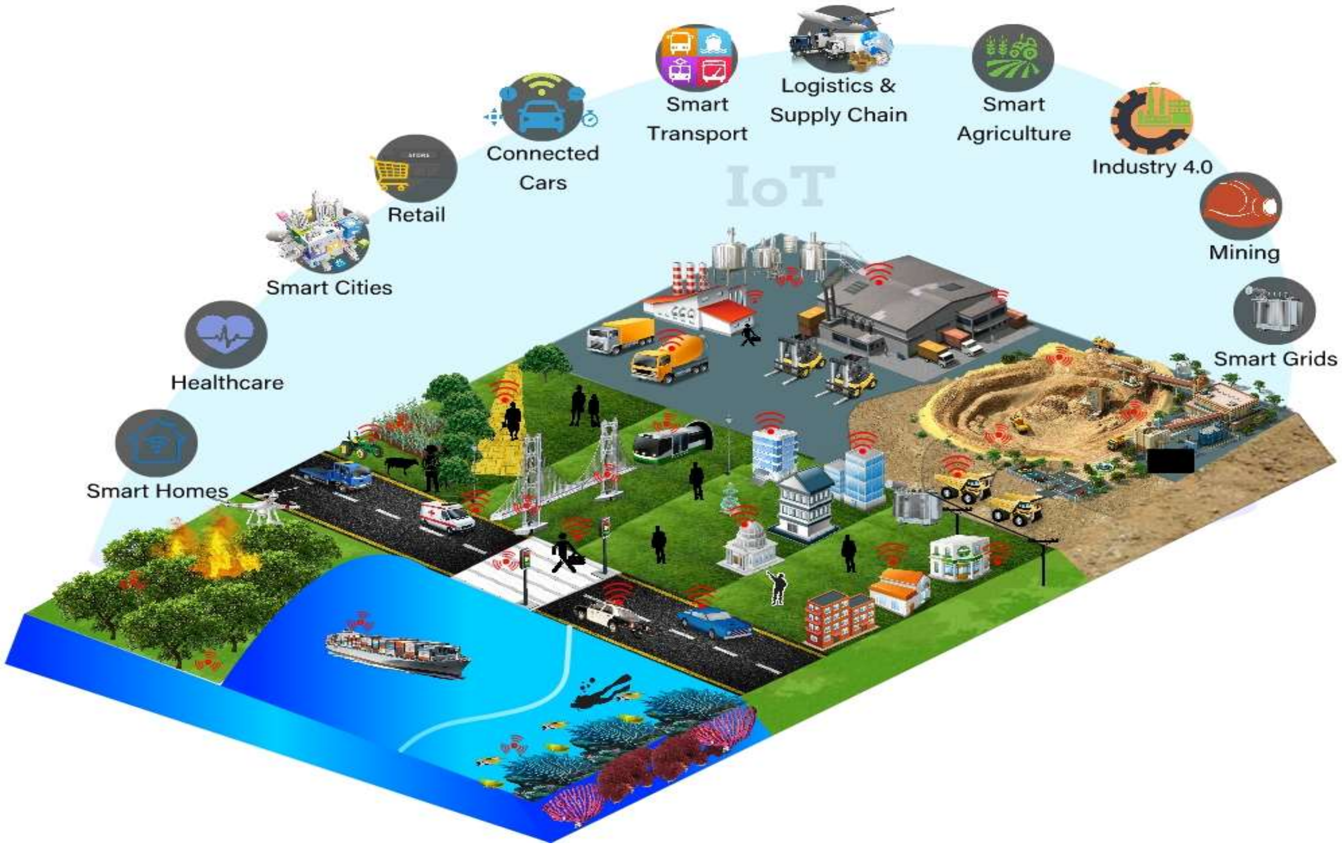
New Horizons in IoT Workflows Provisioning in Edge and Cloud Datacentres for Fast Data Analytics: OSMOTIC COMPUTING APPROACH

Prof. Rajiv Ranjan, PhD SMIEEECS
Professor of Computing Science
Chair of Internet of Things
Newcastle University, United Kingdom
E raj.ranjan@ncl.ac.uk web: http://rajivranjan.net/

Outline

- IoT landscape
- IoT application context
- Big Data context
- Osmotic computing approach
- Research Challenges

Motivation

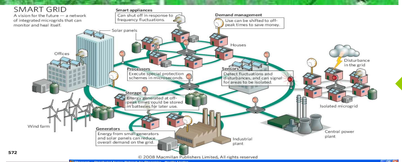

IoT
Smart Homes
Healthcare
Smart Cities
Retail
Connected Cars
Smart Transport
Logistics & Supply Chain
Smart Agriculture
Industry 4.0
Mining
Smart Grids

Internet of Things (IoT) Landscape

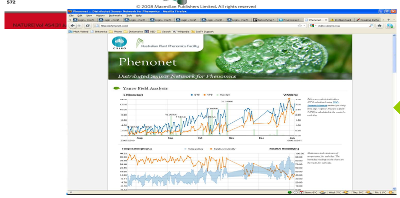
Environmental Sensors

Smart Meters

Water Management



Smart Grids



Smart Agriculture

Software as a Service

Cloud computing

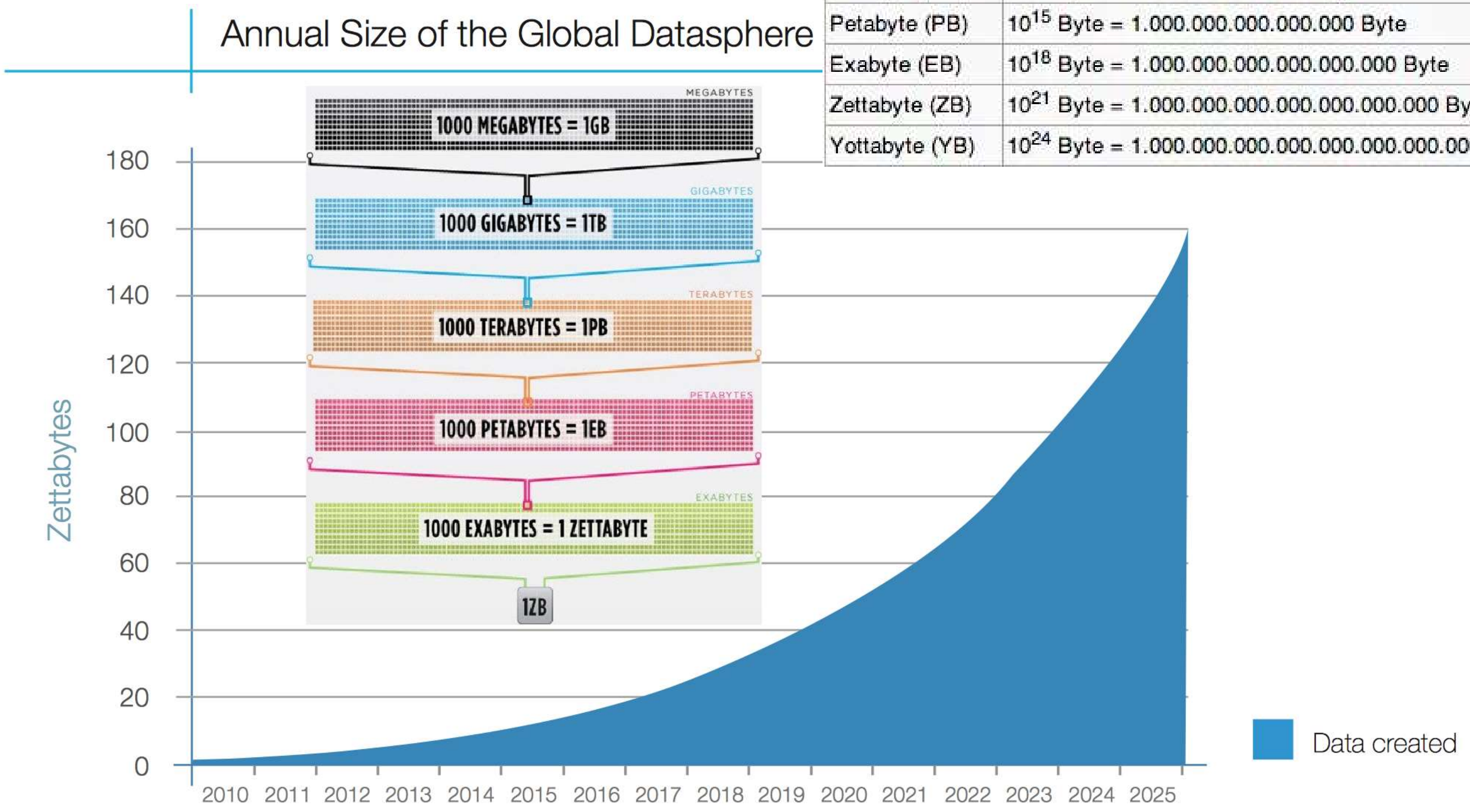
Software Defined Networking

Edge Computing

Ambient services

IoT and Big Data Space

Kilobyte (kB)[G 2]	10^3 Byte = 1.000 Byte
Megabyte (MB)	10^6 Byte = 1.000.000 Byte
Gigabyte (GB)	10^9 Byte = 1.000.000.000 Byte
Terabyte (TB)	10^{12} Byte = 1.000.000.000.000 Byte
Petabyte (PB)	10^{15} Byte = 1.000.000.000.000.000 Byte
Exabyte (EB)	10^{18} Byte = 1.000.000.000.000.000.000 Byte
Zettabyte (ZB)	10^{21} Byte = 1.000.000.000.000.000.000.000 Byte
Yottabyte (YB)	10^{24} Byte = 1.000.000.000.000.000.000.000.000 Byte

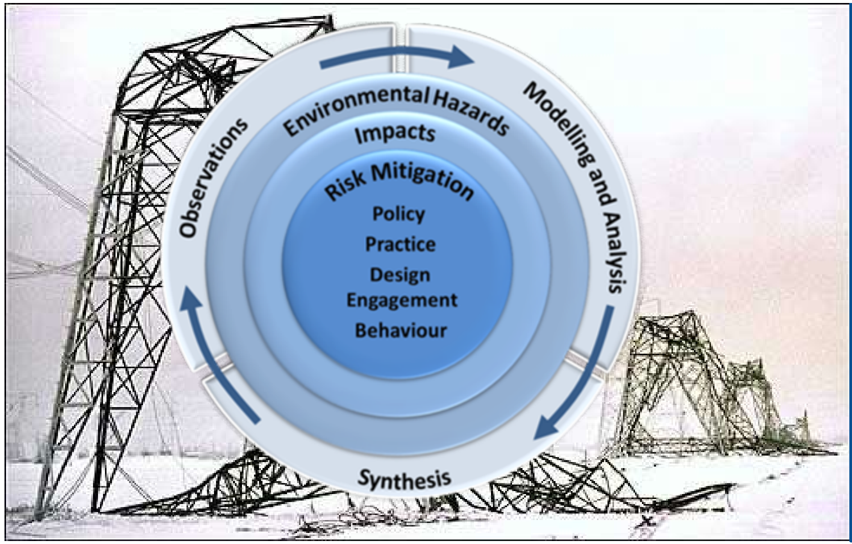


Source: IDC's Data Age 2025 study, sponsored by Seagate, April 2017

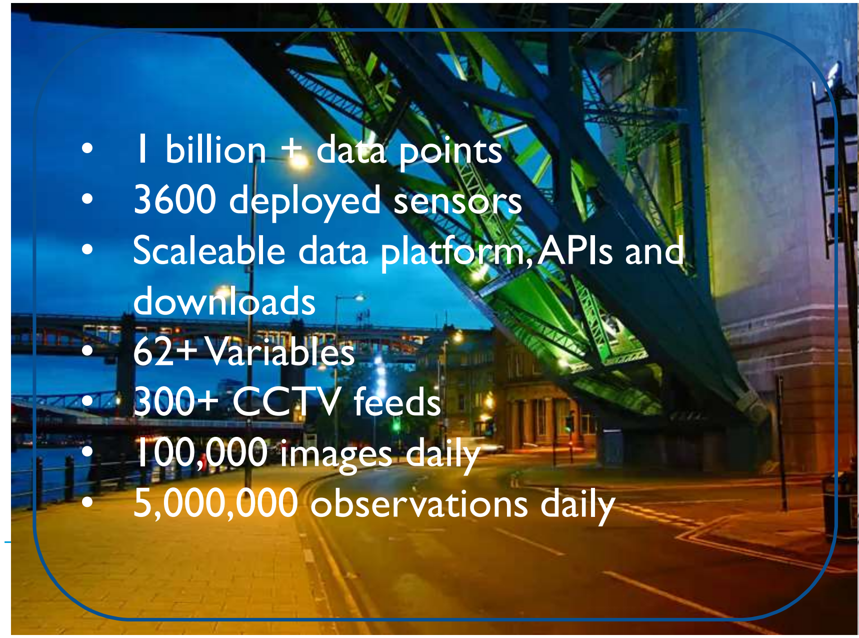
National IoT Research Testbed@Newcastle

- £4.3m total capital investment to 2021
- £25m+ total research revenue
- 3500+ sensors deployed to date
- Largest sensor deployment in the UK
- 1,000,000,000 observations > 2000 per minute
- Largest set of open environment monitoring data in the world (?)
- 64+ variables, 24 platforms
  - Weather, traffic, water flow, water quality, bees, traffic, people flows, air quality, energy consumption, waste and clean water, noise
- Monitored infrastructure and buildings
- CCTV – 240+ cameras > 100,000,000 images
- Relationships with city stakeholders

