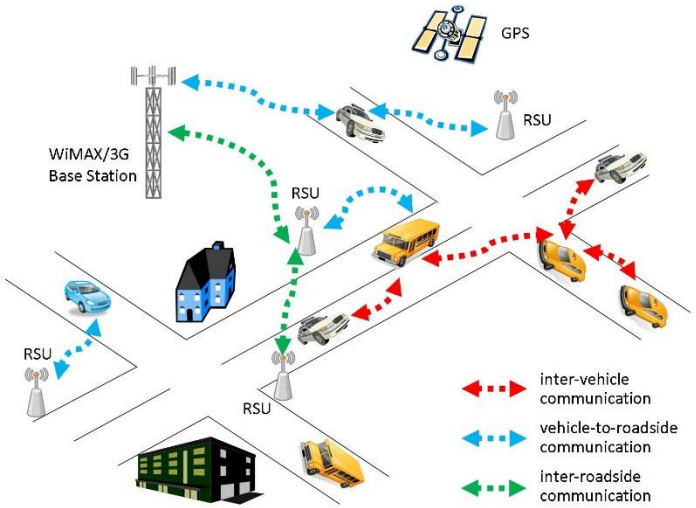
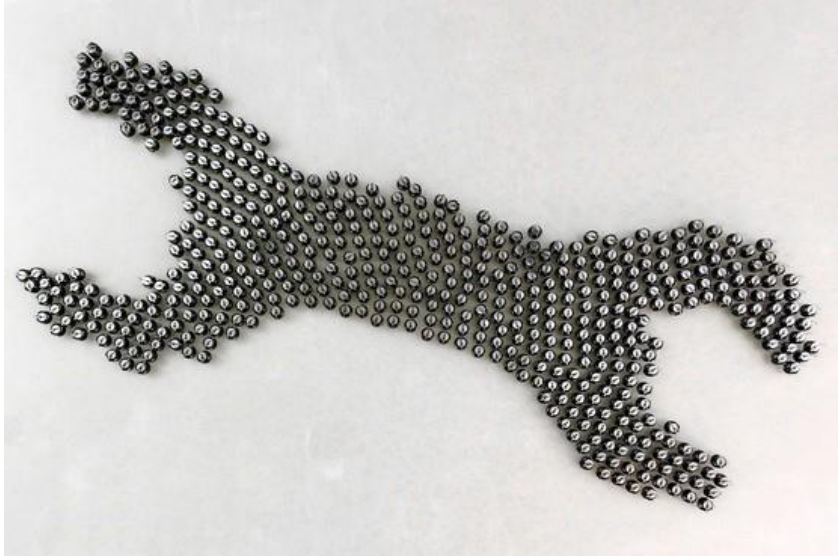
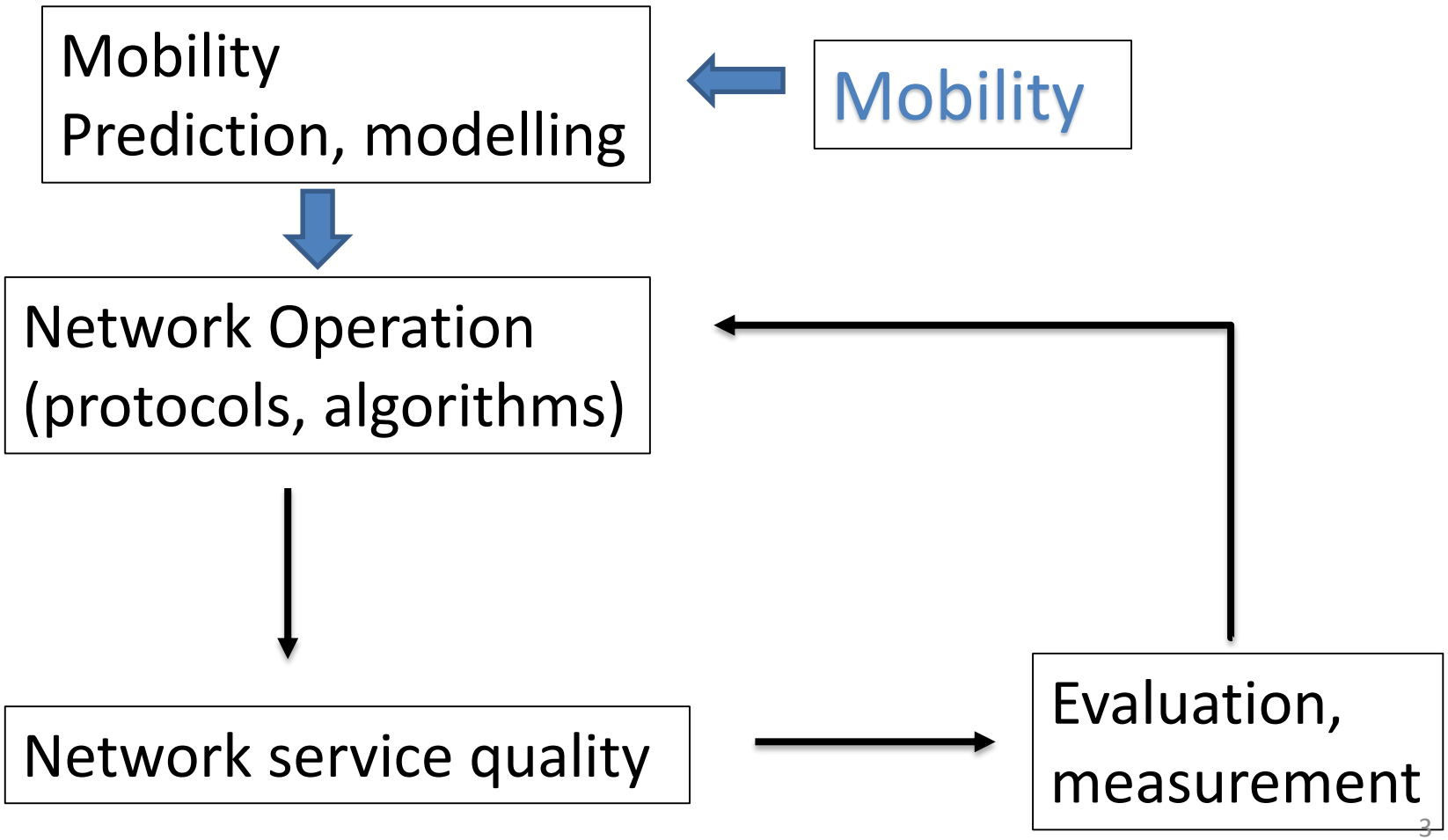
Movement + Networks





