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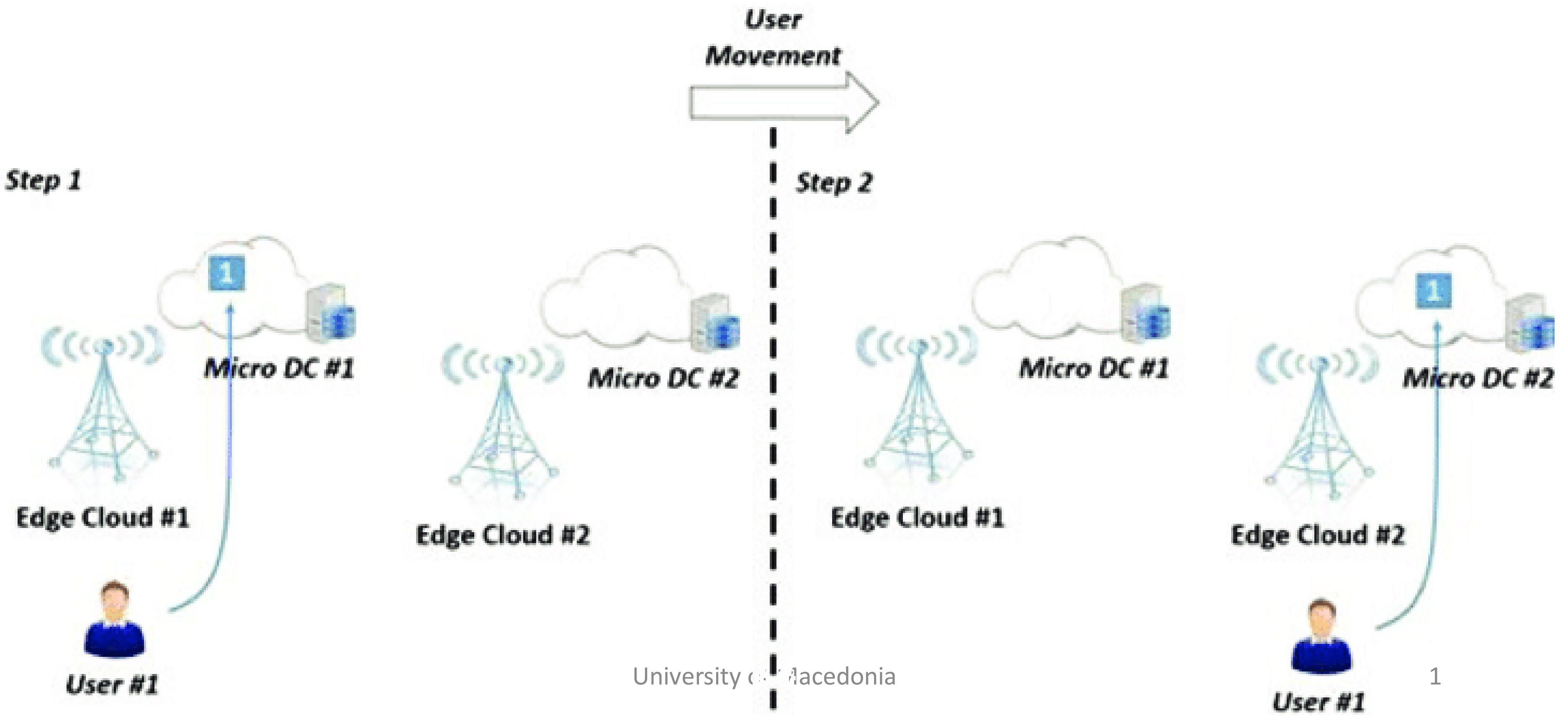
Lightweight clouds for low latency computing at the network edge



