Adaptive Disconnection Tolerant Opportunistic Networks and Systems

and Sensor Networks Clouds, SDNs and Mobile Edge Networking Examples

Dr. Milena Radenkovic

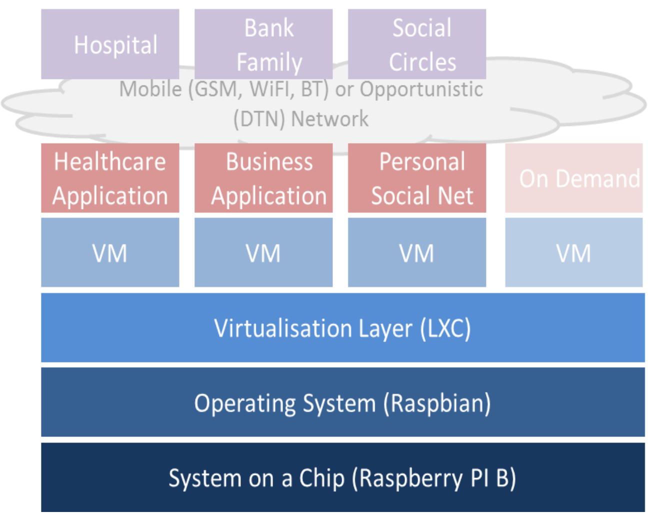


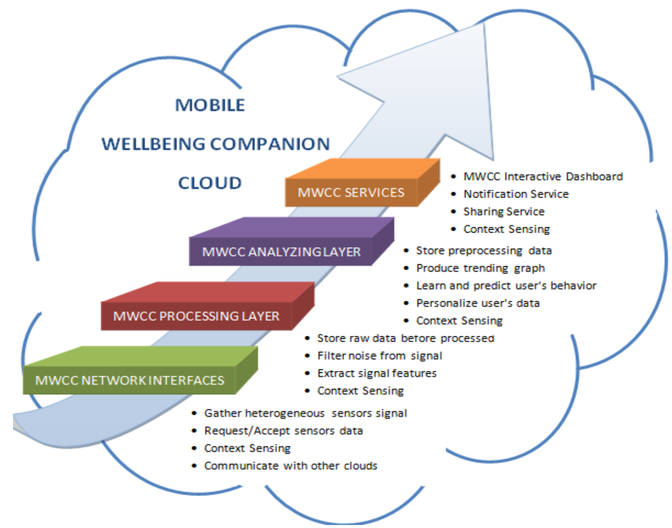
Smart Era

- We live in the era where end devices are capable of learning, predicting the patterns of behaviour of other devices and resources, and dynamically sharing the resources
- My research interest spans the areas of intelligent and distributed systems that are agile and adaptive to users' demands and dynamic patterns of the underlying networks.
- Particular focus is on how to achieve
    - **Mass scaleability and reliability**
    - **Self organisation**
    - **Low cost**
    - **Energy Efficiency**
    - **Congestion awareness**
    - **Self organised security**

Smart World and Smart Mobile Edges, Fogs and Clouds

- I have been awarded multiple EPSRC and EU grants for my research
- I have collaborated with University of Cambridge, INTEL Research, Philips, Microsoft Research, Ford, Fraunhofer Institute, UPV, Arizona University, Clarkson University, National Chiao Tung University Hsinchu, Taiwan





Milena Radenkovic and Natasa Milic-Frayling. 2015. Demo: RasPiPCloud: A Light-weight Mobile Personal Cloud. In Proceedings of the 10th ACM MobiCom Workshop on Challenged Networks (CHANTS '15). ACM, New York, NY, USA, 57-58 http://doi.acm.org/10.1145/2799371.2799373

M. Radenkovic, J. Crowcroft and M. H. Rehmani, "Towards Low Cost Prototyping of Mobile Opportunistic Disconnection Tolerant Networks and Systems," in IEEE Access, vol. 4, pp. 5309-5321, 2016, doi: 10.1109/ACCESS.2016.2606501.

Distributed Partial Mixing, PhD (1998 – 2001)

- Funded by British Telecom, I have explored designing and building multimedia support for large scale distributed teleconferencing systems and heterogeneous users.
- I proposed a self-organised P2P audio service for **interactive** and **collaborative audio** that **adaptively mixes audio streams** to achieve **interflow network fairness** and is **responsive to user** and **application needs.**
- This work has been patented internationally.

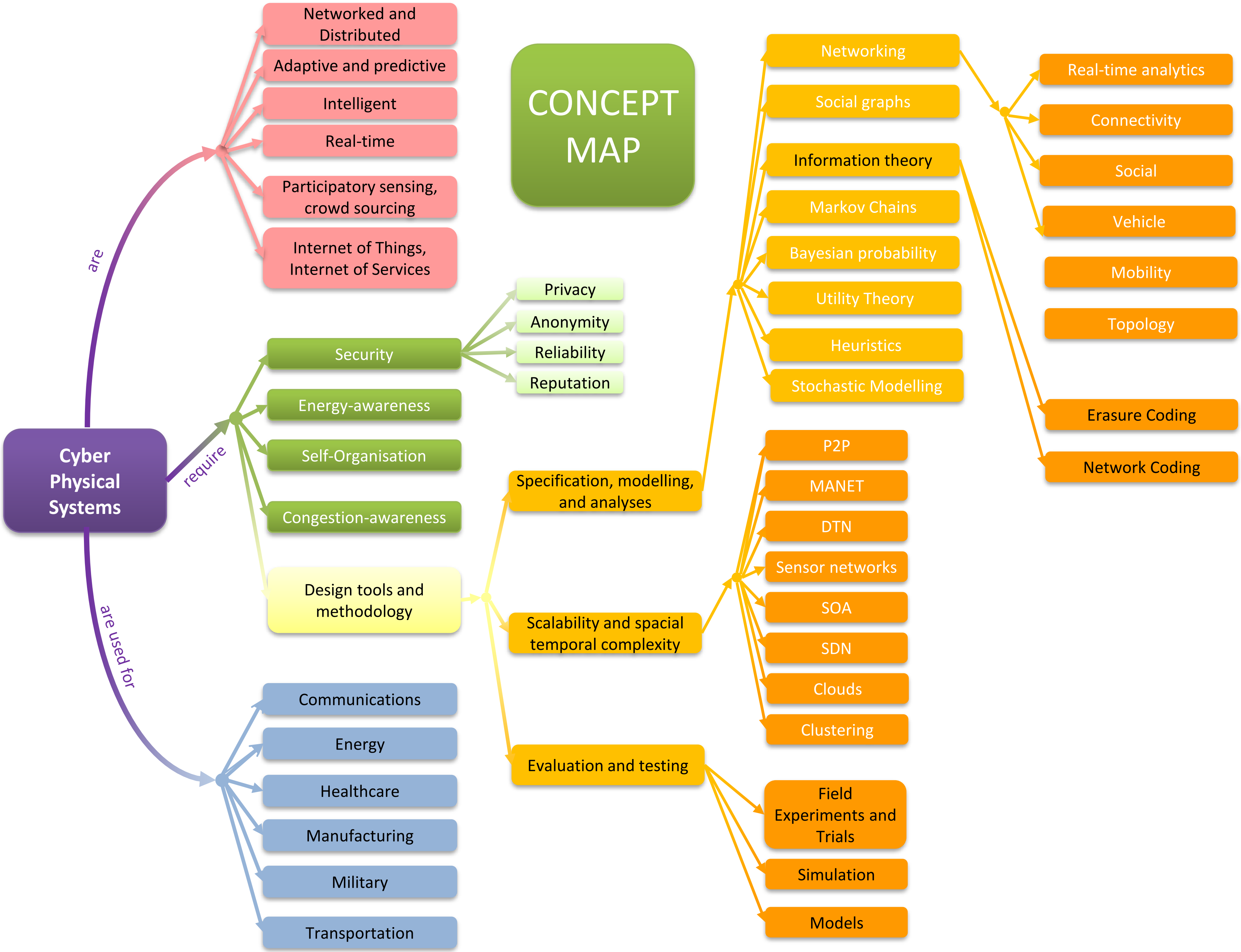
Radenkovic M, et al "Deployment Issues in Multi-Party Audio for CVEs", in the Proceedings of ACM VRST 2002, Hong Kong, November, 2002, pp 179-185.
Radenkovic M, et al "Multi-party Distributed Audio Service with TCP Fairness", in the Proceedings of ACM Multimedia 2002, (MULTIMEDIA2002), France, December , 2002, pp 11-20.

New Communications Paradigm as Foundation of Pervasive Networking

(First Grant, 2006 EP/D062659/1)

- Funded by EPSRC, I have been exploring how to enable communication in **remote** and **urban** areas by designing and building mobile DTN opportunistic networks and services.
- This brought a new set of challenges including unpredictable disconnections and surges of network traffic, energy and bandwidth starvation as well as weak security.
- Utilising network and social geo-temporal complex graph theory together with **real-time predictive stream analytics**, we proposed new intelligent data dissemination and query approaches that support interactive multimedia applications and services that are
  - Energy aware
  - Secure, privacy aware
  - Congestion aware

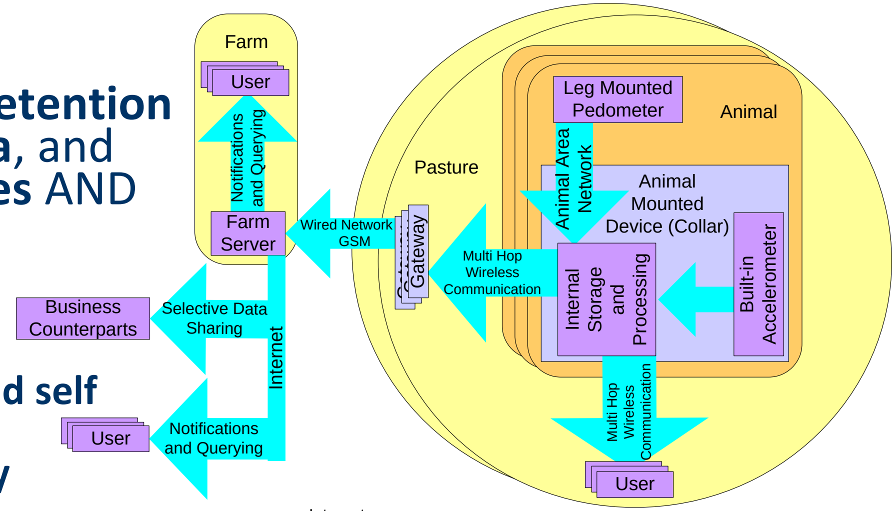
Milena Radenkovic, Andrew Grundy, Efficient and adaptive congestion control for heterogeneous delay-tolerant networks, Ad Hoc Networks, Volume 10, Issue 7, Sep 2012, Pages 1322-1345, ISSN 1570-8705

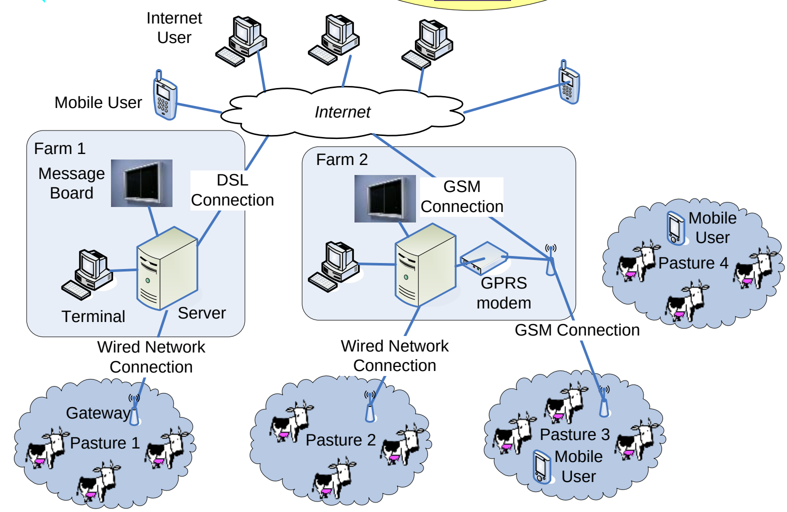


CONCEPT MAP
Cyber Physical Systems
are
Networked and Distributed
Adaptive and predictive
Intelligent
Real-time
Participatory sensing, crowd sourcing
Internet of Things, Internet of Services
require
Security
Privacy
Anonymity
Reliability
Reputation
Energy-awareness
Self-Organisation
Congestion-awareness
Design tools and methodology
Specification, modelling, and analyses
Networking
Social graphs
Information theory
Markov Chains
Bayesian probability
Utility Theory
Heuristics
Stochastic Modelling
Real-time analytics
Connectivity
Social
Vehicle
Mobility
Topology
Erasure Coding
Network Coding
Scalability and spacial temporal complexity
P2P
MANET
DTN
Sensor networks
SOA
SDN
Clouds
Clustering
Evaluation and testing
Field Experiments and Trials
Simulation
Models
are used for
Communications
Energy
Healthcare
Manufacturing
Military
Transportation

Energy Efficient Continuous Monitoring of Animal Health

- Objectives:
  - **Energy efficient dissemination** and **retention** of **multidimensional continuous data**, and support for **in situ** and **remote queries** AND
  - Significant saving for the cost of infrastructure
- Unstable paths from sources to sinks
  - **Sensors mounted on animals cooperate and self organise to forward and disseminate data**
  - **Important to save energy on path discovery**
- Minimizing and balancing energy utilisation
  - New adaptive control of transmitter power
  - Cooperative detection of route availability
  - Passive Clustering with Delayed intelligence (flood control)
  - Selecting routes with longest lifetime
  - Delaying non urgent data exchanges waiting for acquisition of a valid route to a target node from overheard or forwarded packets
  - Using movement patterns





