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CLOSER 2018 Keynote:

Lee Gillam, University of Surrey

Will Cloud Gain an Edge?

Or

CLOSER, to the Edge

A direction in Cloud Computing

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‘Traditional’ Cloud

- NIST SP800-145 (aka Mell and Grance): 3-4-5 & SPI
- Large (economically efficient, easily maintained – but still expensive) datacentres in relatively few, geographical locations (regions) to support large user numbers, *centralized* corporate entity
- A ‘Big Four’ in **Amazon**, Microsoft, IBM, Google

‘New’ Cloud

- Containers (*Docker, kernel-locked*), and Functions (*multiplicity of approaches*) – added “CaaS” and “FaaS”
- **Edge** (*multiplicity of approaches and concerns*)
- (Re-)*distributed* Computing, and ‘new’ problems (new ‘traditional’ problems)
- ‘Big Four’?

Overview of this talk

<u>'Traditional' Cloud</u>
(Big Four) Clouds are big
Cost and performance (=cost) variation
Performance variation and implications for energy efficiency

<u>'New' cloud</u>
'serverless' and performance
Multiplicity of Edges
'serverless' Edges

<u>An application</u>
Cloud Cars and exemplars

<u>Summary and take home</u>

‘Traditional’ Cloud

Clouds are ‘big’

(Illusion of) Infinite capacity - consider one (big) provider:

AWS: 2014 based on 11 regions and 28 AZs: 2.8-5.6m servers (Morgan, 2014) based on datacenter of up to 80k servers

12 Jun 2012, 1 trillion objects in S3.

13 April 2013, 2 trillion

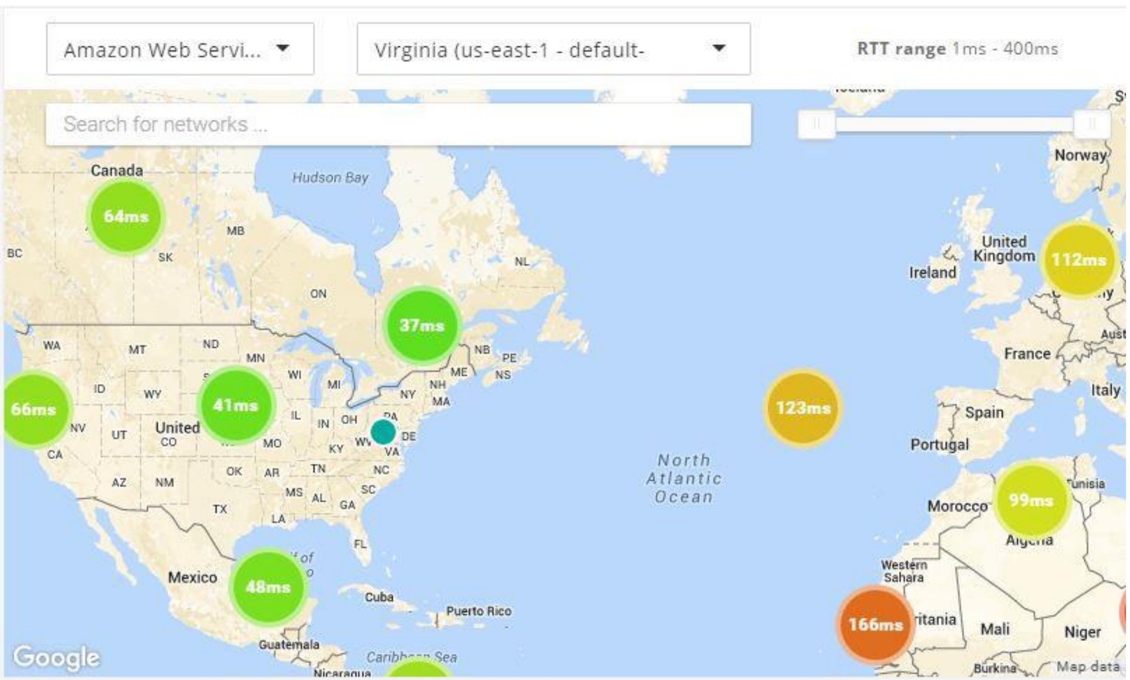
2018, **18** regions, **54** AZs, 5 more regions coming: ~**<u>10m</u>** servers?

T. P. Morgan, A rare Peek Intro The Massive Scale of AWS, 2014, https://www.enterprisetech.com/2014/11/14/rare-peek-massive-scale-aws/

Clouds are ‘big’

Regions: Contain big datacenters at distance but with big networking also

Edges: *a shorter distance to something that does something useful for compute*



Comparison of significant cloud data centres		Sq Footage
Google	Lenoir, NC	476,000
	Dalles, OR	206,000
Apple	Apple, NC	500,000
Microsoft	Chicago, IL	700,000
	San Antonio, TX	470,000
YAHOO!	Lockport, NY	190,000
	La Vista, NE	350,000

Manchester United pitch ~80,000 sq ft

Figure sources: Datapath.io and Make IT Green: Cloud Computing and its Contribution to Climate Change, Greenpeace

Clouds are 'big' – with cost variation

27/4/16	vCPU	ECU	Mem (GiB)	US-E (NV)	EU-W (Ire)	EU-W (Fra)	SA (SP)
t2.nano	1	Variable	0.5	**$0.0065**	$0.007	$0.0075	$0.0135
t2.micro	1	Variable	1	**$0.013**	$0.014	$0.015	$0.027
m4.xlarge	4	13	16	**$0.239**	$0.264	$0.285	N/A
m4.2xlarge	8	26	32	**$0.479**	$0.528	$0.57	N/A
m4.4xlarge	16	53.5	64	**$0.958**	$1.056	$1.14	N/A
m4.10xlarge	40	124.5	160	**$2.394**	$2.641	$2.85	N/A
m3.medium	1	3	3.75	**$0.067**	$0.073	$0.079	$0.095
m3.large	2	6.5	7.5	**$0.133**	$0.146	$0.158	$0.19
m3.xlarge	4	13	15	**$0.266**	$0.293	$0.315	$0.381
m3.2xlarge	8	26	30	**$0.532**	$0.585	$0.632	$0.761
c4.large	2	8	3.75	**$0.105**	$0.119	$0.134	N/A
c4.xlarge	4	16	7.5	**$0.209**	$0.238	$0.267	N/A
c4.2xlarge	8	31	15	**$0.419**	$0.477	$0.534	N/A
c4.4xlarge	16	62	30	**$0.838**	$0.953	$1.069	N/A
c4.8xlarge	36	132	60	**$1.675**	$1.906	$2.138	N/A
c3.large	2	7	3.75	**$0.105**	$0.12	$0.129	$0.163
c3.xlarge	4	14	7.5	**$0.21**	$0.239	$0.258	$0.325
c3.2xlarge	8	28	15	**$0.42**	$0.478	$0.516	$0.65
c3.4xlarge	16	55	30	**$0.84**	$0.956	$1.032	$1.3
`c3.8xlarge	32	108	60	**$1.68**	$1.912	$2.064	$2.6