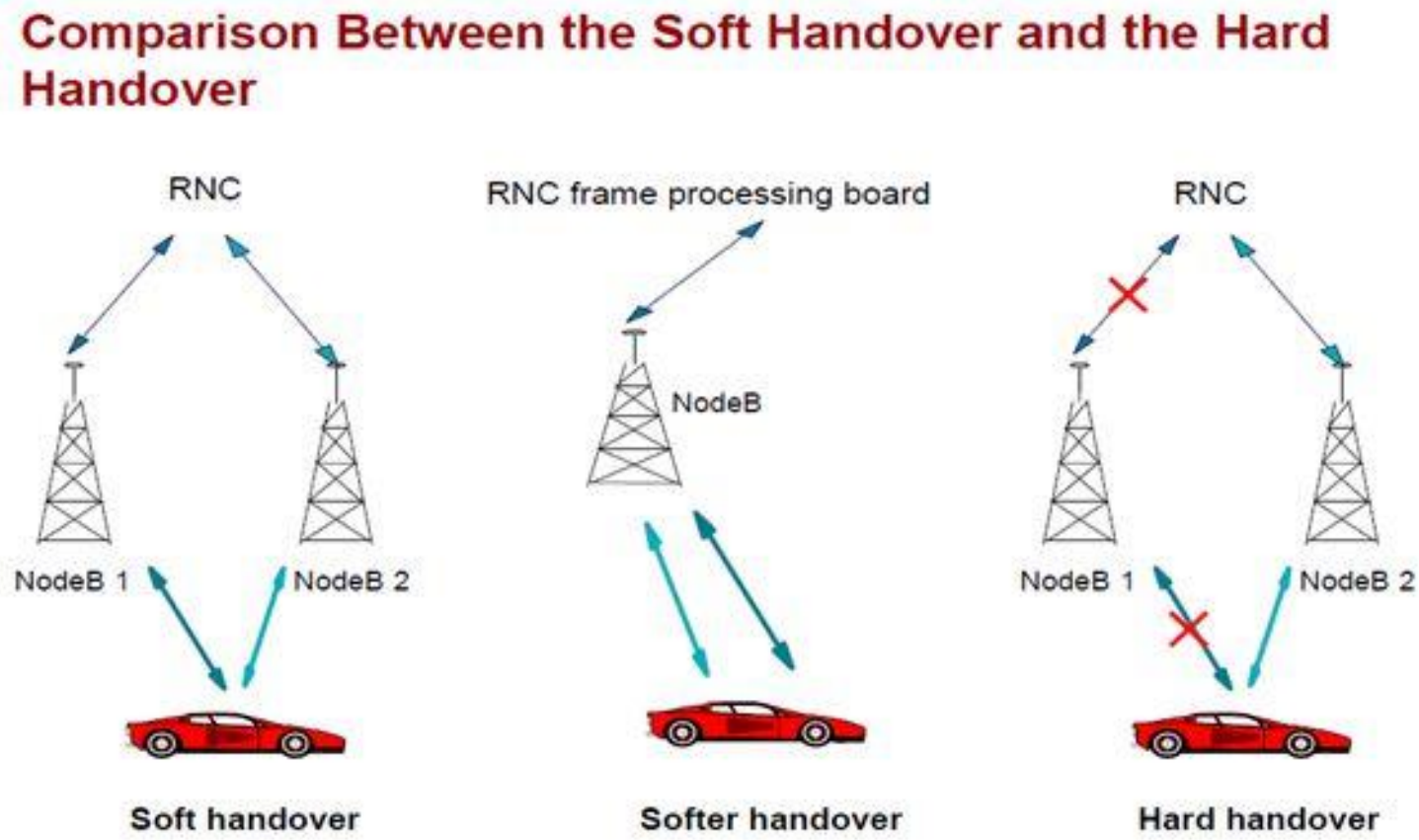
Network development process is an engineering process



Managing mobility

- Networks depend on a reliable physical connection to carry data
- In the networks of moving objects, this reliability cannot be assumed
- their point of attachment to the network is constantly changing

Traditionally…



In the Internet of ‘things’…

- Problems are multiplied
  - Networks are now built as simple distributed systems, rather than complex Base Station-based networks
- Particularly important is the local mobility
  - Compared with the ‘global’, GPS-based mobility

Complexity here is in…

- … the scale, not the models
- … the operation, not the optimisation

- Optimisation is often not interesting, frequently ignored and never implemented

- ‘best effort’ approach to research and development

Mobility models, simulation and generation

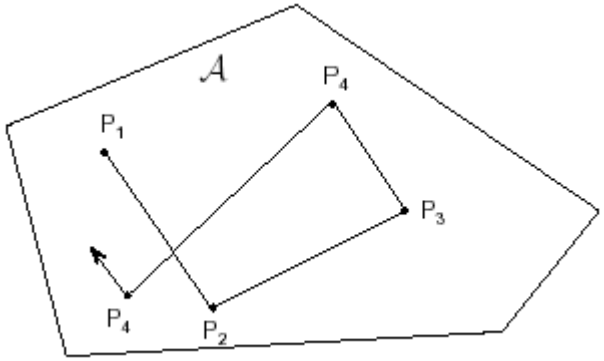
- Currently there are two types of mobility generators used in the simulation of networks:
  - trace-based
  - synthetic models
- Trace-based are those mobility patterns that are observed in real life systems.
- Synthetic models attempt to realistically represent the behaviors of MNs without the use of traces
- Hidden markov models
  - Used in modelling of animal/human movement

Mobility models – synthetic

- **Random Walk Mobility Model** (including its many derivatives): A simple mobility model based on random directions and speeds.
- **Random Waypoint Mobility Model**: A model that includes pause times between changes in destination and speed.
- **Random Direction Mobility Model**: A model that forces MNs to travel to the edge of the simulation area before changing direction and speed.
- **A Boundless Simulation Area Mobility Model**: A model that converts a 2D rectangular simulation area into a torus-shaped simulation area.
- **Gauss-Markov Mobility Model**: A model that uses one tuning parameter to vary the degree of randomness in the mobility pattern.
- **A Probabilistic Version of the Random Walk Mobility Model**: A model that utilizes a set of probabilities to determine the next position of an MN.
- **City Section Mobility Model**: A simulation area that represents streets within a city.