Milena Radenkovic, Bartosz Wietrzyk: Mobile Ad Hoc Networking Approach to Detecting and Querying Events Related to Farm Animals. ICNS 2006: 109

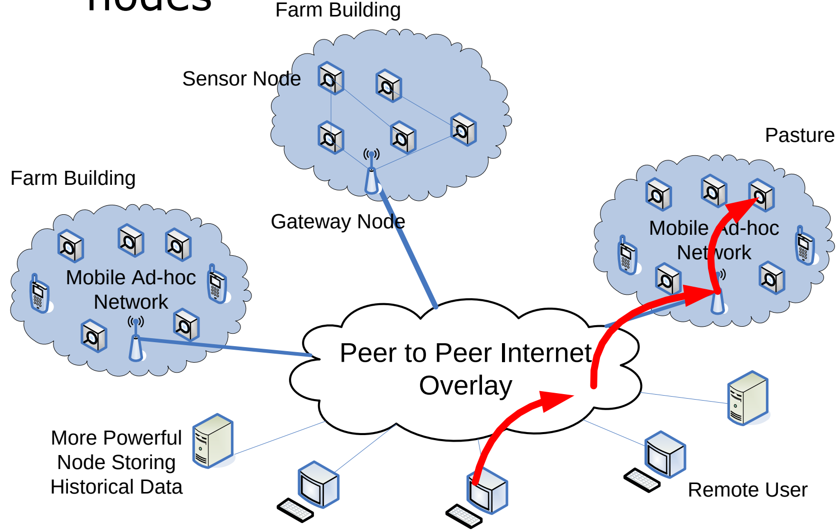
Bartosz Wietrzyk, Milena Radenkovic: Energy Efficiency in the Mobile Ad Hoc Networking Approach to Monitoring Farm Animals. ICN 2007: 1

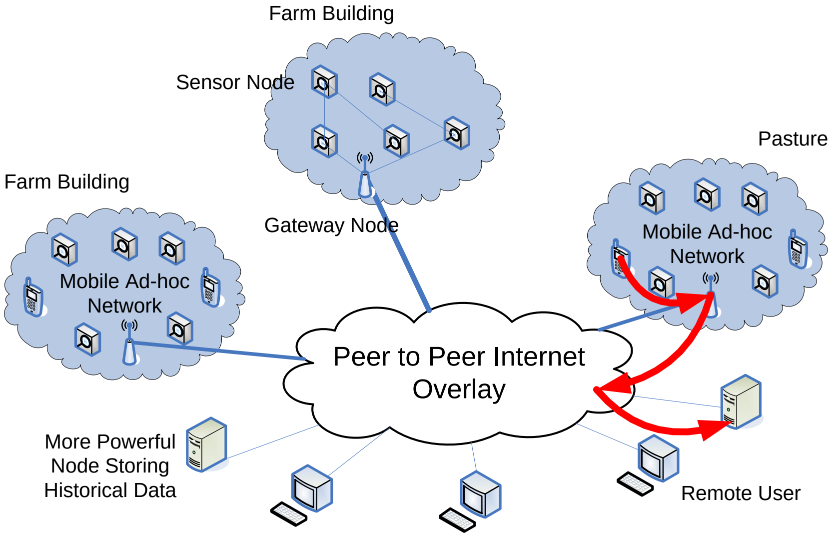
Moving from Small and Medium Scale to Mass Scale Sensor Monitoring

- Novel Distributed Hash Tables (DHT) **substrate** (Layer 3 routing) optimised for data storage and query in mobile and disconnection prone environments
  - New algorithms for self organised caching to improve data store and query and new addressing schemes
  - Passive caching dependant on nodes' storage strategies and proactive caching (with beam packets for a certain time interval)
- Novel locality preserving Distributed Hash Tables (DHT) **overlays** optimised for mobility and disconnections
  - New algorithms for forwarding and replication that utilise heterogeneity of nodes
  - Opportunistic utilization of locally available resources

DHT Substrate to address low cost data communication for high mobility and disconnections

- State
  - Contains data related to animal's health and location
  - Is identified by animal's ID (combination of location anchor and time)
  - Every node stores its own state and up to *k* states from other nodes

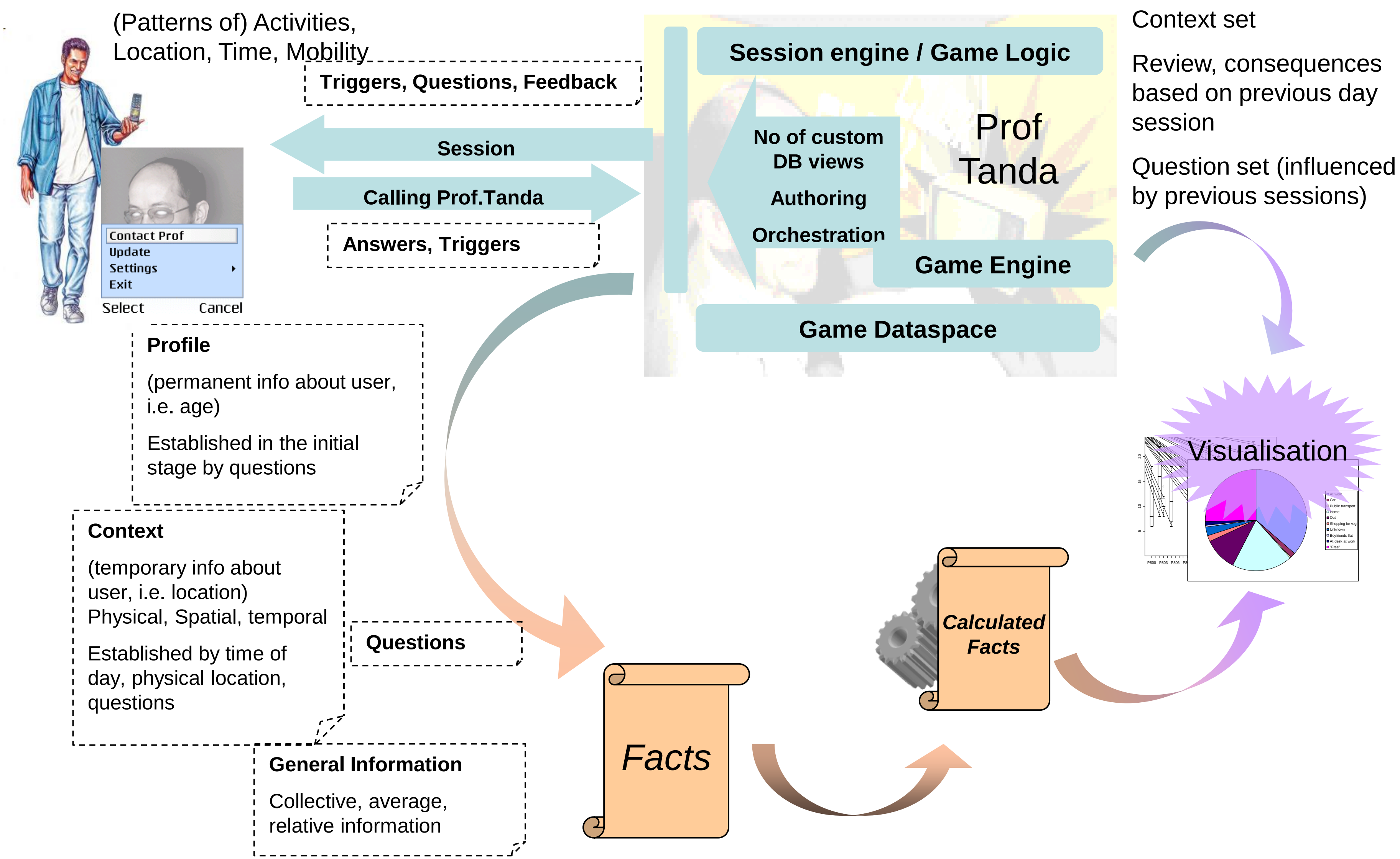




- Objective
  - route a message to a node with the ID numerically closest to its ID
- Results
  - Success ratio twice as high as state of art work in the case of increased mobility and disconnections while not increasing network overhead

Grassroot On-demand Sensing and Context Capture

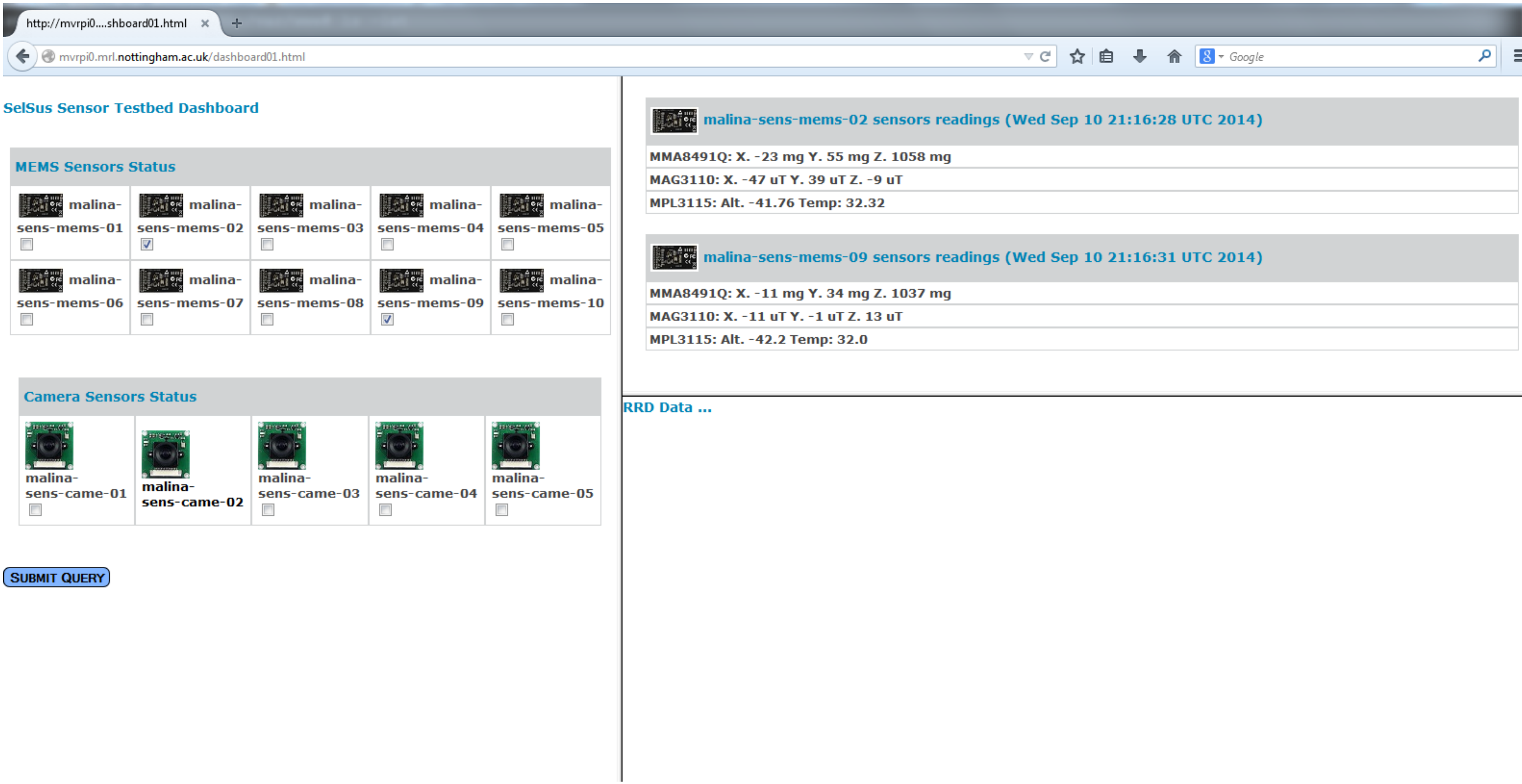
Funded by EPSRC, PARTICIPATE, CI, (2006)