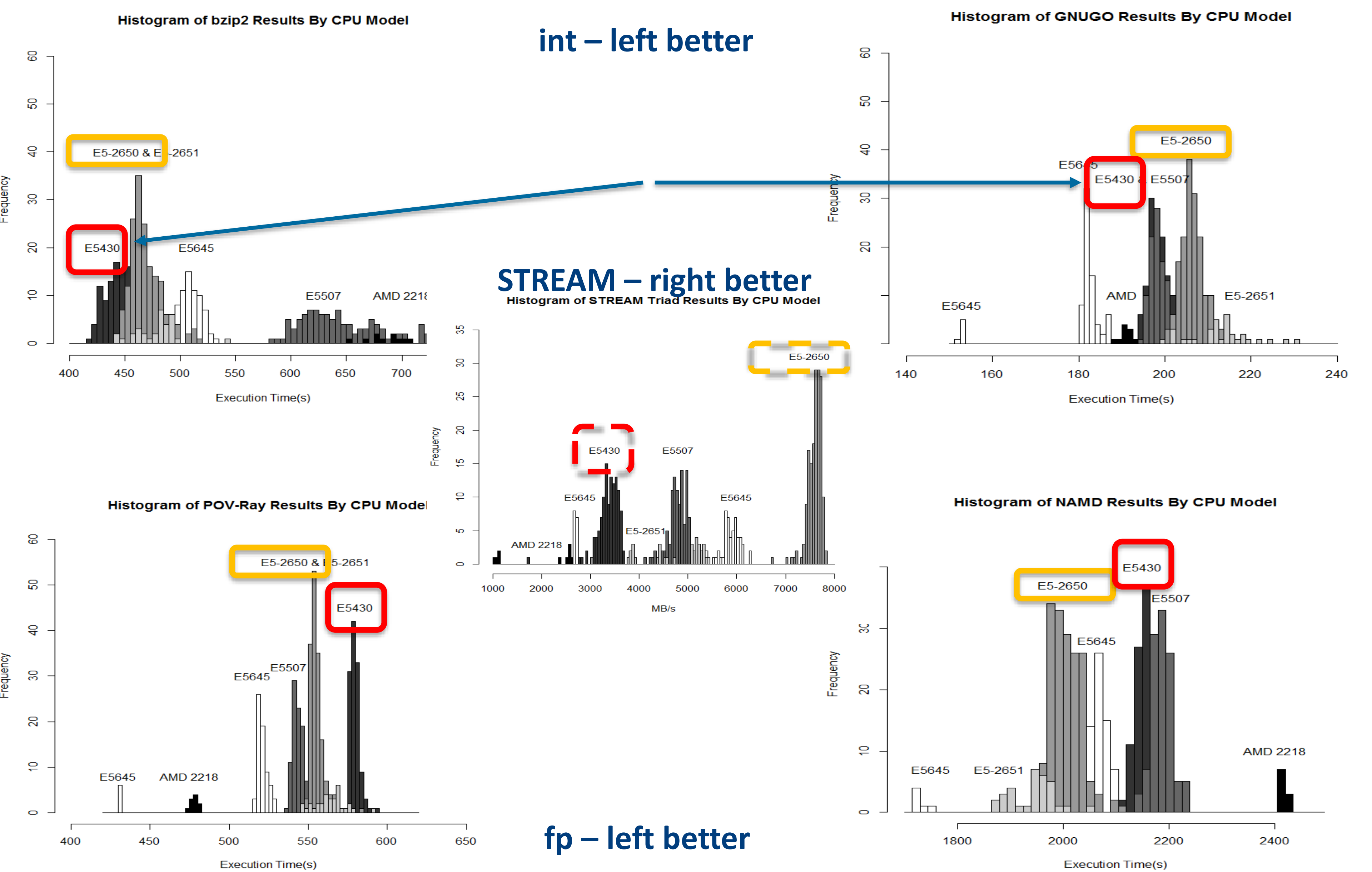
Clouds are 'big' – with hardware variation

CPU model discovery - for ~700 EC2 FGS Instances for 1 user – **1 instance type**

Region	AZ	***E5430***	*E5-2650*	*E5645*	*E5507*
US East N.Virginia 2006 [year Region started] *Cheapest – but latencies*	*us-east-1a*	31%	0	25%	**44%**
	us-east-1b	5%	**59%**	29%	7%
	us-east-1c	0	47%	**52%**	1%
	us-east-1d	18%	31%	**44%**	7%
EU West Dublin 2007	*eu-west-1a*	4%	**75%**	19%	2%
	eu-west-1b	28%	0	**44%**	28%
	eu-west-1c	4%	0	**63%**	33%
US West N. California 2009	*us-west-1b*	0	0	13%	**87%**
	us-west-1c	8%	0	18%	**74%**
SA San Paulo 2011	*sa-east-1a*	0	**81%**	19%	0
	sa-east-1b	0	**86%**	14%	0
US West Oregon 2011	*us-west-2b*	0	**73%**	27%	0
Asia Pacific Sydney 2012	*ap-southeast-2a*	0	**64%**	36%	0
	ap-southeast-2b	0	**75%**	25%	0

Cost, latency, computational capability (moving up stack)

Performance varies by CPU



Cost-efficient use

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Heterogeneous hardware complicates costs

(at minimum) a user needs to:

- Identify suitable (cost-based?) instance offerings (**price determination**)
- Rank 'best' by workload (**performance determination**)
- Determine AZs (latency) offering those resources (**location selection**)
- Attempt to obtain them (**instance lottery**)
- For users with more than one account this may need to be done per account basis (**account selection**)

• **Costs** are incurred in (1) **performance determination** (2) **location selection** and (3) **instance lottery**, for every (4) **account selection** *(AND infrastructure composition changes over time)*

Spend involved with getting cost-efficiency (performance gaming / deploy-and-ditch) - potentially expensive!

Cost-efficient use

Can't eliminate resource uncertainty

Performance can be 'stable' over a long period for a given benchmark – past a good indicator of future - but may be subject to abrupt changes and severe degradation

One instance, **1379s** for POV-Ray – ~13 standard deviations from the mean (639, 54)

Rarer: **'The requested Availability Zone is currently constrained and we are no longer accepting new customer requests for X/Y/Z instance types'**

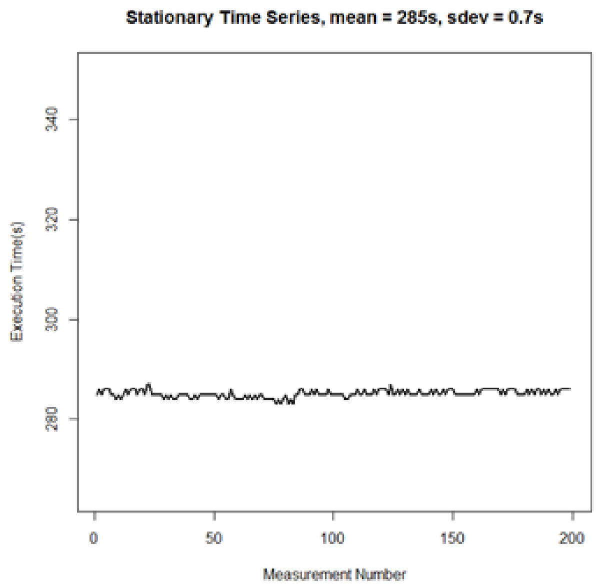
- Go elsewhere, but other AZs may not be cost-efficient – AZ lock-in

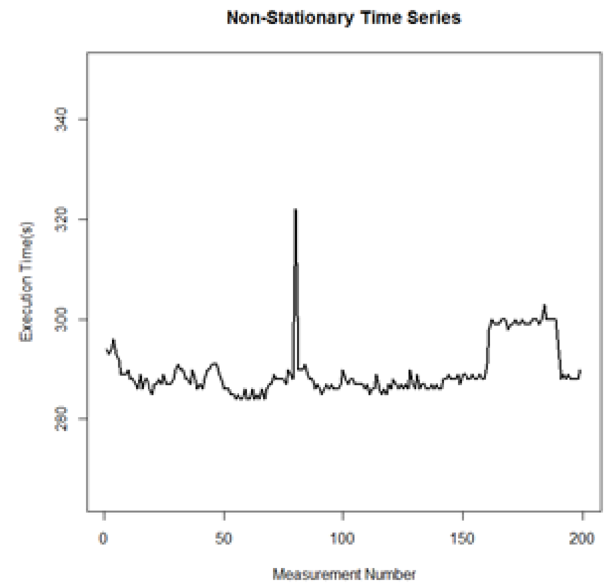
Unusually for a service: better can be cheaper

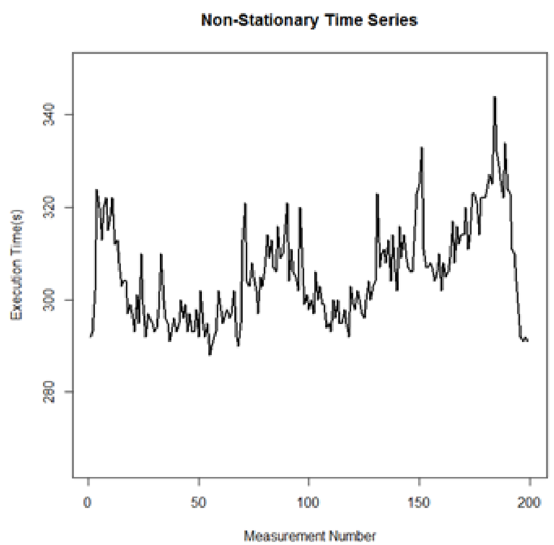
But much work around performance continues to assume homogeneity