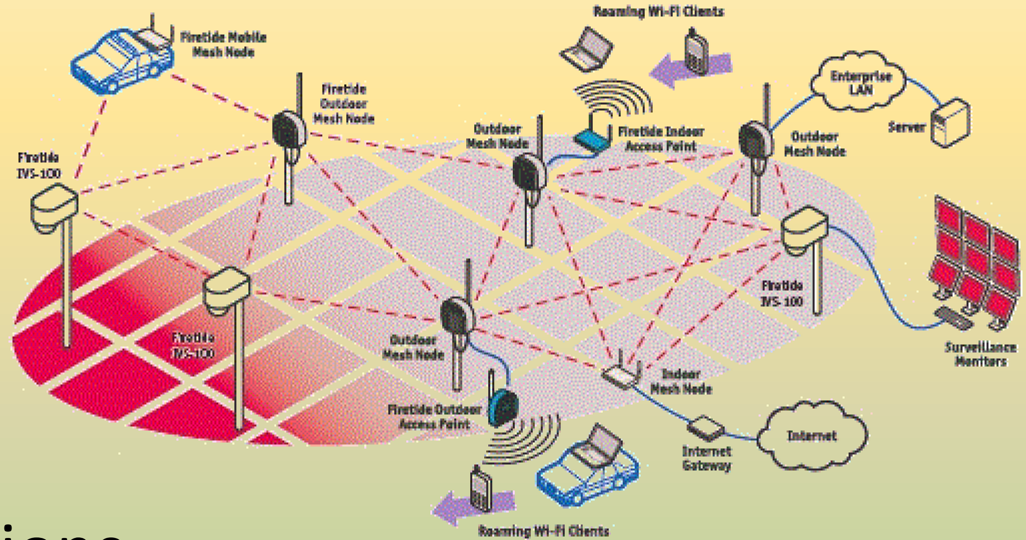
Abbreviations

- **SDN** Software Defined Network(s)
- **NFV** Network Function Virtualization
- **VNFs** Virtual Network Functions
- **CN** Cellular Core Networks
- **MEC** Mobile Edge Computing