Random waypoint model

- Briefly, in the RWP model:
  - Each node moves along a zigzag line from one waypoint Pi to the next Pi+1.
  - The waypoints are uniformly distributed over the given convex area, e.g. unit disk.
  - At the start of each leg a random velocity is drawn from the velocity distribution. (in the basic case the velocity is constant 1)
  - Optionally, the nodes may have so-called "thinking times" when they reach each waypoint before continuing on the next leg, where durations are independent and identically distributed random variables.
- Common problems:
  - Zig-zag trajectories
  - Poor choice of velocity distribution



at every instant, a node randomly chooses a destination and moves towards it with a velocity chosen uniformly and randomly from pre-defined ranges such as [0, *Vmax*],

Trace-based modelling

- Acquiring traces
  - use a particular tool to monitor the location of the devices being traced
  - monitor the communication of the devices to base stations of a communication system
  - monitor the contacts between mobile devices
  - the Global Positioning System (GPS) is the most widely used outdoor localization system
  - If more accurate positioning is needed, an RFID-based approach can be used

Trace based models

- CrawDaD, http://crawdad.org/
- ETH MMTS, http://www.lst.inf.ethz.ch/research/ad-hoc/car-traces/
- UMASS DieselNet, https://dome.cs.umass.edu/umassdieselnet
- MIT Reality Mining, http://realitycommons.media.mit.edu/realitymining.html

Monitoring communications

- The location of a device can be approximated by monitoring the signal strength of the base station/access point (BS/AP) and/or the connectivity events of the device
- Mostly used indoors
- The accuracy of this communication monitoring approach is limited for two reasons:
  - the accuracy depends on the density of the access points. if the density of the access points is quite high, a node may not be connected to the nearest access point
  - a strong correlation exists between a device's signal strength and its distance to the access point. This assumption is unlikely to hold, especially in environments where deep fading occurs.

Global location and mobility tracking - example

- cTrack/vTrack – MIT
- match a sequence of GSM tower observations, rather than a single point at a time

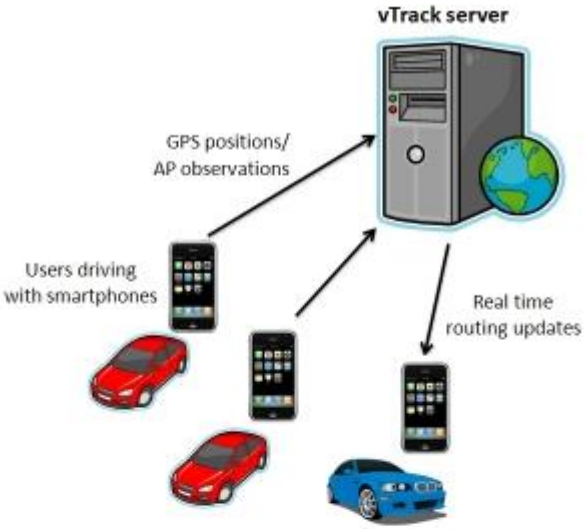
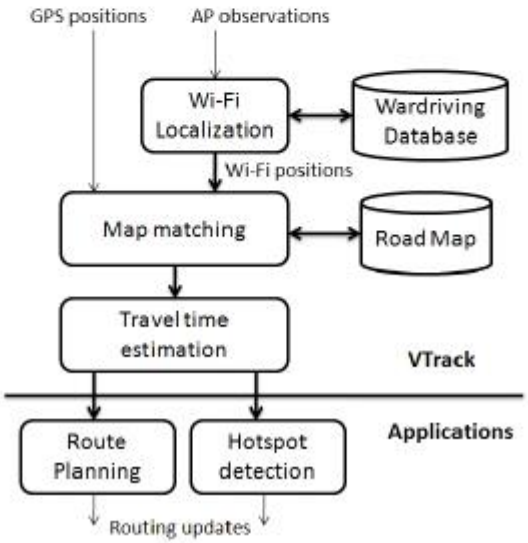
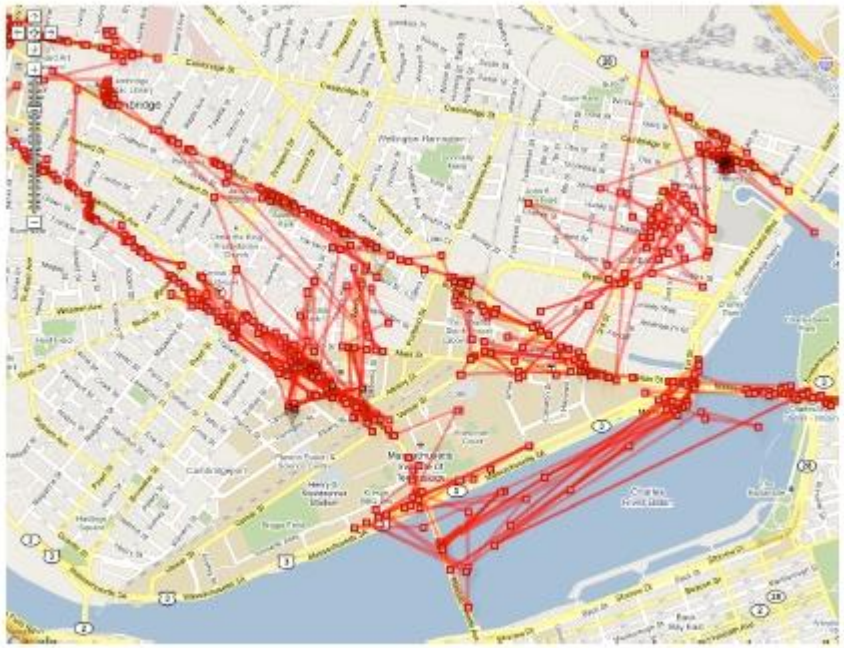