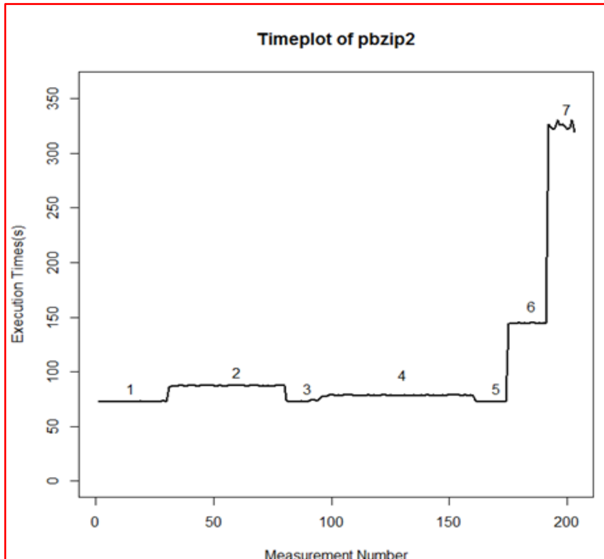
John O.Loughlin and Lee Gillam (2014) "Should Infrastructure Clouds be Priced Entirely on Performance? An EC2 Case Study". International Journal of Big Data Intelligence

Cost-efficient use









An aside – 'brokers' seem popular

Cloud Service Brokers (e.g. aggregators) might address performance issues

Instances with known performance characteristics

• A match-making service between user application performance needs and available resources

Re-price based on desired performance

• Make more suitable instances more expensive, and less suitable less so.

Extensive simulations suggested:

- Assuming clouds are opaque makes it difficult to avoid instance gaming.
- <u>**Very difficult to make a profit**</u>, even with careful pool management! - high vol.
- Opportunities in value of utility rather than price

Rare to find discussion of broker profit – Rogers & Cliff has been a notable exception

O'Loughin, J. (2018): A Workload-Specific Performance Brokerage for Infrastructure Clouds (unpub PhD thesis).
Rogers, O. & Cliff, D., 2012. A Financial Brokerage Model for Cloud Computing. Journal of Cloud Computing: Advances, Systems and Applications, 1(2)

Energy implications of performance

Performance and energy trade-off for different kinds of workload

- *runtime variable with hardware (heterogeneity)*
- how much power needed to deliver runtime on given hardware
- best performance might not equate to most energy efficient
- performance → runtime; user cost higher with longer runtime

Put workloads on best machines for it: consolidation (implies migration)

- **risk of being own noisy neighbour** → longer runtimes
- additional energy use for period of migration: at least costs of equvalent resources plus network
- question of recoverability depends on continued use
- for providers, opportunity to switch off / maintain (may not be an incentive to)

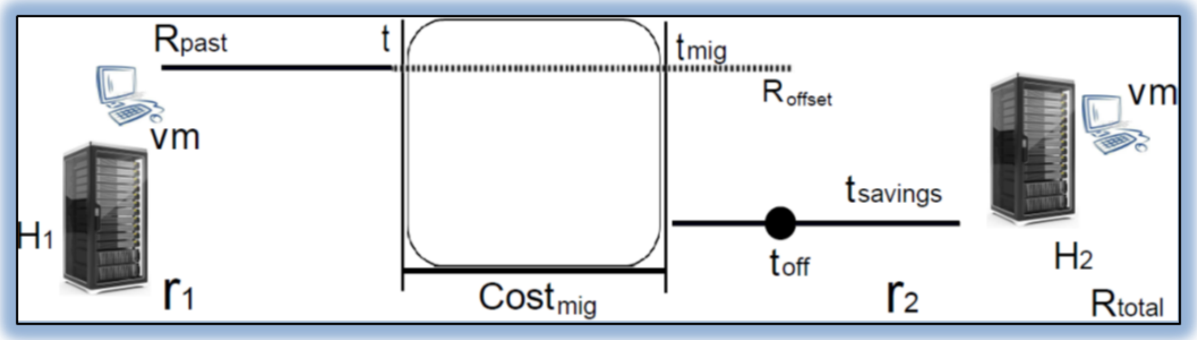
Energy implications of performance

Workload-related CPU model ranking

- w1: A > B > C > D;   w2: D > C > B > A
- VM allocation: B allocated as available; A preferred
- VM consolidation: migration beneficial if workload can recoup cost of migration – implies performance maintained (contention)

Consolidation with Migration Cost Recovery (CMCR)

- Migrate to more efficient hosts
- VM terminated before [t_{off}], the effort is wasted
- Recover migration overhead [$Cost_{mig}$], efficient gain after [t_{off}]



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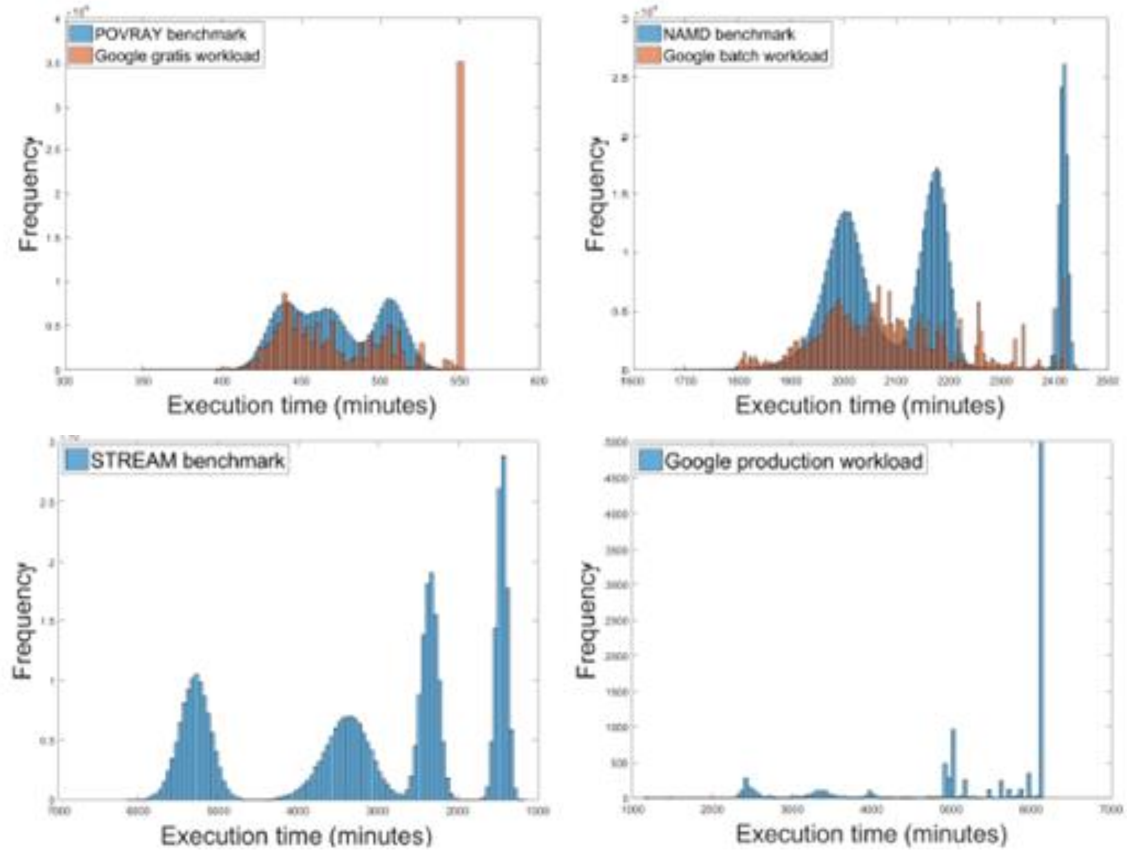
Broad characterisation: **9** scheduling approaches, several types of consolidation (+ none), CloudSim model using **12,583** heterogeneous hosts, **25m** VMs (tasks) in Google workload trace data, **5** minimum-runtime settings, migration rounds at 5 minute intervals (host utilization < 20%). **<u>On-demand</u>** VM allocation

CPU info not provided, so map Google priorities to benchmark results (range scaled) for preferences (Gratis (0) : POVRAY, Batch (2) : NAMD, Production (9) : STREAM). *Distributions typically skewed lognormal per CPU model.*

Then relate power ratings of these 'Cloud' CPUs – simulation results can be related to real VMs.