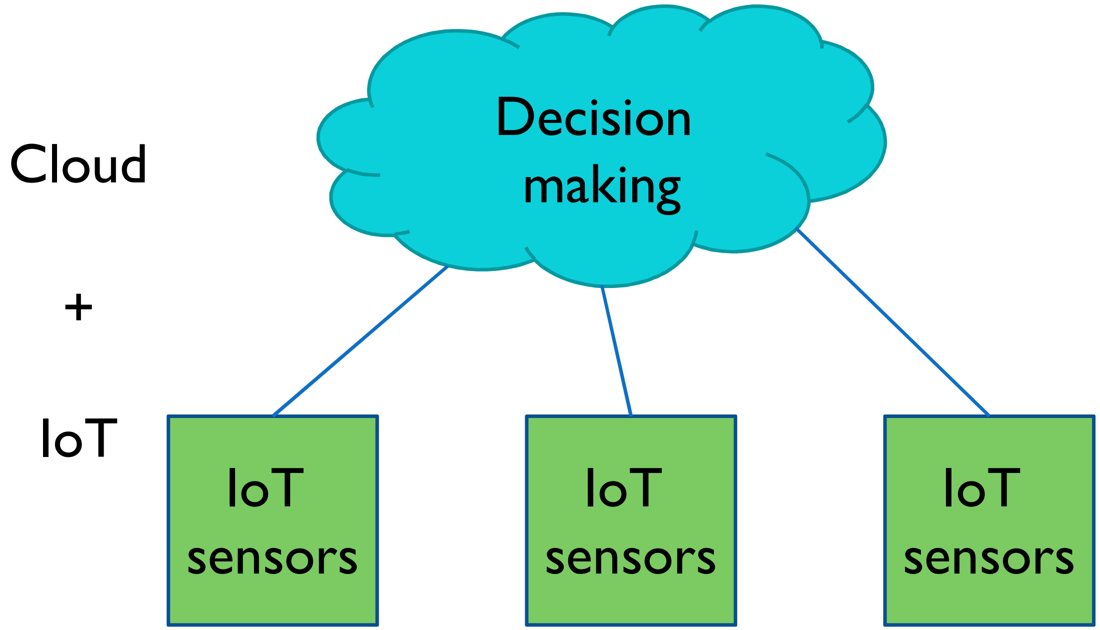
Newcastle University | TU WIEN | FAKULTÄT FÜR INFORMATIK Faculty of Informatics | CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD | UFRN UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE | SWINBURNE UNIVERSITY OF TECHNOLOGY



National Urban Observatory Facility Newcastle ***http://newcastle.urbanobservatory.ac.uk***



Cloud + IoT + Big Data Approaches



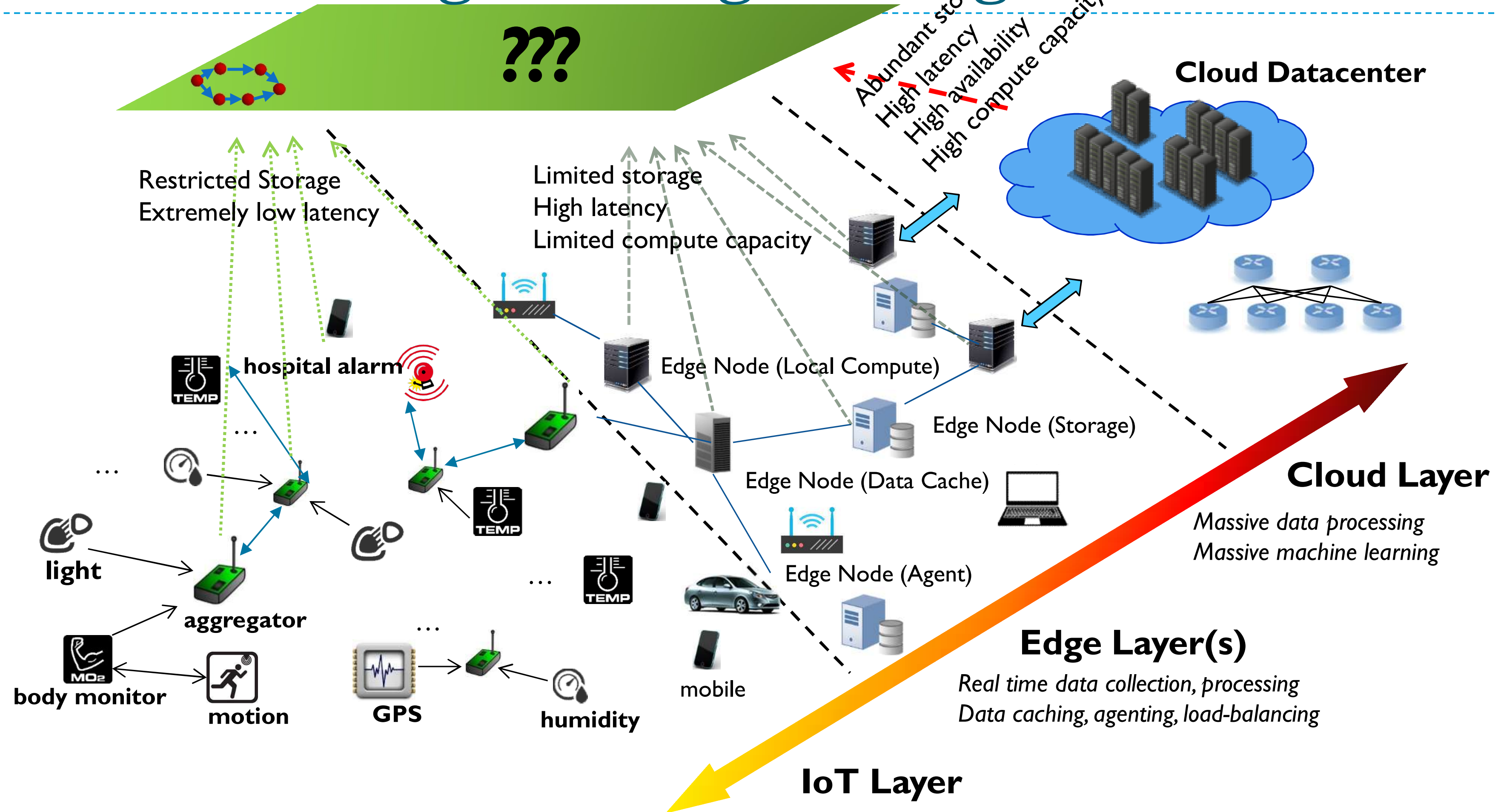
- High latency
- Wasting of bandwidth

AWS IoT

Azure IoT

Google Cloud IoT

New IoT Programming Paradigm



Motivation

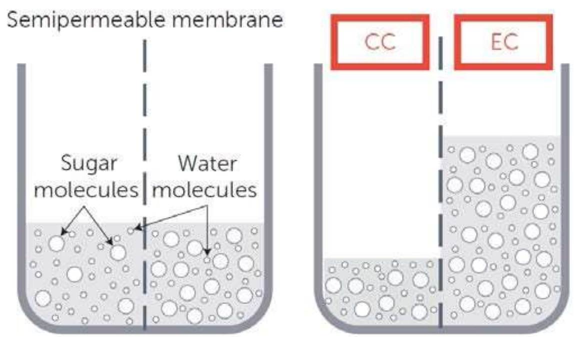
Osmotic Computing

Osmotic computing is a new paradigm to support the efficient execution of Internet of Things (IoT) services (microservices) and applications between cloud datacenter and the network edge by providing increased resource and data management capabilities at the edge of the network.

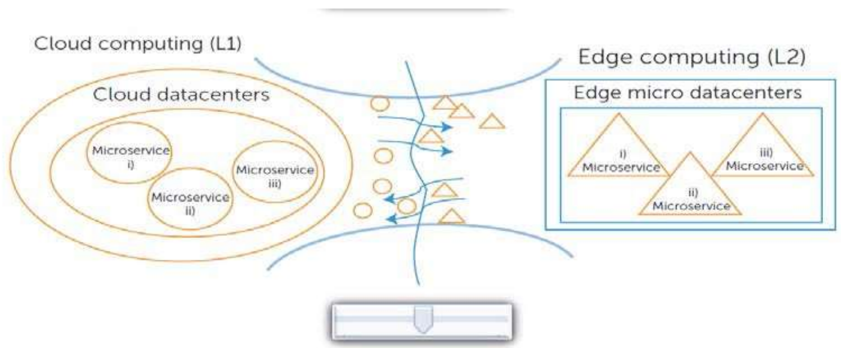
M. Villari, M. Fazio, S. Dustdar, O. Rana, and R. Ranjan, "Osmotic computing: A new paradigm for edge/cloud integration," IEEE Cloud Computing, vol. 3, pp. 76–83, Nov 2016.

Osmosis Process

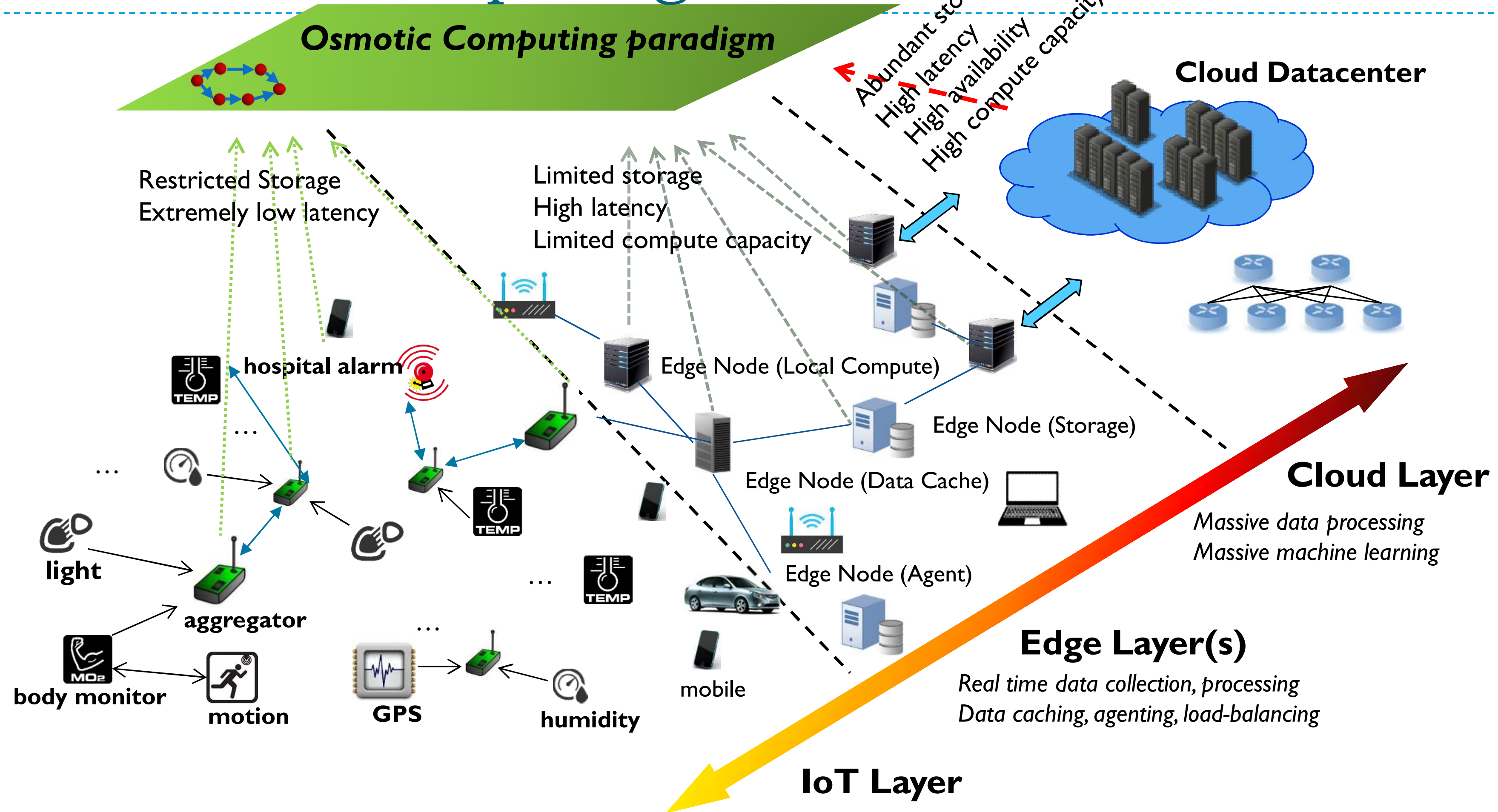
- In chemistry, "osmosis" represents the seamless diffusion of molecules from a higher to a lower concentration solution.



- Dynamic management of (micro)services across cloud and edge datacenters
  - deployment, networking, and security, …
  - providing reliable IoT support with specified levels of QoS.