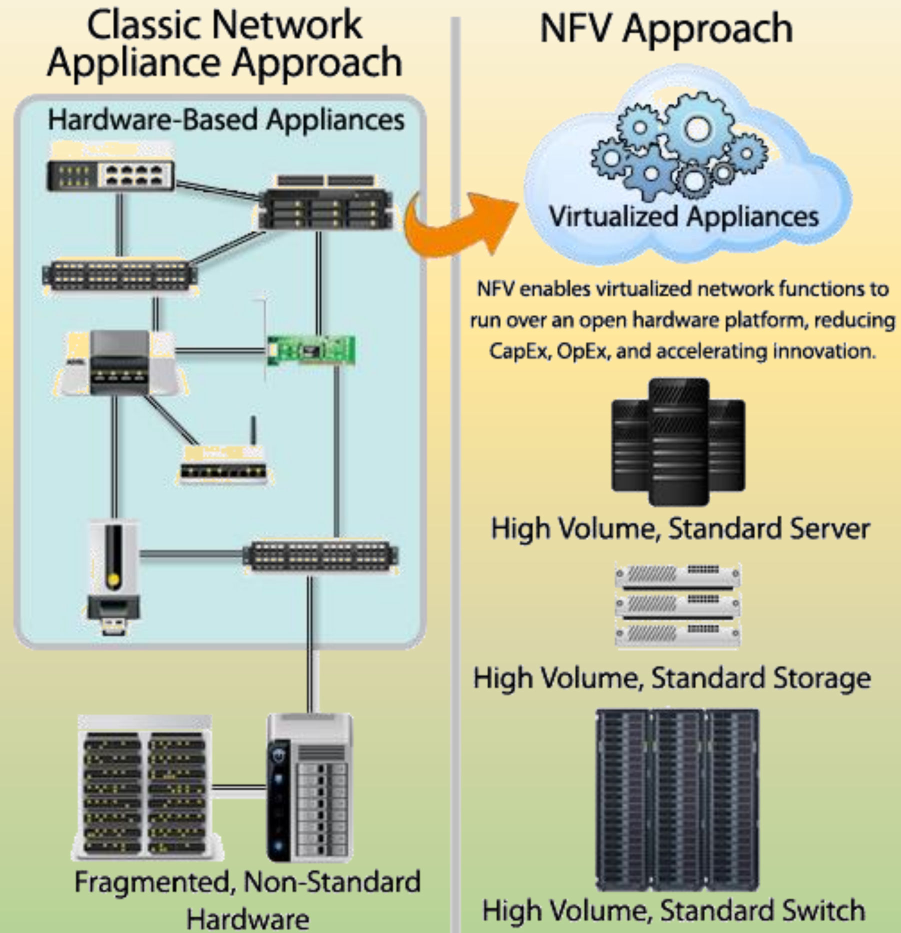
The Trend

Internet is being extended by incorporating heterogeneous wireless networks:

- 5G mobile networks
- IoT
- sensor networks
- challenging issues
- rapid mobility
- communication disruptions
- resource constraints
- variations in QoS (signal issues, interference, etc.)



Network Function Virtualization



Classic Network Approach vs NFV Approach

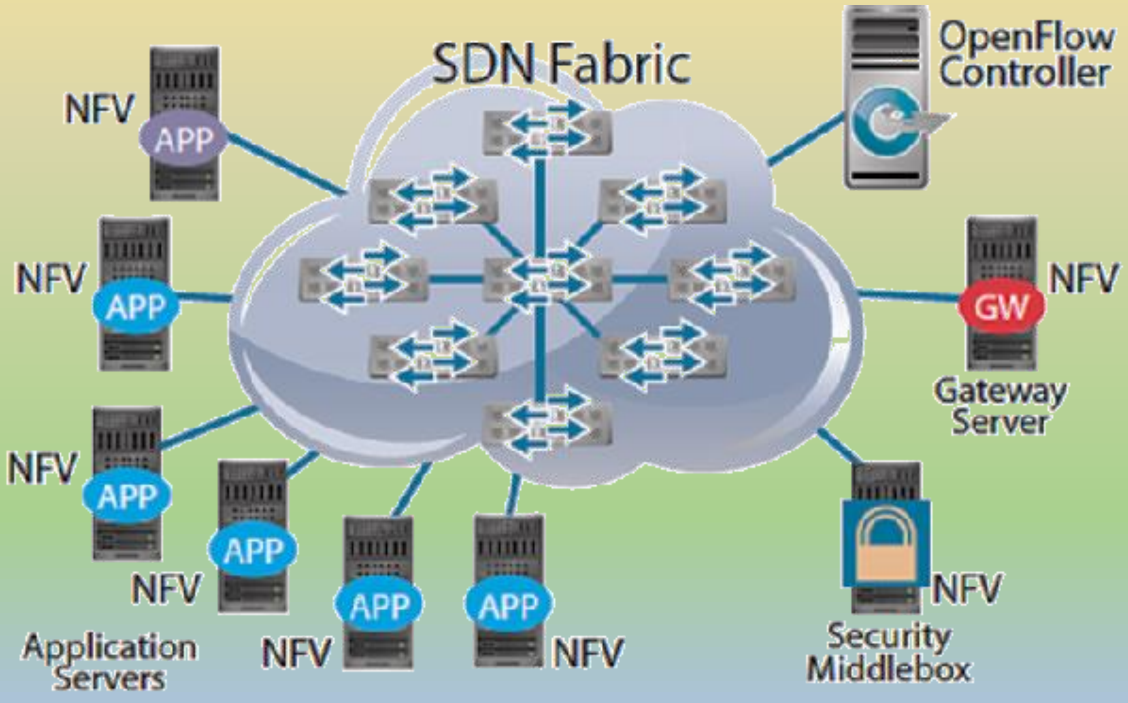
- Adds new **capabilities** to communications networks
- **Decouples software implementations of Network Functions** from the **computation, storage**, and networking **resources**
- **Can be chained with other VNFs** and/or Physical Network Functions (PNFs) to realize a Network Service (**NS**)
- Exposes a **new set of entities**