Workload	Bench mark	CPU Model	Real benchmarks (μ)	(σ)	Min	Max	CoV	Google data (μ)	(σ)	Min	Max	CoV
Gratis	POVRAY	E5430	439	11	421	467	0.025	438.06	9.42	421	467	0.022
		E5-2650	468	12	451	500	0.026	473.87	11.93	451	500	0.025
		E5645	507	10	490	535	0.02	498.55	10.44	490	535	0.021
Batch	NAMD	E5-2651	1994	41.9	1952	2036	0.021	1991	39.51	1800	2040	0.02
		E5-2650	2007	28.5	1978	2036	0.014	1963.4	28.41	1900	2015	0.015
		E5645	2043	96.4	1946	2140	0.047	1931.4	93.43	1800	2170	0.048
		E5430	2160	20.7	2135	2189	0.01	2103.6	22.1	2080	2150	0.011
		E5507	2187	18.1	2162	2217	0.008	2191.8	15.69	2150	2200	0.007
Production	STREAM	E5430	1446	66	1328	1572	0.045	1404.4	44.33	1328	1572	0.032
		E5507	2348	104	2078	2448	0.044	2346.7	107.21	2078	2448	0.046
		E5645	3395	287	2995	4008	0.085	3388.7	238.22	2995	4008	0.07
		E5-2650	5294	191	4935	5860	0.036	5294.5	197.52	4935	5860	0.037

Experimental work



Findings confirmed: *sensible* allocation better (easier) than consolidation; migrate longer running VMs – but **assumes clouds are not opaque**. (i.e. provider has knowledge of workload)

Zakarya, M. (2017): A Workload-Specific Performance Brokerage for Infrastructure Clouds (unpub PhD thesis) .

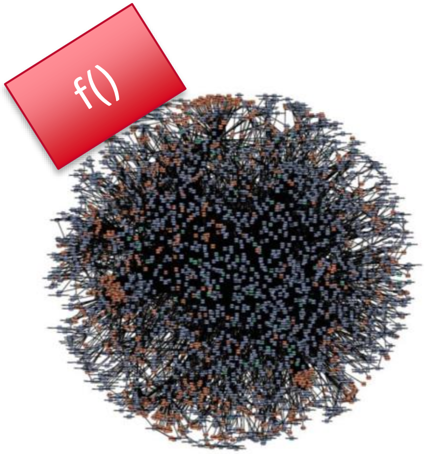
‘New’ Cloud

A look at so-called 'Function as a Service'

'serverless' computing (yet servers are **essential**)

- You're not supposed to "worry" about provisioning
- Billing per 100 milliseconds (AWS Lambda, Google Cloud Functions; Azure has at least 2 ways to pay incl. based on memory consumption)
- Functions may be time-constrained – 5 mins, Lambda/Azure; though HTTP timeout of 30s (e.g. AWS API Gateway) gives 29s runtime

Are performance/cost questions relevant?



Relevance to ‘new’ Cloud - performance

A look at so-called ‘Function as a Service’ – AWS Lambda

AWS Lambda runs a Function in a Container on a VM (‘serverless’)

IP address may over time change – 2 functions run gave e.g.: ip-10-23-17-3, ip-10-14-98-122.

Short runtimes good: a small test - 113.44 ms, then 114.34 ms, 102.65 ms, 113.57 ms – all rounded to nearest 100 (200ms) for billing; reasonable consistency.

Underlying process:

```
USER        PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
490           1  1.3  0.3 212024 15372 ?        Ss   16:49   0:00
/usr/bin/python2.7 /var/runtime/awslambda/bootstrap.py
490           7  0.0  0.0 117208  2476 ?        R    16:49   0:00 ps auxw
```

Through several uses, underlying process remains.

Relevance to 'new' Cloud - performance

A look at so-called 'Function as a Service' – AWS Lambda

Limitations exist, e.g. can't run 'ifconfig', no 'sudo' so can't install as root, and can't get at AWS metadata of VM. But can find out *CPU model* (/proc/cpuinfo [dual 'core' **c4**]) and underlying system (uname [**AWS Linux**]),

```
model name      : Intel(R) Xeon(R) CPU E5-2666 v3 @ 2.90GHz
cpu MHz         : 2900.066
cache size      : 25600 KB
```

```
Linux ip-10-23-17-3 4.4.35-33.55.amzn1.x86_64 #1 SMP …
x86_64 x86_64 x86_64 GNU/Linux
```

Others have seen:

- **Intel(R) Xeon(R) CPU E5-2680 v2 @ 2.80GHz** - a **c3** instance: http://zqsmm.qiniucdn.com/data/20150416152509/index.html.

A look at so-called 'Function as a Service' – AWS Lambda

Can run a [small –time limit!] arbitrary linux application – e.g. a benchmark such as STREAM [~**2GB/s**], if:

- Precompiled elsewhere, downloaded into local filestore for Function (/tmp), made executable (chmod), executed and output returned
- *Variations **per execution**, with rounding; **performance**/location/lottery/account **remains important***

```
-------------------------------------------------------------
STREAM version $Revision: 5.10 $
-------------------------------------------------------------
...
-------------------------------------------------------------
Function      Best Rate MB/s  Avg time     Min time     Max time
Copy:             1979.3      0.091534     0.080836     0.116964
Scale:            1974.5      0.099291     0.081033     0.117087
Add:              2370.4      0.122582     0.101247     0.157255
Triad:            2362.9      0.126896     0.101569     0.157570
```

Multiplicity of Edges

Will Cloud gain an **Edge**?

Network **Edge** *devices* – devices that have sensors (a mobile phone?)

Customer **Edge** (/Edge router) – router on premises

Provider **Edge** – a provider's router

Edge Datacenter (/***Cloudlet**** /Content Delivery Network) – datacenter

Multi-access (/mobile) **Edge** – datacenter + RAN (e.g. 5G)

Also, ***FOG***

Edge is also Microsoft's web browser, and a Ford vehicle

*** Should not be confused with Cloudlet in CloudSim, which is a Task***

The Fog of Fog?

Fog "**complements and extends** the Cloud to the **edge** and endpoints" , Bonomi et al

- Fog is **additional to and complementing Cloud**,
- Example distributed applications: "A has one **Cloud component**, and two **Fog components** [..] B has one **cloud component**, one **component in the Core**, and a **Fog component**".

OpenFog Consortium: "a system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along **the *continuum* from Cloud to Things**".

- OpenFog documents represent Fog diagrammatically as:
  - **between** Cloud and Things;
  - **including** Cloud;
  - '**in**' Cloud Computing.
- OpenFog Consortium: Fog is "often erroneously called edge computing, but there are key differences. Fog **works with** the cloud, whereas **edge is defined by the exclusion of cloud**".

Fog has not proven an entirely helpful notion

Multi-access Edge Computing (until recently, Mobile Edge Computing) – ETSI specification

- provide **capabilities of Cloud Computing close to the Radio Access Networks** in 4G and 5G telecommunications and converge with other radio access technologies (e.g. WiFi or Satellite).
- “can be seen as **a cloud server running at the edge of a mobile network**”.

ETSI MEC server supports VMs into which “MEC applications from vendors, service providers and third-parties are deployed and executed”.

VMs → Containers → Functions

[MEC authors: PaaS for “future releases”].