Figure 1: Architecture



Smoothing algorithms…



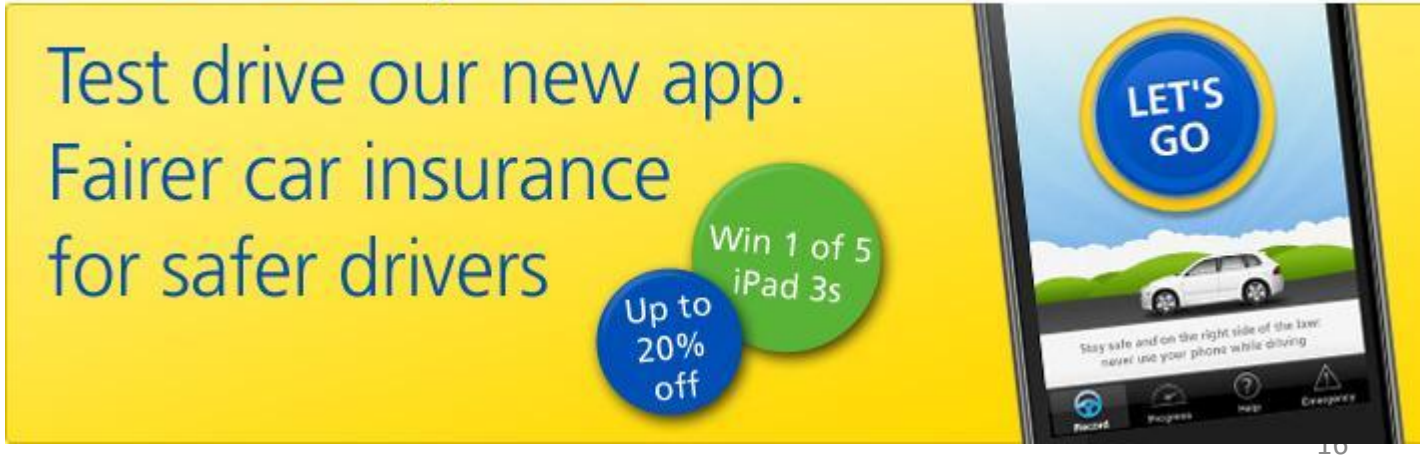
(a) Raw points before sequencing

(d) Final map-matched output

Accurate, Low-Energy Trajectory Mapping for Mobile Devices.
A Thiagarajan, L Ravindranath, H Balakrishnan… - NSDI, 2011

Applications….?

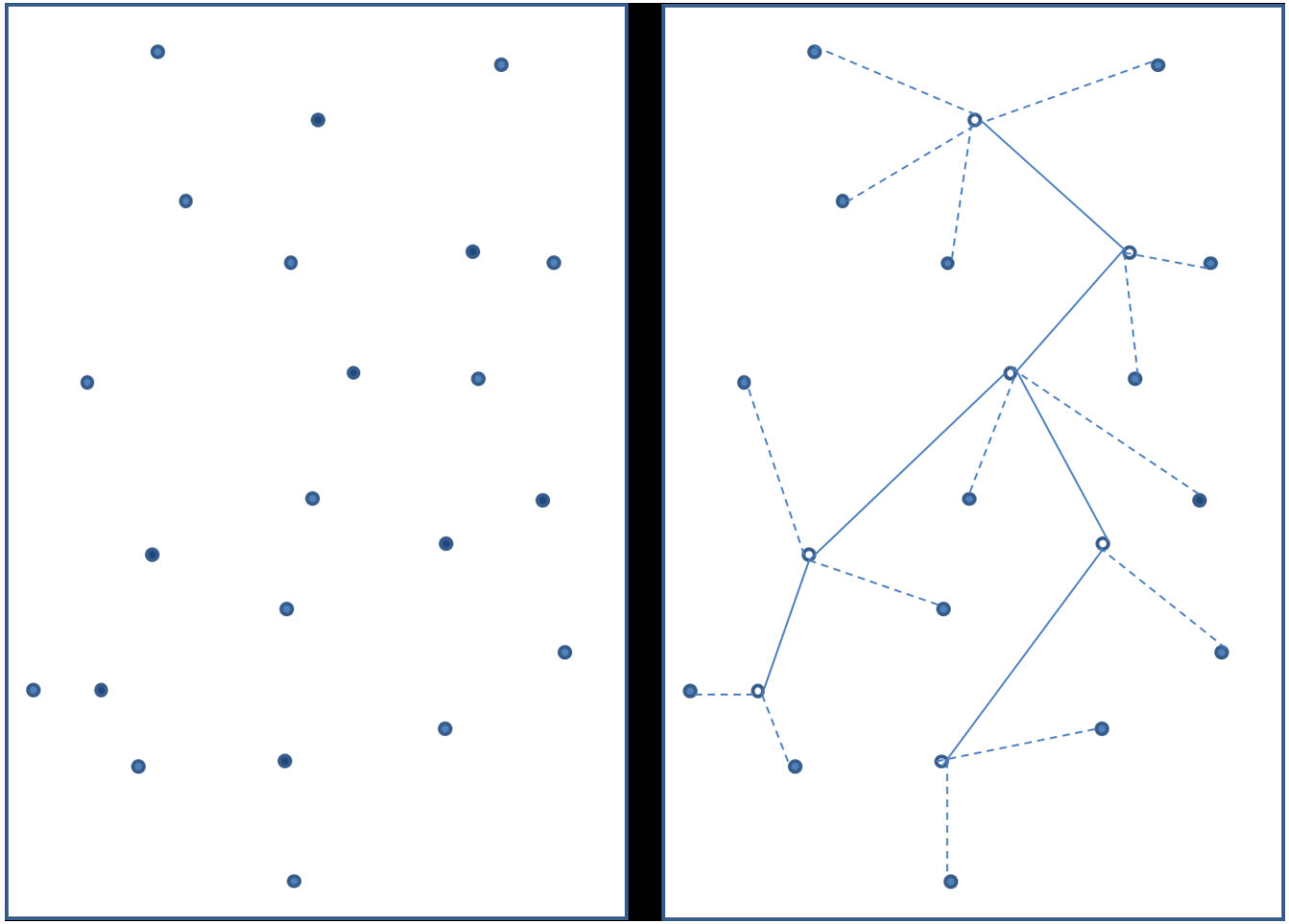
Aviva RateMyDrive



Mobility and clustering

- generation of groups of nodes which share some common features and communicate to the rest of the network via their leader (often called the clusterhead), rather than individually
- other features, such as speed of movement, application interest or established trust agreements can be considered

