Containers and Clusters for Edge Cloud Architectures

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Motivation

- Cloud technology is moving
  - distribution across multi-clouds
  - inclusion of devices – IoT / edge cloud / fog computing

- Lightweight virtualisation
  - for smaller, virtualised devices to host application/platform services
  - Containerisation as a lightweight virtualisation solution.
- Containers relevant for Platform-as-a-Service (PaaS) clouds
  - application packaging and orchestration.
  - this can help to manage and orchestrate applications as containers

- Agenda:
  - review edge cloud requirements
  - discuss suitability of container and cluster technology

Agenda

- Edge Cloud
- Virtualisation and Containers
- PaaS Clouds and Containers
- Clusters and Distribution in the Cloud
- Container-based Edge Cloud
- Edge Cloud Management
- Use Cases

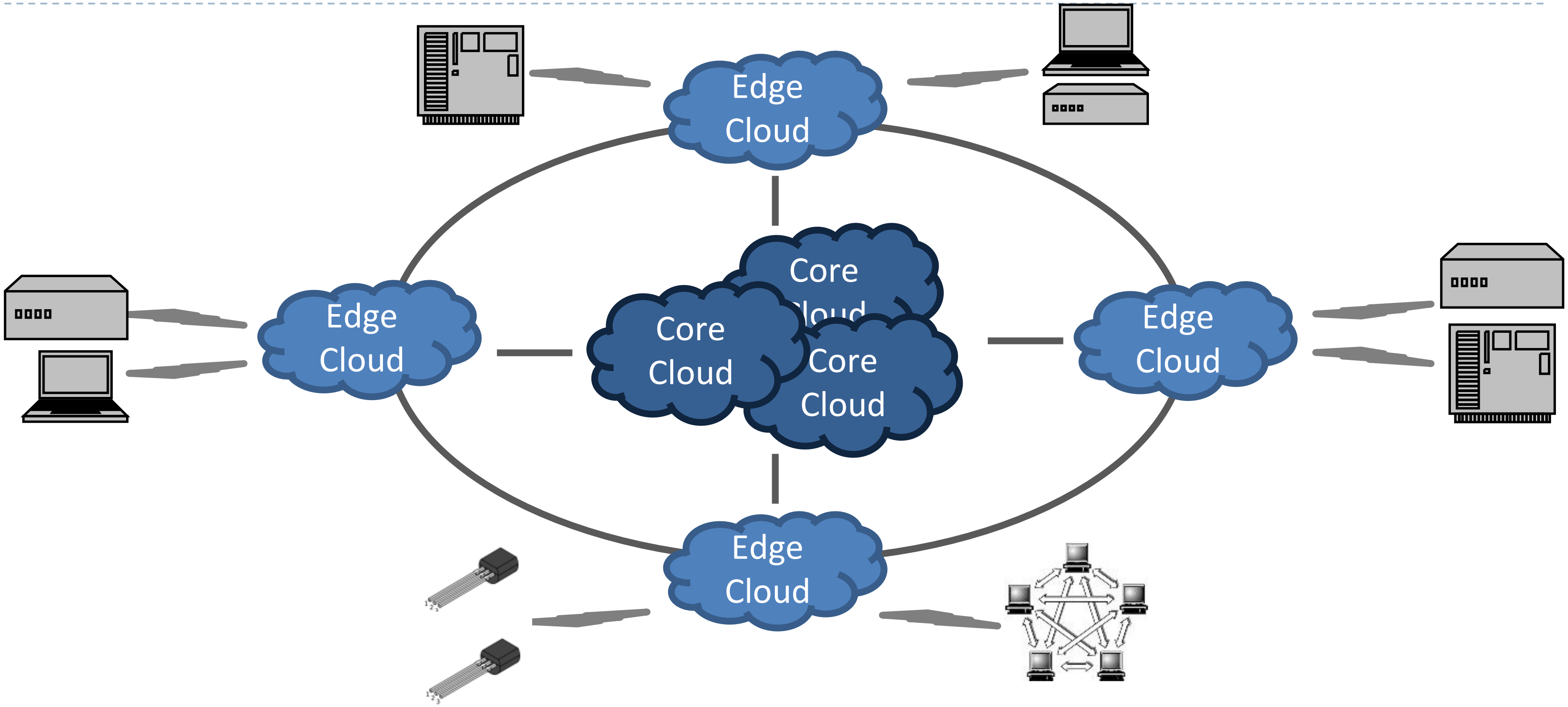
Edge Cloud – Architectural Requirements

- Challenges:
  - Virtualisation and interoperable application packaging
  - Distributed delivery and orchestration of infrastructure and application services

Edge Cloud – Architectural Requirements

- Classify distributed clouds into three architectural models:
  - **Multi-datacentre clouds** with multiple, tightly coupled data centers under control of the same provider.
  - **Loosely coupled multi-service clouds** combine services from different cloud providers.
  - **Decentralized edge clouds** utilize edge resources to provide data / compute resources in a highly dispersed manner
- Needs infrastructure and application services to be placed at source of data

Edge Cloud – Architectural Requirements



- Infrastructure Support:
  - Location awareness, computation placement, local replication/recovery
  - Packaging, deployment, orchestration
  - Data transfer between virtualised resources

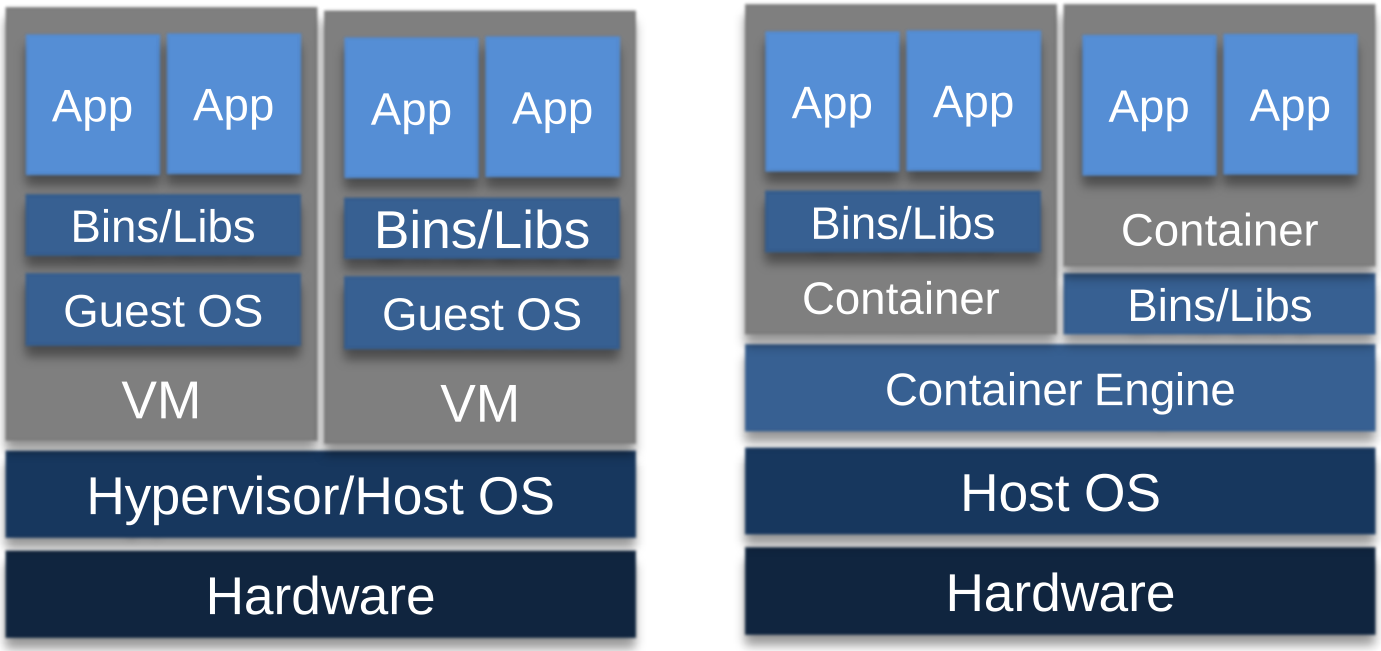
Edge Cloud – Architectural Requirements

- Development support for these architectures
  - supported through orchestration based on topology patterns + orchestration plans
  - reflecting common and reference architectures
- Application packaging through containerisation:
  - Containers to distribute service and applications to the edge
  - Docker has been used to do this
- Programmability:
  - Orchestration support through topology specification
    - TOSCA topology patterns
  - Service orchestration needs to cover whole life-cycle
    - deploy, patch, shutdown
  - Operations are mapped to cloud infrastructure management
    - TOSCA engine runs on top of edge cloud infrastructure