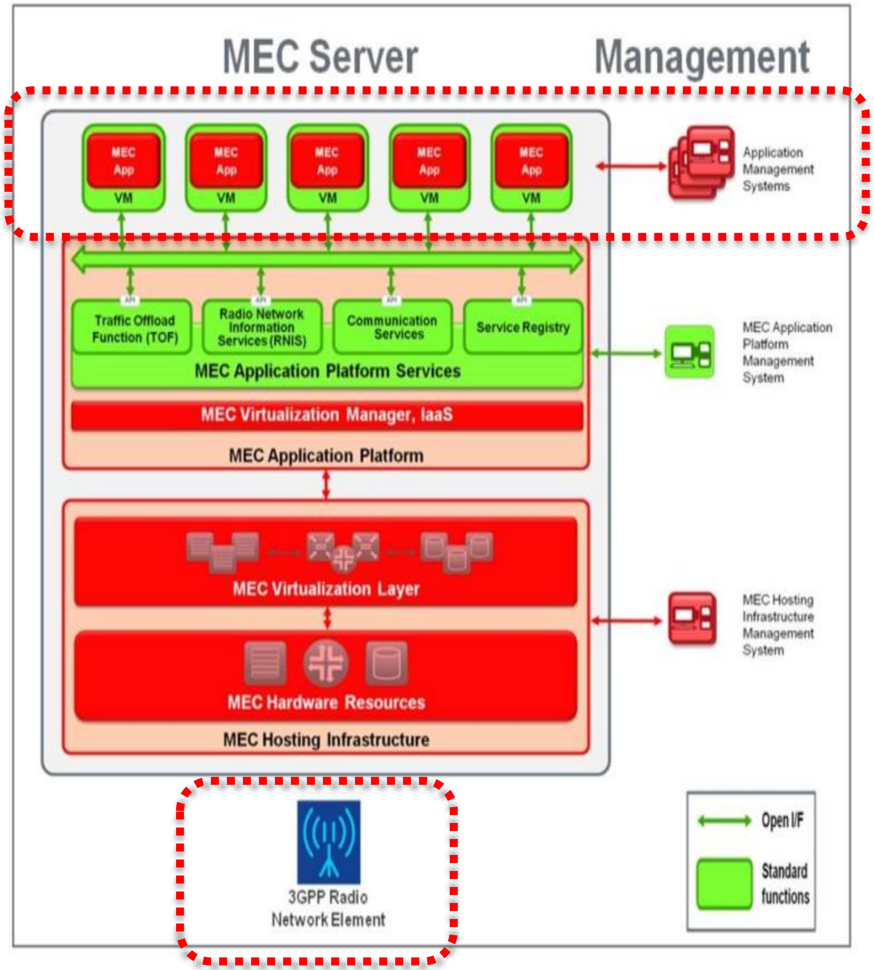


Figure 9: MEC server platform overview

Cloudlet

Not just one MEC server per Edge?

Cloudlet (Carnegie Mellon University (CMU) notion) - middle tier of a 3-tier hierarchy: “mobile device - **cloudlet** – cloud”.

A “**datacentre in a box**”, implying multiple servers, local to the user, similar to MEC (and some characterisations of Fog).

CMU formed Open Edge Computing initiative in 2015, together with Intel, Huawei, and Vodafone, intending to synchronize work with ETSI MEC, leading so far to OpenStack++ allowing for ***migration between OpenStack clusters****.*

Integration with telecommunications per MEC does not appear yet to be paralleled.

Functions at the Edge?

Intended benefits of Edge: reduced end-to-end latency; smaller data volumes travelling shorter distances – computational capability and storage is nearer the user.

Intended benefits of Functions: small, fast-executing, provider-scaled capability.

Faster, smaller implies more suitable for cloud-assisted, or cloud-driven, control services.

But: susceptible to hardware variations (performance), including due to contention, as well as provider-driven energy management.

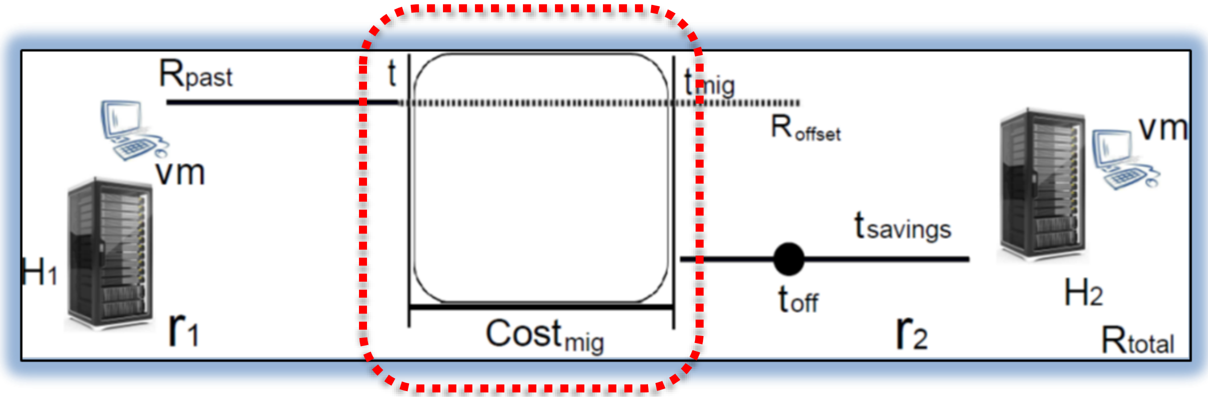
*See, also, AWS Lambda at **Edge** (CDN-related FaaS).*

Multiplicity of Edges

Edges running VMs / Containers / Functions, using various data

Migration when user moves to another edge

Execution would vary with hardware (slowdown/speedup may imply needing more/less resource for equivalence at the target – and need to know this)



Is a user highly likely to keep moving quickly between edges?

An Application

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Socio-economic forces

Safety

- 8m accidents, 1.3m fatalities, 7m injuries*

Economy

- 90b hours in traffic jams*

Environment

- 20-35% of global CO_2 emission

Passenger Comfort

Market forces

JAGUAR LAND ROVER, BMW, Mercedes, Audi, VW, Ford, Volvo, GM Canada, Mazda, Nissan, Hyundai, Honda, Toyota, Aston Martin, Bentley

*CISCO report

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(How) Can cars become fully independent?

What technology advances are required?

Antilocking Brake System (ABS)

Electronic Stability Program (ESP)

Adaptive Cruise Control (ACC)

Lane Keeping Assist

Parking Assist

Autonomous Driving in Traffic Jam and Highway

Full Autonomy

How will humans and vehicles interact with each other and their environment?

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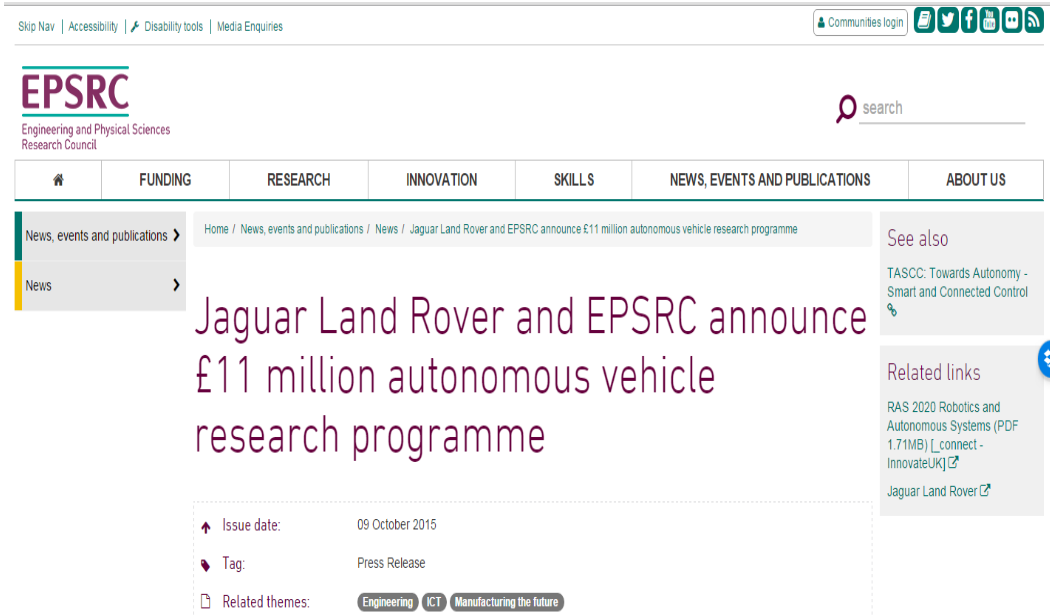
5 year UK research programme - Cloud-Assisted Real-time Methods for Autonomy (CARMA) project