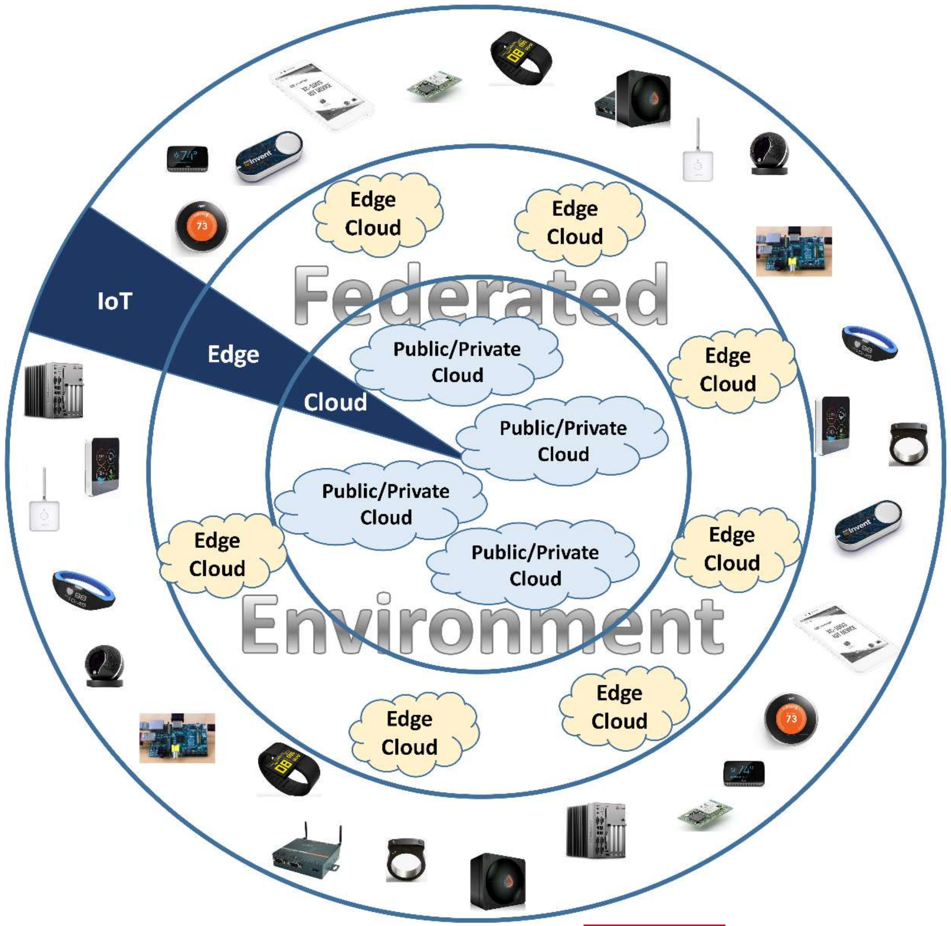


Osmotic Computing



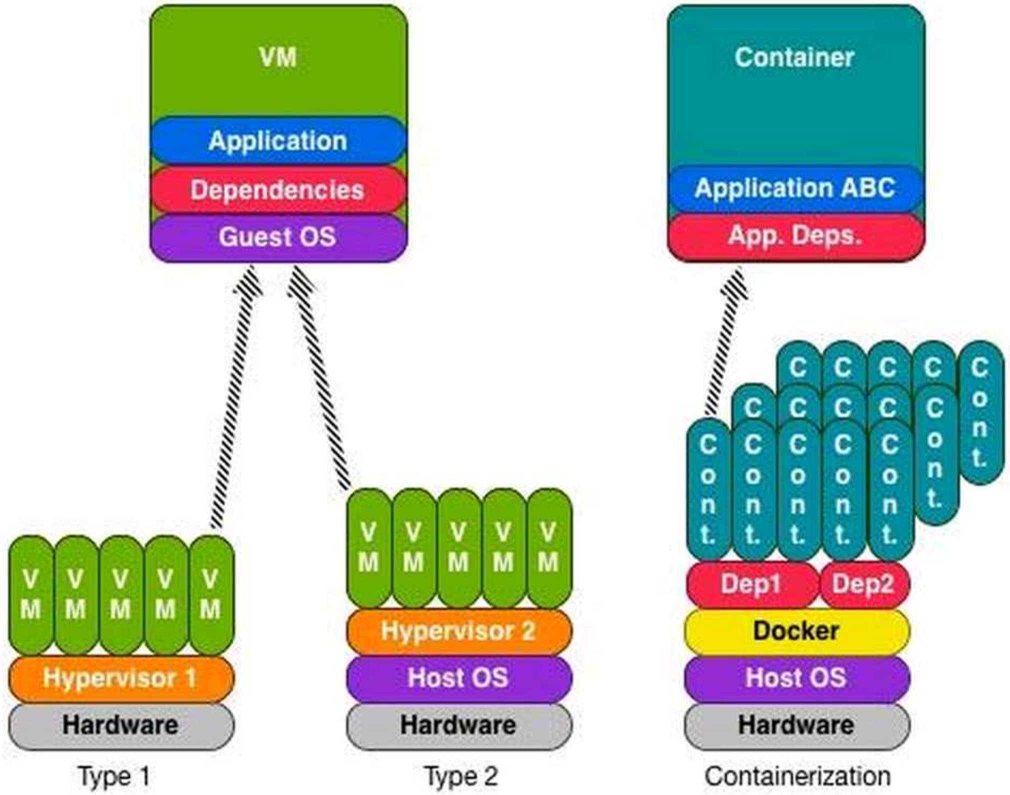
Newcastle University | TU WIEN | FAKULTÄT FÜR INFORMATIK Faculty of Informatics | CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD | UFRN UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE | SWINBURNE UNIVERSITY OF TECHNOLOGY

Osmotic Computing: Federated View



Building Blocks: Containerized Microservices

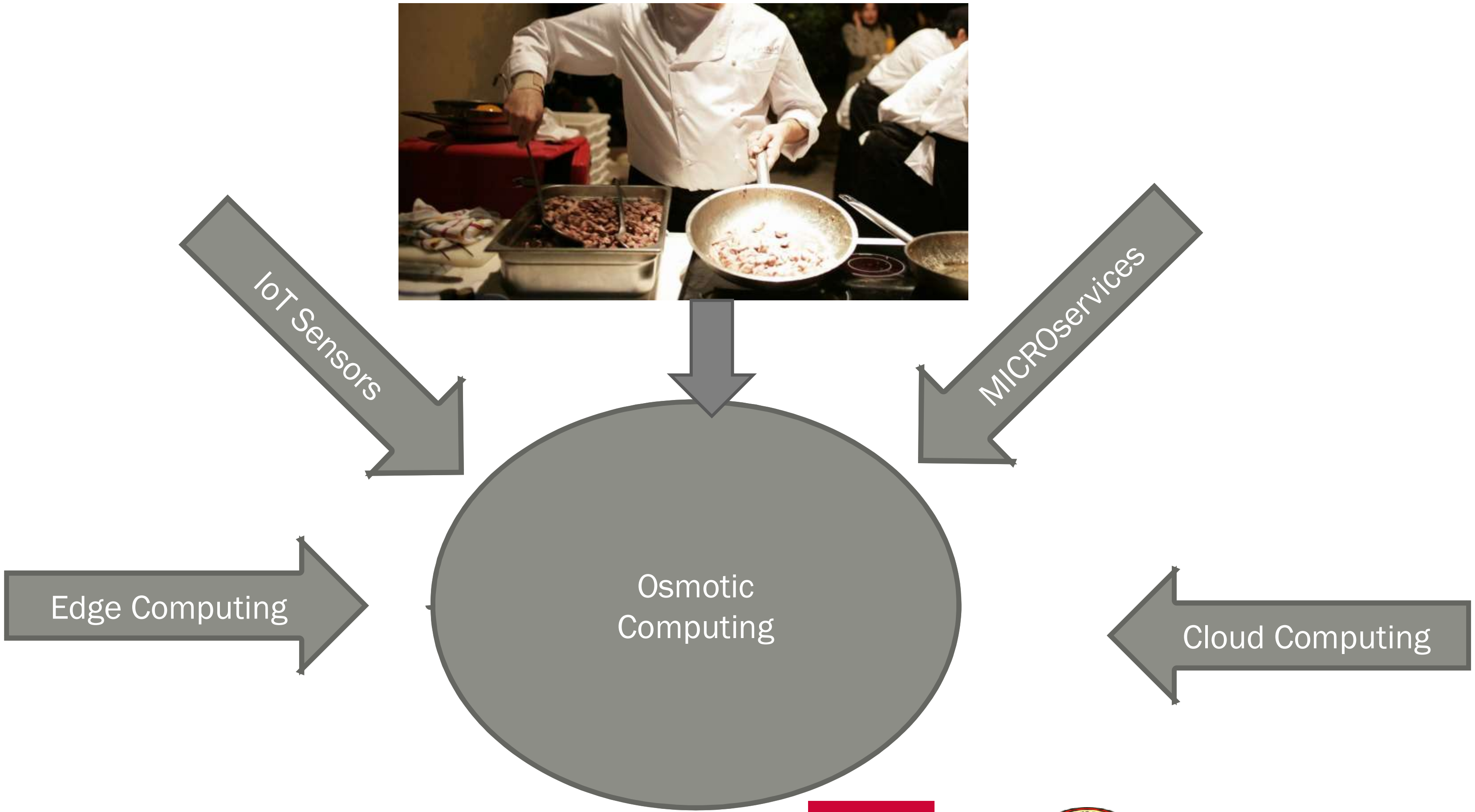
- **Division of functionality in to multiple components**
- **Easy to manage and upgrade**
- **Lightweight**
- **Improved performance**