Virtualisation and Containers

- VM instances: full guest OS images – large files
- Space and time constraints

Virtualisation and Containers



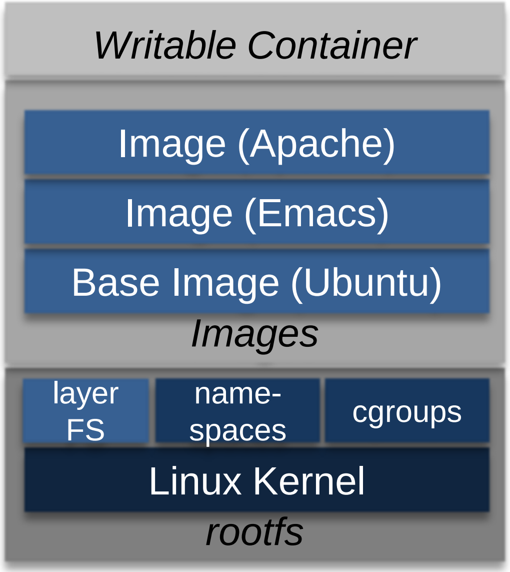
- Containers
  - Packages, self-contained, ready-to-deploy set of parts of applications
  - In the form of binaries and libraries to run applications

Virtualisation and Containers

- Recent Linux distributions - Linux container project LXC
  - kernel mechanisms to isolate processes on shared operating system
  - Mechanisms: namespaces and cgroups
- Namespace isolation
  - allows groups of processes to be separated
  - different namespaces for process isolation, access to inter-process communication, mount-points, for isolating kernel and version identifiers
- cgroups (control groups)
  - manage and limit resource access for process groups
  - enables better isolation between isolated applications on a host
  - restricts containers in multi-tenant host environments
  - cgroups allow sharing hardware resources between containers
    - if required, setting up limits and constraints

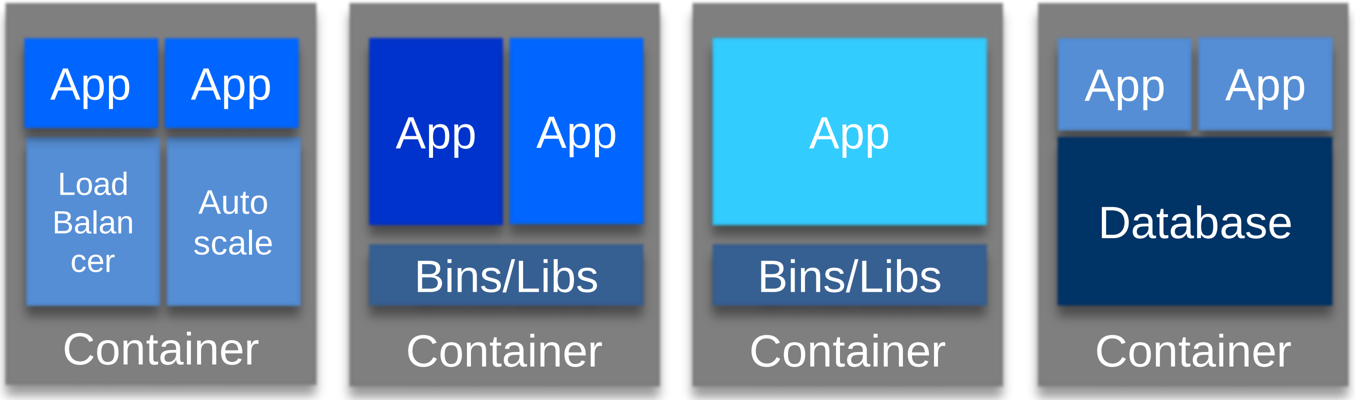
Virtualisation and Containers

- Boot process:
  - traditional Linux boot: kernel mounts root FS as read-only, then switches rootfs volume to read-write mode
  - Docker mounts the rootfs as read-only, but instead of changing FS to read-write mode, it uses a union mount to add a writable file system on top
- Mounting (union mount):
  - allows multiple read-only FS to be stacked on top of each other
  - can create new images by building on top of base images
  - each of these FS layers is a separate image loaded by the container engine for execution.
- Container:
  - only the top layer (container) is writable
  - container can have state and is executable - directory for everything



Virtualisation and Containers

Container-based Application Architecture – Scenarios:



- Container solution:
  - Repositories
  - API: create, define, compose, distribution
  - Storage and network functions:
    - shared volumes, links for data transfer

PaaS Clouds and Containerisation

- PaaS:
  - Built farms
  - Routing layers
  - Schedulers to dispatch workloads

PaaS Clouds and Containerisation

- Evolution of PaaS:
  - **first** PaaS generation:
    - classical fixed proprietary platforms
    - such as Azure or Heroku.
  - **second** PaaS generation:
    - open-source solutions such as Cloud Foundry or OpenShift
    - allow users to run their own PaaS (on-premise or in the cloud)
    - already with a built-in support of containers.
      - Openshift moves from own container model to Docker model
      - Cloud Foundry does as well through its internal Diego solution
  - **third** PaaS generation:
    - Dawn, Deis, Flynn, Octohost and Tsuru,
    - built on Docker from scratch
    - deployable on own servers or on public IaaS clouds
    - Clustered, distributed architecture management

PaaS Clouds and Containerisation

- Microservices architectural style
  - developing a single application as a suite of small services
  - each running in its own process and lightweight communication
- Microservices are
  - independently deployable
  - supported by automated deployment and orchestration
- They require
  - ability to deploy often and independently at arbitrary schedules
- Microservice dev/arch concerns are PaaS concerns
  - Containerisation provides ideal mechanism for flexible deployment schedules and orchestration needs
  - particularly, if these are to be PaaS-provisioned