Sensor Cloud Testbed Prototypes

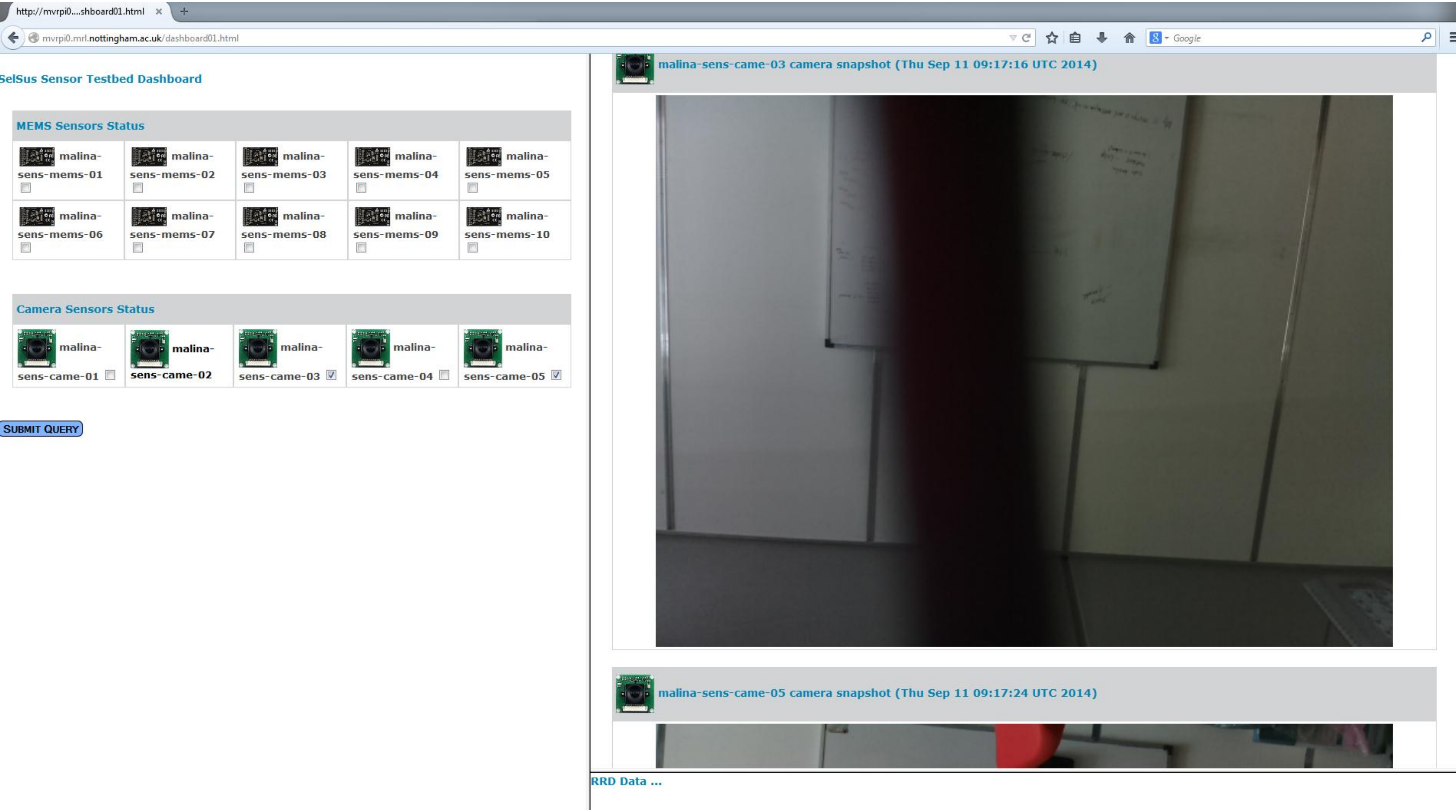
- 80 Raspberry Pi B
- 40 Pis with Raspberry Pi camera board
- 40 pis with sensors boars. Each sensor board has:
  - Low power 3D magnetometer,
  - 3-Axis digital accelerometer,
  - temperature / high precision pressure sensor
- Pi: ARM710, 700MHz, 512MB RAM, 8GB SD Card

Sensor Cloud exposes Selsus Components as services and provides access to raw and processed sensor data and events



Milena Radenkovic: Cognitive Privacy for Personal Clouds. Mobile Information Systems 2016: 7107103:1-7107103:17 (2016)

Milena Radenkovic, Jon Crowcroft, Mubashir Husain Rehmani: Towards low cost prototyping of mobile opportunistic disconnection tolerant networks and systems. In IEEE Access . ISSN 2169-3536 (2016)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Google
SelSus Sensor Testbed Dashboard
MEMS Sensors Status
malina-sens-mems-01
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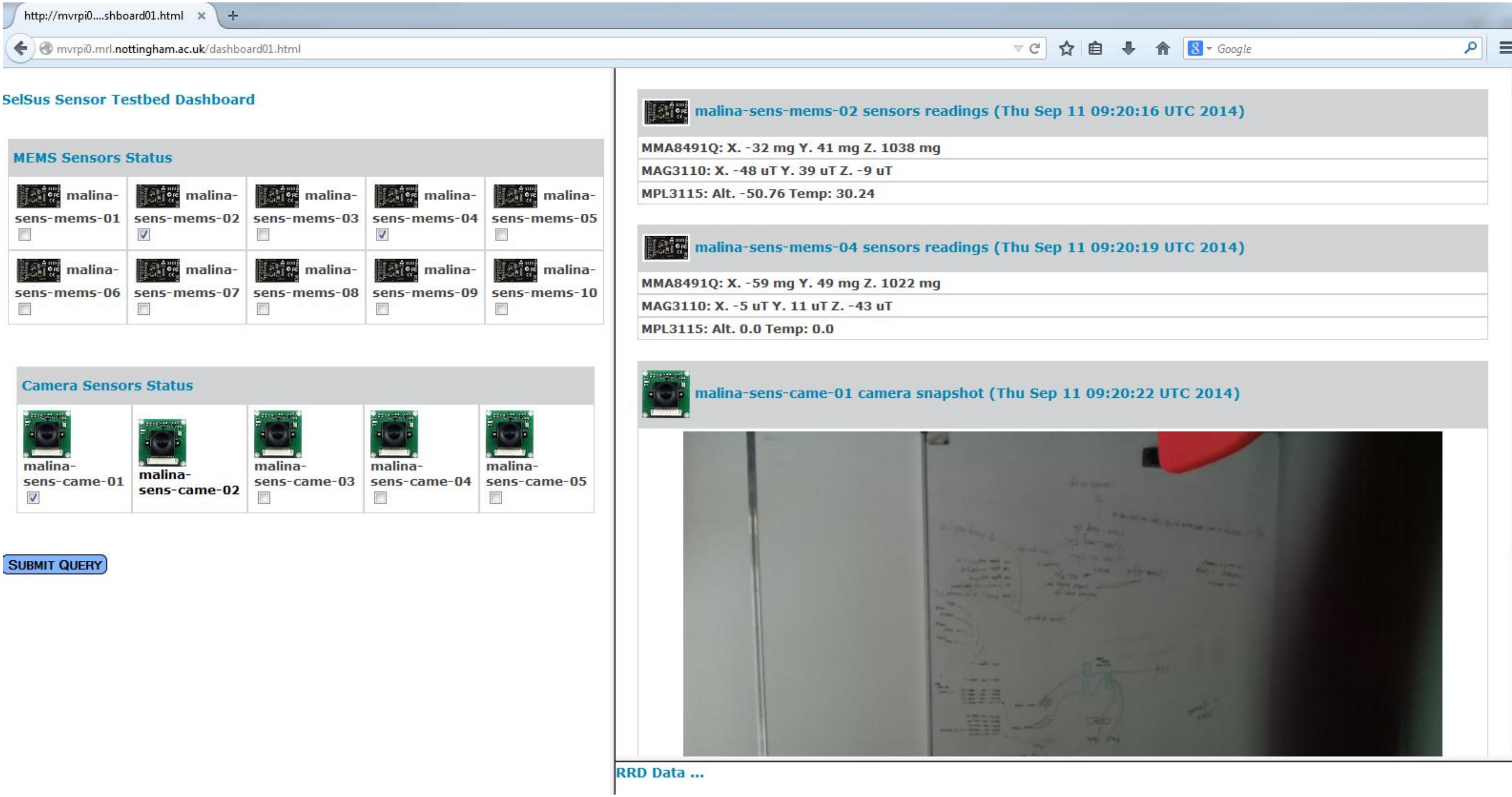
malina-sens-mems-03
malina-sens-mems-04
malina-sens-mems-05
malina-sens-mems-06
malina-sens-mems-07
malina-sens-mems-08
malina-sens-mems-09
malina-sens-mems-10
Camera Sensors Status
malina-sens-came-01
malina-sens-came-02
malina-sens-came-03
malina-sens-came-04
malina-sens-came-05
SUBMIT QUERY
malina-sens-came-03 camera snapshot (Thu Sep 11 09:17:16 UTC 2014)
malina-sens-came-05 camera snapshot (Thu Sep 11 09:17:24 UTC 2014)
RRD Data ...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Camera Sensors Status
malina-sens-came-01
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malina-sens-came-03
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malina-sens-came-05
SUBMIT QUERY
malina-sens-mems-02 sensors readings (Thu Sep 11 09:20:16 UTC 2014)
MMA8491Q: X. -32 mg Y. 41 mg Z. 1038 mg
MAG3110: X. -48 uT Y. 39 uT Z. -9 uT
MPL3115: Alt. -50.76 Temp: 30.24
malina-sens-mems-04 sensors readings (Thu Sep 11 09:20:19 UTC 2014)
MMA8491Q: X. -59 mg Y. 49 mg Z. 1022 mg
MAG3110: X. -5 uT Y. 11 uT Z. -43 uT
MPL3115: Alt. 0.0 Temp: 0.0
malina-sens-came-01 camera snapshot (Thu Sep 11 09:20:22 UTC 2014)
RRD Data ...

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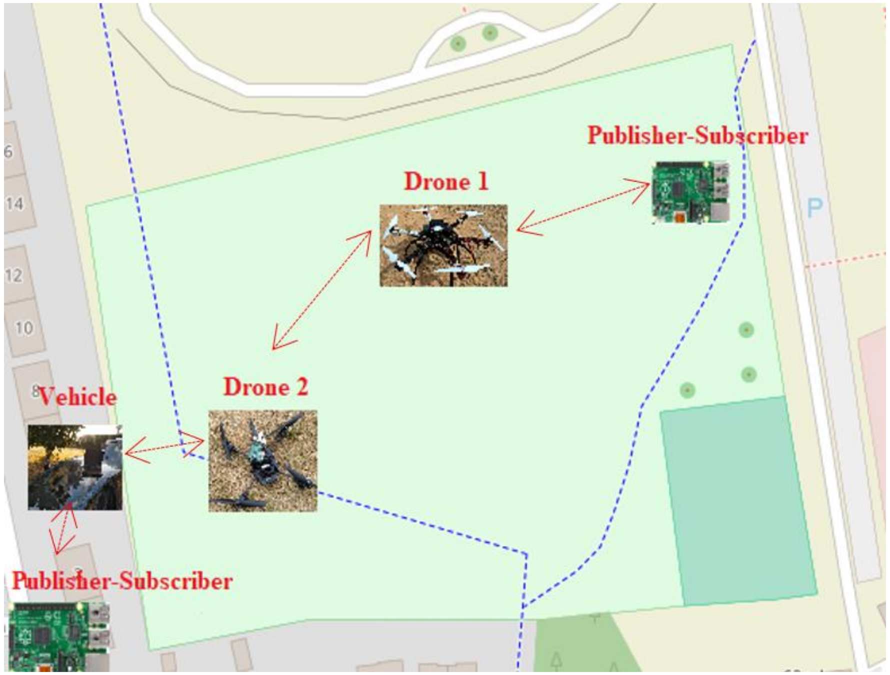
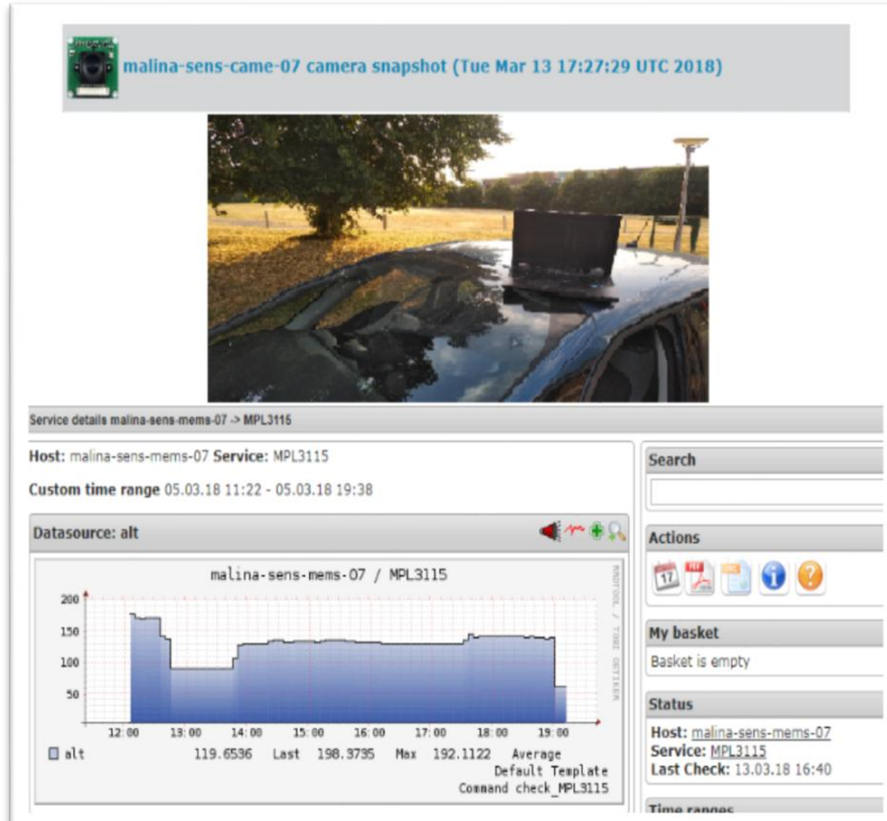
MPL3115: Alt. 0.0 Temp: 0.0
malina-sens-came-01 camera snapshot (Thu Sep 11 09:20:22 UTC 2014)
Service details malina-sens-mems-04 -> MPL3115
Host: malina-sens-mems-04 Service: MPL3115
25 Hours 10.09.14 8:21 - 11.09.14 9:21
Datasource: alt
malina-sens-mems-04 / MPL3115
-50.0
-100.0
-150.0
-200.0
Wed 12:00
Thu 00:00
alt -51.6868 Last -26.2652 Max -39.0606 Average
Default Template
Command check_MPL3115
Datasource: temp
malina-sens-mems-04 / MPL3115
40
30
20
10
Wed 12:00
Thu 00:00
temp 30.9751 Last 34.8570 Max 32.2017 Average
Search
Actions
My basket
Basket is empty
Status
Host: malina-sens-mems-04
Service: MPL3115
Last Check: 11.09.14 9:18
Time ranges
Overview
One Hour
4 Hours
25 Hours
One Week
One Month
One Year
Services
MAG3110
MMA8491Q