Virtual Machines

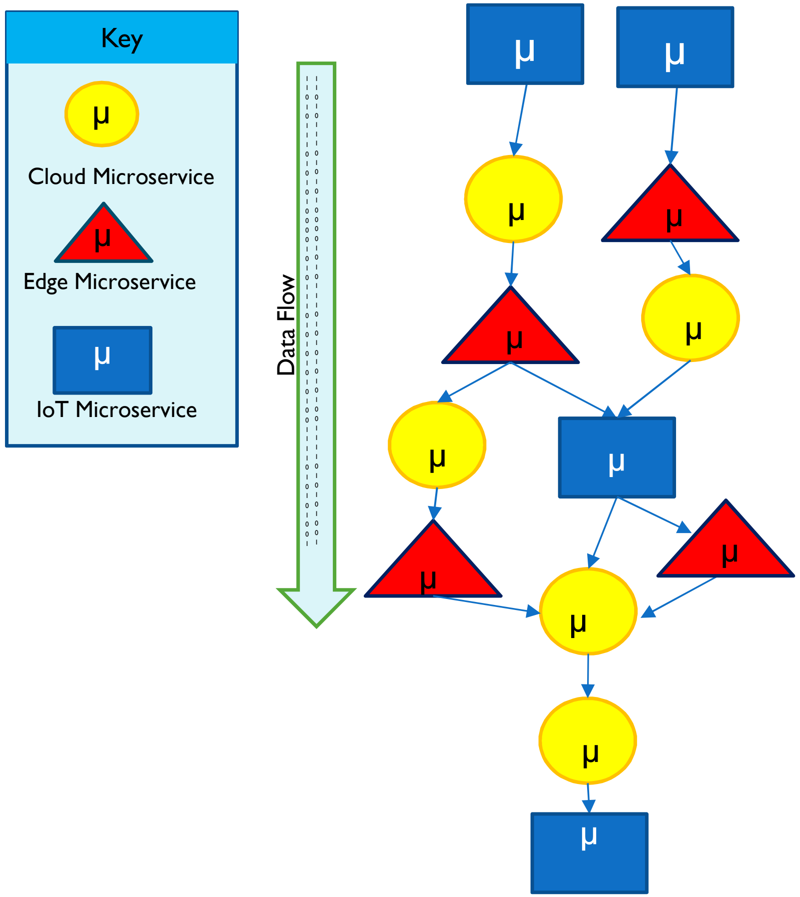
Containers

Mixing Up

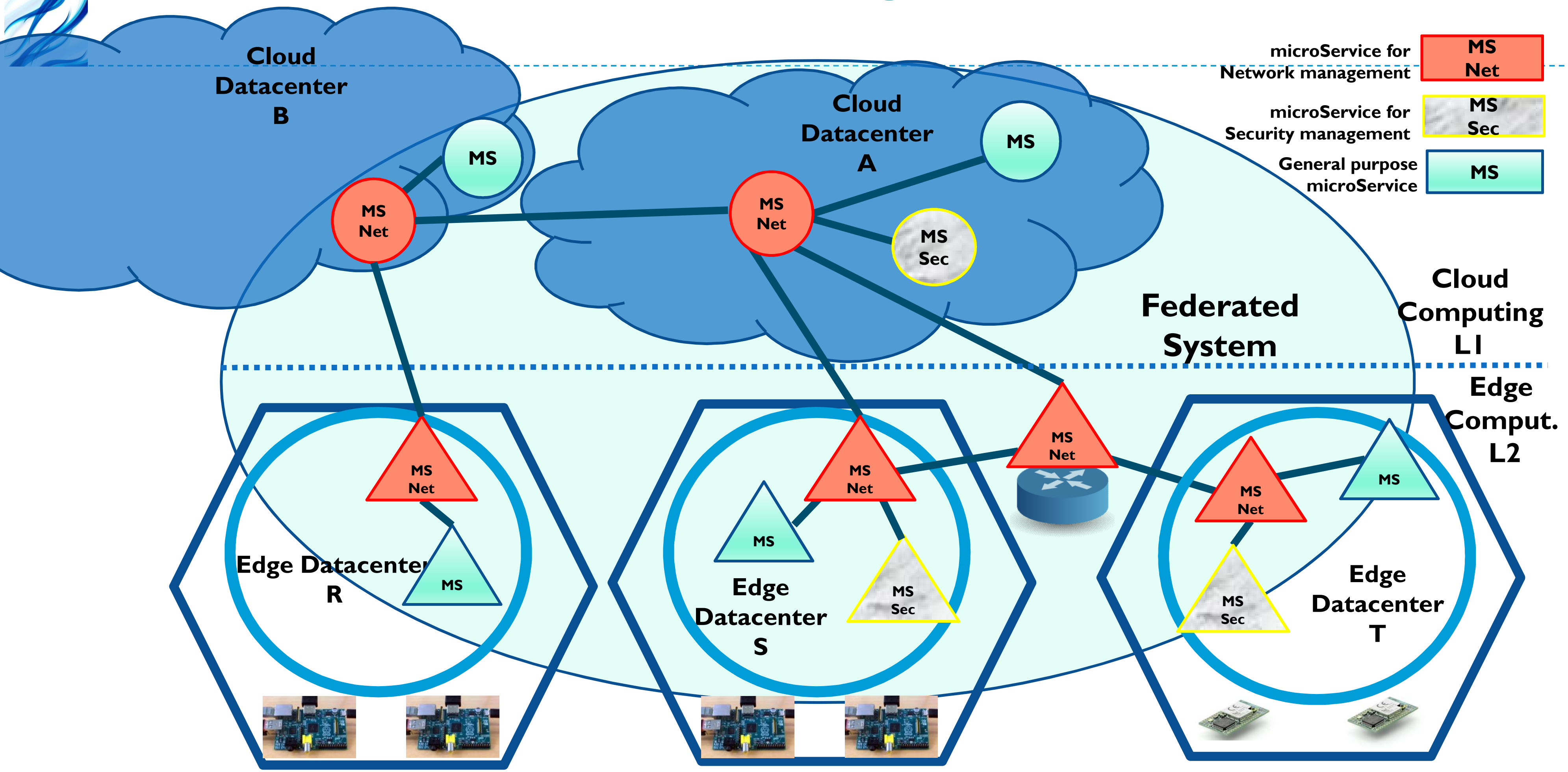

IoT Sensors
MICROservices
Edge Computing
Osmotic Computing
Cloud Computing

Abstract View of Osmotic IoT Application

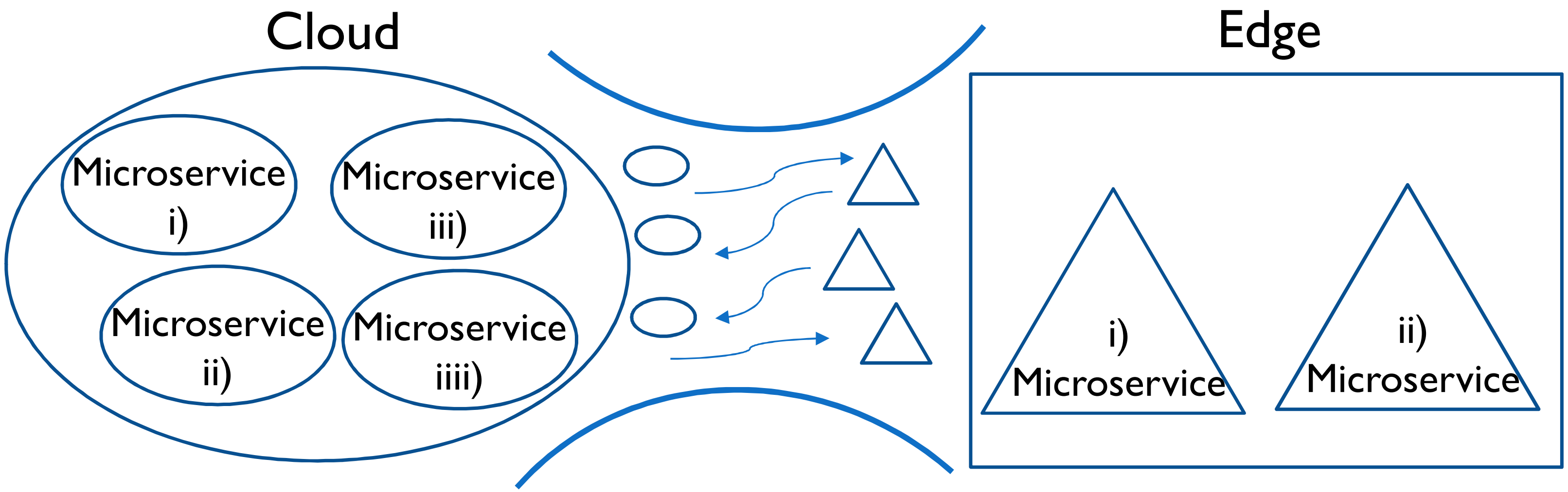
- The dependency among various microservices is represented by a topologically ordered directed acyclic graph (DAG).
- Each microservice belongs to either a set of pre-defined IoT functions Ψ or user-defined functions Ω,
- Each microservice has specific hardware and software requirements RH and RS respectively. Some QoS constraints are also associated with each microservice



Osmotic Computing Model



Osmotic Computing Concept



A tunable configuration of the resource involvement

- Adapt to the available resources
- Meet application requirements (latency in this paper)

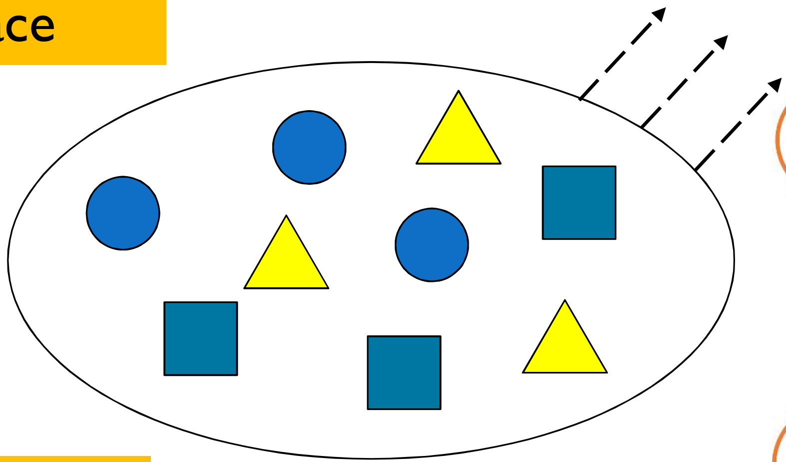
Osmotic Computing Concept

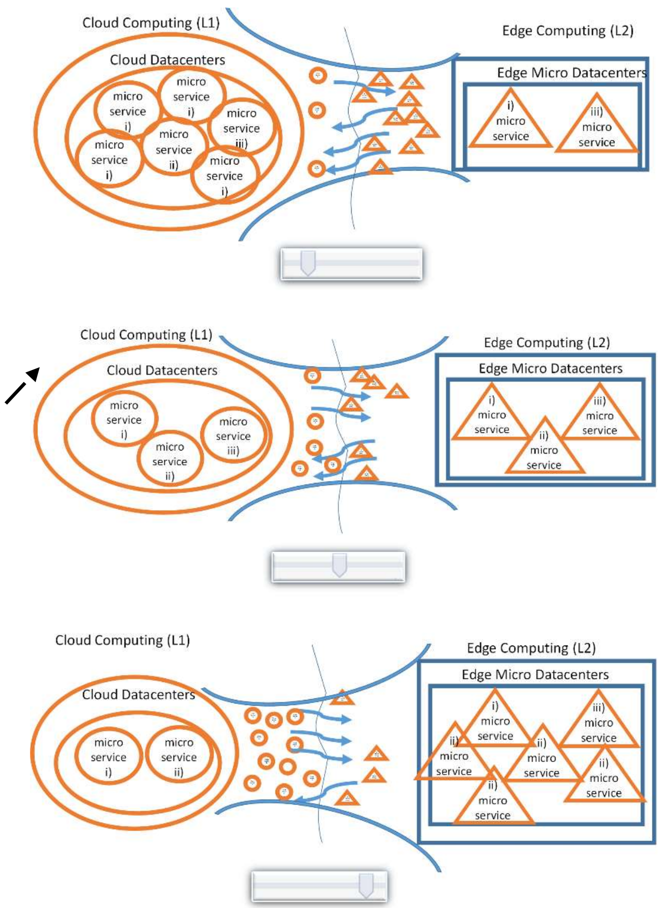
IoT application

Larger search space

Partitioning

Distribution





Verification is hard

Osmotic Computing Challenges

How to abstract IoT Data Analysis and Flow Patterns?

IoT analysis patterns

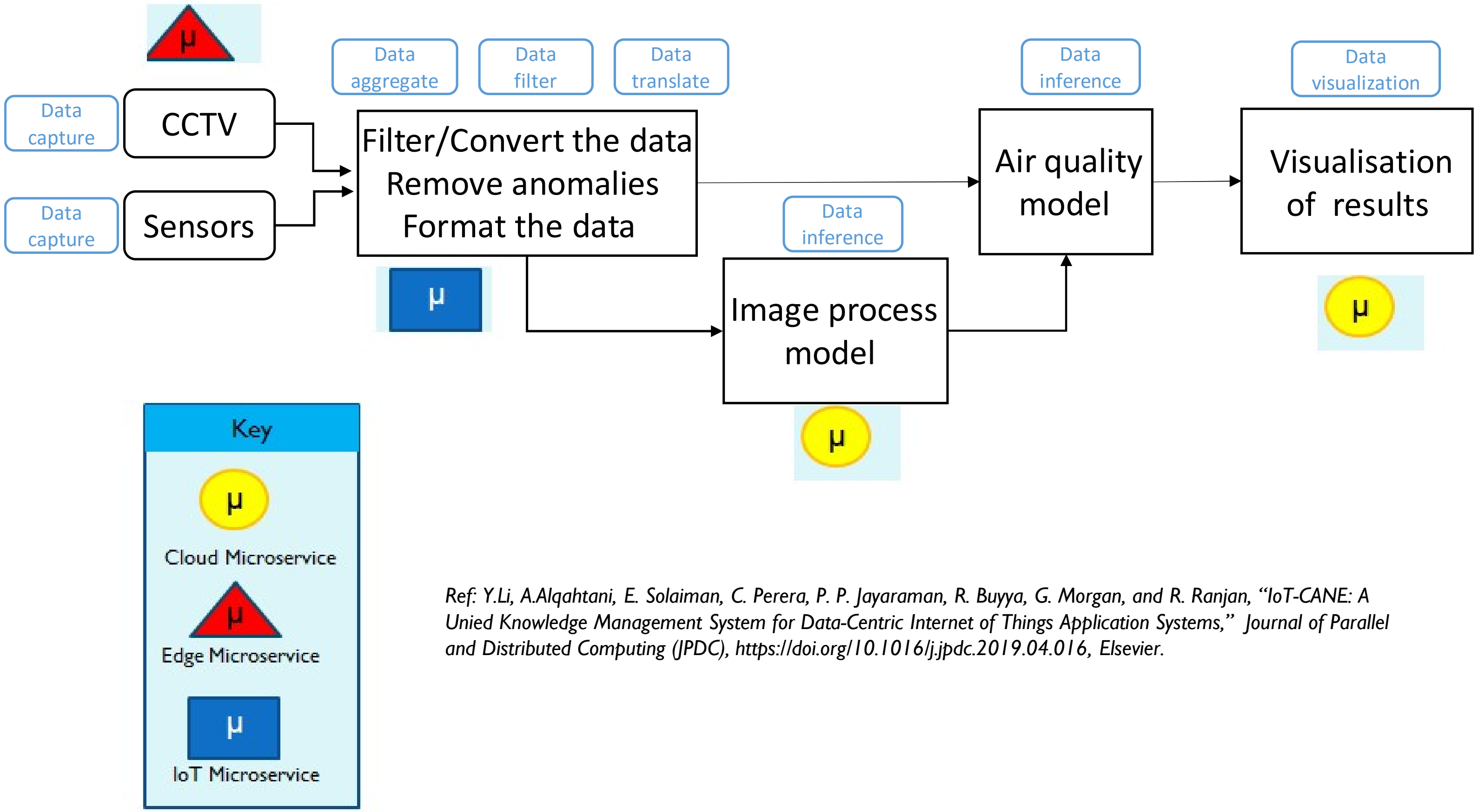
- Data capture
- Data Store
- Data inference
- Data filter
- Data aggregate
- Data visualization
- Data translate
- Actuation

Data flow patterns

- IoT connect
- Data transfer
  - Edge to Edge
  - Edge to Cloud
  - Cloud to Cloud
- Cloud to Edge

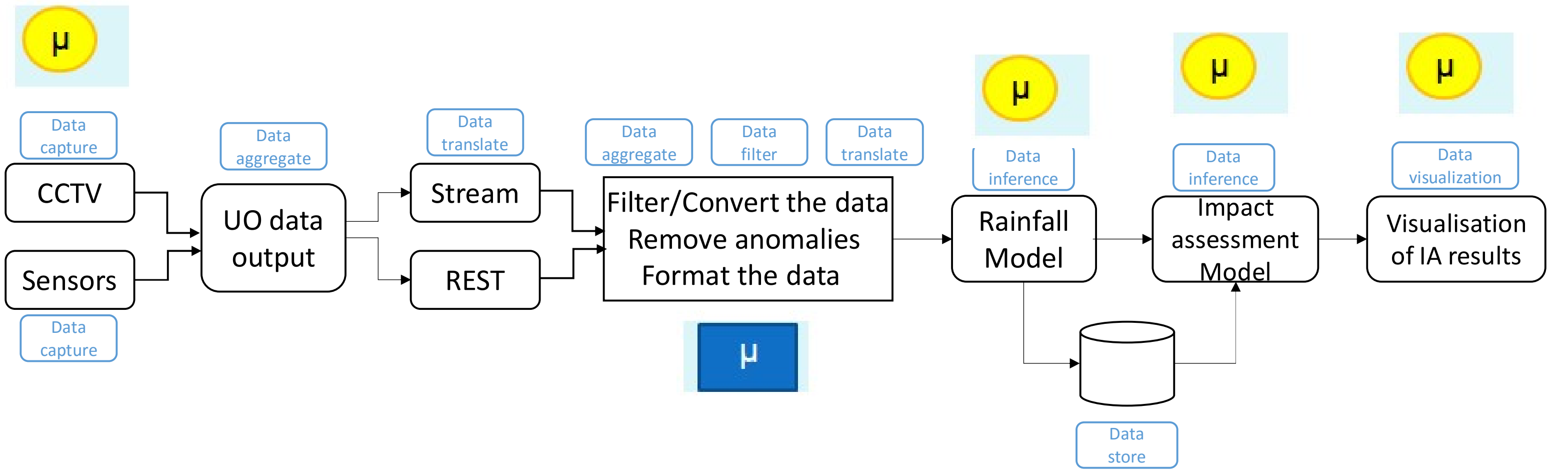
Ref: Y.Li, A.Alqahtani, E. Solaiman, C. Perera, P. P. Jayaraman, R. Buyya, G. Morgan, and R. Ranjan, "IoT-CANE: A Unied Knowledge Management System for Data-Centric Internet of Things Application Systems," Journal of Parallel and Distributed Computing (JPDC), https://doi.org/10.1016/j.jpdc.2019.04.016, Elsevier.

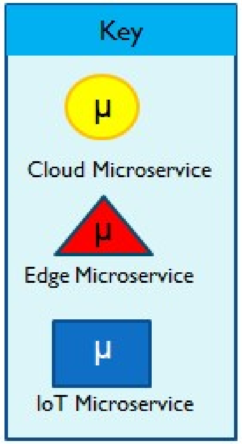
Air Quality IoT Data Analysis Workflow



Ref: Y.Li, A.Alqahtani, E. Solaiman, C. Perera, P. P. Jayaraman, R. Buyya, G. Morgan, and R. Ranjan, "IoT-CANE: A Unied Knowledge Management System for Data-Centric Internet of Things Application Systems," Journal of Parallel and Distributed Computing (JPDC), https://doi.org/10.1016/j.jpdc.2019.04.016, Elsevier.