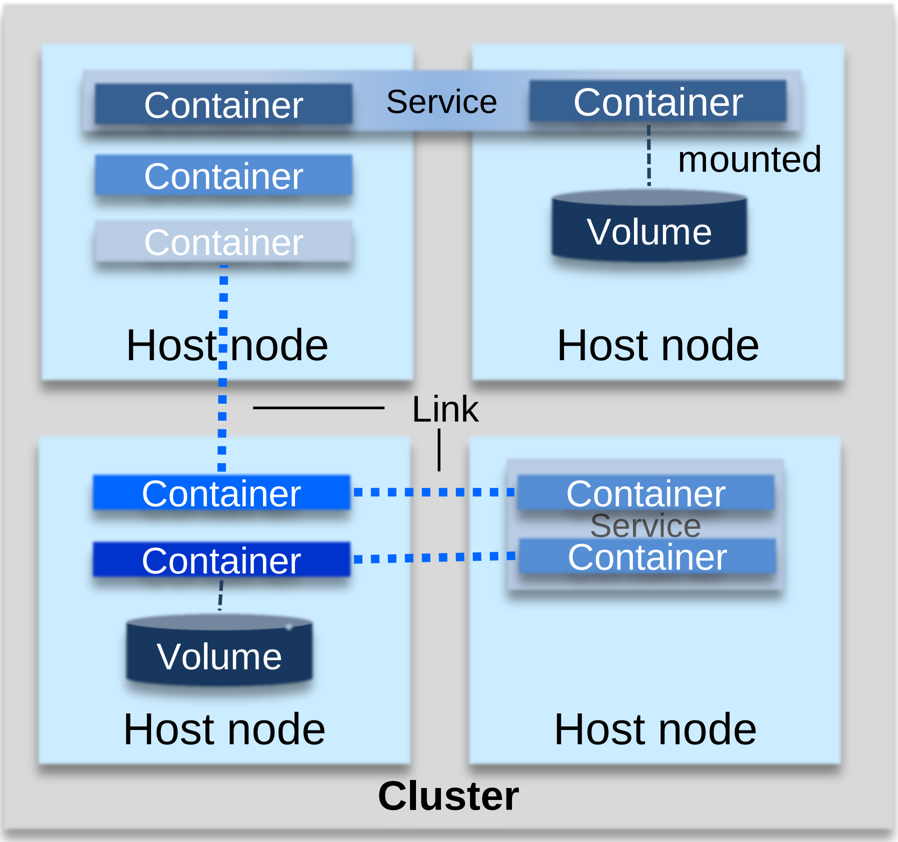
Clustering and Distribution

- Cluster architecture:
  - Multiple clusters in multiple clouds

Clustering and Distribution

Container clusters

- **Features:**
  - Failover
  - Load balancing
  - Scalability



- **API:**
  - Platform service mgmt
  - Lifecycle mgmt
  - Cluster head node

Clustering and Distribution

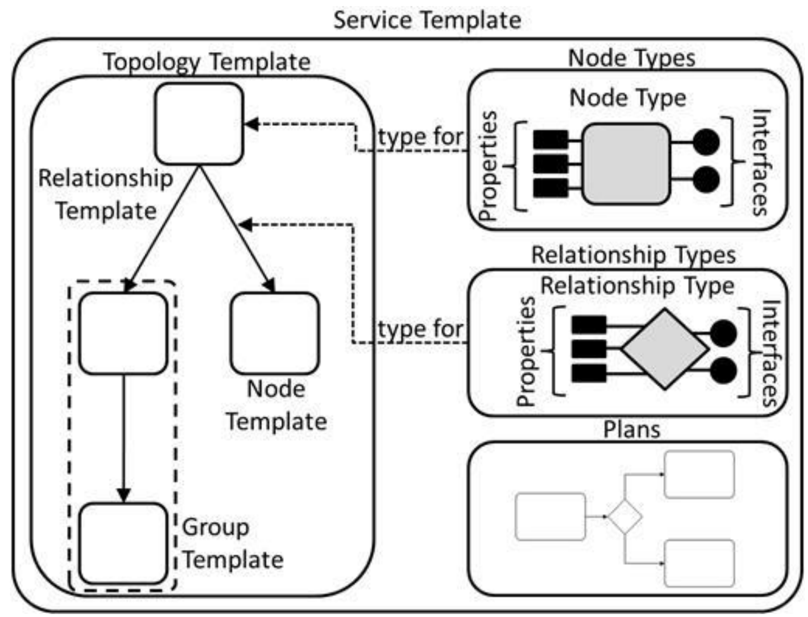
- Requirements for a lightweight virtualised cluster architecture :
  - Hosting containerised services
  - Providing secure communication between these services
  - Auto-scalability and load balancing support
  - Distributed and scalable service discovery and orchestration
  - Transfer/migration of service deployments between clusters
- Tools:
  - Mesos and Kubernetes …

Clustering and Orchestration

- **Cluster architecture:**
  - Interoperable orchestration

Clustering and Distribution

- TOSCA supports a number of features:
  - interoperable description of application & infrastructure services
    - here implemented as containers hosted on nodes in an edge cloud,
  - relationships between parts of the service
    - here service compositions and links as relationships,
  - operational behaviour of the services in an orchestration plan
    - such as deploy, patch or shutdown

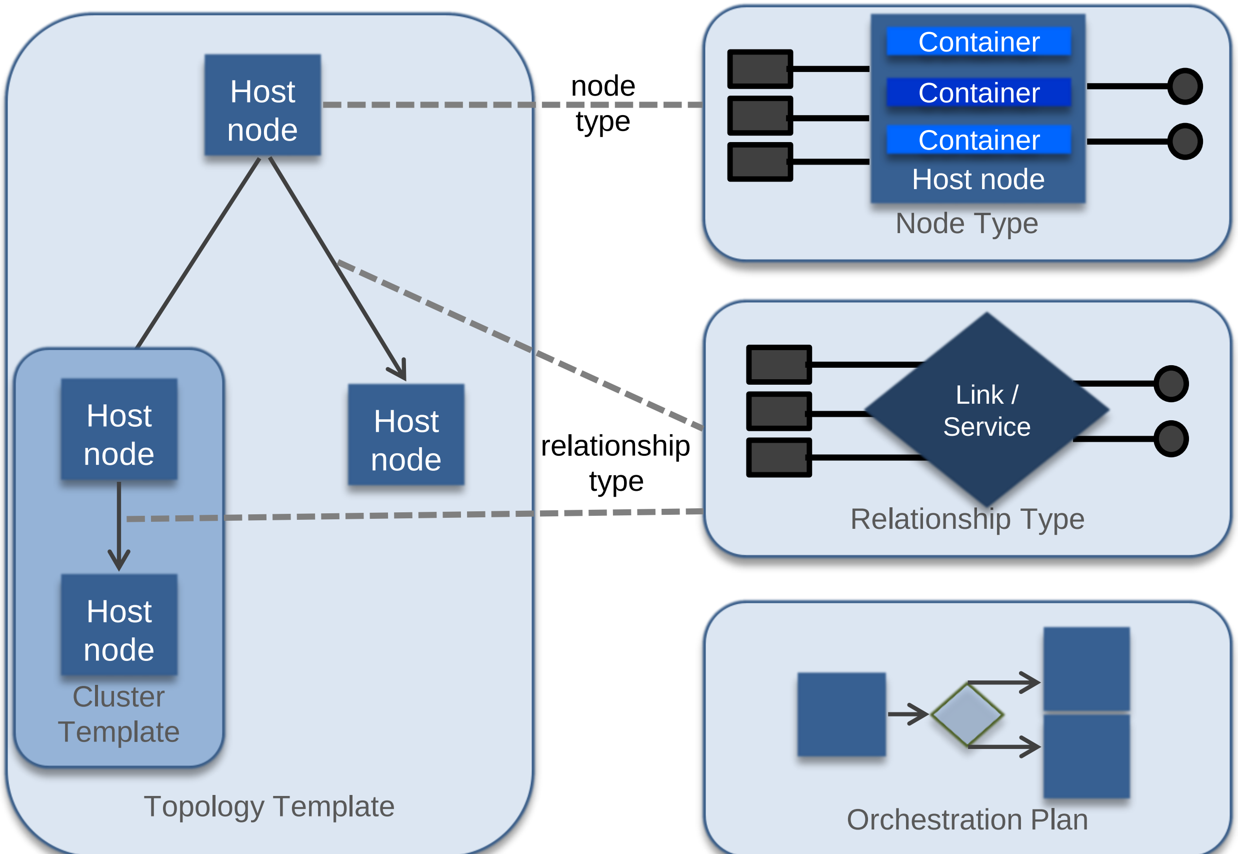


TOSCA for Container Orchestration

- Needed: a TOSCA-based modelling language
  - To describe the features of a container in abstract terms
  - to compose multiple containers to build an application
  - to orchestrate the deployment and management of multi-container applications in distributed clusters
- Specifically:
  - Need: manage applications over multiple and heterogeneous clouds,
  - Solution: services have to be described and orchestrated in a standardized fashion