Agricultural Monitoring Applications: Networked Drones and Vehicles



Milena Radenkovic, Vu San Ha Huynh, Robert John, Pietro Manzoni: Enabling Real-time Communications and Services in Heterogeneous Networks of Drones and Vehicles. WiMob 2019: 1-6

Agricultural Monitoring Applications: Networked Drones and Vehicles - Dashboard



Milena Radenkovic, Vu San Ha Huynh, Robert John, Pietro Manzoni: Enabling Real-time Communications and Services in Heterogeneous Networks of Drones and Vehicles. WiMob 2019: 1-6

Congestion in DTN Opportunistic Networks

Defining Congestion in Mobile Opportunistic Networks

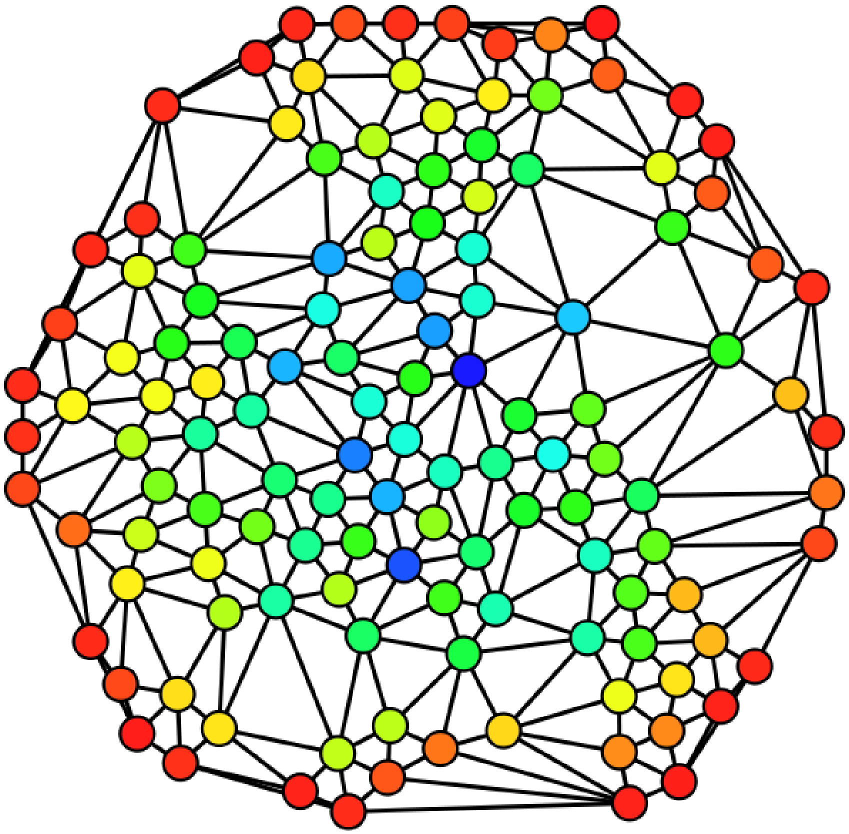
First Grant, 2006

- Funded by EPSRC, I have explored approaches for scaling mobile opportunistic network.
- A number of **social network analysis techniques** have been successfully applied in mobile opportunistic networks in order to increase the "**probability to deliver**" to a destination node and to minimise **delays**.
- Our work has identified that using social metric only leads to the **load unfairly being distributed** towards nodes which are **better connected**.
- Unfair load distribution and high unrestricted volumes of traffic can **produce single node** (RSUs, Aps) and **network wide congestion**. This can cause the networks to quickly become unusable.
- It is essential to take **resources** into account: distributed **real time predictive analytics of temporal and spatial resources**, and prediction is key

Milena Radenkovic, Andrew Grundy, Efficient and adaptive congestion control for heterogeneous delay-tolerant networks, Ad Hoc Networks, Volume 10, Issue 7, Sep 2012, Pages 1322-1345, ISSN 1570-8705

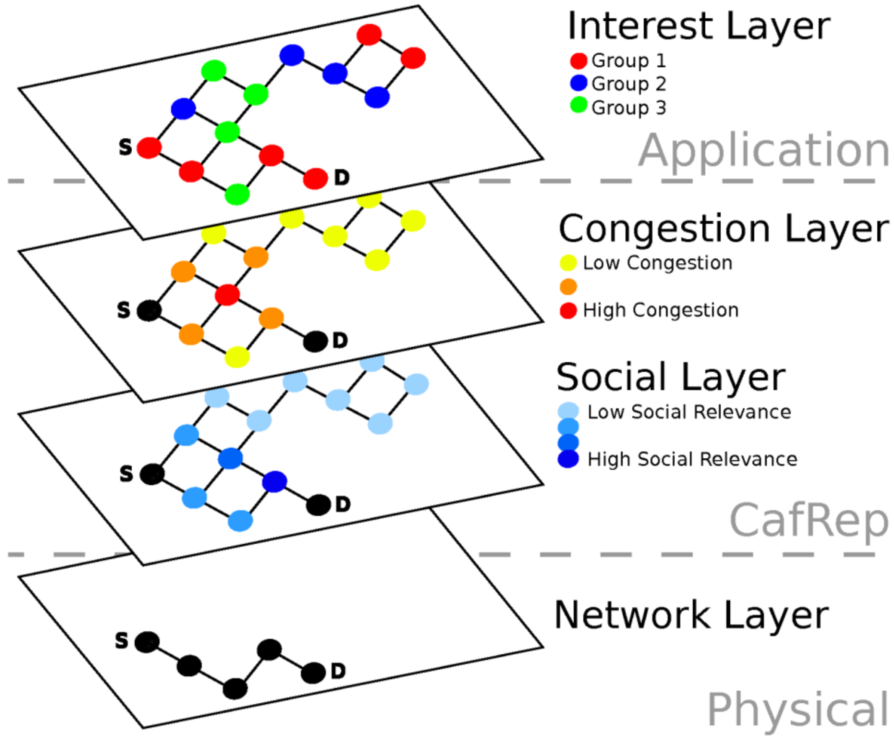
Spatial-Temporal Social Complex Graphs

- Metrics :
  - Complex social network theory
  - Centrality
  - Contact similarity
  - Betweens
  - Tie strength
- Keep directionality with forwarding
- Improve delivery probability
- but do not solve congestion, energy and fairness problems



Milena Radenkovic, Andrew Grundy, Efficient and adaptive congestion control for heterogeneous delay-tolerant networks, Ad Hoc Networks, Volume 10, Issue 7, Sep 2012, Pages 1322-1345, ISSN 1570-8705
Milena Radenkovic, Andrew Grundy, "Congestion Aware Forwarding in Delay Tolerant and Social Opportunistic Networks", In the Proc. of IEEE WONS 2011, Bardoneccia, Italy, pp 60-67

Congestion Aware forwarding and Replication (CaFReP)



MILENA RADENKOVIC and VU SAN HA HUYNH, 2017. Collaborative cognitive content dissemination and query in heterogeneous mobile opportunistic networks, In Proceedings of MOBICOM/SMARTOBJECTS, Snowbird, Utah, USA, 2017

Vu San Ha Huynh, Milena Radenkovic: Interdependent Multi-layer Spatial Temporal-based Caching in Heterogeneous Mobile Edge and Fog Networks. PECCS 2019: 34-45Milena Radenkovic, Andrew Grundy, Efficient and adaptive congestion control for heterogeneous delay-tolerant networks, Ad Hoc Networks, Volume 10, Issue 7, September 2012, Pages 1322-1345, ISSN 1570-8705

Novel Congestion Aware Forwarding and Replication CafRep

- Adaptive forwarding and resource pooling
  - Detect and predict congesting nodes and parts of the network
  - Move away the traffic from the congested nodes and parts of the network into freer parts of the network
  - Adapt in-network sending rates (determine exact number of messages to send based on the prediction of the network state)
- Combines three types of implicit analytics and heuristics:
  - Social (contact analytics),
  - Node congestion (predictive storage and delay)
  - Ego network congestion (temporal and spatial regional prediction of resources)

  - Fully open loop
  - Fully localised
  - Relative utility based

Milena Radenkovic, Andrew Grundy, Efficient and adaptive congestion control for heterogeneous delay-tolerant networks, Ad Hoc Networks, Volume 10, Issue 7, Sep2012, Pages 1322-1345, ISSN 1570-8705

Fault and Disconnection Aware Smart Sensing (FDASS) Framework

Challenges in Large Scale Sensor Networks - Motivation for Smart Architecture

Funded by EC Selsus, 2014-2018

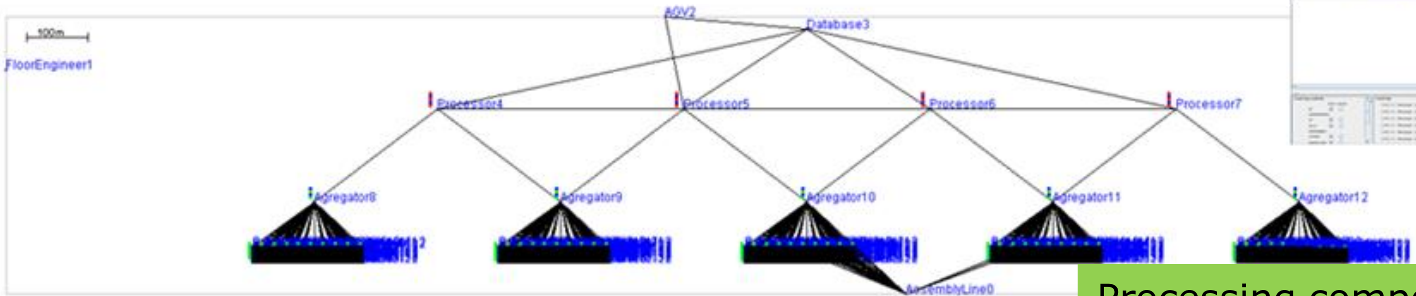
- Efficiency of the static multi-layered architecture is limited
- Given potentially disconnected topology or faulty nodes, it is crucial that the faulty nodes are discovered quickly, avoided and notifications provided
- Large-scale sensor networks raise new demands for
  - reliable data communication,
  - distributed storage and processing of information,
  - especially where they involve mobile and disconnection prone sensors, diverse sensing technologies and span multiple organisations.
- We propose new distributed architectures to support future sensor networks to enable smart manufacturing.

M. Radenkovic, I. Kostadinov and B. Wietrzyk, "Increasing communication reliability in manufacturing environments," 2015 International Wireless Communications and Mobile Computing Conference (IWCMC), Dubrovnik, 2015, pp. 1377-1383

FP7 SelSus FDASS Architecture - Overview

Basic requirements and challenges :
- constant long term monitoring
- limited maintenance and deployment cost
- high reliability

Central node/database stores both real time and historic data and its rich provenance, can detect the user defined events and issue notifications about these events.



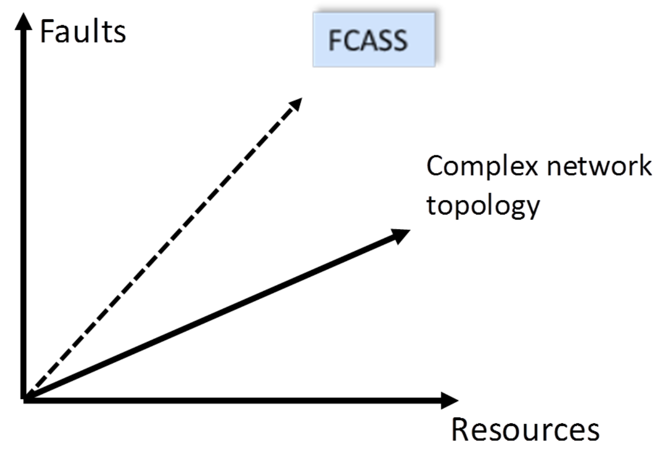
Aggregating components can store, statistically analyze sensor measurements, forward them to other nodes and send notifications.

Processing components can store and perform more complex intelligent distributed algorithms for predictions and communications as well as issue notifications.