Flood Prediction IoT Data Analysis Workflow





Ref: Y.Li, A.Alqahtani, E. Solaiman, C. Perera, P. P. Jayaraman, R. Buyya, G. Morgan, and R. Ranjan, "IoT-CANE: A Unied Knowledge Management System for Data-Centric Internet of Things Application Systems," Journal of Parallel and Distributed Computing (JPDC), https://doi.org/10.1016/j.jpdc.2019.04.016, Elsevier.

Osmotic Computing Challenges

Microservices' Performance Characterisation:

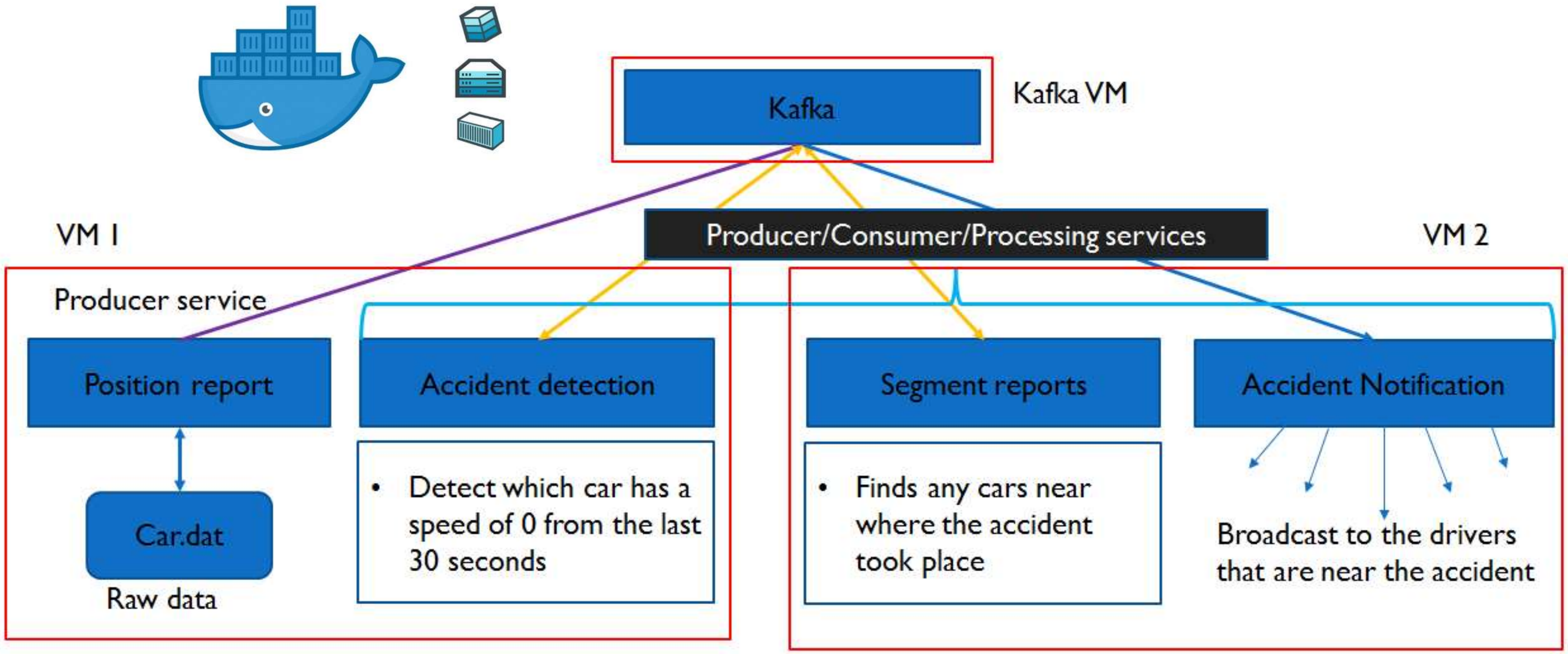
- How to systematically undertake performance characterisation of data analysis activities (e.g., microservices) across different parts of the infrastructure (Cloud, Edge, and IoT)?
- How to reason about heterogeneous QoS implications across Cloud, Edge and IoT?
  - The performance of a data analysis activity mapped to a Cloud layer is quite different from a gateway and/or device in the Edge and IoT layer
  - Network stability, throughput optimality, routing delays, fairness in resource sharing, available bandwidth, and sensor battery state . [Edge and IoT]
  - End-to-end response times, platform scalability and reliability, virtual server utilizations, and the costs of moving data to and from the Cloud. [Cloud]

Microservices' Performance Characterisation

- Current benchmark kernel implementation can only test performance of specific type of IoT data analysis activities
  - TPCx-IoT can benchmark Edge layer (data aggregation, real-time analytics and persistent storage)
  - Google ROADEF & Linear Road kernels for benchmarking stream processing data analysis activity at the Edge layer.
- None, by themselves, can reveal the true bottleneck of whole IoT application graph,
- Possible research directions
  - To identify/build different suitable benchmarks from each type of the data analysis activities and hierarchically/logically combine them to draw accurate conclusions across an IoT graph in a holistic way.

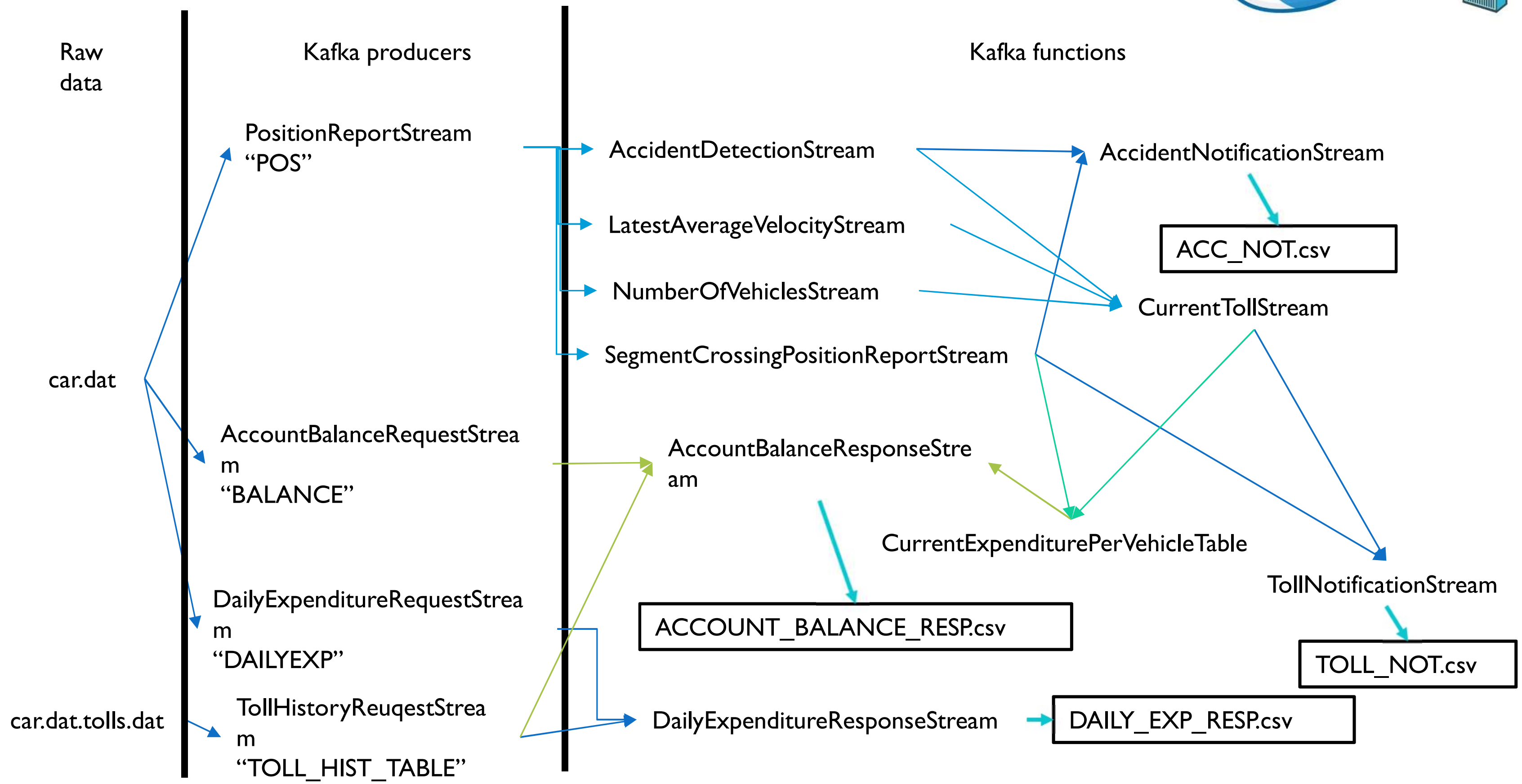
Dockerizing Benchmark Kernel: Our Approach

Linear Road Kernel

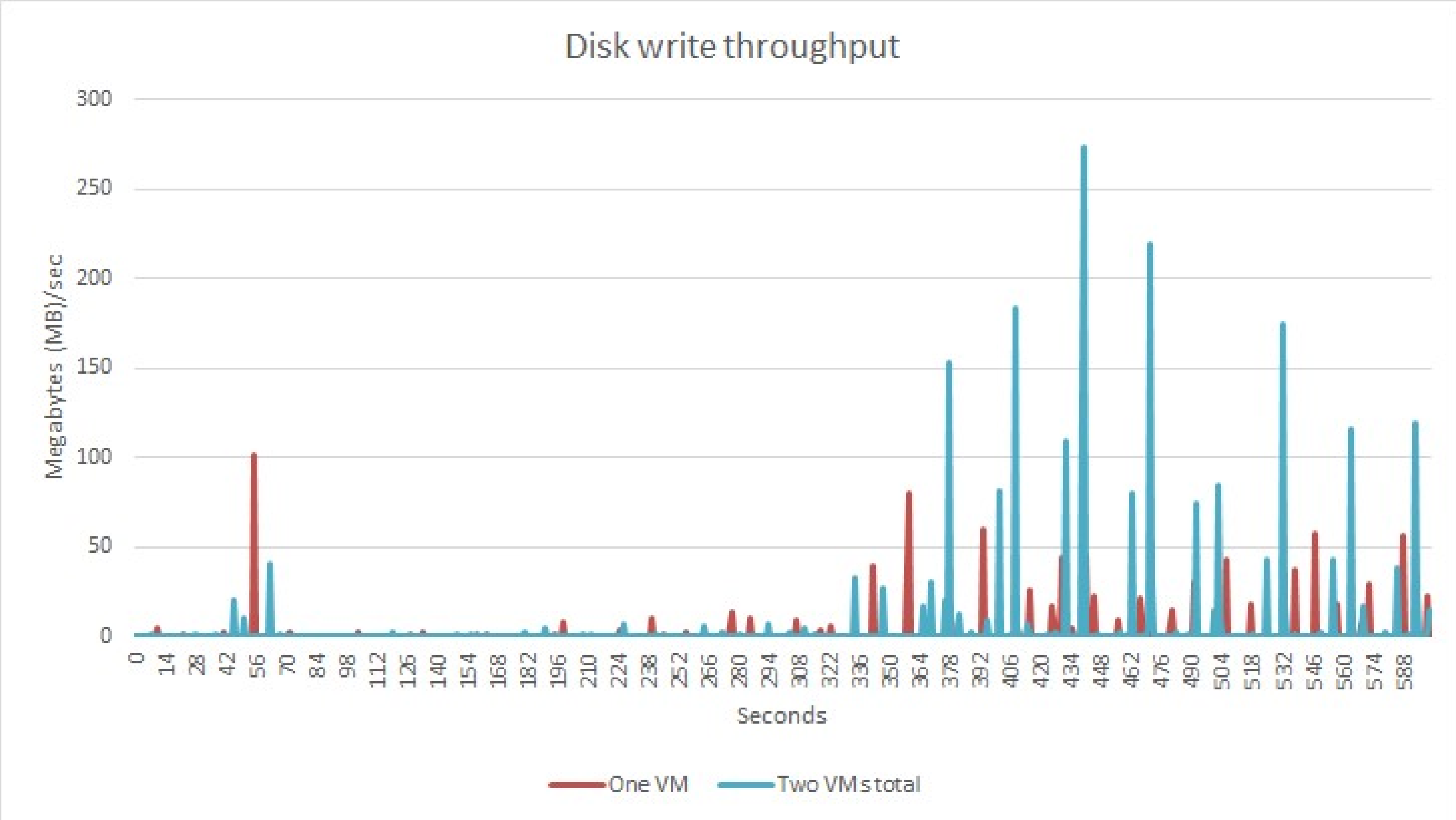


Standford University, MIT, Brandeis University, OHSU/OGI (2004) Linear Road: A Stream Data Management Benchmark https://www.cs.brandeis.edu/~linearroad/linear-road.pdf

Dockerizing Linear Road Kernel



Testing results – Throughput



New Benchmark Kernels

urban observatory

National Urban Observatory Facility
Newcastle
http://newcastle.urbanobservatory.ac.uk