Clustering and Distribution

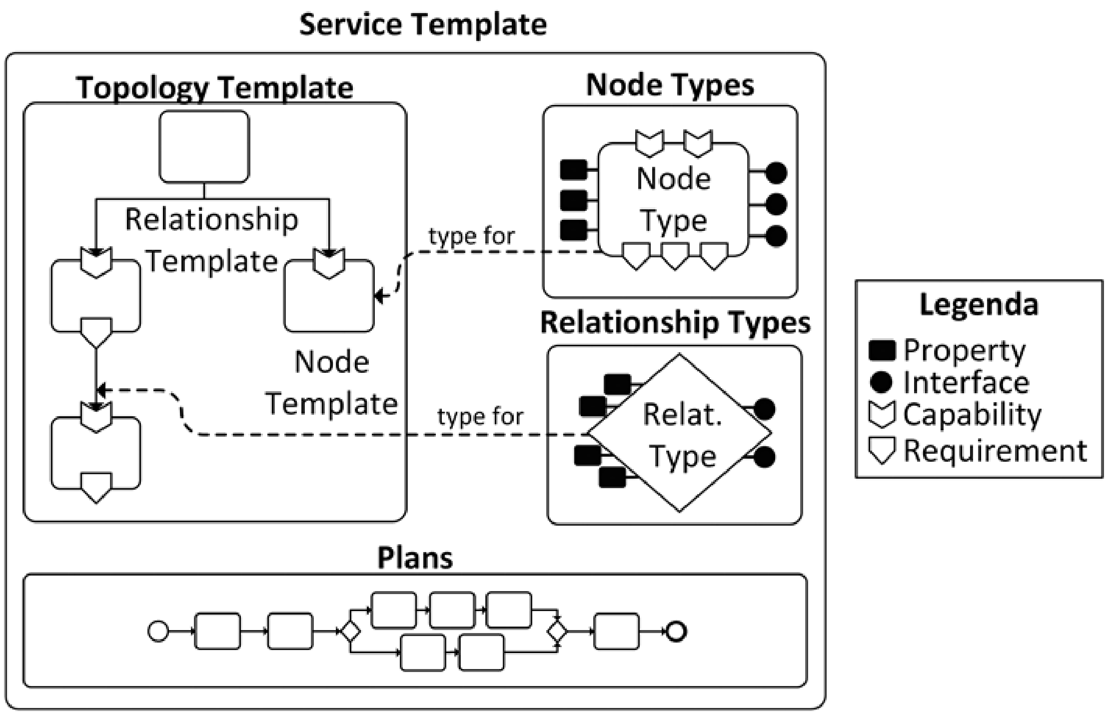
Orchestration and Topology

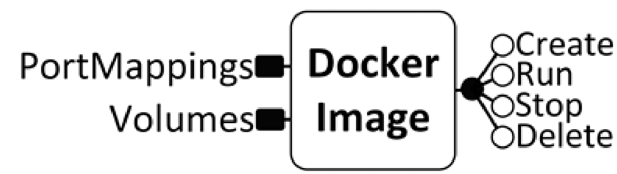


Cluster

TOSCA

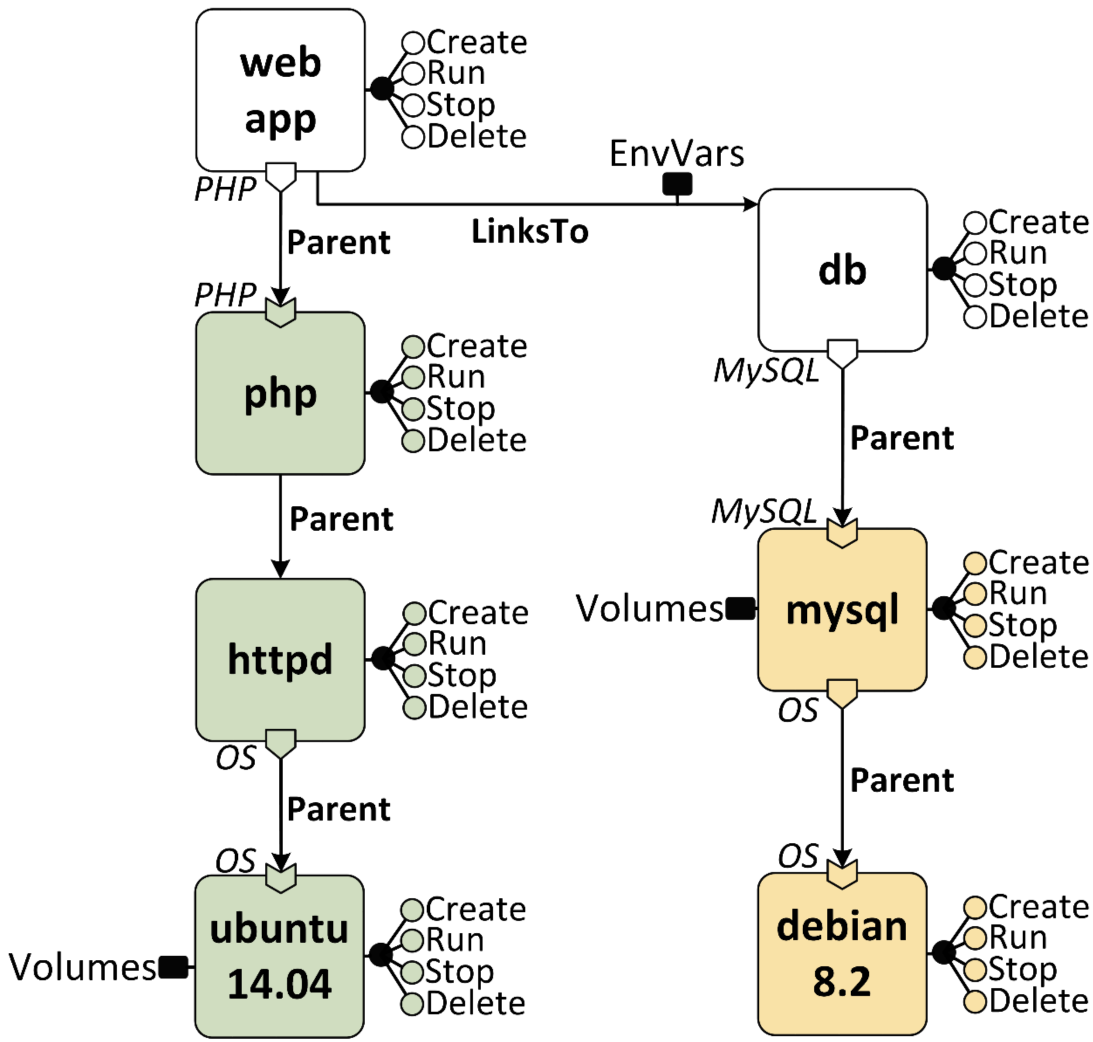
TOSCA Service Templates for Containers





[joint work with A. Brogi, J.Soldani @ University of Pisa]