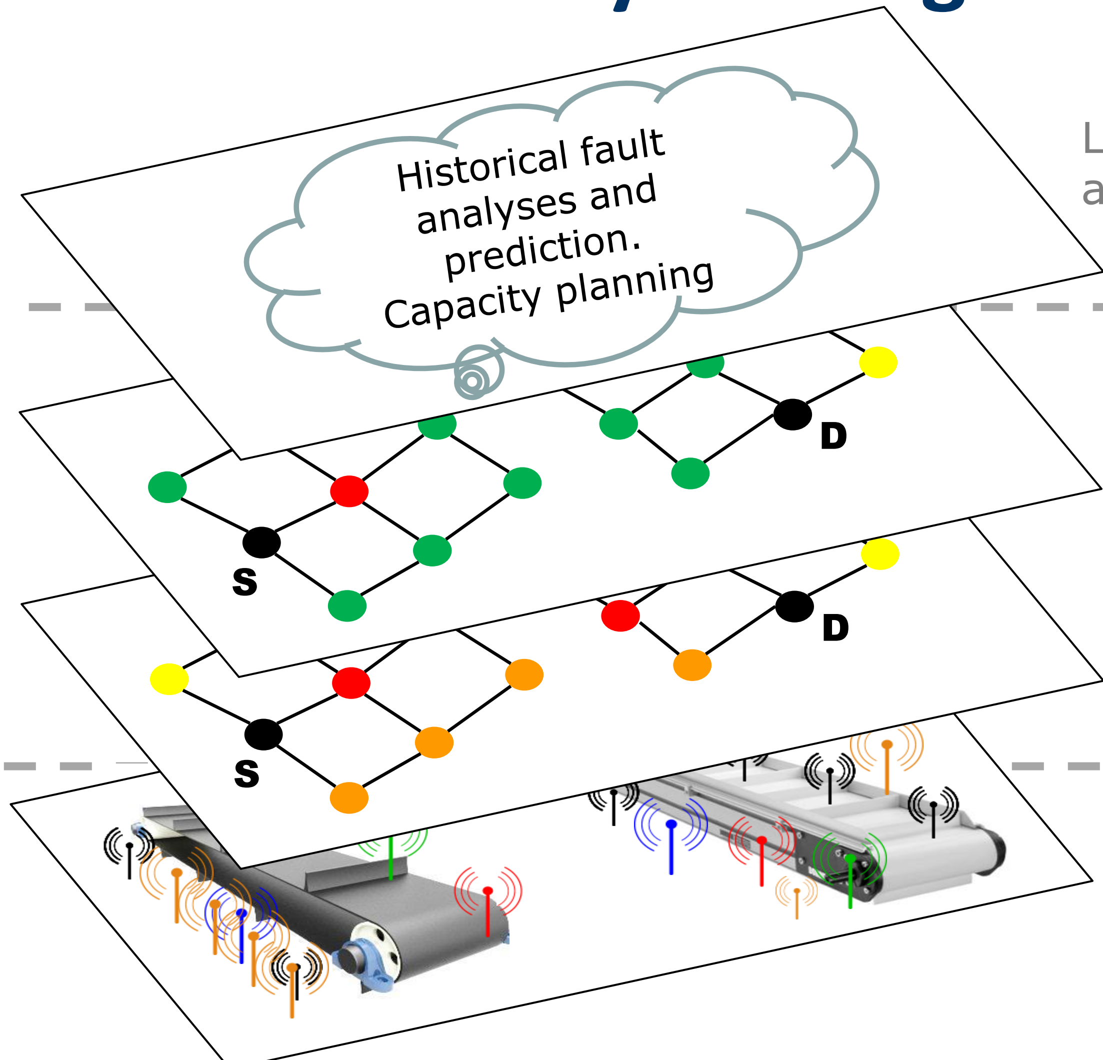
Aggregators and Processors can collaborate with sensors, Automated Guided Vehicles (AGV), Floor Engineers (FEs) and Assembly Line (AL) and Assembly Station (AS), to collect, store, process and forward row and processed data. AGV, FE and AL are mobile sinks and can issues a range of simple and complex queries regarding both local and global updates.

Fault and Disconnection Aware Smart Sensing (FDASS) Framework

- Unified adaptive fault-aware forwarding and replication management framework for complex sensor networks in manufacturing environments includes:
  - Intelligent routing improves reliability of the manufacturing plant in the face of varying, non-uniform faults that can be of different types
  - Ability to identify misperforming nodes and regions in a fully distributed fashion in order to:
    - Isolate problem areas,
    - reroute traffic away from them,
    - notify sinks about the types of failures, their location and time while maintaining:
      - resource efficiency
      - low delays and
      - avoiding congestion



FDASS Multi Layer Design



Long term cloud storage and data mining

Cloud

Adaptive forwarding and replication with notifications

FDASS

Complex Network with fault and disconnection analytics

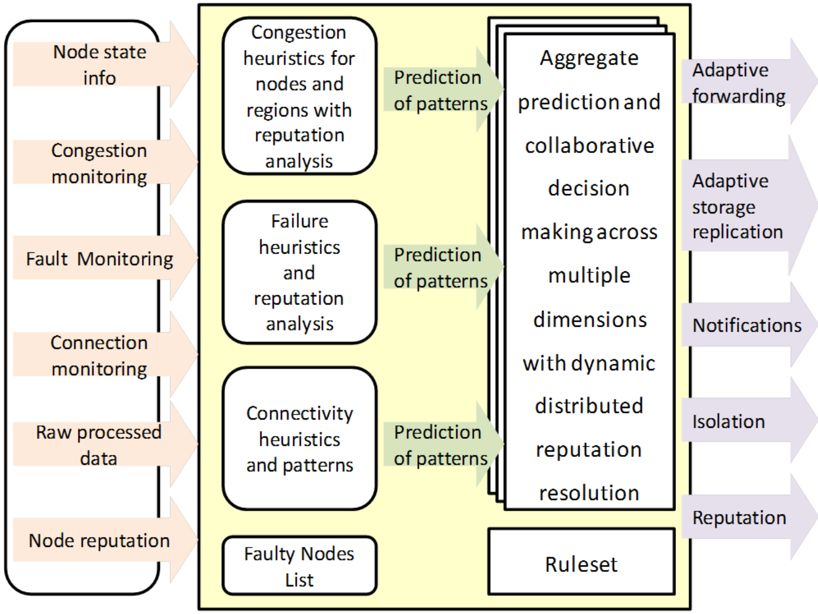
Physical

Interconnected machines, assembly lines and sensor networks

M. Radenkovic, I. Kostadinov and B. Wietrzyk, "Increasing communication reliability in manufacturing environments," 2015 International Wireless Communications and Mobile Computing Conference (IWCMC), Dubrovnik, 2015, pp. 1377-1383

FDASS node overview

- Retentiveness refers to predicting node's and region's remaining available storage
- Receptiveness refers to in-network delays which is important indication that a node or a region has volume of traffic greater than it can handle.
- Fault Likelihood, Congesting and Disconnection Rate signals predict how likely is it that a node/region is likely to get faulty, congested, disconnected
  - core for helping to ensure reliability and stability
- FCASS allows nodes to aggregate fault and resource observations disseminated by neighbours in order to form dynamic regional perspective of the network



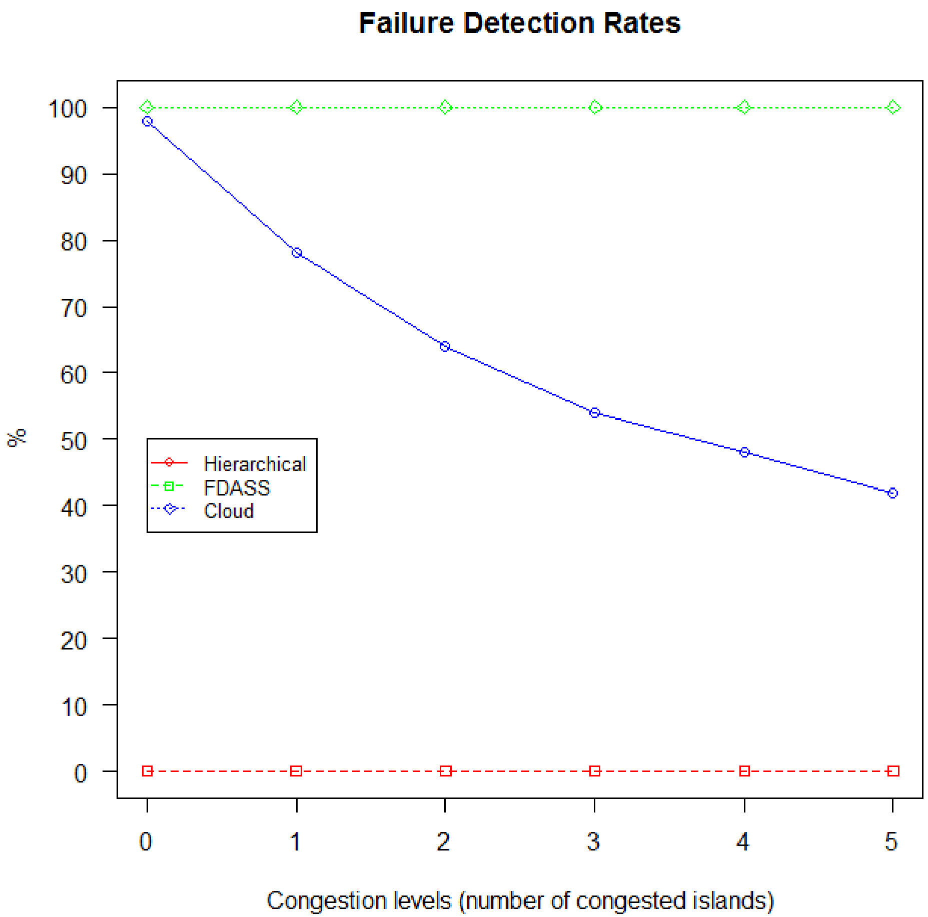
Distributed reputation used to reflect node ratings :

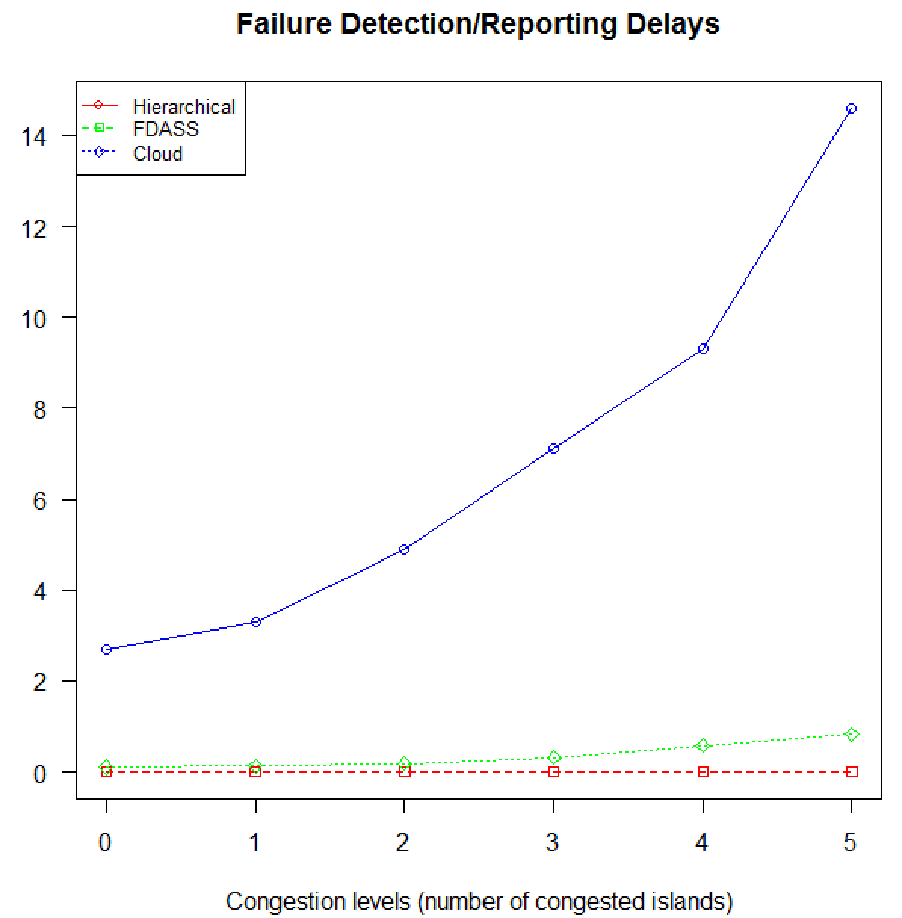
- Both direct and indirect reputation used to quickly isolate faulty nodes and help converge the reputation across all the nodes:
  - local/regional distributed reputation resolution
  - Network wide reputation resolution

Fault Heuristics and Collaboration

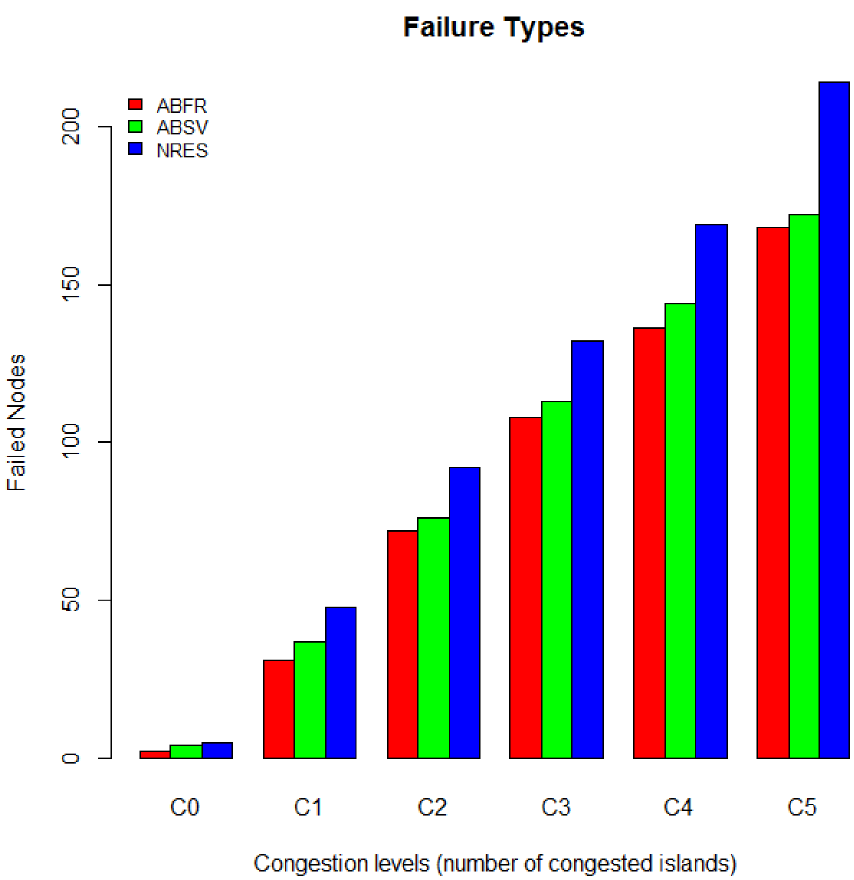
- Driven by fault profiles analysis that is based on similarity of tuples of attributes:
  - Location
  - nodeID,
  - time interval,
  - event-category,
  - summary vector
  - Which nodes exchange when they exchange data.
- Fault profile similarity is based on the number of matched profile attributes versus the number of total attributes (L), denoted as FaultSimilarity
- In this way, nodes can learn faster about:
  - potentially multiple different faults occurring on the same node, or
  - the same fault occurring at different times or in different regions.
- Through collaboration the nodes and better understanding of the type of the faults, the nodes can faster decide on the actions