Ad hoc networks - clustering



Mobility based clustering

(1) clusterhead election process
(2) cluster maintenance

- The movement generates the following problems:
  - The clusters become unstable, because members of the clusters move and can often disappear out of the range of the clusterhead
  - the lack of stability of the cluster can have a major impact on the quality of the aggregated data
  - the amount of time the nodes are not connected into the networks increases

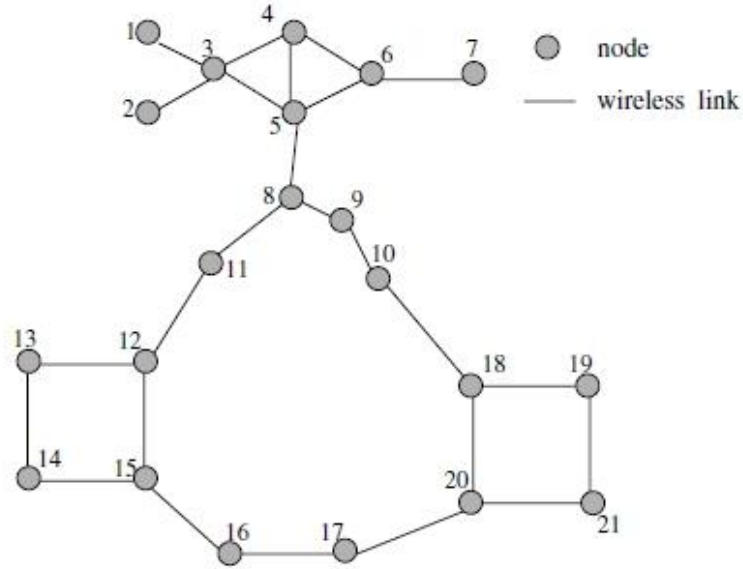


Figure 1. The system topology

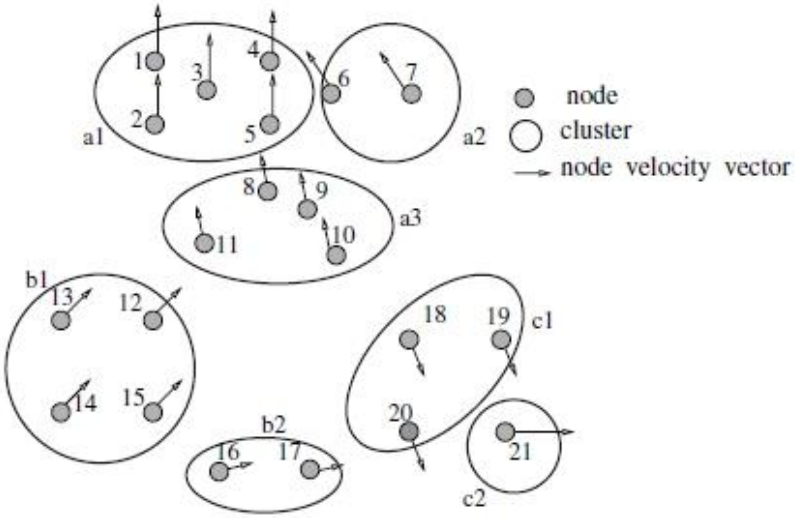


Figure 2. Basic concept of MBC

Clustering of moving objects

- The general idea in research on clustering of mobile objects is:
  - All nodes measure their mobility metric / index
  - They share the metric with other nodes in periodic ‘hello’ messages
  - This is then used in leader election, spanning tree, node-weight and other clustering algorithms
- Or: predicts the mobility of each mobile host based on the stability of its neighbourhood (i.e., how different is its neighbourhood over time).

Relative mobility measurements

- MOBIC protocol [Basu et al], where estimation of nodes speed variance is used in the clusterhead election process, with nodes with low speed variance having a better chance of becoming clusterheads
- it is the local mobility, the relative speed/location difference between the nodes that is of interest
- the received power as the estimate of the distance between the nodes

Relative mobility metric

- the relative mobility metric
  - the ratio of the received signal power between the old and the new packet that was exchanged between two nodes

$$M_y^{Rel}(x) = 10log_{10}\frac{Pr_{x->y}^{new}}{Pr_{x->y}^{old}}$$

  - For this to work, regular exchange of the packets is necessary. Regular exchange of packets is a feature of ad hoc networks, where periodic 'Hello' packets are exchanged between the neighbours

Relative mobility metric

- The aggregated local mobility for any node is then the variance with regard to zero of all relative mobilities for the neighbouring nodes:

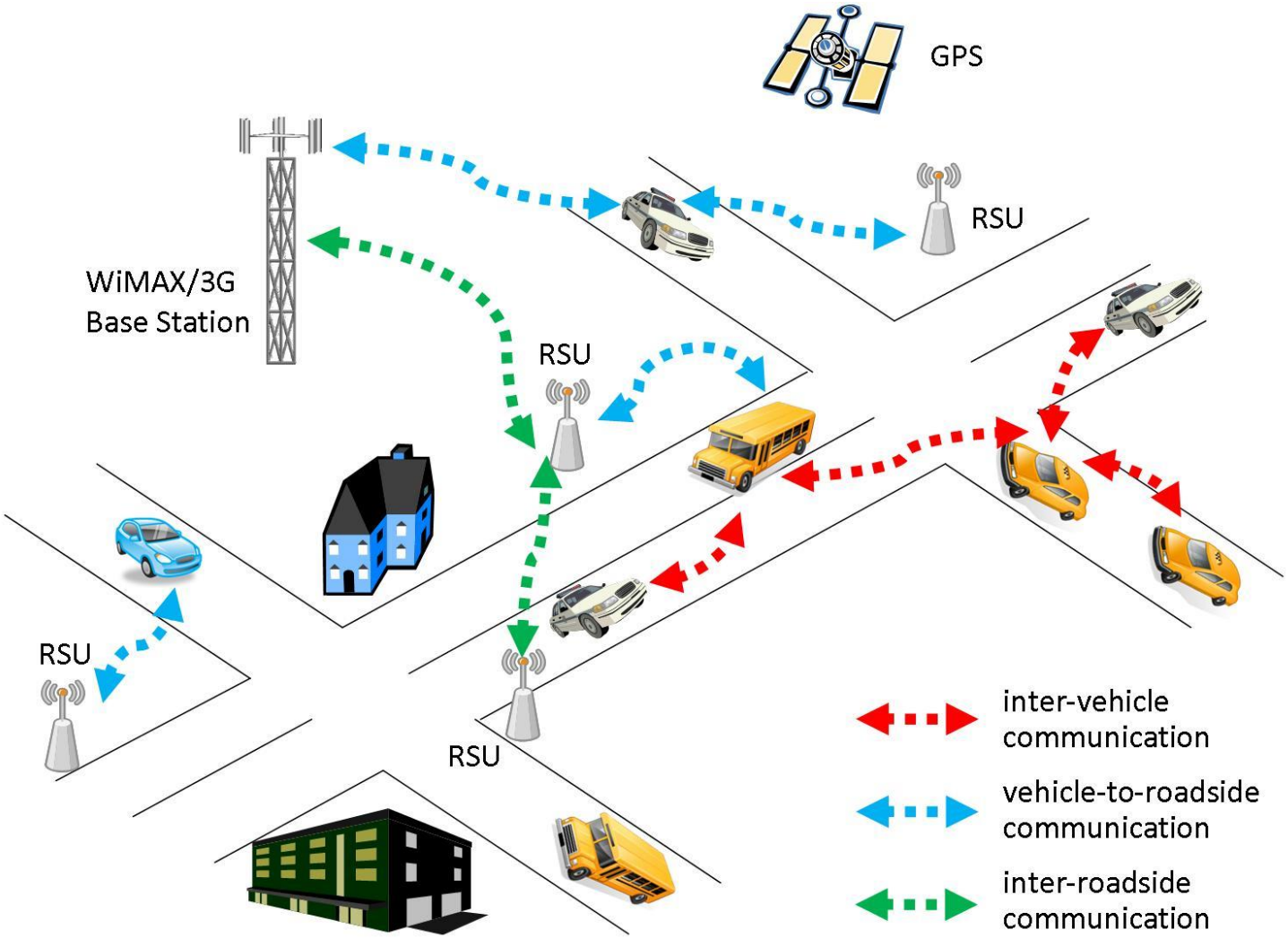
$$M_y = var_0(M_y^{Rel}(x_1), M_y^{Rel}(x_2), M_y^{Rel}(x_3), ..., M_y^{Rel}(x_m)) = E[(M_y^{rel})^2]$$

- the node with the smallest variance of relative mobilities should be identified as the clusterhead, as this would maximise the cluster stability

Application of mobility research

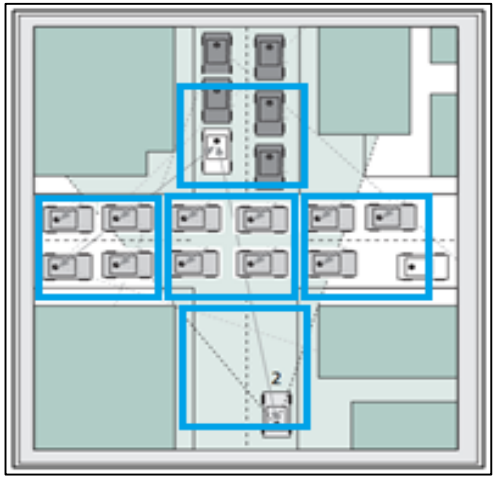
- Vehicular networks
  - Global mobility can be used to develop location-based applications and protocols
  - Local mobility can be used to develop efficient ad hoc vehicular networks (VANETs)
  - Same principles can work on UAVs (just in 3D – not a lot of work has been done on this)

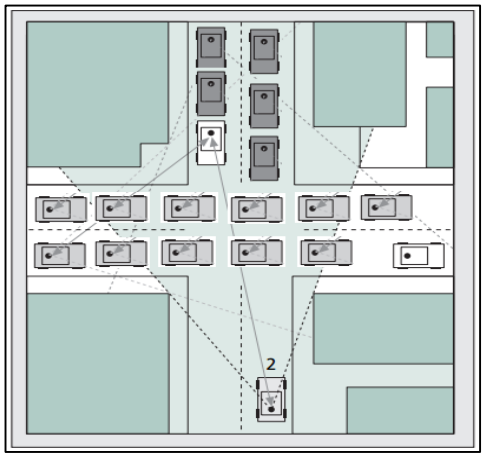
Vehicular networking

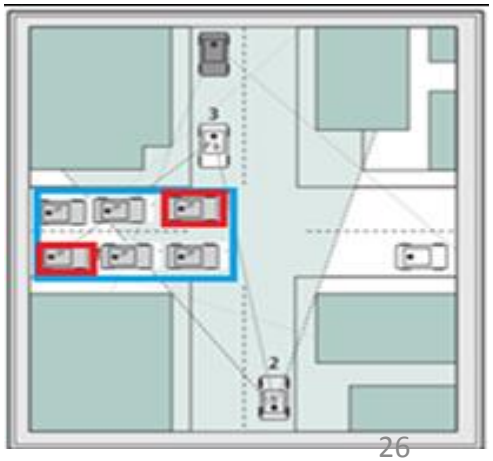


Location-Aware Data Aggregation for Efficient Message Dissemination in VANET

- Problem divided in 2 tasks:
  1. Traffic sensing and estimation
     - Area parameter
     - Congestion parameter
  2. Traffic information dissemination
     - Periodic broadcasting (flooding)?
     - Data aggregation?