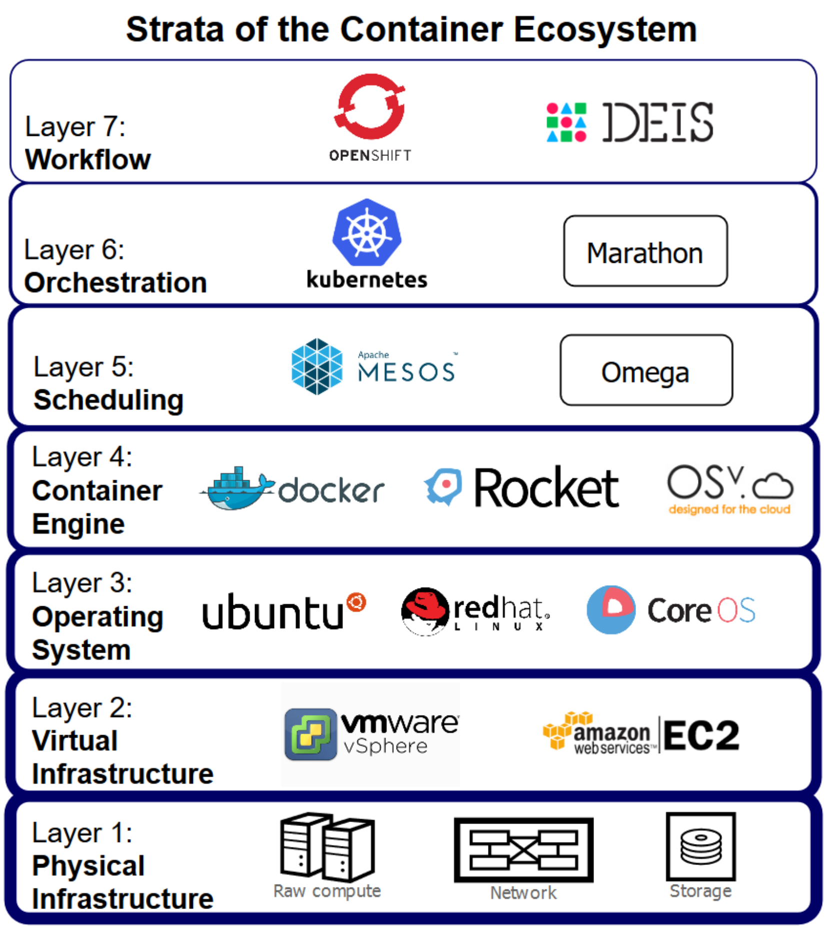
Docker Orchestration Example



Container-based Edge Cloud Deployment

- Cluster architecture for edge cloud scenarios:
  - Cloud deployment on resource-constrained devices

PaaS & Container Ecosystem



Beyond PaaS: Devices for the Edge Cloud

- Driver:
  - Bring computation to the edge
  - infrastructure + application services placed at source of data
- Assumption:
  - Resource-constrained devices
  - Capable of carrying out some remote calculations
- Solution
  - *Hardware*: Raspberry Pi (or similar)
  - *Software/application packaging*: Docker
  - *Cluster management*: Kubernetes
  - *Orchestration*: TOSCA

Raspberry Pi and Linux

- Raspberry Pi 2 Model B - second generation Raspberry Pi
  - 900MHz quad-core ARM Cortex-A7 CPU
  - 1GB RAM

  Replaced the original Raspberry Pi 1 Model B+ in Feb'15.
- Processor: ARMv7 + 1GB
  - can run the full range of ARM GNU/Linux distributions,
  - support of Raspbian - a free operating system based on Debian optimized for Raspberry Pi hardware

Docker on Raspberry Pi

From [https://blog.docker.com/2015/09/update-raspberry-pi-dockercon-challenge/]

- Describes demo running 500 Docker containers on a Raspberry Pi 2 device

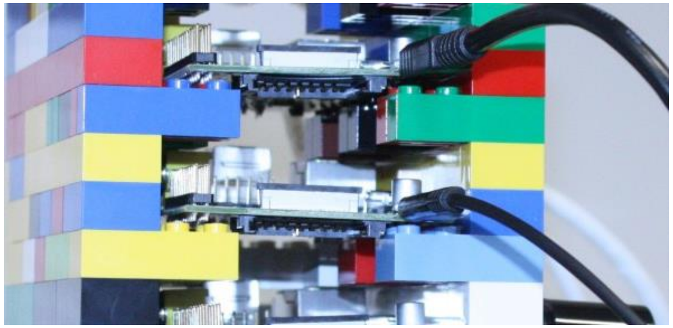
- As of now (?), the current record stands at **2334 web servers** running ir containers on a single Raspberry Pi 2.

Sample configuration

- Resources:
  - A RPi 2 has 1Gb of RAM (about 975 Mb available)
  - Memory footprint of single web server outside a container is 0.3 Mb
  - Can use ~700 Mb (2300 instances) for "real" processes,
  - Leaves 300 Mb for the system and the Docker engine
- Specs for set-up:
  - Raspberry Pi 2 (4x core, 1 GByte memory)
  - Docker 1.8.1 (stock version, without any optimisations)
  - Linux: Debian Wheezy (HypriotOS) with Kernel 3.18.11 (used for DockerCon demo)
  - Web server: Docker Image "hypriot/rpi-nano-httpd:minimal" (available on Docker Hub)

Raspberry Pi – Cloud and Cluster

- University of Glasgow:
  - https://raspberrypicloud.wordpress.com/blog/
  - Glasgow Raspberry Pi Cloud (PiCloud)
    - scale model of data centre (DC) composed of clusters of Raspberry Pi
  - The Pi Cloud emulates all layers of a cloud stack
    - ranging from resource virtualisation to network behaviour



- University of Bozen-Bolzano:
  - http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6735414
  - The UniBZ Raspberry Pi cluster creates a small DC infrastructure

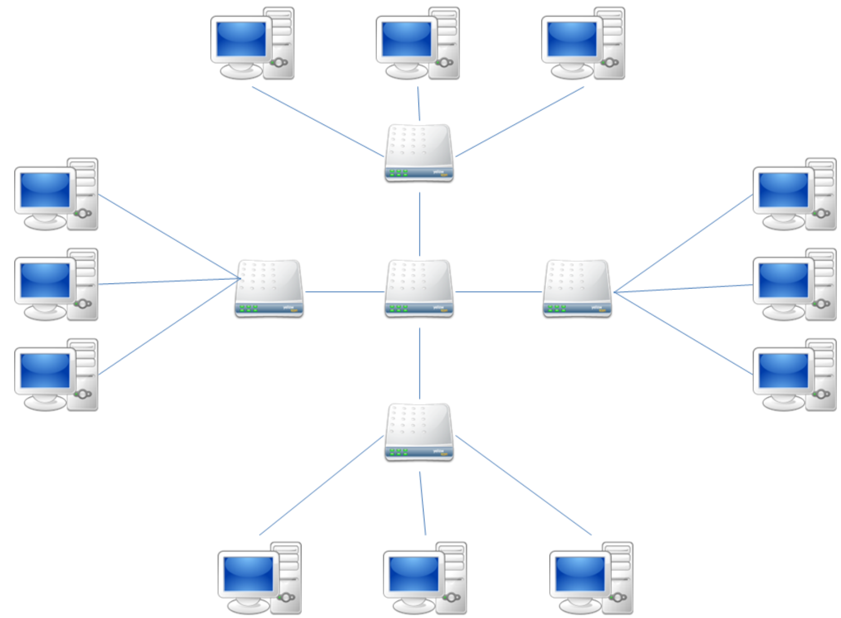
The University of Bozen-Bolzano (BZ) Raspberry Pi Cluster

Freie Universität Bozen
Libera Università di Bolzano
Università Liedia de Bulsan

- Aim:
  - small-scale cloud data centre for teaching /research purposes.
- Focus:
  - particularly interested in mobility
  - i.e., how to move clusters to locations where they are needed
  - e.g. in difficult terrain or in emergency circumstances
- Architecture:
  - 300 nodes in star topology

BZ Raspberry Pi Cluster

- **Architecture**: 300 nodes
  - *Network topology*: star
  - *Rack*: bespoke
  - *Power Supply* …
  - *OS* Debian 7

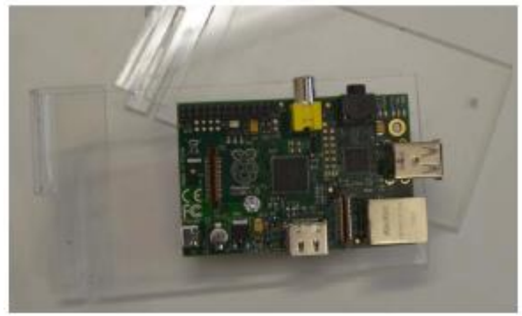


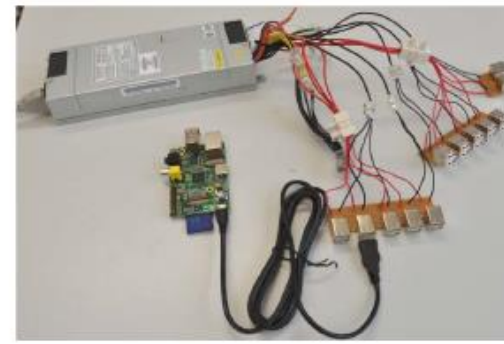
- Cluster management
  - Own solution
  - Low-level cluster configuration, monitoring, and maintenance:
    - boot master
    - register RPis
  - could use Kubernetes in the future …