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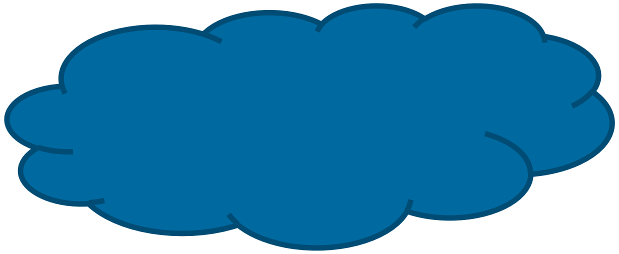
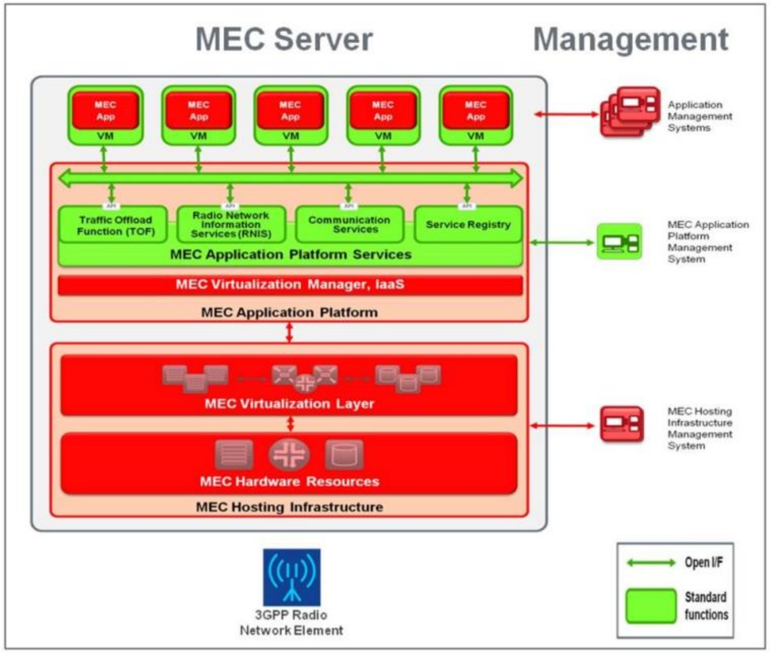




*Internet of Things (Tractors, Kettles, Fridges, **Cars** ….)*

Waymo generates 1GB data **per second** (2 PB/car/year)

Estimate of 2 billion total vehicles by 2020

Some of this 1GB/s may be usefully processed close to the vehicles, with vehicles connecting through the RAN to access or provide e.g. local road information

Some data may aggregated over MEC Servers, or where capability is not needed immediately, or if not available locally

CARMA's vision: design and validate a novel, secure framework to *enable* implementation of safe and robust semi-autonomous and fully autonomous functions

Main objectives

Address key technical research challenges

Validate through proof-of-concept demonstrators

Evaluate scalability

Multi-access/mobile edge, 5G , Cloud.

Security and effects on ***performance*** *and* ***latency***

Safety *remains paramount*

CARMA Core (Cloud):

- Based on commercially available **public cloud** resources
- Services where **higher latency** is tolerable, information is coming from a **wider geography**, longer term storage needs, and so on.

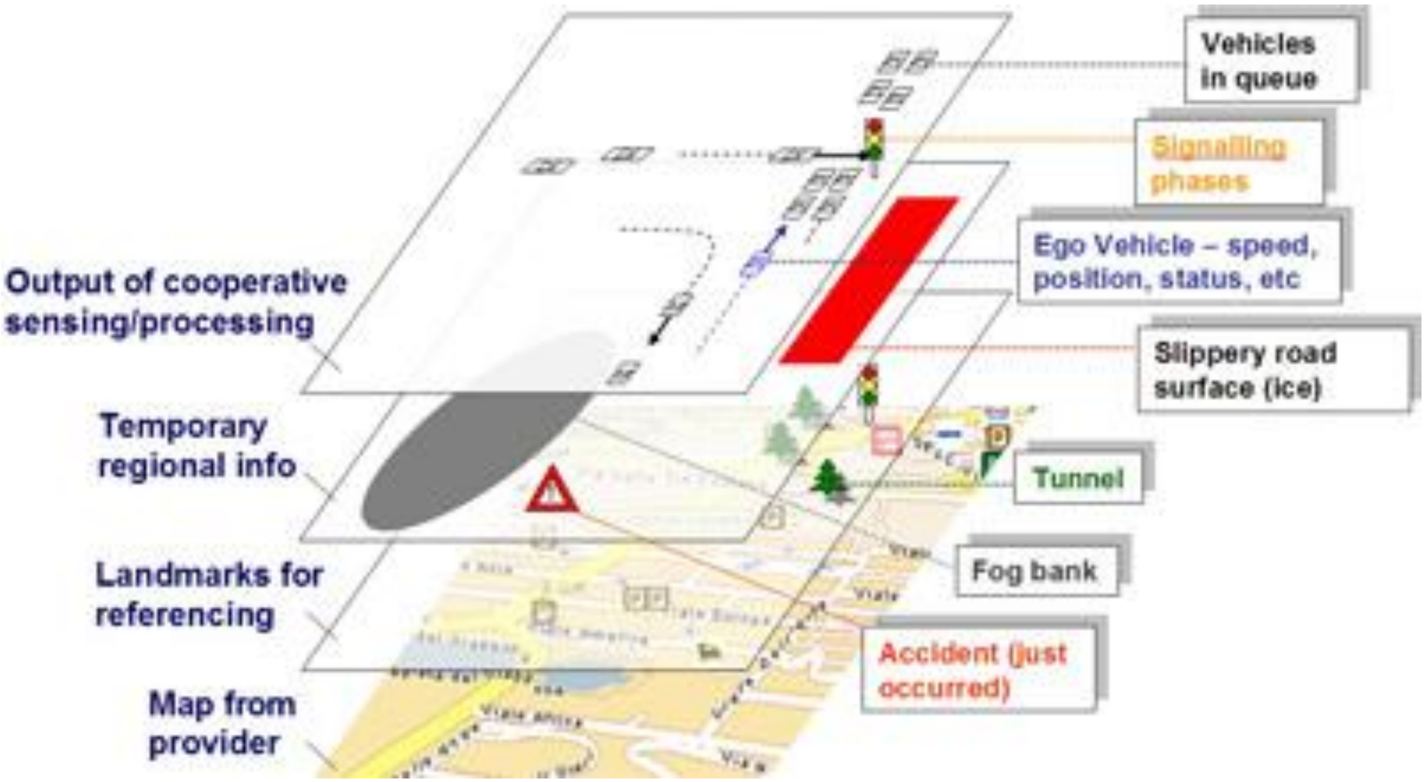
CARMA Edge (MEC, 5G):

- Host beneficially **off-board** (low latency) processes
- Information collected from *around* vehicles to support **cooperativity** and computation beyond capabilities, including sensor ranges, of a given vehicle.