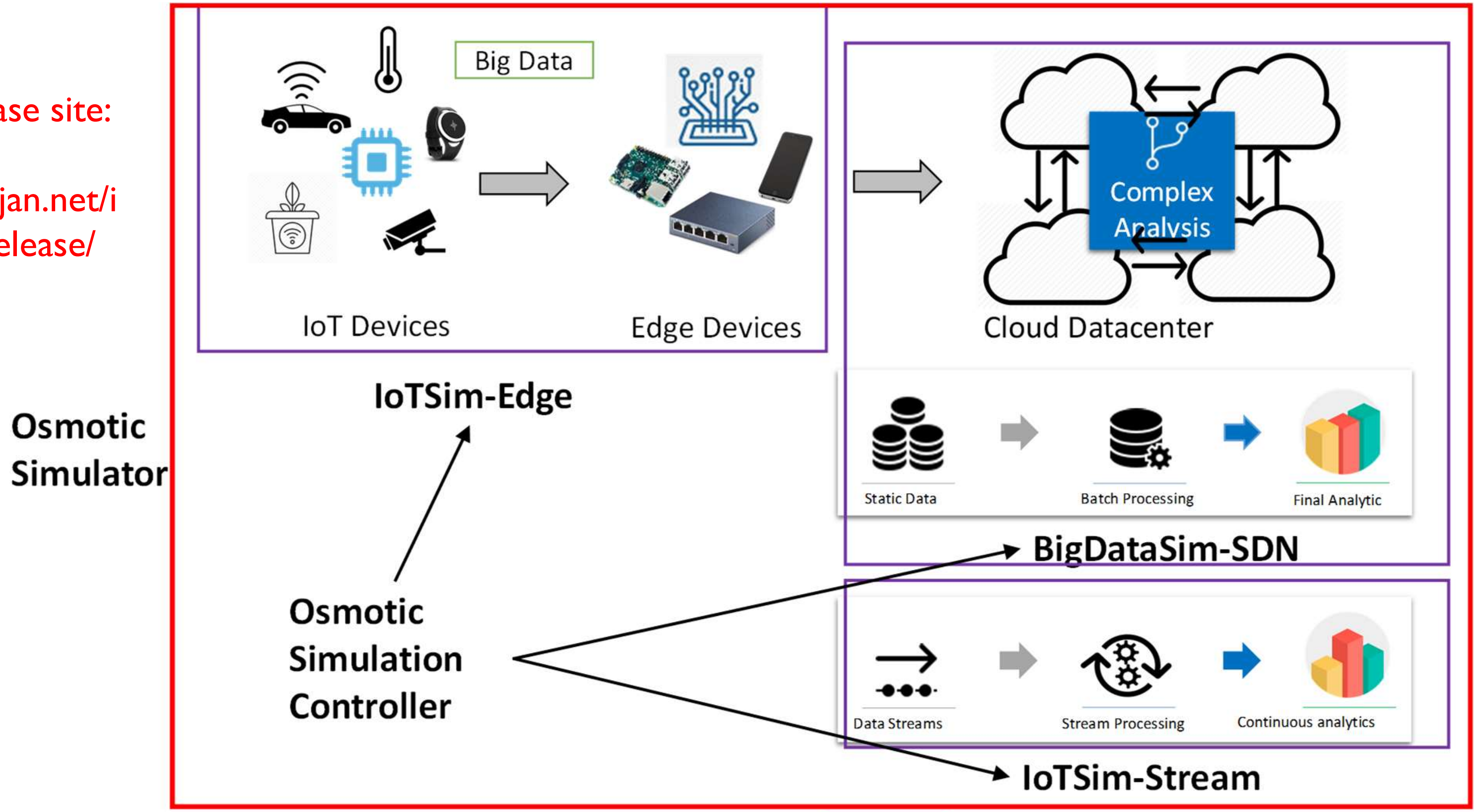
Microservices’ Performance Characterisation

- Challenges with setting up real-world benchmarking experiments in context of Osmotic Computing
  - Complexity and heterogeneity of end-point networks (e.g. WiFi, 4G, Bluetooth)
  - Heterogeneity of cloud, edge and IoT hardware resources and software stack
  - Mobility of IoT and edge devices
  - Complex interactions between the IoT and edge layers
  - Hard (if not) impossible to scale

Microservices' Performance Characterisation: Osmotic Simulator

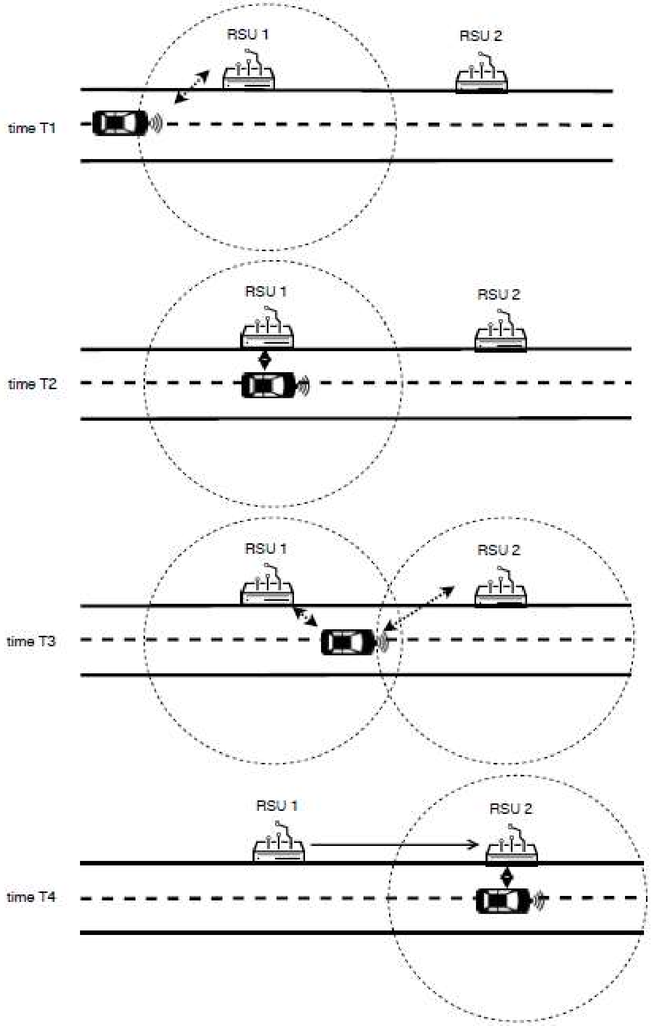
Simulator release site:

https://rajivranjan.net/iotsim/iotsim-release/



Newcastle University · TU WIEN Fakultät für Informatik, Faculty of Informatics · Cardiff University Prifysgol Caerdydd · UFRN Universidade Federal do Rio Grande do Norte · Swinburne University of Technology

IoTSim-Edge Case Study
- Capacity Planning for Road Side Units (RSUs)



IoTSim-Edge Case Study
- Capacity Planning for Road Side Units (RSUs)

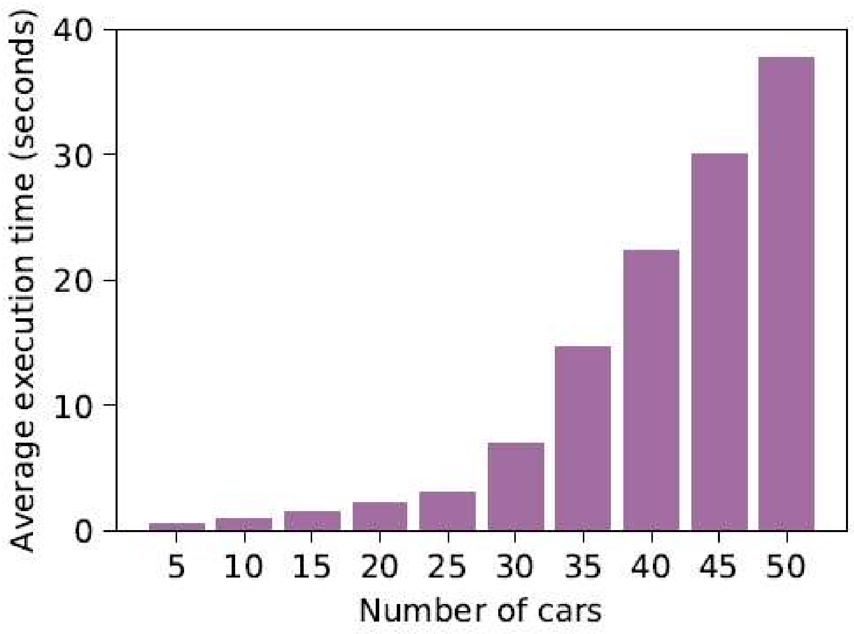
IoT device	
Current location	0, 0, 0
IoT type	car
Movable	true
Data frequency	1
Data generation time	1
Network protocol	bluetooth
IoT Protocol	XMPP
Max battery capacity	70
Battery drainage rate	1
Number of entity	'variable'
Velocity	0.5

Edge device 1	
Type	Raspberry Pi
Location	0, 0, 0
Movable	false
Signal range	25+25
Max IoT device capacity	10000
Max battery capacity	200000 units
MIPS	10000
RAM	10000
Bandwidth	10000

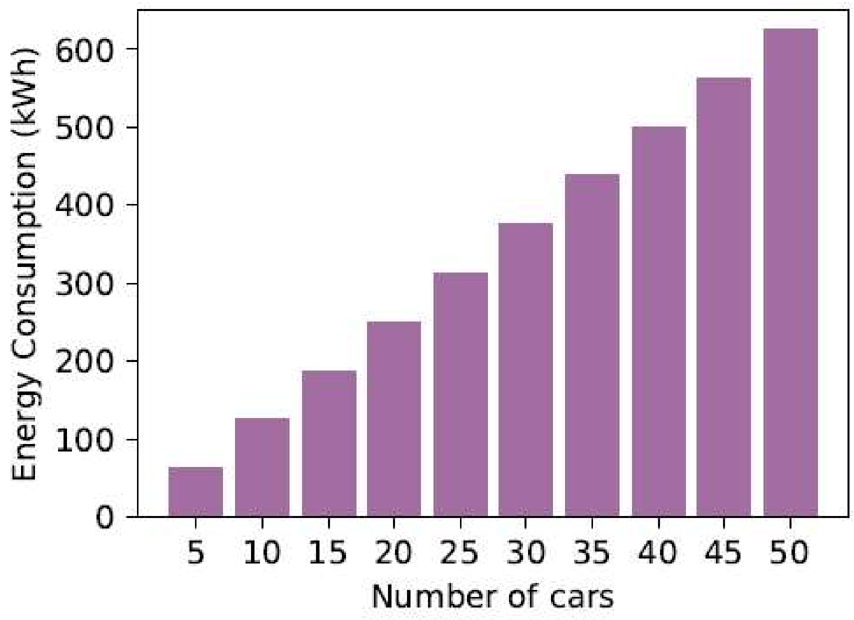
Microservices	
id	1
MIPS	10000
RAM	10000
BW	10000
Shrinking factor	'variable'
Network protocol	bluetooth
Uplink	-
Downlink	2

Simulation Configuration for IoT device, Edge device and Microservices

IoTSim-Edge Case Study
- Capacity Planning for Road Side Units (RSUs)



(a) Average execution time for each edgelet



(b) Average energy consumption by the edge devices

Osmotic Computing Challenges

Microservice deployment:

- How to map microservices to Edge, IoT, and Cloud layers based on non-functional requirements?
- How to solve the NP-hard deployment problem?
- To this end, novel decision-making techniques based on multi-criteria optimization and multi-criteria decision making techniques should be investigated.

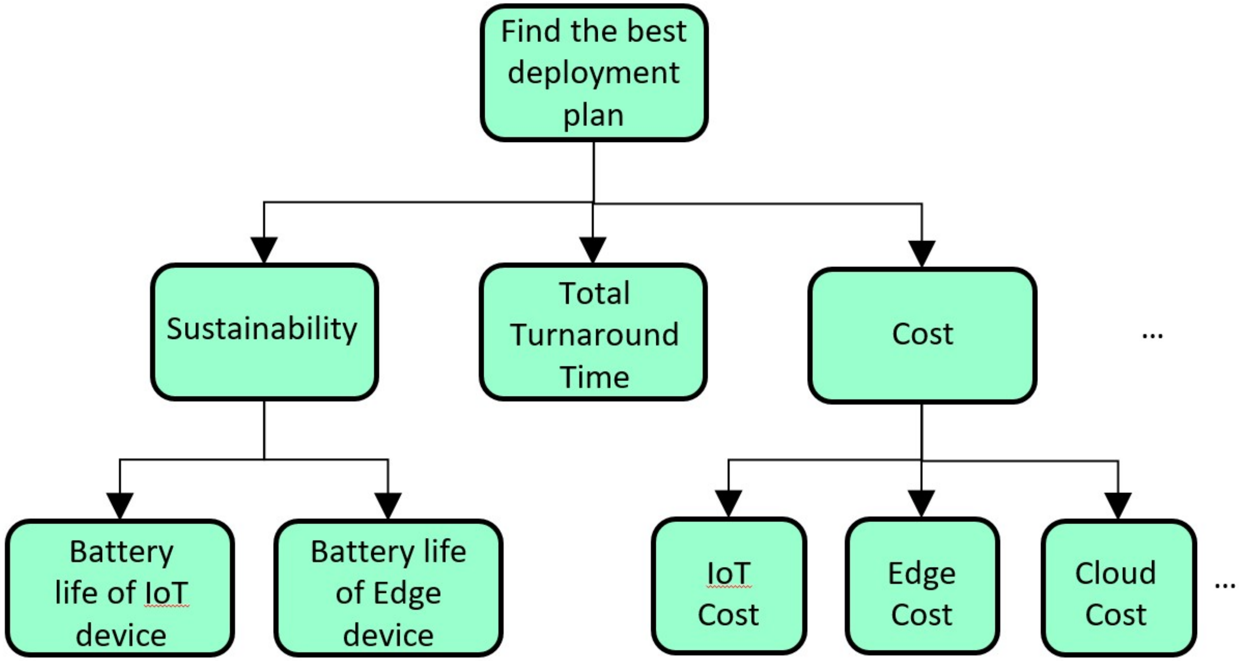
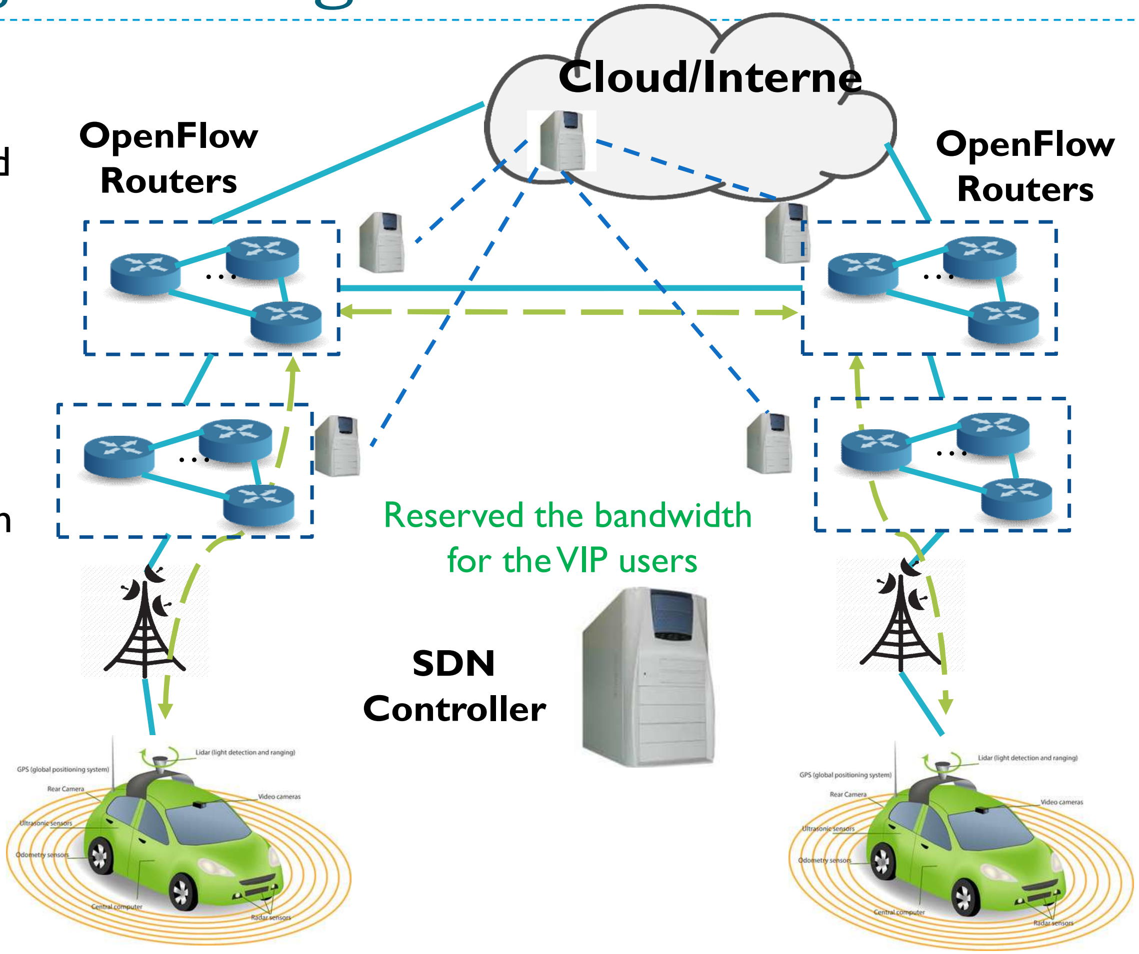