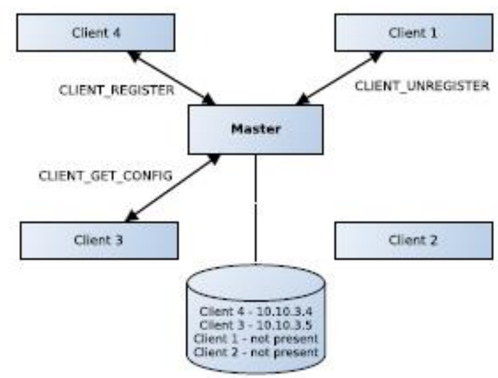
kubernetes

BZ RPi Cluster Management

- Cloud platform
  - include centralized management of:
    - resource pool
    - usage monitoring
    - automated service provision
    - online access to acquired resources
  - focus resource management:
    - subcluster organization
    - storage







Cluster orchestration

- The whole cluster is split into subclusters:
  - allowing different users to run processes in parallel on different parts of the infrastructure
- Orchestration:
  - Static orchestration:
    - At the moment a subcluster is composed of a predefined set of RPis.
  - Dynamic orchestration:
    - It is possible to move an RPi from one subcluster to another one
    - We are working on a solution to make this switch dynamically:
      - i.e., switch while the system is running
      - without burdening the system's resources too heavily

Cluster storage

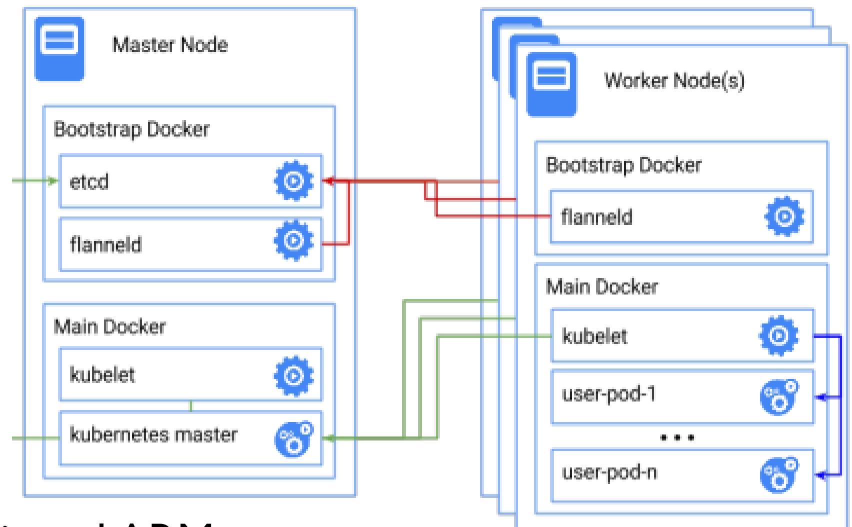
- SD cards slow: use a network storage system
  - to improve the performance of the overall system
  - to make a common filesystem for the cluster available
- Implementation:
  - a four-bay Network Attached Storage (NAS) from QNAP Systems, allows us to replace the original firmware with a custom Debian image.
  - This NAS forms part of the master node
  - Inside the NAS:
    - every subcluster has a dedicated volume managed by LVM (logical vol mngr)
    - which is shared by all the RPis belonging to that subcluster
  - The RPis mount a volume locally via Network File System (NFS) v.4
    - we used NFS rather than iSCSI (Internet Small Computer System Interface)
    - allows sharing of same volume between different nodes,
    - thus making inter-node communication via file system possible

Kubernetes on Raspberry Pi 2's

- https://raspberrypicloud.wordpress.com/2015/08/11/how-to-kubernetes-multi-node-on-raspberry-pi-2s/

  - Kubernetes is a powerful orchestration tool for containerised applications across multiple hosts.

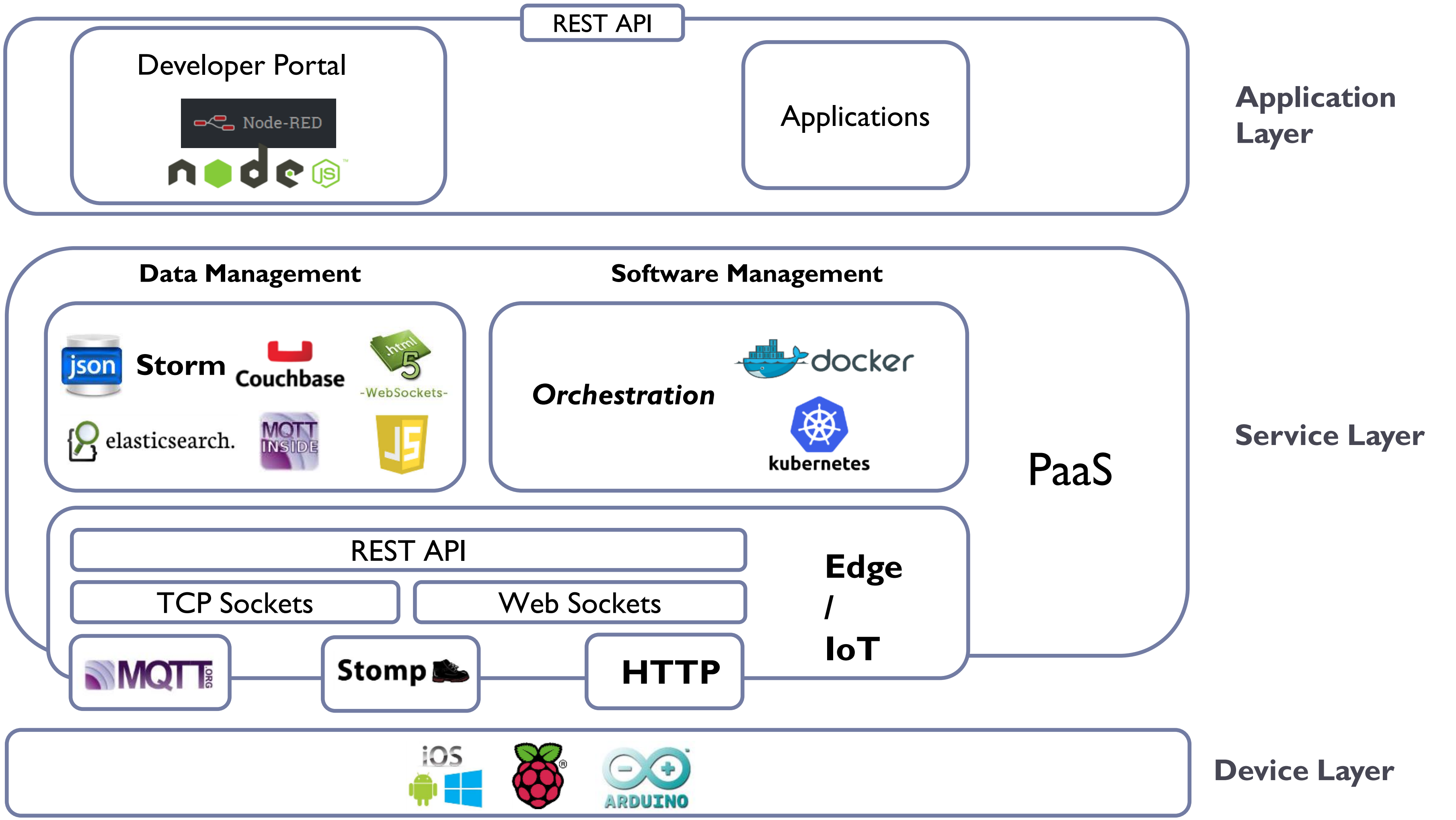
  - Glasgow Cluster:
    - Fully running implementation of Kubernetes on Raspberry Pi 2
    - Min config:
      - 2 Raspberry Pi 2s
      - Two SD cards loaded with Arch Linux | ARM