Benefits of Network Function Virtualization

- Management and Orchestration
- Elasticity
- Security
- Energy Efficiency
- Migration and co-existence with existing platforms

Notice that migration can happen gradually

- Less complexity
- Flexibility
- Lower Capex and Opex
- Portability
- Performance



Network Function Virtualization is critical for IoT

- NFV aims at the disruptive **replacement of sophisticated middleboxes** (those with dedicated hardware and proprietary software for media caching/ service) with simple commodity servers, switching, and storage [Gember- Jacobson 2014]
- *Almost every aspect of our business and our personal life will use IoT*
- **The communication infrastructure for the IoT revolution will be virtualized** and based on the service provider's NFV cloud infrastructure.

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1957-2017

Open research issues

- The systems are becoming more complex but also more automated and softwarized
- Open innovation and open software will be key components:
  - New routing protocols, new operating systems developed specifically to run into tiny devices with limited power

References

- Eriksson White paper, *Cellular networks for massive IoT*, https://www.ericsson.com/en/publications/white-papers/cellular-networks-for-massive-iot--enabling-low-power-wide-area-applications,January 2016.
- M. K. Weldon*, The Future X Network, A Bell Labs Perspective*. CRC Press, 2016.
- A. Gember-Jacobson *et al.*, "OpenNF: Enabling innovation in network function control," in *ACM SIGCOMM Computer Communication Review*, 2014, vol. 44, pp. 163–174.
- Published ETSI NFV white paper: http://portal.etsi.org/NFV/NFV_White_Paper2.pdf

Cloud Computing

- Cloud computing has the benefits of economies of scale through:
  - the concentration of network
  - processing and storage resources
- Clouds can operate at the edge of the fixed infrastructure and support mobile communications

Mobile Edge Computing

- Virtualization of the CN stack through NFV enables lightweight, scalable software instances of VNFs deployed on commodity servers
- VNF processing resources can be scaled to match its specific load, the costs of managing and provisioning resources for network functions can be mitigated
- Hence it is possible to deploy core VNFs and application-layer services on general purpose hardware at many smaller Data Centers located closer to the edge, creating a MEC
- MEC networks, enabled by SDN/NFV, offer opportunities for operators to optimize their networks and enhance service(s) for end-users

Relatively new Definitions

No consensus in the basic definitions yet

- ***Mobile Edge Computing*** [2] the ability to run IT based servers at network edge
- ***Mobile Cloud Computing*** (MCC) mobile services and applications delivered from a centralized virtualized data center to a mobile device [3]
- ***Fog Computing*** highly virtualized platform that provides compute, storage, and networking services between end-devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network [4]

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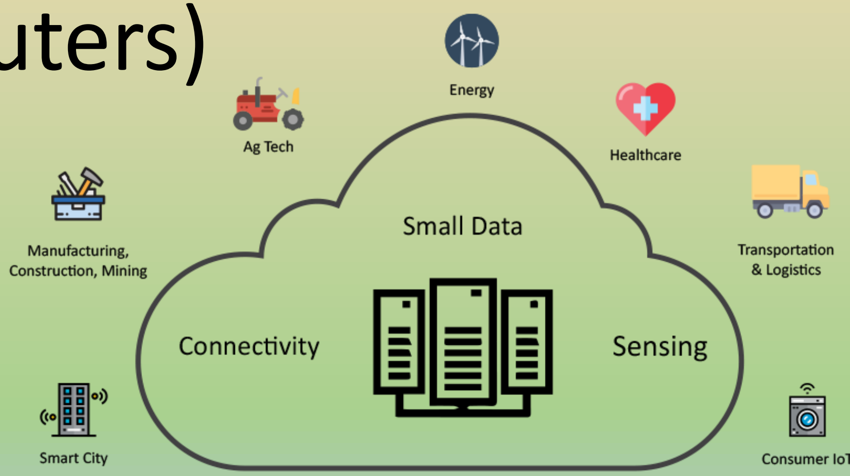
Comparison