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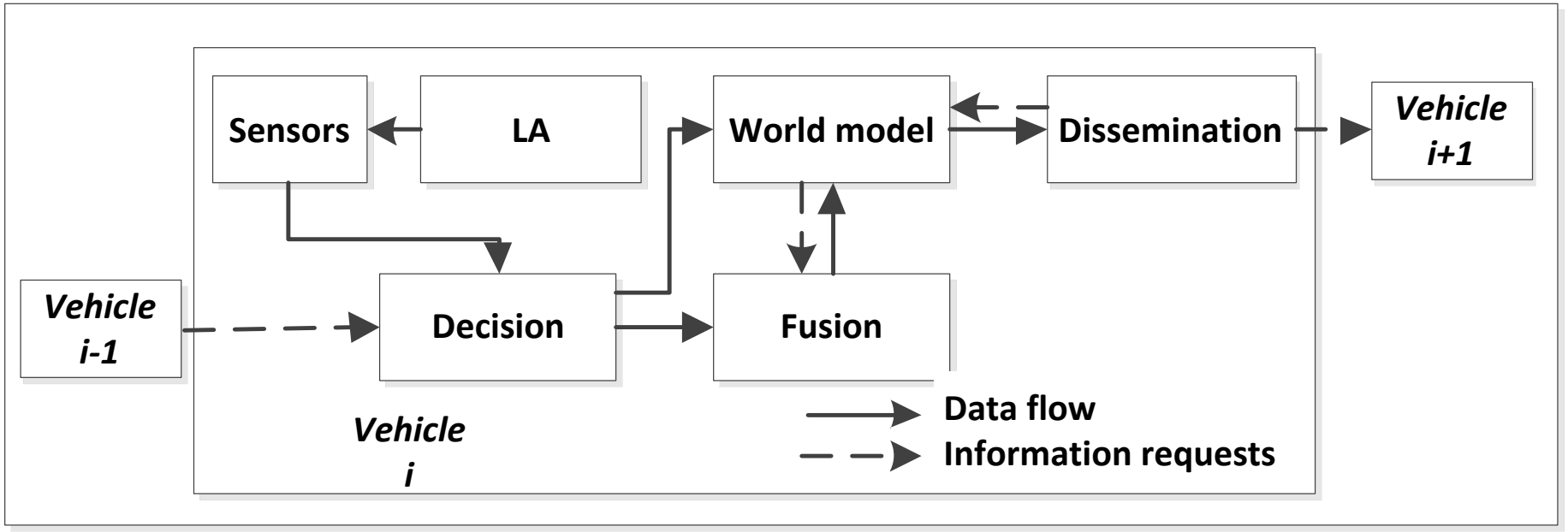
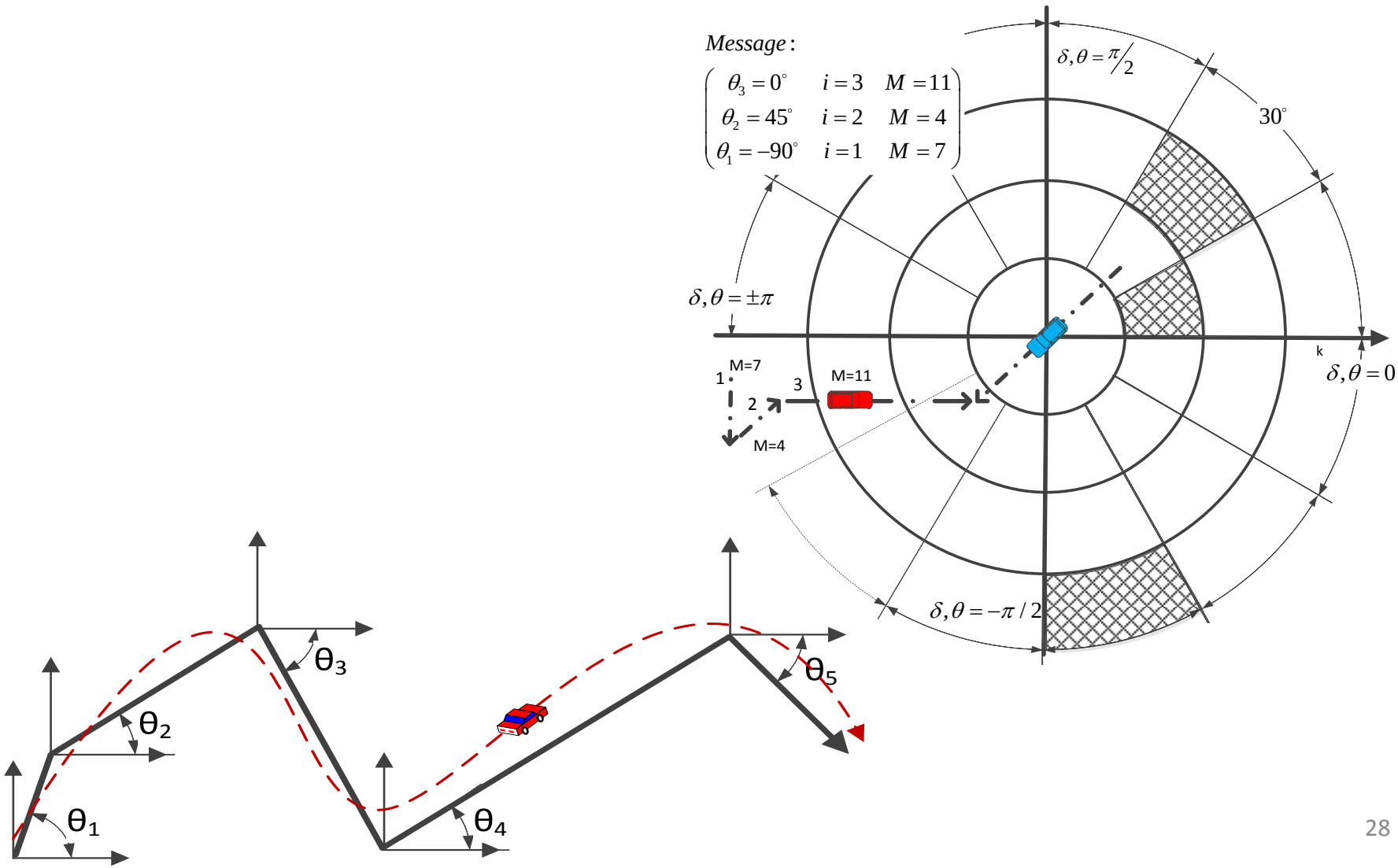