Edge Cluster Management Implementation

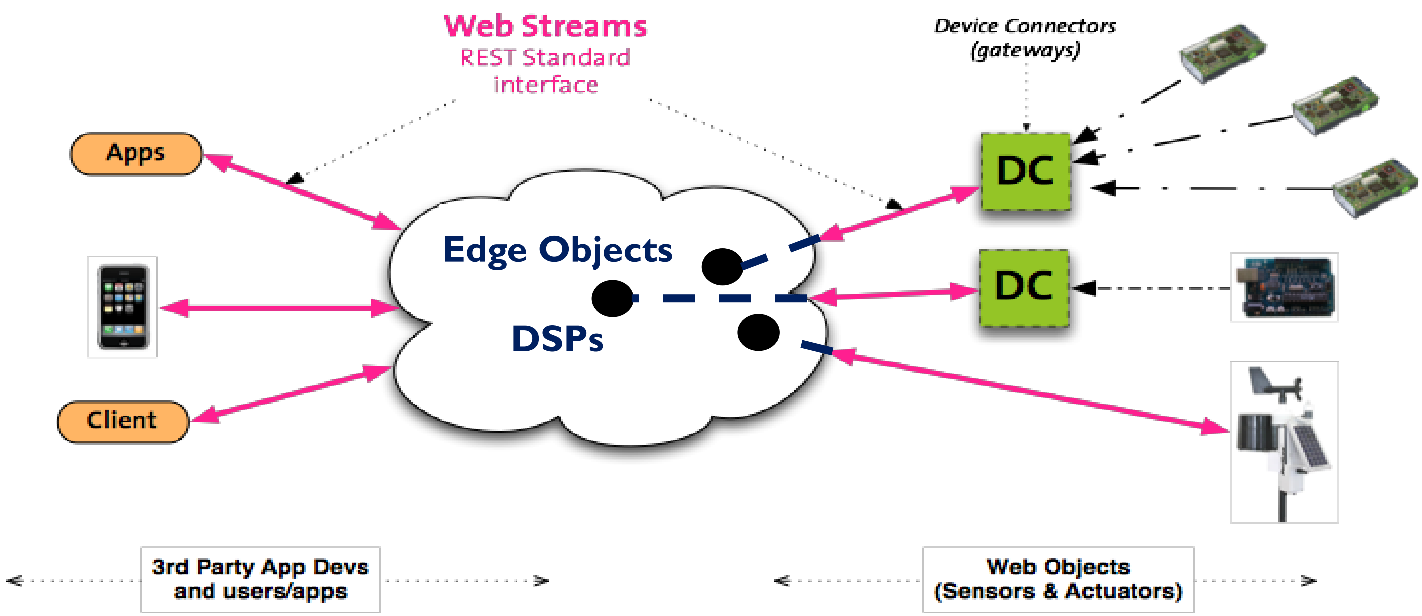
- Architecture
- Data and Software Management

Technology Stack

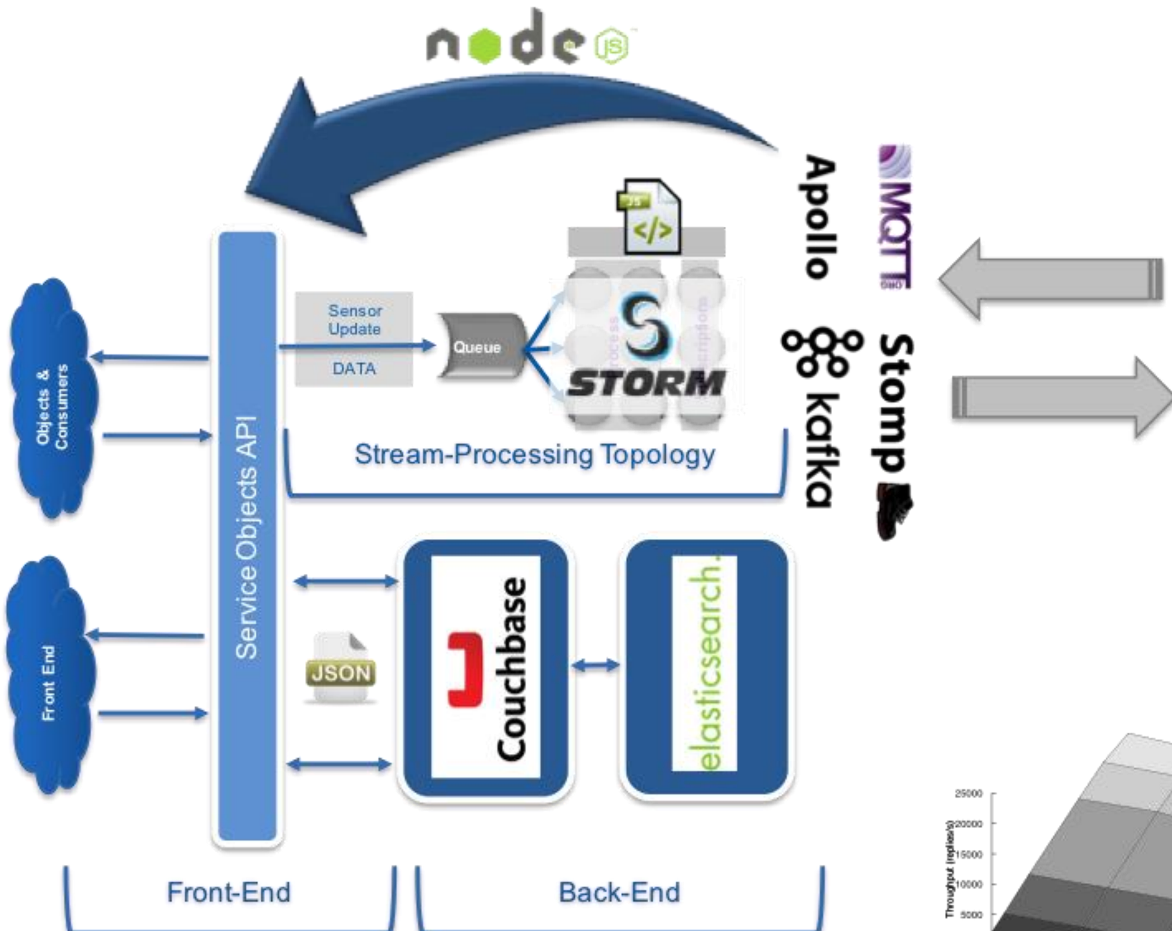


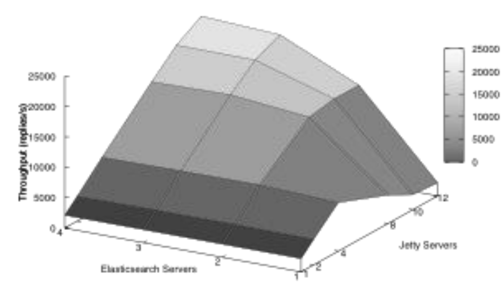
Entities

- Edge Object (EO) – Cloud Object (CO) – Data/Software Processing (DSP)