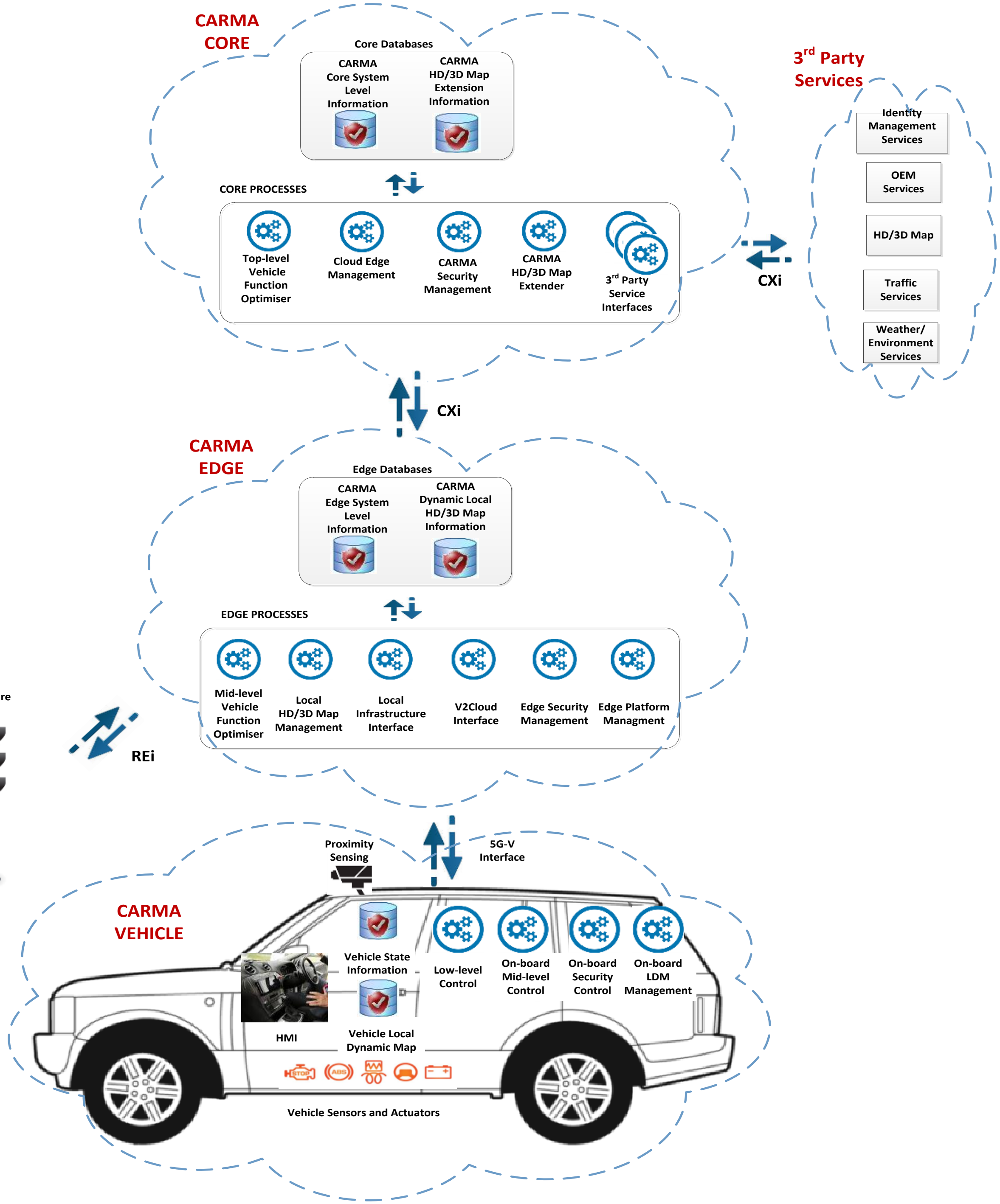
CARMA Vehicle:

- **On-board vehicle network** across all sensors, infotainment, actuators etc.
- *Significant increases in on-board computational capability to be expected.*

Cooperativity beneficial for maps where information has varying transience – information around vehicles and beyond sensor ranges



CARMA Platform: Logical Design

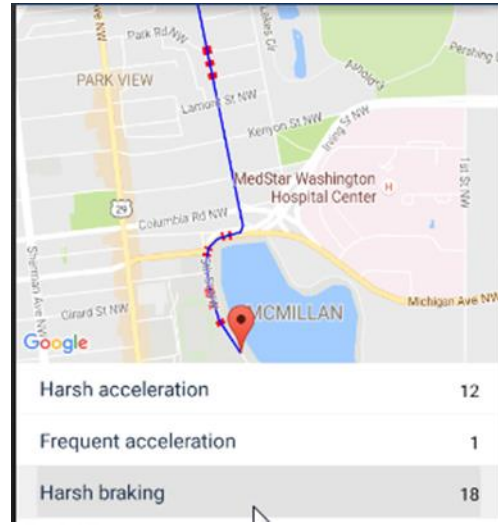


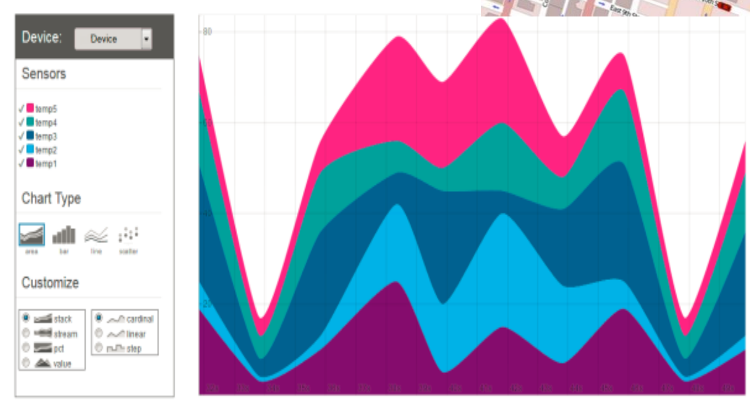
Public Cloud Exemplars

IBM Cloud-connected Vehicles

Largely Vehicle to Cloud

- IBM Watson IoT Driver Behavior Service
- IBM Connected-car IoT app with Geospatial Analytics.
- Microsoft Connected Vehicle Platform
- Google Connected Vehicle Platform
- ….





A hint of Edge, in -

- AWS Connected Vehicle Solution
- IBM Edge (Apache Edgent) analytics …

<u>None of these address Autonomous</u>

Public Cloud Exemplars

AWS Connected Vehicle Solution

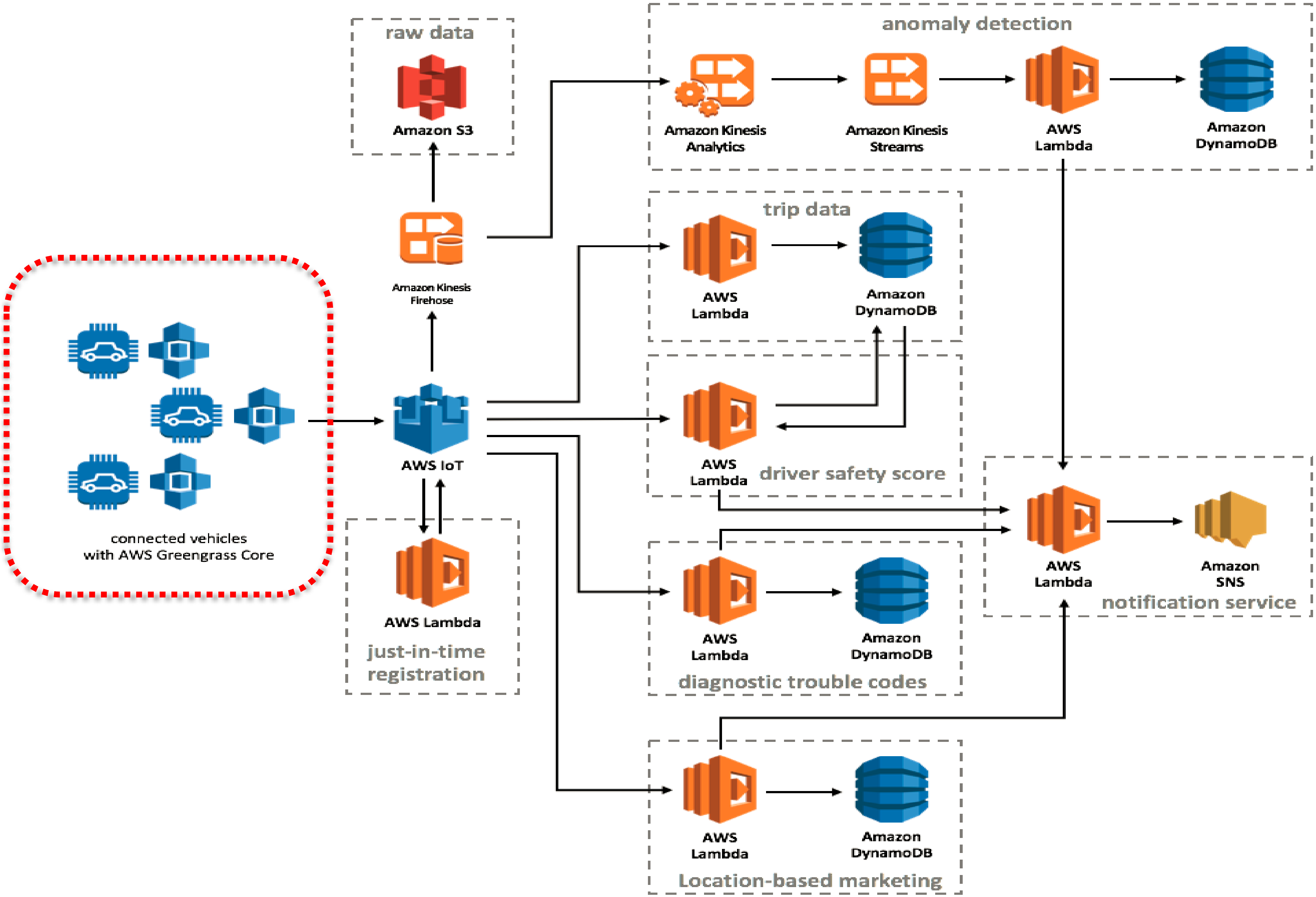
AWS suggests an application stack launchable from a template for multiple services