Modelling and managing mobility

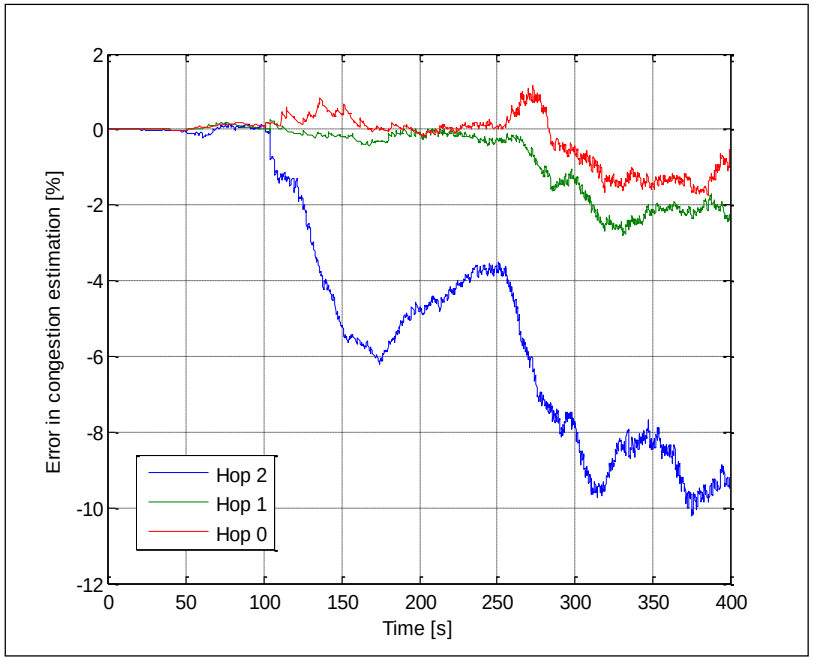


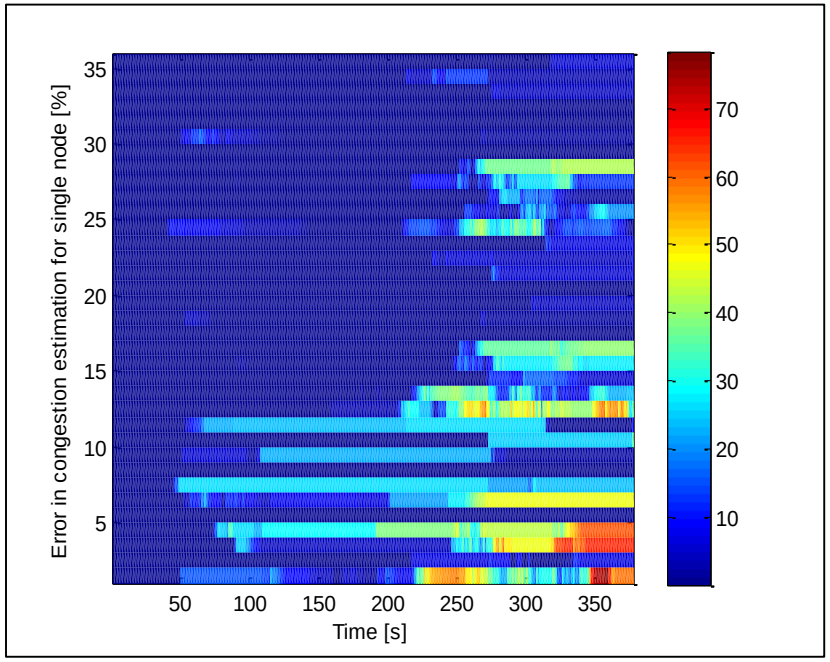
Evaluating errors

Application of passive clustering and data aggregation

The aim of this work was to estimate the error introduced by mobility- and location-aware data dissemination

To estimate the tradeoff between message exchange overhead and accuracy





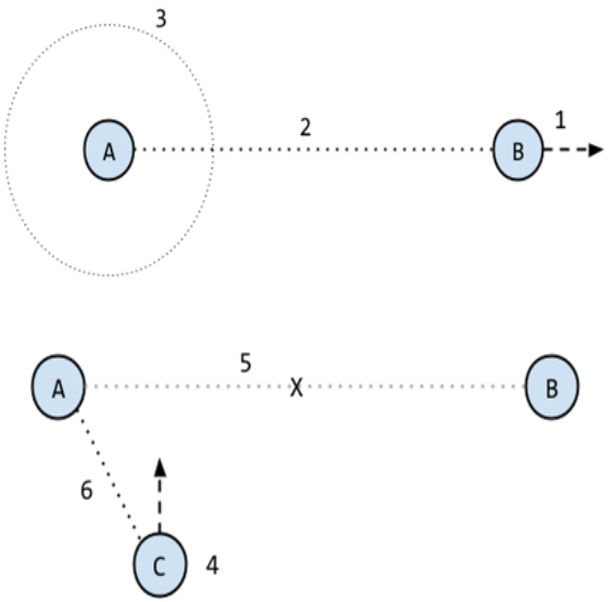
Distributed caching and content distribution in networks of moving objects

- Decentralised, opportunistic content distribution
- Taking node movement in consideration

Current progress:

- Raspberry Pi nodes experimental set-up
- Nodes choosing content source based on link quality (signal strength) during file transfer
- Reducing file transfer time

Current progress



1. Original source B starts moving away
2. Link quality decreases
3. Node A enters search mode
4. Node C approaches
5. Original link is broken
6. New link is formed