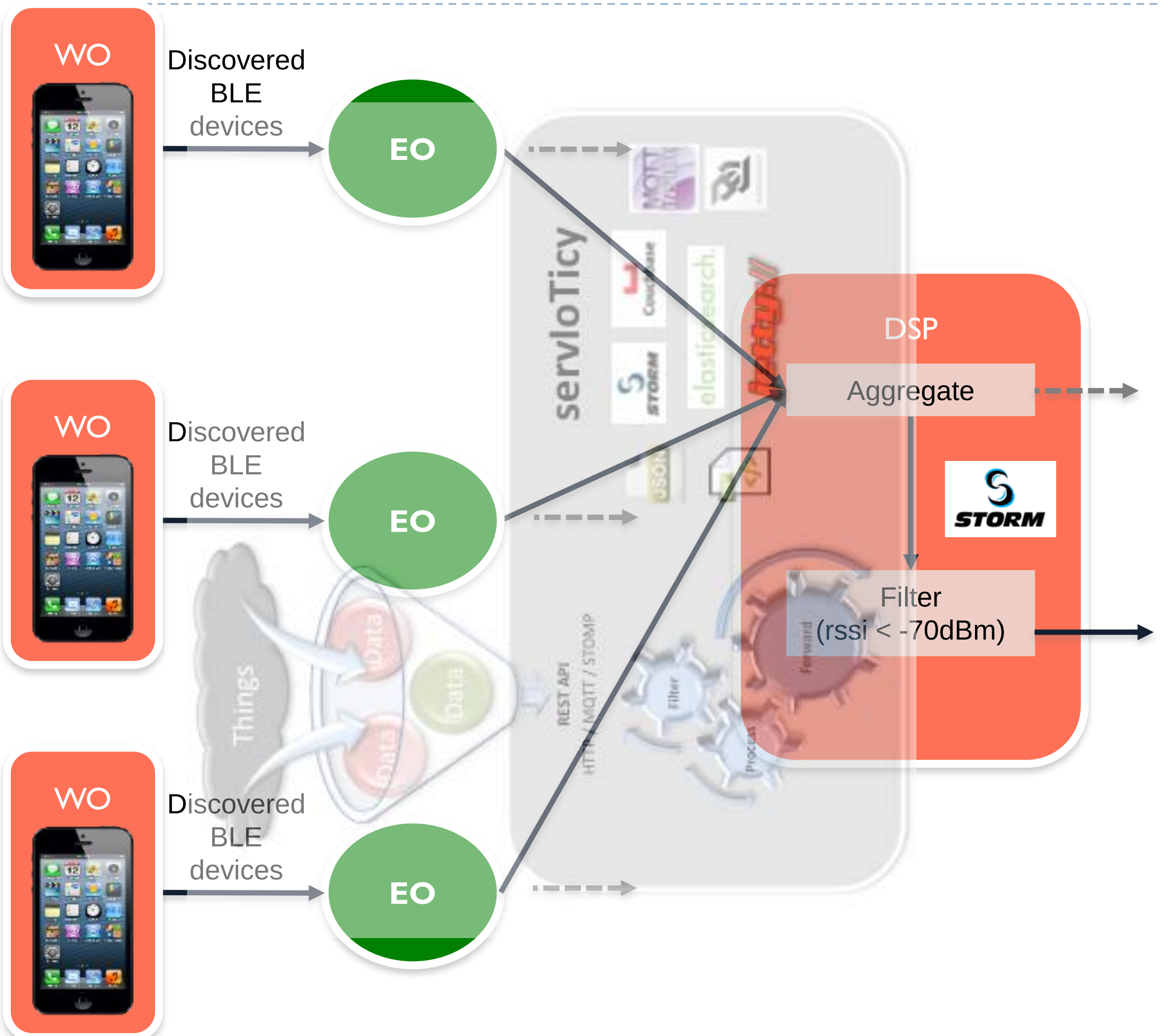


Management Architecture





Configuration based on ServIoTicy



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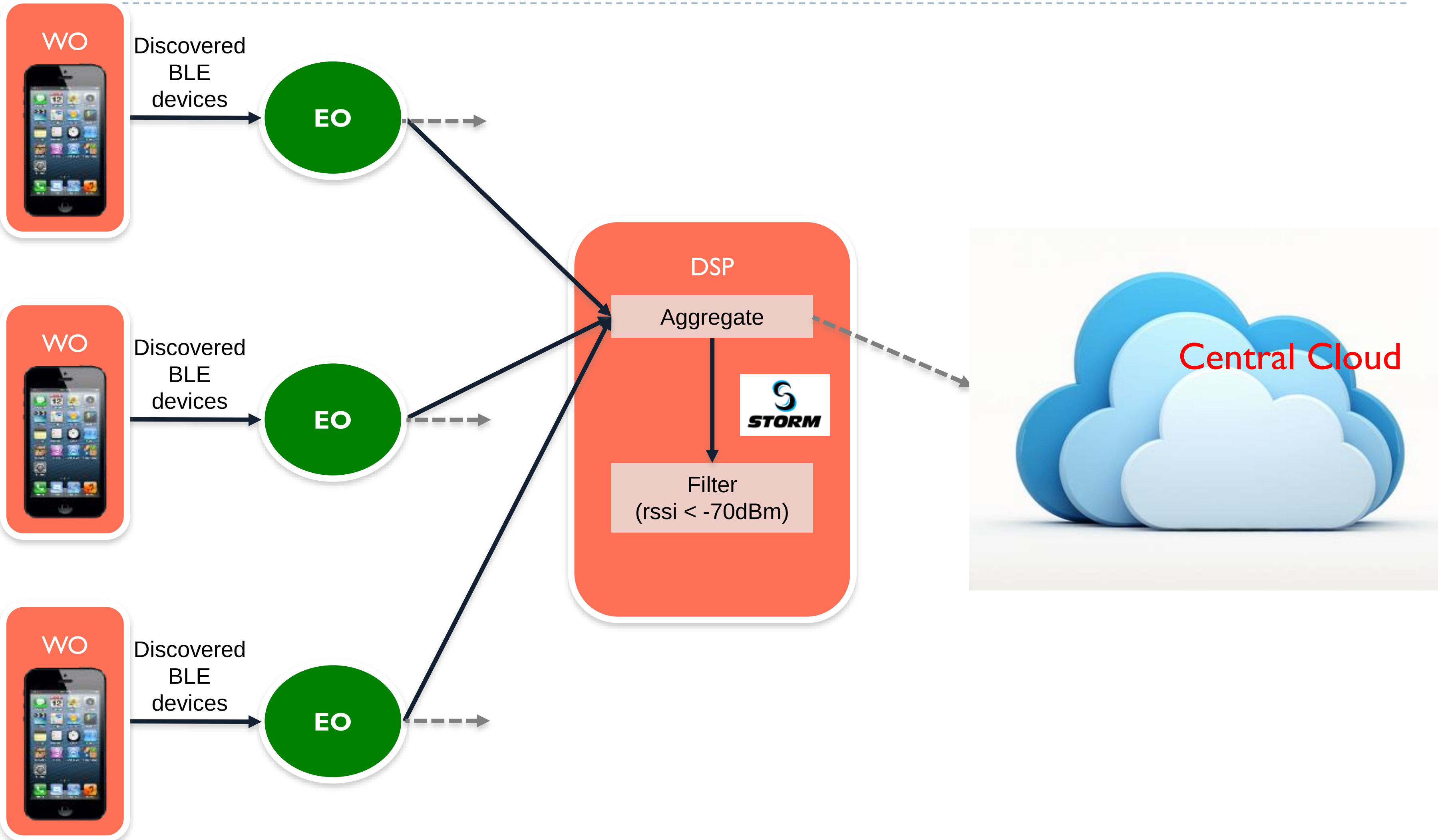

Use Cases - Requirements

Use Cases

- Smart City
  - Traffic management
    - Cameras
    - Sensor coordination
    - Space occupancy
- Smart Area
  - Tourism
    - Sensor management: temperature, people counters
  - Agriculture
    - Sensors and actuators: sun/precipitation -> irrigation

- Technology:
  - Web objects
    - HTTP-enabled devices
    - connect to edge clouds DC or cloudlets (e.g. containers on Raspb Pi)

Requirements for use cases

- Why Docker/Kubernetes on Raspberry Pi:
  - Need full data centre (DC) capabilities
  - Need easy orchestration
  - Need portability / interoperability
- Meets requirements of Edge Cloud architectures

Conclusions

Conclusions

- Edge clouds move the focus from heavy-weight data centre clouds to more lightweight virtualised resources
  - Use emerging container technology and container cluster management for edge clouds
  - Some PaaS have started to address limitations in the context of programming (orchestration) and DevOps for clusters.
- Observation: cloud management platforms are still at an earlier stage than the container platforms they build on
- Container technology has the potential to
  - advance PaaS technology towards distributed heterogeneous clouds
  - through lightweightness and interoperability

Thank you!

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