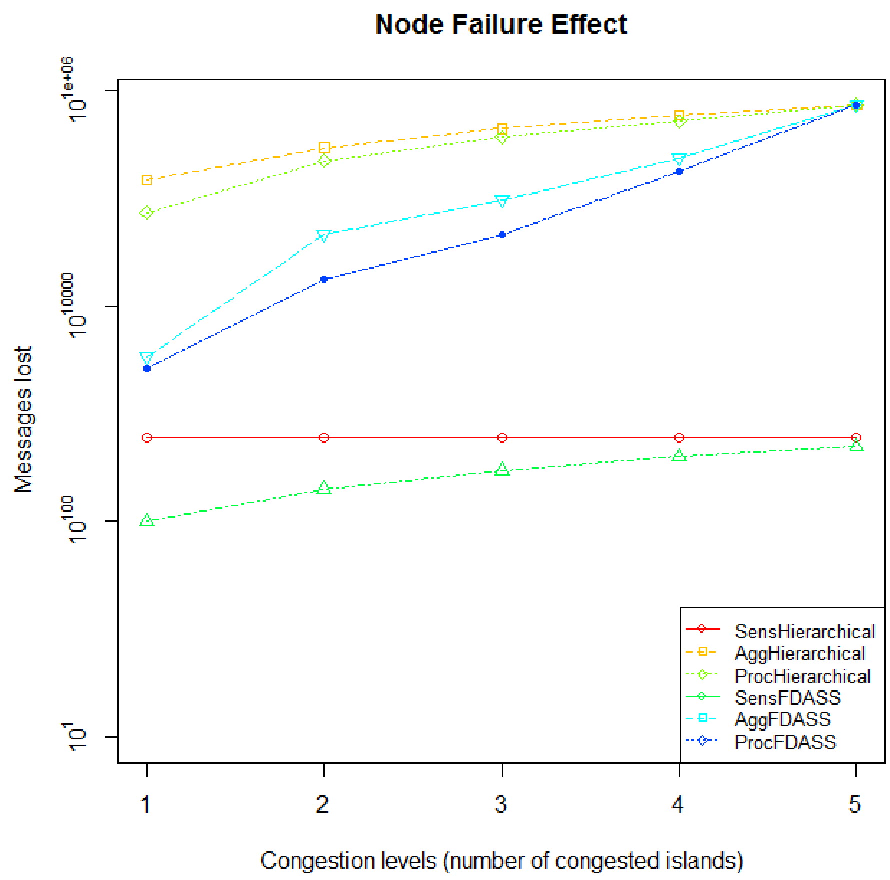
Failure Detection Rates and Reporting Delays



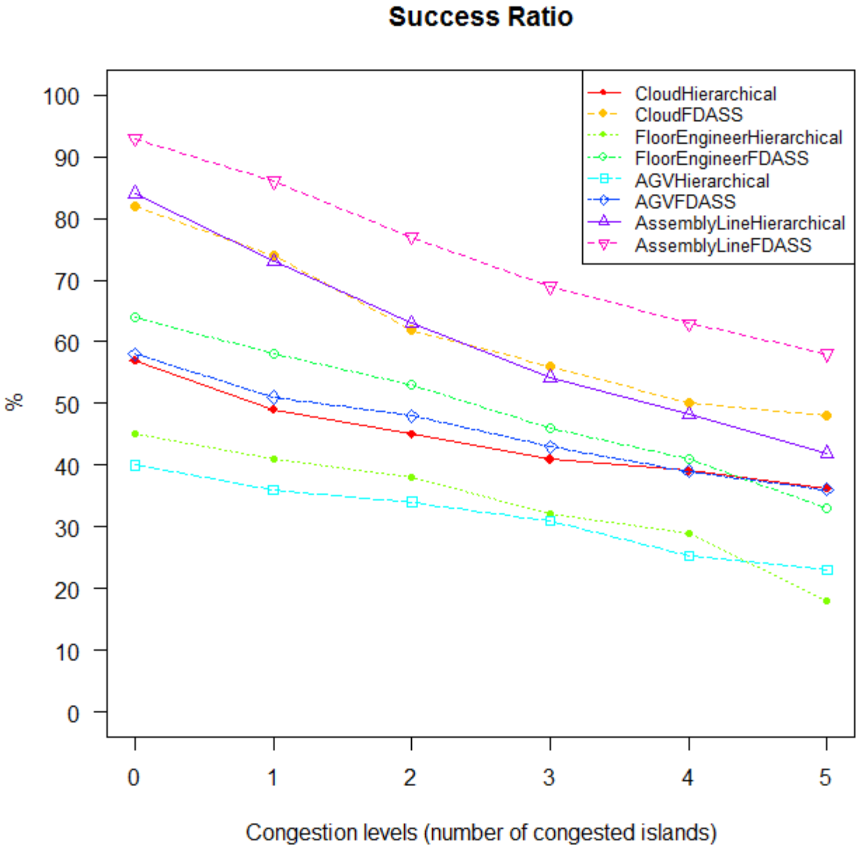


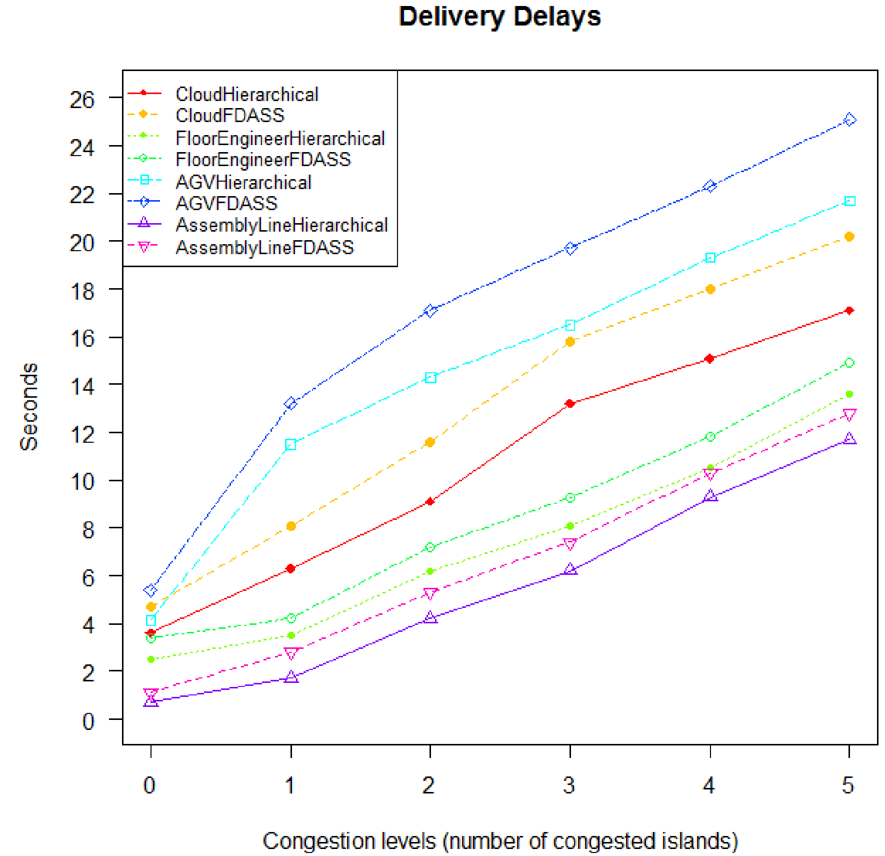
Identifying Failure Types and Measuring Failure Effects





Success Ratios and Delivery Delays





Self organised Security, Trust and Privacy

Self organised Security, Trust and Privacy

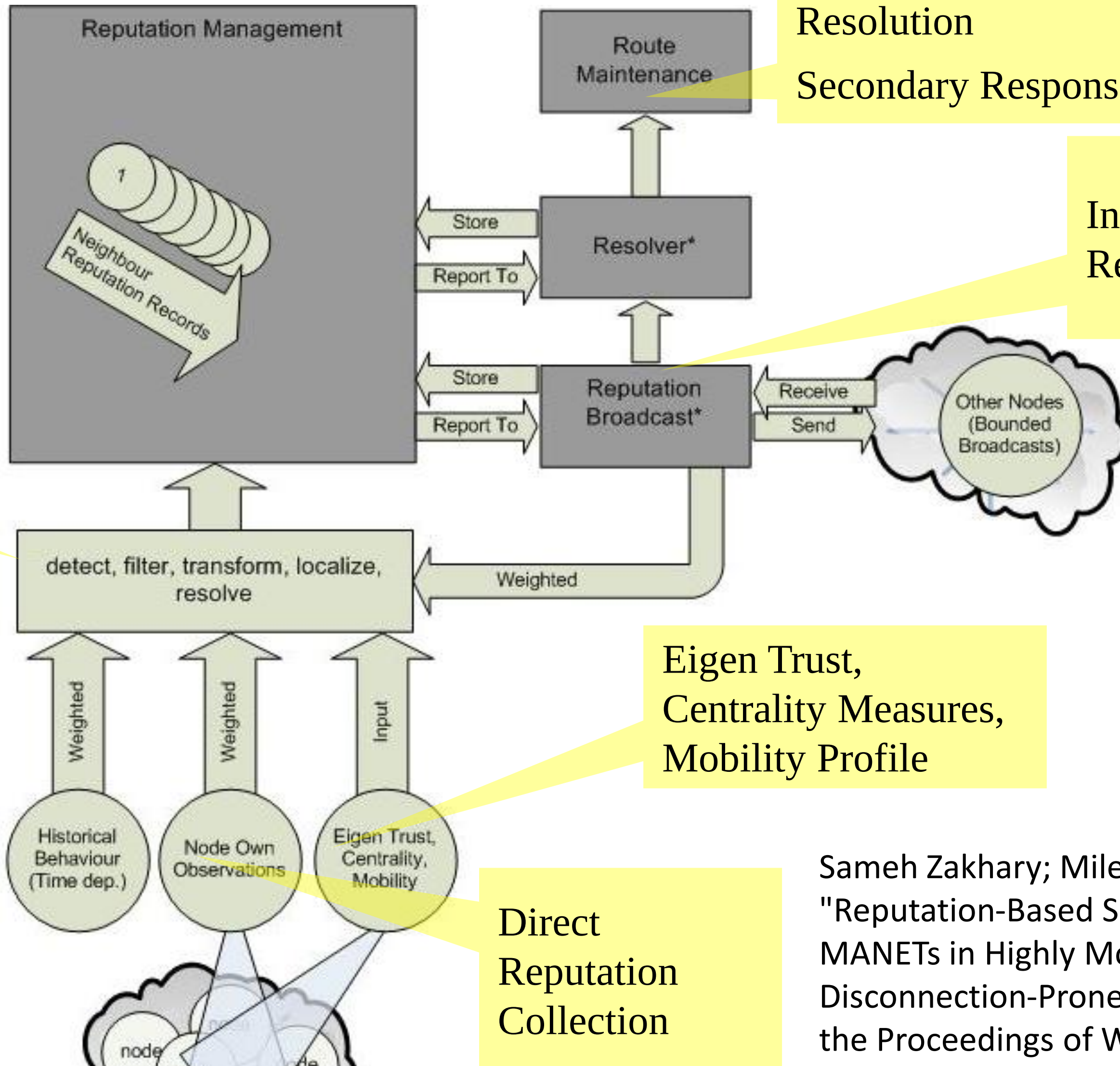
I have been working on self-organised protocols that are aware of real life **social connectivity**, **mobility patterns** and **node behaviour** and utilised them for the purpose of intelligent, efficient and **self organised reliable trust building** (via distributed reputation) and data communication.

- With the open data paradigm of the era we live in, the privacy issues become significantly more challenging, especially in terms of **identity and location anonymity**.
- Enabling these is the key for many pervasive technologies being adopted by the users and services being deployed.