Fig: Non-functional Requirements

Osmotic Computing Challenges

Microservice Networking

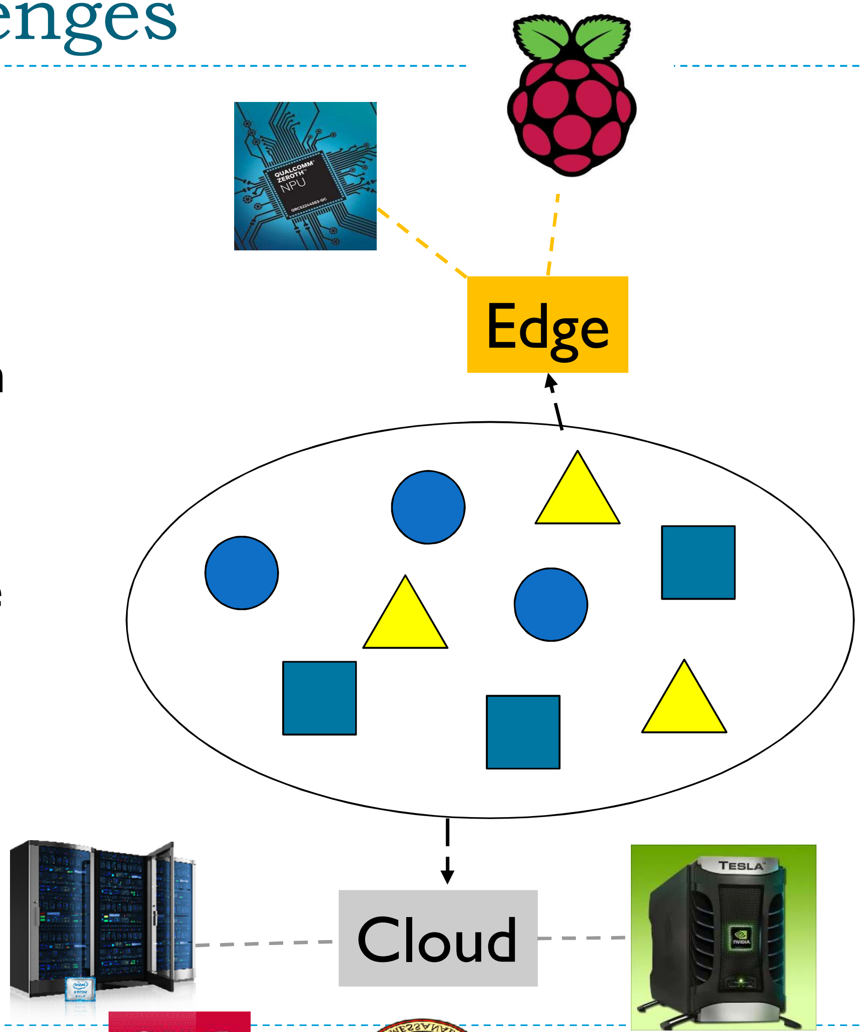
- Limitation of Software Defined Networking (SDN) in context of IoT includes:
  - having a centralized controller
  - connecting millions of IoT devices to a centralised controller is not scalable
- One of the important research direction will be to
  - first subdivide the controlling layer to create hierarchy of controllers
  - develop algorithms for coordinating bandwidth allocation across controllers



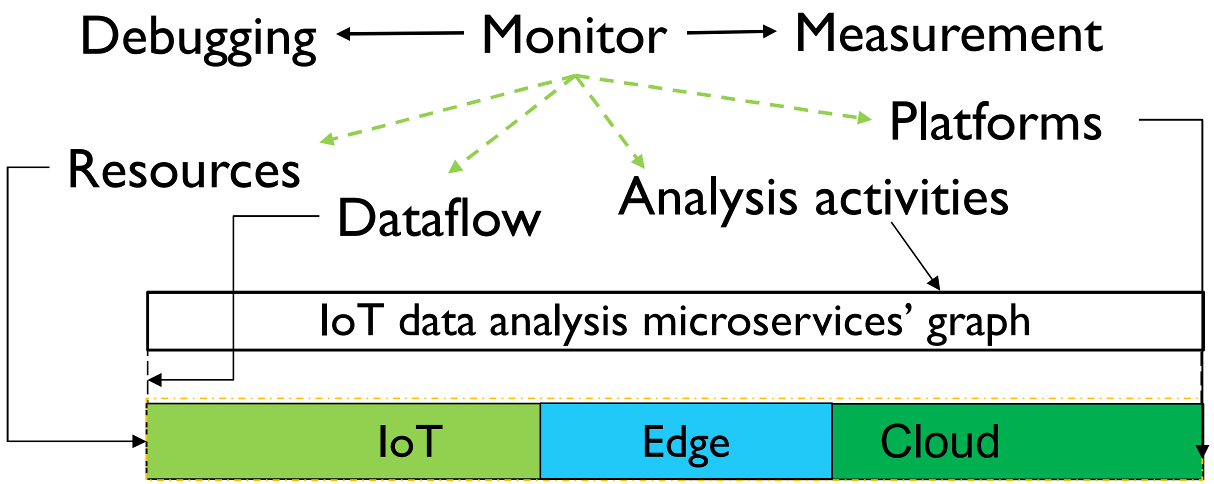
Osmotic Computing Challenges

Microservice Contention

- The co-deployed microservices on Cloud or Edge datacenters can lead to contention problems which will affect QoS.
- Research in Osmotic Computing should be focus on novel microservice consolidation techniques that can dynamically detect and resolve resource contention.



Osmotic Computing Challenges



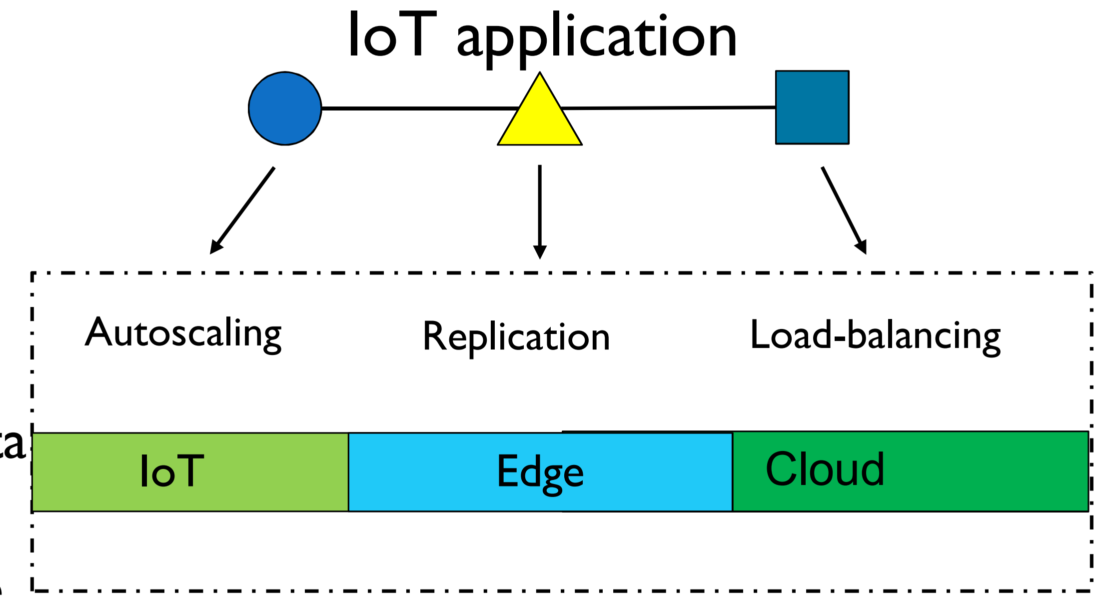
Microservice Monitoring

- How to monitor & debug IoT applications in real-time?
- How to effectively analyze collected monitoring data to detect root causes of QoS violations and failures?

Osmotic Computing Challenges

Microservice orchestration and elasticity control

- How to holistically autoscale?
- How to replicate data to avoid data loss?
- How to load-balance based on resource and data flow?



Publications Related to Osmotic Computing

- M. Villari, M. Fazio, S. Dustdar, O. Rana, and R. Ranjan, "Osmotic computing: A new paradigm for edge/cloud integration," IEEE Cloud Computing, vol. 3, pp. 76–83, Nov 2016.
- . Ranjan, O. Rana, S. Nepal, M. Yousif, P. James, Z. Wen, S. Barr, P. Watson, P. P. Jayaraman, D. Georgakopoulos, M. Villari, M. Fazio, S. Garg, R. Buyya, L. Wang, A. Y. Zomaya, and S. Dustdar, "The Next Grand Challenges: Integrating the Internet of Things and Data Science," Volume 5, Issue 3, Pages 12-26, May./Jun. 2018,
- T. Rausch, S. Dustdar, and R. Ranjan,"Osmotic Message-Oriented Middleware for the Internet of Things," IEEE Cloud Computing, IEEE Computer Society, May 2018.
- A. Morshed, P. P. Jayaraman, T. Sellis, D. Georgakopoulos, M. Villari, and R. Ranjan, "Deep OSMOSIS: Holistic Distributed Deep Learning in Osmotic Computing," IEEE Cloud Computing, IEEE Computer Society, Dec 2017.
- D. Georgakopoulos, P. P. Jayaraman, M. Fazia, M. Villari, and R. Ranjan, "Internet of Things and Edge Cloud Computing Roadmap for Manufacturing," IEEE Cloud Computing, Volume 3, Issue 5, 2016, IEEE Computer Society.
- D. Puthal, S. Nepal, R. Ranjan, and J. Chen, "Threats to Networking Cloud and Edge Data Center in the IoT," IEEE Cloud Computing, Volume 3, Issue 4, 2016, IEEE Computer Society.
- M. Vogler, J. M. Schleicher, C. Inzinger, S. Dustdar, and R. Ranjan, "Migrating Smart City Applications to the Cloud," IEEE Cloud Computing, Volume 3, Issue 2, 2016, IEEE Computer Society.
- A. Souza, Z. Wen, N. Cacho, A. Romanovsky, P. James, and R. Ranjan, "Using Osmotic Services Composition to Dynamic Load Balancing of Smart City Applications," The 2018 (11th) IEEE International Conference on Service Oriented Computing and Applications (SOCA 2018), IEEE Computer Society.
- A. Souza, N. Cacho, A. Noor, P. P. Jayaraman, A. Romanovsky, and R. Ranjan, "Osmotic Monitoring of Microservices between the Edge and Cloud," The 20th IEEE International Conference on High Performance Computing and Communications (HPCC 2018),