- Long term data storage
- Treatment of telematics anomalies
- Capture of trip data
- Calculation of a driver safety score
- Diagnostics and reporting

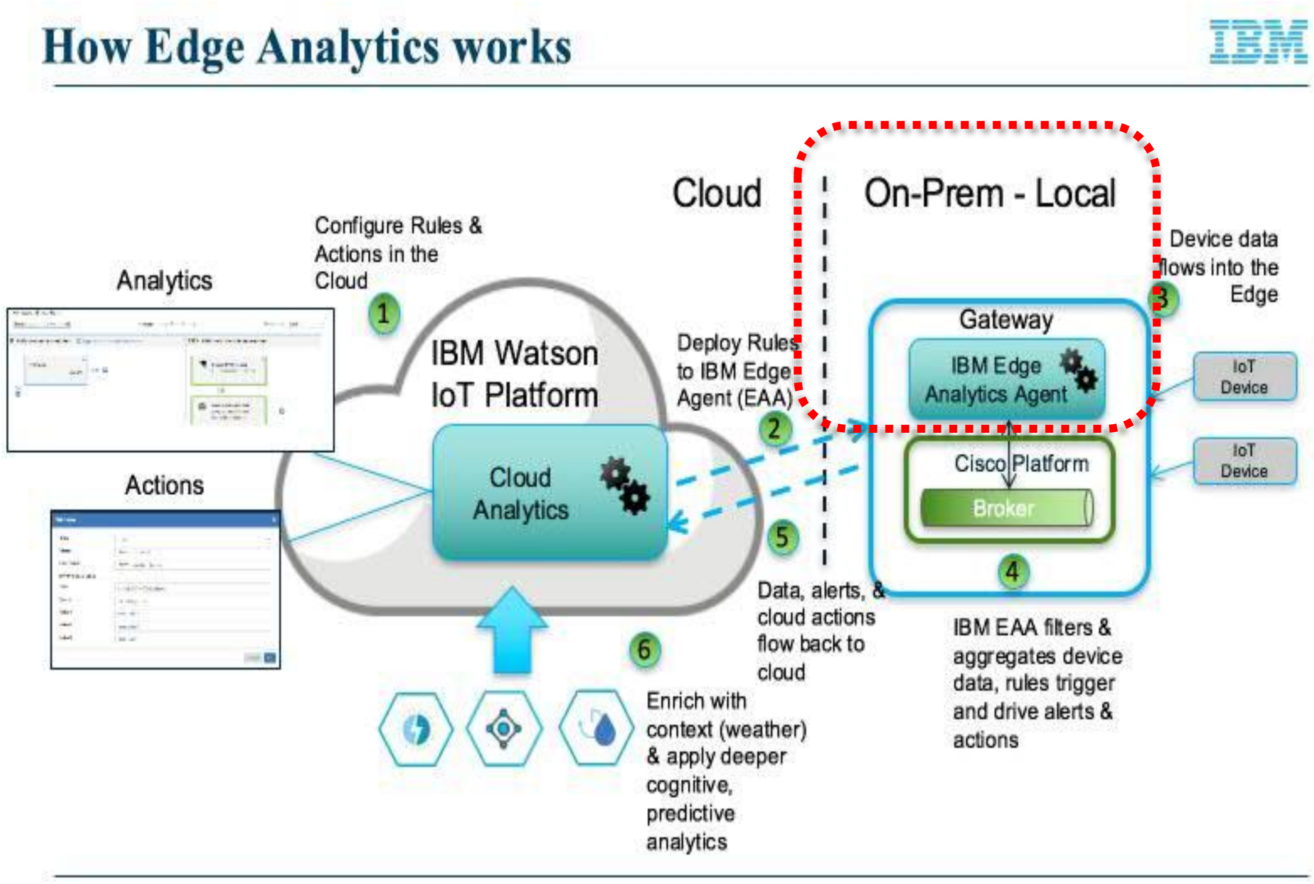
Messages through IoT gateway (Message Queue Telemetry Transport – MQTT, pub/sub): hierarchy of topics, and data payloads; rules on messages trigger execution of Lambda Functions for applications.

Includes AWS Greengrass for the ***<u>Edge</u>***, but **<u>most of the work in Cloud</u>**

Public Cloud Exemplars



IBM Edge Analytics: Edge Agent on a Raspberry Pi and the DGLux tool.



Public Cloud Exemplars

Edge offerings largely not yet replicating Clouds; actions, per provider, required in order to achieve.

- **AWS** IoT rules not yet deployable to (Greengrass) Edge; local versions of other services largely also unavailable.
- **IBM** “Edge Analytic Rule(s) are pushed to the edge device” but no other services
- *Microsoft IoT Edge requires a device running Windows 10 or Windows server with Docker*
- *Google IoT seems not to relate to Edge capability as yet.*
- Vendors also promoting their **own** flavour of Function as a Service.

MQTT (Advanced Message Queuing Protocol), tending to be supported – AMQP and others less so.

This is an improving situation.

Summary and take home

Summary

Will Cloud gain an Edge?

Which Edge? For us, MEC, but market forces…

'Traditional' Cloud
(Big Four) Clouds are big
Cost and performance (=cost) variation
Performance variation and implications for energy efficiency

'New' cloud
'serverless' and performance
Multiplicity of Edges
'serverless' Edges

An application
Cloud Cars and exemplars

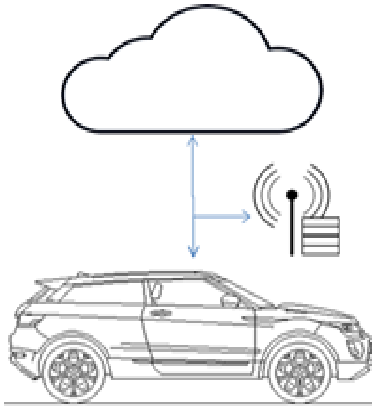
Summary and take home

Take home messages 1/2

Will Cloud gain an Edge?

Provider challenges include:

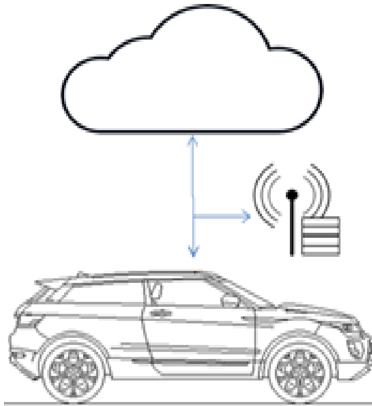
- What to provide <u>in</u> hardware
  - light lifting (rPis)
  - heavy lifting (servers, stacks)
  - telecommunications connectivity
  - “Moore’s law”
- What to provide <u>on</u> hardware
  - Bare metal
  - VMs/Containers/Functions
- Where to locate
- How to maintain
- Support for **Migration**
- How to secure
- To what quality of service
- At what price



Take home messages 2/2

Application/user challenges, as well as services to prioritise, include:

- Which Clouds/Edges to use? Vendor(s) lock-in? (hostage to functionality)
- What runs where in V/E/C, when?
  - Fixed, or dynamic, accounting for limited, heterogeneous, resources under contention? (dynamic reconfiguration)
  - What **Performance** – guarantees?
- **Migration** between V/E/C and/or across Edges? (c/w elastic / scalable)
  - Live migration – uninterruptible?
- How to secure? (What to secure? When to secure?)
- How to price across V/E/C? Who pays whom for what?
  - Fixed / dynamic
  - Based on services and/or demand?



CARMA

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An opportunity for an interested researcher ….

Cloud Assisted Real-time Methods for Autonomy (CARMA)

Research Fellow in Mobile/Multi-access Edge Cloud Computing

Deadline: 8 April

https://jobs.surrey.ac.uk/Vacancy.aspx?id=4701

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Thank You

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Twitter: @leegillam
Journal: http://www.journalofcloudcomputing.com/ - fully open access to in-depth Cloud research

https://jobs.surrey.ac.uk/Vacancy.aspx?id=4701

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