- **MEC** and **MCC** focus on 5G networks
- **MCC** on a thin-client operation of mobile devices
- **Fog Computing** relates with IoT and deployment of the virtualized resources in edge devices (routers)

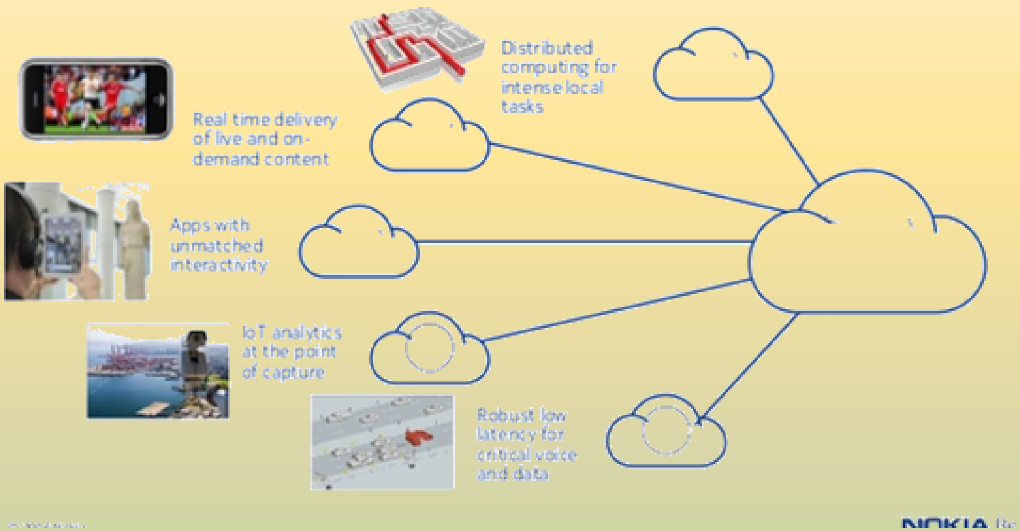


Fog Computing

MEC can cover

Different types of wireless / mobile networks

- *5G*
- *wireless sensor networks*
- *Wi-Fi & IoTs deployments*



Deployed services will be associated with orchestrated Service Function Chains and logically-centralized data flow manipulation (SDN, NFV paradigm)

MEC’s improvements

- Those unified environments can provide:
  - ultra-low latency
  - high bandwidth
  - real-time access to radio network data, leveraged by the applications