HOTLINK PROTECTION ACTIVATED - NOTE: Empty or Blank Referrals are not Allowed

Protected by: ByREV WP-PICShield - HOTLINK Defence

Newcastle University

TU WIEN

FAKULTÄT FÜR INFORMATIK

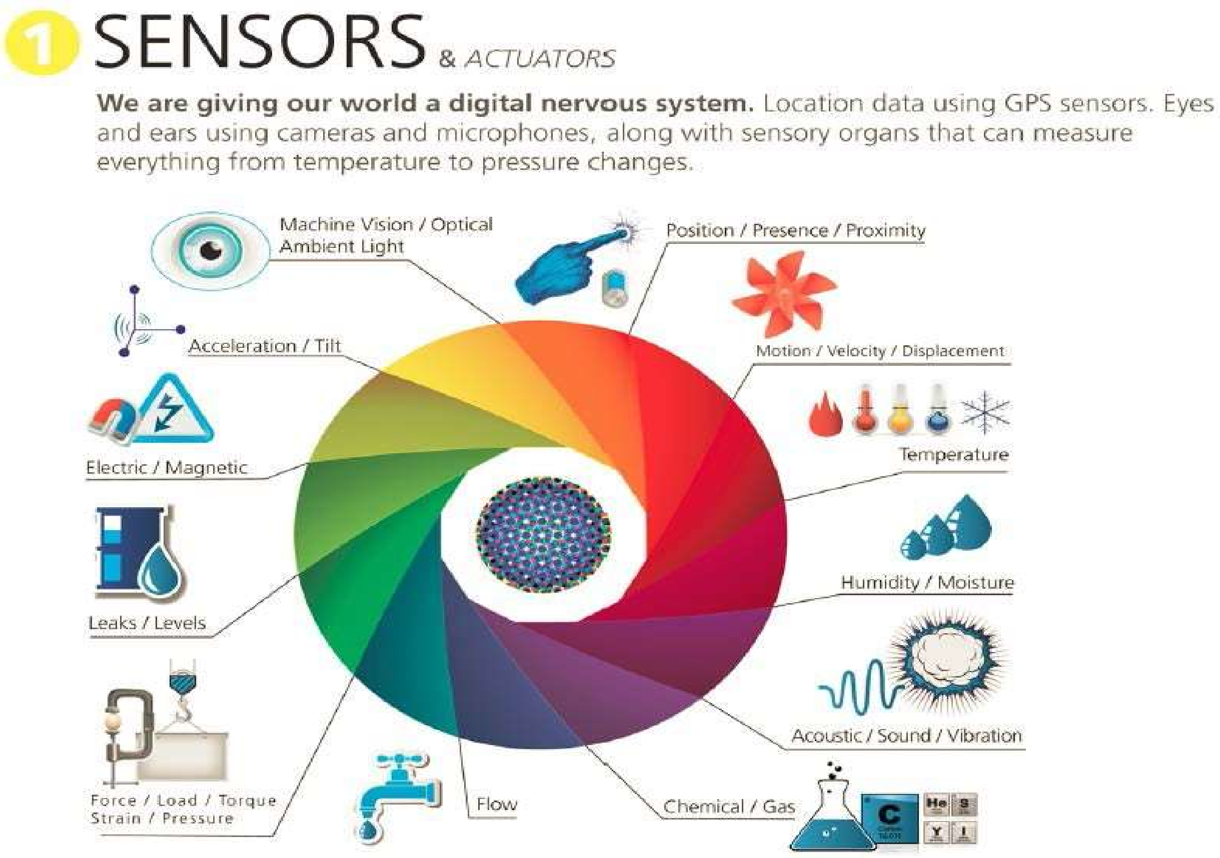
Faculty of Informatics

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

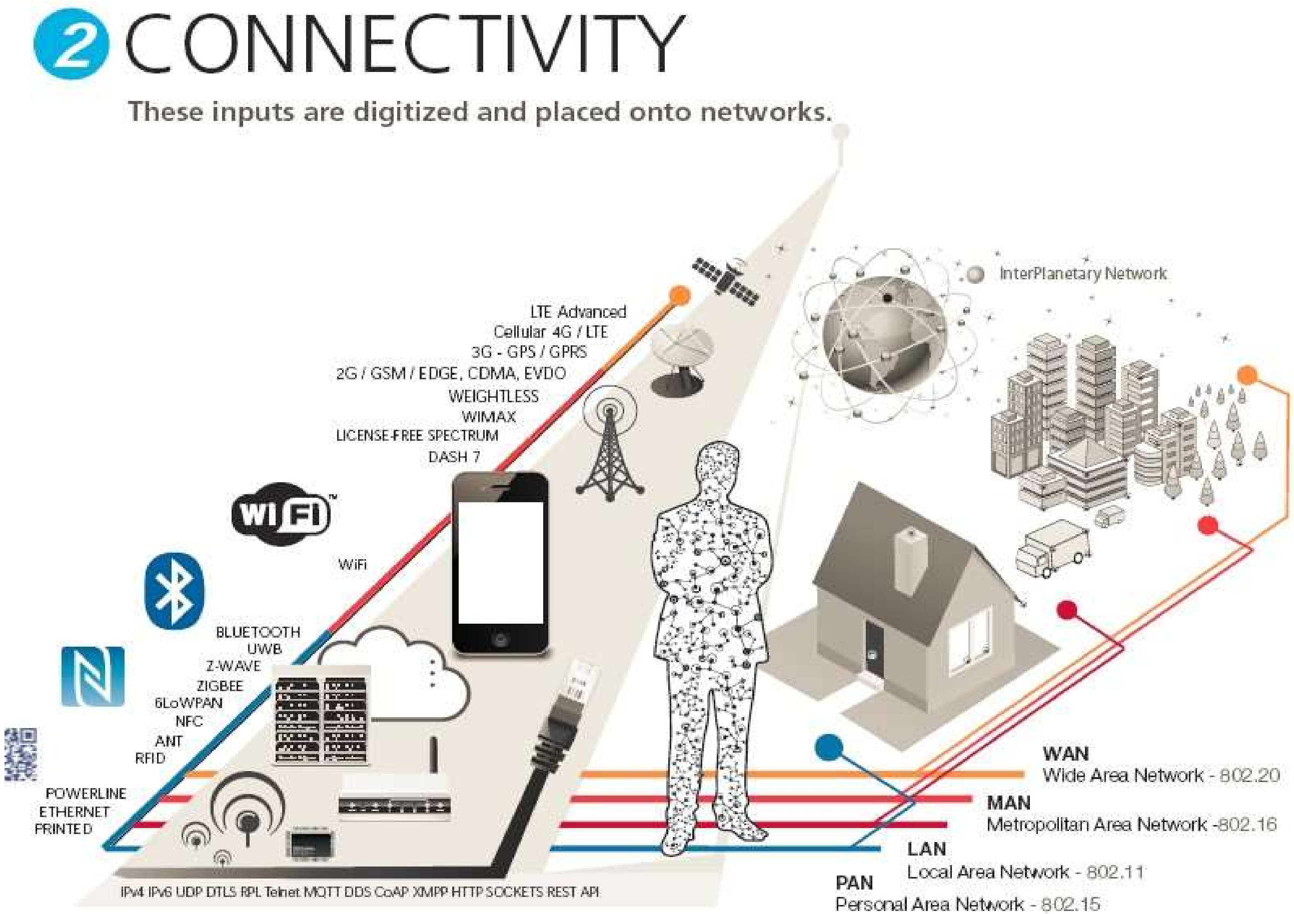
UFRN UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE

SWIN BUR NE SWINBURNE UNIVERSITY OF TECHNOLOGY

Building Blocks: IoT Sensors and Acutators

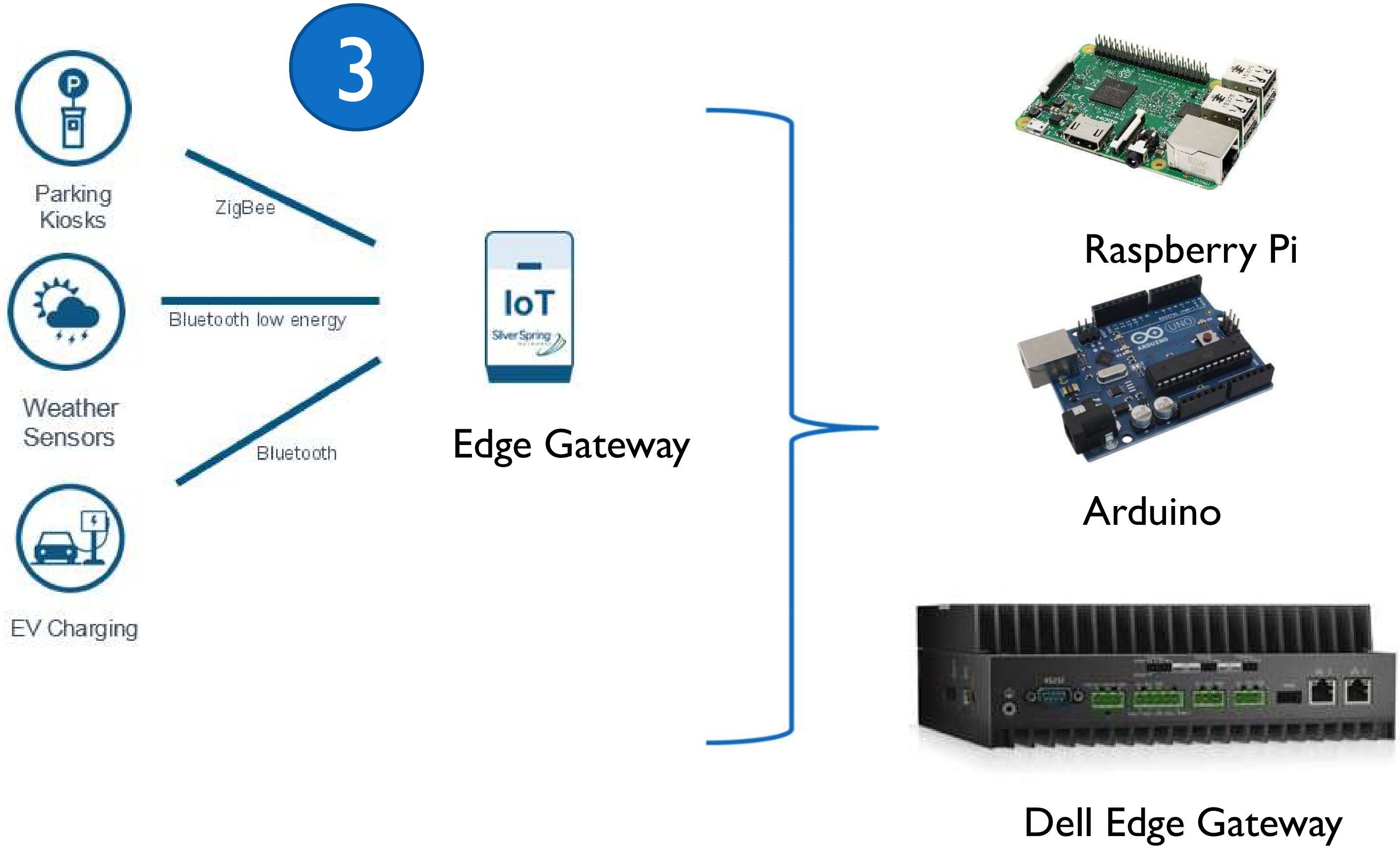


Building Blocks: Connectivity

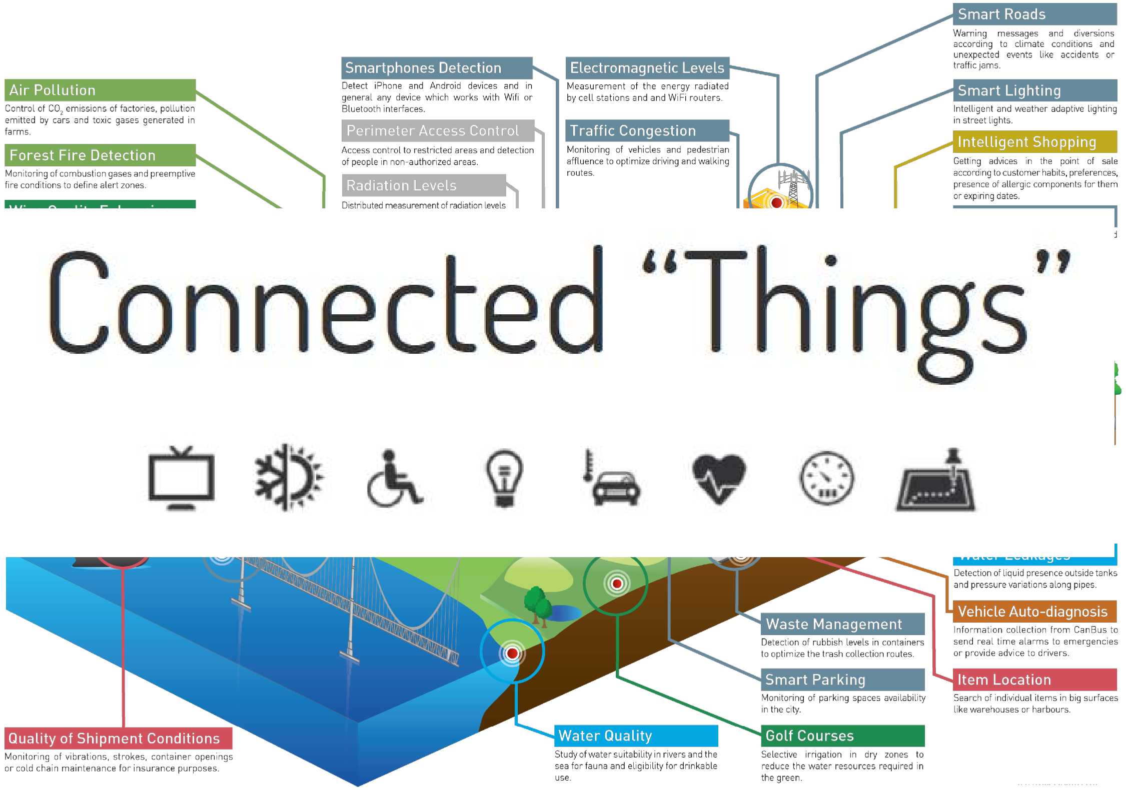


Newcastle University · TU Wien Fakultät für Informatik Faculty of Informatics · Cardiff University Prifysgol Caerdydd · UFRN Universidade Federal do Rio Grande do Norte · Swinburne University of Technology

Building Blocks: Edge Computing



Smart World of Things in Connected "Cities"



Source: http://images.libelium.es/content/applications/libelium_smart_world_infographic_big.png