Radenkovic, M.; Benslimane, A.; McAuley, D., "Reputation Aware Obfuscation for Mobile Opportunistic Networks," Parallel and Distributed Systems, IEEE Transactions on , vol.PP, no.99, pp.1,1, 2014

Benslimane, A.; Radenkovic, M.; Zakhary, S., "Efficient Location Privacy-Aware Forwarding in Opportunistic Mobile Networks," Vehicular Technology, IEEE Transactions on , vol.PP, no.99, pp.1,1, 0, 2014

Self-organised Trust Building



Resolution

Secondary Response

Indirect Reputation

Selective Deviation Test,

Noise Cancelation

Reputation Discounting

Eigen Trust,
Centrality Measures,
Mobility Profile

Direct Reputation Collection

Sameh Zakhary; Milena Radenkovic, "Reputation-Based Security Protocol for MANETs in Highly Mobile Disconnection-Prone Environments", In the Proceedings of WONS 2010, Kranjska Gora, Slovenia, Feb. 2010

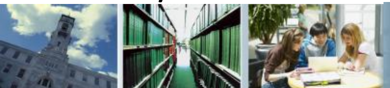
Anonymity through Obfuscation

- This (typically) refers to how to “hide” a user among **more** users (e.g. Tor chooses obfuscating users randomly or via social links taken from user’s “friends” from e.g. Facebook)
- We extend that concept so that we hide the user among **both** higher number of users **and more diverse** users to minimise predictability

Strong Anonymity has to be Responsive – AdaptAnon

- In order to provide **strong anonymity** for
  - changing underlying topologies (both dense and sparse),
  - mobility patterns (both vehicular and walking) and
  - user interests (both isolated queries and mass queries when events happen)
- AdaptAnon needs to be responsive and adaptive to all the above metrics.
- We dynamically combine three types of implicit **fully localized heuristics** that enable better identify and select anonymisation nodes (based on local monitoring, analytics and predictions)
- Because improving anonymity can have negative impact on success ratio and latency of the user-service communication (e.g. Successfully delivered and queries),
- it is essential to **dynamically balance the tradeoffs** between the **anonymity** and **the actual quality of service**

Milena Radenkovic, Ivan Vaghi, Adaptive User Anonymity for Mobile Opportunistic Networks, CHANTS 2012, ACM MobiCom Workshop on Challenged Networks August 22, 2012, Istanbul, Turkey, DOI: 10.1145/2348616.2348635



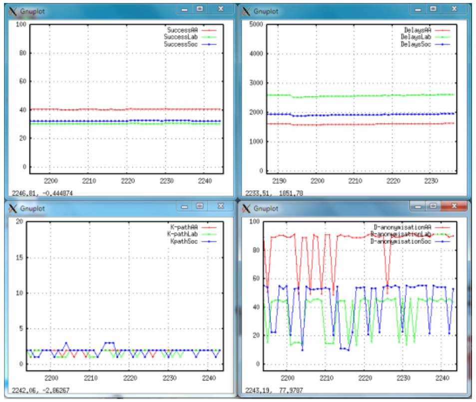
AdaptAnon Analytics Example

- Each node monitors and performs multiple analytics of a range of parameters including:
  - How often the next hop has anonymised it
  - How often the next hop has anonymised it for a particular service
  - How often it has anonymised other nodes
  - How often it has anonymised other nodes for this service
  - Calculates the ratio of how often the node has anonymised a particular source for a particular service versus all other nodes for all other services
- Aim is to allow
  - Adaptive reuse of the anaonymisation nodes
  - And keep balance between re-using the same nodes and the nodes that already have experience in performing the anonymisation service

AdaptAnon Real Time Testing

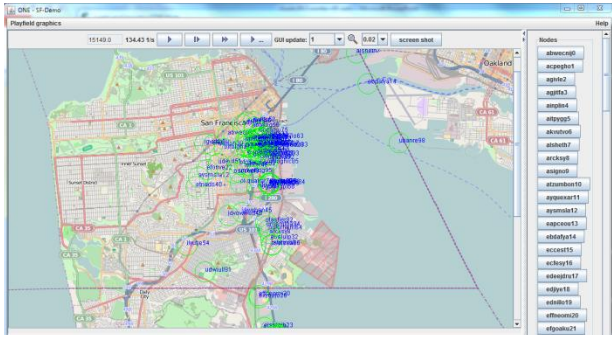
Our live demonstration of AdaptAnon uses the Cabspotter API to retrieve real-time coordinate based position updates describing the movement of mobile nodes (SF taxi cabs). We show that:

- live AdaptAnon achieves high quality of anonymisation and high quality of service
- real time “privacy analytics” is feasible



CabSpottingMovementReader


```
<cab id="eoswshy" minutes="1">
   <point
      cab="eoswshy"
      lat="37.75309"
      lon="-122.39918"
      status="E"
      time="1329437401"
   />
</cab>
```

RealTimeReport

Location Anonymity through Obfuscation – Markov Proximity

- We proposed a novel fully distributed and collaborative K-anonymity protocol (LPAF) for managing location privacy in mobile opportunistic environments.
- We use lightweight multi hop Markov-based stochastic model for location prediction to ensure that messages are forwarded closer to the LBS's location.
- Each node on the obfuscation path maintains a temporal mapping table
- Each node calculates and shares "Multi-hop Markov Proximity" (MMP) upon an encounter
- Nodes calculate this probability by combining:
  - Visiting the LBS location directly (MP).
  - The average combined probability of possible future contacts (Other friends' MP probability

Benslimane, A.; Radenkovic, M.; Zakhary, S., "Efficient Location Privacy-Aware Forwarding in Opportunistic Mobile Networks," Vehicular Technology, IEEE Transactions on , vol.PP, no.99, pp.1,1, 0, 2014

Cognitive Vehicular Charging

Motivation and Open Questions for Smart Vehicular Charging

- As the popularity of electronic vehicles (EVs) increases, **demand on the existing electrical grid** is set to rise **leading to more frequent power surges**.
- There are multiple **research, government and industry initiatives** which aim to make **electric vehicles more sustainable and scalable**.
- For example, proposals for Smart Grids (SGs) integration with EVs (by supporting two way energy flows and two way communication flows (e.g. V2G) is a promising way forward.
- However, most of the current Smart Grid proposals focus is **on centralized SG management** and **optimization via SDNs and centralized scheduling (e.g. EVPP, Danish Edison Project).**
- **Social vehicle charging** is another approach which aims to enable **V2V charging,** however it also encompasses **centralized decision making and optimization which** assumes **a priori global knowledge of vehicle schedules and coordinates .**

Milena Radenkovic and Adam Walker. 2018. CognitiveCharge: Disconnection tolerant adaptive collaborative and predictive vehicular charging. In Proceedings of the 4th ACM MobiHoc Workshop on Experiences with the Design and Implementation of Smart Objects (SMARTOBJECTS ’18). Association for Computing Machinery, New York, NY, USA, Article 2, 1–9., 2018

Milena Radenkovic, Vu San Ha Huynh, Energy-Aware Opportunistic Charging and Energy Distribution for Sustainable Vehicular Edge and Fog Networks, The Fifth International Conference on Fog and Mobile Edge Computing (FMEC 2020), 30 Jun - 03 Jul 2020, Paris, France

Open questions and Challenges

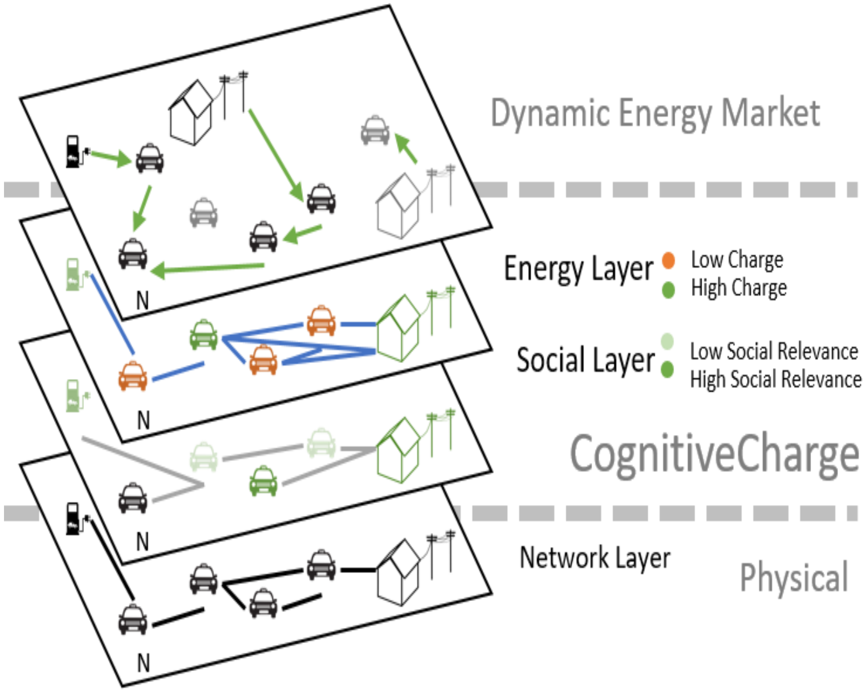
- Centralized decision making and assumption of a priori knowledge do not allow for
  - distributed real time responsive adaptation and
  - fairness of distributed dynamic charging supply and demand patterns.
- Previous research has shown that **centralized optimization and global optimum** are
  - not suitable for highly dynamic disconnection prone topologies which vehicular networks form and that
  - attaining a global optimum often disadvantages some parties e.g. nodes may be unfairly exploited

CogntiveCharge: Proposal in a Nutshell

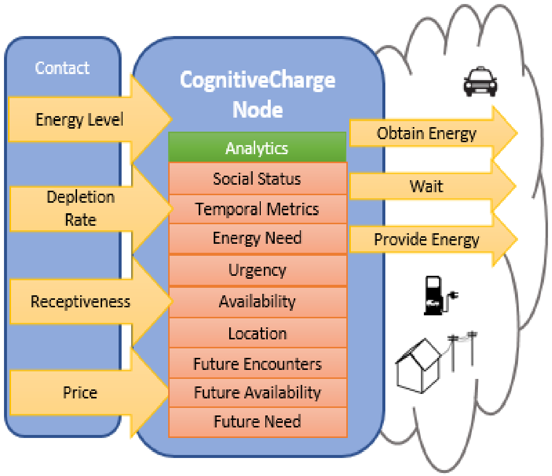
- We propose fully distributed **multi-layer cognitive charging**, CognitiveCharge, approach which **enables two-way vehicle-to-vehicle and vehicle-to-grid information** and **energy flows** in order to allow nodes to **collaborate** and **adaptively share** distributed energy resources in **disconnection tolerant dynamic topologies**.
- CognitiveCharge is **able to predict** and **adapt in real time to local dynamically changing mobility topologies** and **dynamically varying energy supply** and **demand topologies while minimising delays.**
- **We propose several novel multidimensional predictive analytics and dynamic predictive relative utilities**

CognitiveCharge distributed collaborative multi layer design

- At the **network layer:** interconnected vehicles and the grid communicate opportunistically
- At the **social temporal graph layer:** dynamically changing vehicular connectivity patterns: contact durations/frequency etc.
- **At the energy layer:** energy of the vehicles where vehicles with surplus energy may be willing to share it with those in need of energy
- Each of these layers **are complementary**
- **CognitiveCharge adaptively manages trade-offs between these multiple dimensions**



CogntiveCharge Node



CognitiveCharge nodes use **novel real time local and ego network analytics for decision making**:

- depletion rate,
- congesting rate,
- receptiveness,
- retentiveness, and
- pricing.

- Has **two types of flows**:
  - **two-way energy flows** and
  - **two-way information flows**
- **Controls energy flow** for a single node **in a dynamically changing disconnection tolerant complex network**
- Uses **multiple types of the inputs obtained through contacts with neighbours** as well as **the derived predictive analytics**
- **Allow utilities have access to real-time information and at the same time nodes control dynamic energy flows** and **collect various power and connectivity related parameters**.

Node and Ego Network Depletion Rate

- CognitiveCharge **builds on contact and resource predictive in network heuristics and utilities proposed in CafRep**.
- Nodes **will deplete at different rates** as a **direct result of their mobility patterns** and **available charging opportunities.**

$$DR(X) = \frac{100 \cdot \frac{T_{Cap}(X)}{T_{Total}(X)}}{\frac{1}{N} \cdot \sum_{i=1}^{N} Ts_i(X) - Te_i}$$

Node and Ego Network Congesting Rate

- The congestion rate of a CognitiveCharge node **refers to the rate at which the queue for energy from that node is increasing**.
- A given node **is limited in the number of peers it can simultaneously exchange energy with** (e.g. a fuel station has only a limited number of outlets) **however nodes can 'queue' for energy from both static and mobile nodes whilst others engage in transfer**.

$$CR(X) = \frac{100 \cdot \frac{T_{Queue}(X)}{T_{Total}(X)}}{\frac{1}{N} \cdot \sum_{i=1}^{N} Ts_i(X) - \ Te_i}$$

Receptiveness for Node and Ego Network

- Receptiveness refers to the **predictive delay of a node to its next charging opportunity.**
- For **predicting whether to charge at any time**, CognitiveCharge **nodes estimate the availability of a potential future neighbours based on energy level data from past encounters**.

$$Rec(n) = \mu Rec_{old}(n) + (1-\mu) Rec_{current}(n)$$

Node and Ego Network, Retentiveness /Energy Level

- The **retentiveness/energy level of a node refers to its ability to maintain charge beyond that which it requires for itself.**
- Retentiveness is distinct from depletion rate because it **focuses on the withholding of surplus energy.**

$$Ret(n) = Surplus(X)$$

Dynamic Pricing

- The price of a given neighbour’s energy **is dynamic and related to implicit dynamically changing parameters which are monitored and predicted in real time**.
- Dynamic pricing may be **considered as an incentive for maintaining energy levels beyond need only**.

$$MobilePrice(n) = StaticPrice + \frac{100 - Battery\%(n)}{100} + \frac{QueueLen(n) - 1}{10}$$

CognitiveCharge Utility

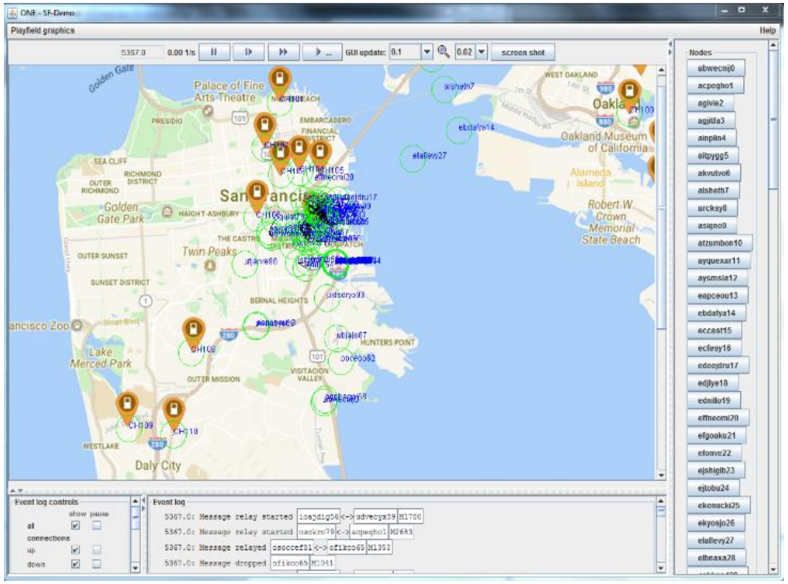
- The decision as to **whether or not to charge** from a given node n at time t **is based on the predicted depleting rate, congesting rate, receptiveness, retentiveness, and price of nodes and their ego networks**.

$$CogntiveChargeUtil(n,t) = \sum_{Utility\ \epsilon\ Utilities}^{Utility} Utility(n,t)$$

CognitiveCharge Experiment Methodology (1)

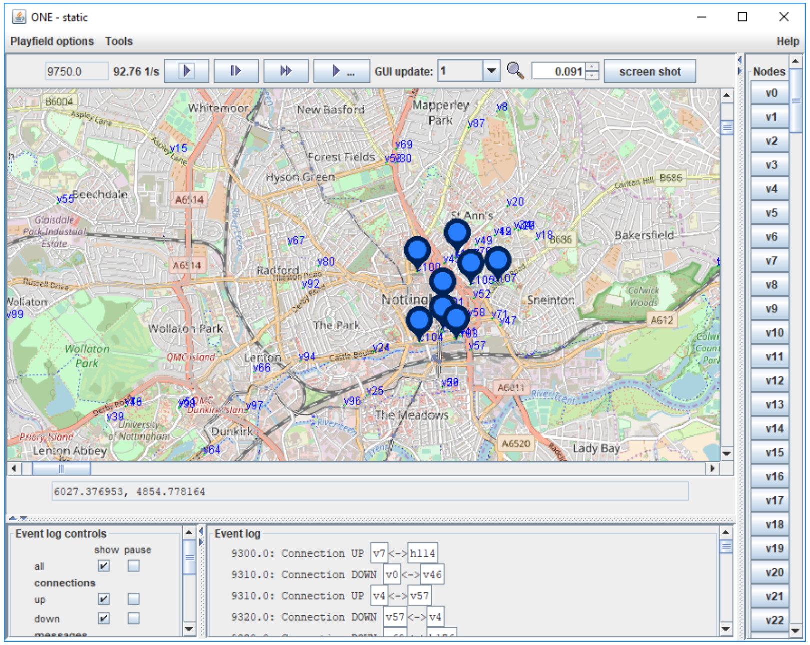
- We provide multi criteria evaluation of CognitiveCharge over **two real word city traces**:
  - **San Francisco, USA** and
  - **Nottingham,** UK,
  - With **two different mobility patterns**
    - **real world taxi cabs** and **urban work pattern**
    - and **existing real-world set-up of EV charging infrastructure**.

CognitiveCharge Experiment Methodology (2)

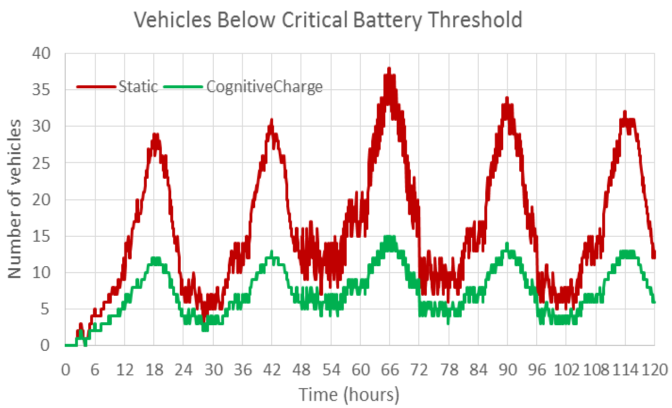


- To evaluate CognitiveCharge, we **use San Francisco trace and assume vehicles are EVs.**
- We use **100 cars over a 5-day period.**
- **We overlay the real world charging points at locations closest to where cars are observed to congregate**.

- **100 EVs in Nottingham urban area** over **typical working days with commuter traffic over 5 days**
- We use **vehicular geo-social mobility model derived from multiple data sources**
- We model **two tiers of charging : 'fast-charge' points at car parks and fuel stations and regular charging from household mains electricity**.

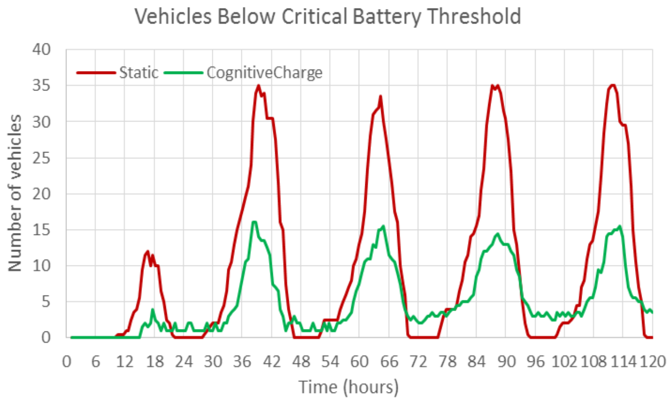


CognitiveCharge - Number of vehicles with critically low battery levels analysis



San Francisco

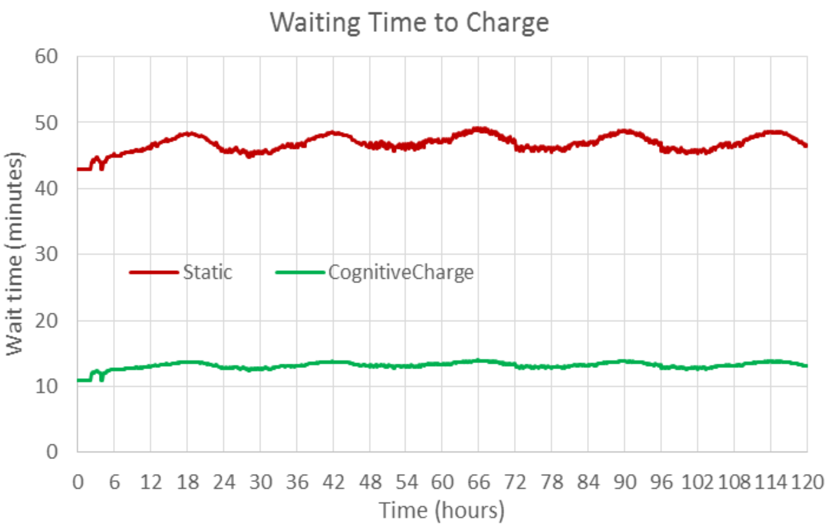
- The **overwhelming majority of the time for CognitiveCharge**, an average of just **7% of nodes** identify as having **a low battery threshold**.
- However, these nodes **do not reach the level of criticality of nodes reliant on infrastructure charging points** and **are never fully depleted.**

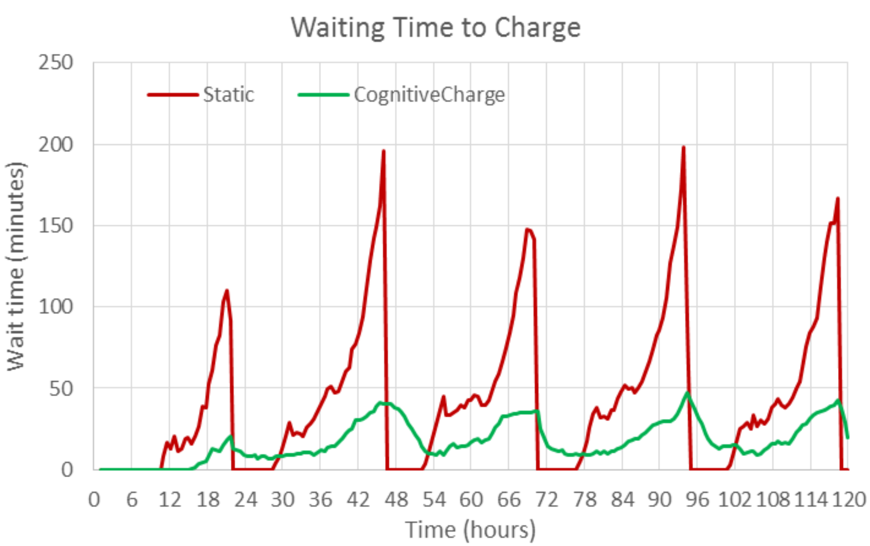


Nottingham

- For CognitiveCharge we see an **average of 4%** of nodes identifying as being in need of energy **rising to 14% during peak times**.
- For nodes using CognitiveCharge who reach the low energy threshold, the severity of energy depletion is **light and only for brief time periods**.

CognitiveCharge – Delay analysis





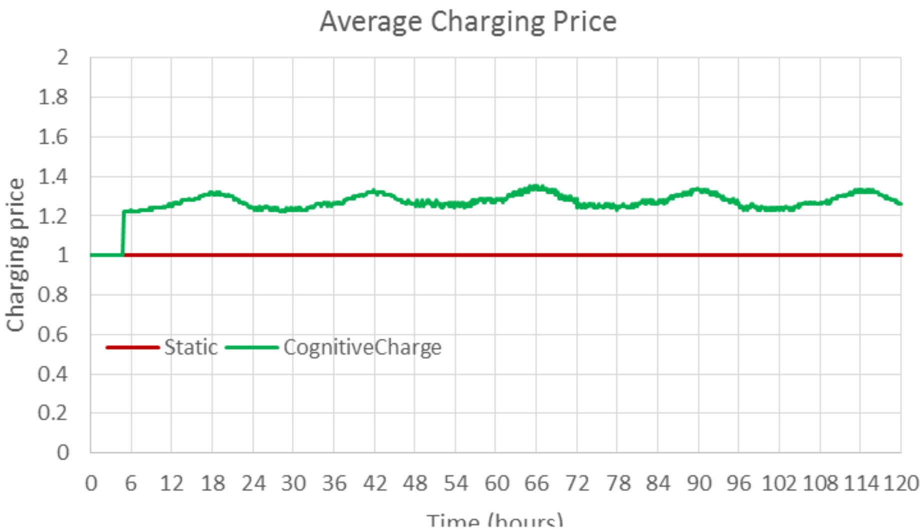
San Francisco

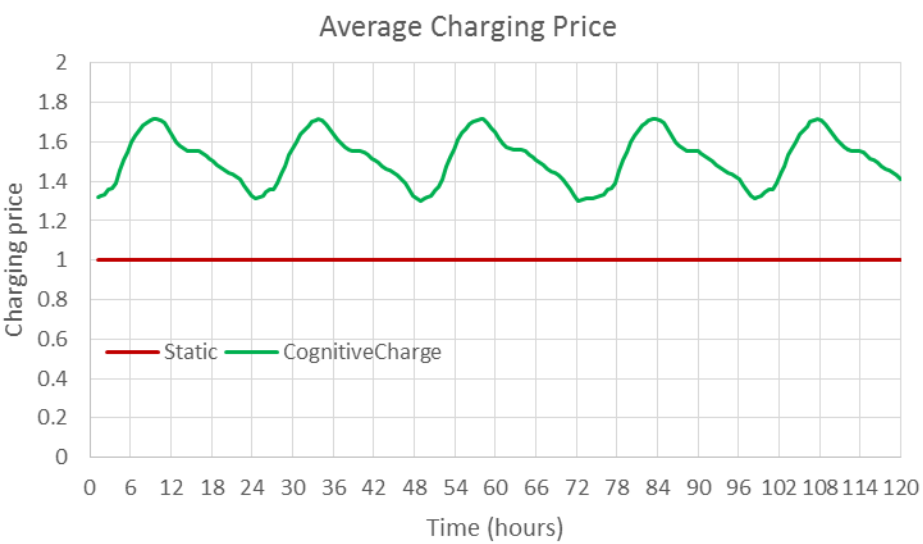
- **CognitiveCharge greatly increases the opportunities for charging** and as a result of **this there is a fourfold reduction in the time a vehicle must wait** until it can acquire energy when it needs it.
- **CognitiveCharge additionally reduces the fluctuations**

Nottingham

- CognitiveCharge sharply reduces wait time for nodes to acquire energy.
- CognitiveCharge further reduces the time that a node is in a low energy state and reduces the fluctuations

CognitiveCharge in San Francisco - Price analysis





San Francisco

- CognitiveCharge price fluctuates over time as the price adjusts in response to the dynamic energy supply and demand.

Nottingham

- Under CognitiveCharge the fluctuations in energy price for Nottingham are **marginally greater than for San Francisco**
- Suggesting more **isolated islands of nodes with limited V2G opportunities relying upon V2V energy** exchange to satisfy the demand of both themselves and their ego-network.

Conclusion

- We proposed **multiple novel adaptive opportunistic mechanisms** to **improve QoS, security and privacy** and **energy efficiency** for **community edge-clouds**.
- We performed multi-criteria evaluation of our protocols in real-word connectivity traces and in the face of realistic workloads in order to compare our protocols.
- We envisage that our protocols will be desirable in **heterogeneous dynamic geo-temporal clusters of mobile user scenarios** such as **mobile personal clouds in pervasive health services** and **cognitive privacy for personal mobile clouds**.