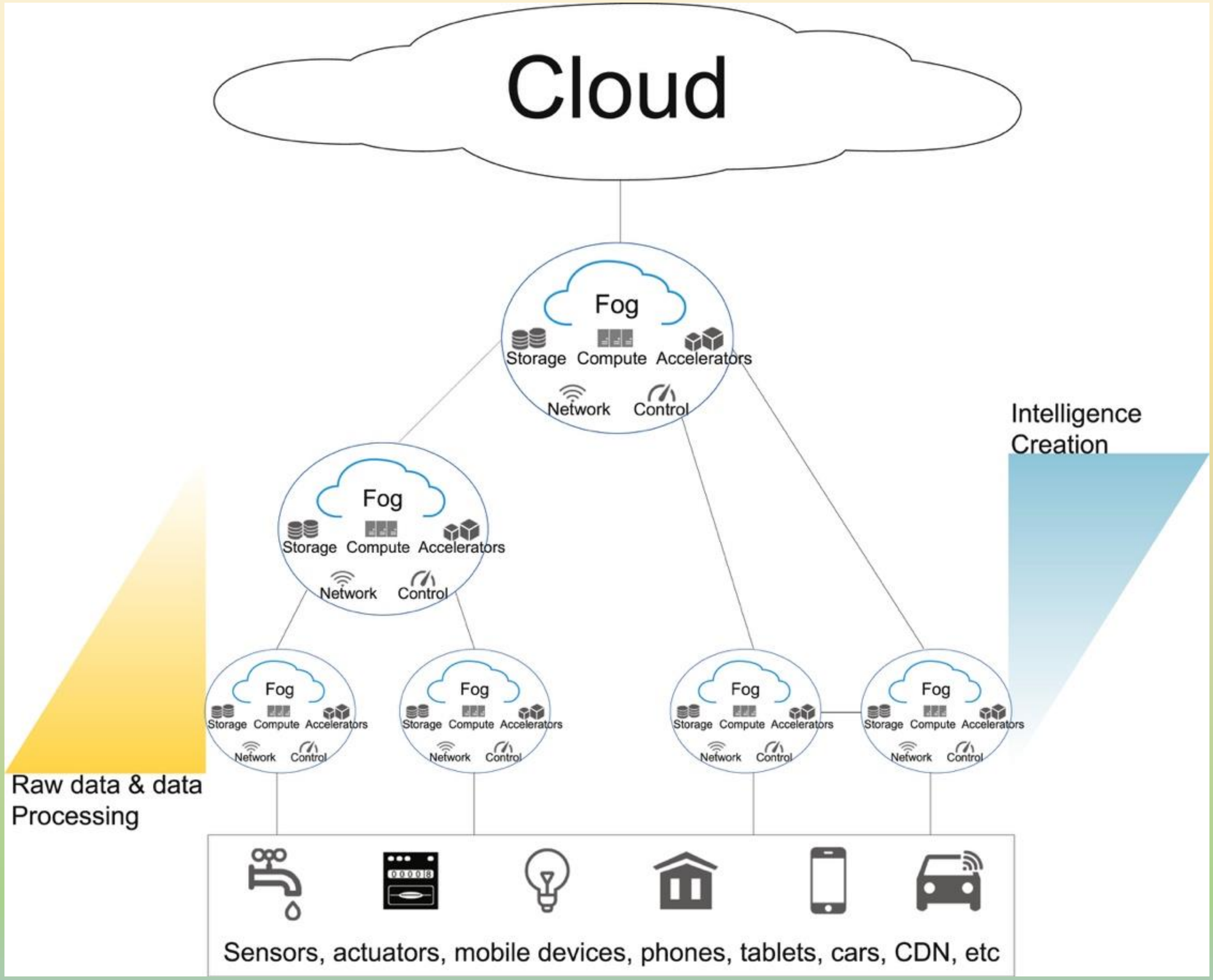
Fog Computing

According to the OpenFog consortium, leading the Fog Computing Standardization Activities:

"Fog computing is a system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from Cloud to Things"

Source: Ai, Yuan, Mugen Peng, and Kecheng Zhang. "Edge cloud computing technologies for internet of things: A primer." Digital Communications and Networks (2017).

Typical Fog Computing Architecture



Source: Ai, Yuan, Mugen Peng, and Kecheng Zhang. "Edge cloud computing technologies for internet of things: A primer." Digital Communications and Networks (2017).

How Fog Computing Addresses IoT Challenges

- **Latency:** Performs time-sensitive tasks close to end-users
- **Bandwidth:** Hierarchical data processing along the cloud-to-things continuum
- **Resource-constraints:** Carries out resource-intensive tasks on behalf of devices
- **Uninterrupted services:** Autonomous operation of a local Fog
- **IoT security:** Perform a wide range of security functions (malware scanning, monitoring, exploit local knowledge, etc.)

Source: M. Chiang and T. Zhang, "Fog and IoT: An Overview of Research Opportunities," in IEEE Internet of Things Journal, vol. 3, no. 6, pp. 854-864, Dec. 2016.

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Fog Computing Approaches

- Architectural Proposals include:
  - the OpenFog Reference Architecture, enabling data-intensive requirements of the IoT, 5G and artificial intelligence (AI) applications
  - a hierarchical fog computing architecture for big data analysis in smart cities
- Special use-case proposals / implementations:
  - for crowdsensing road surface condition monitoring, vehicle networks, face identification, and medical cyber-physical systems
- Security and privacy aspects

Not many real deployments and experiments!

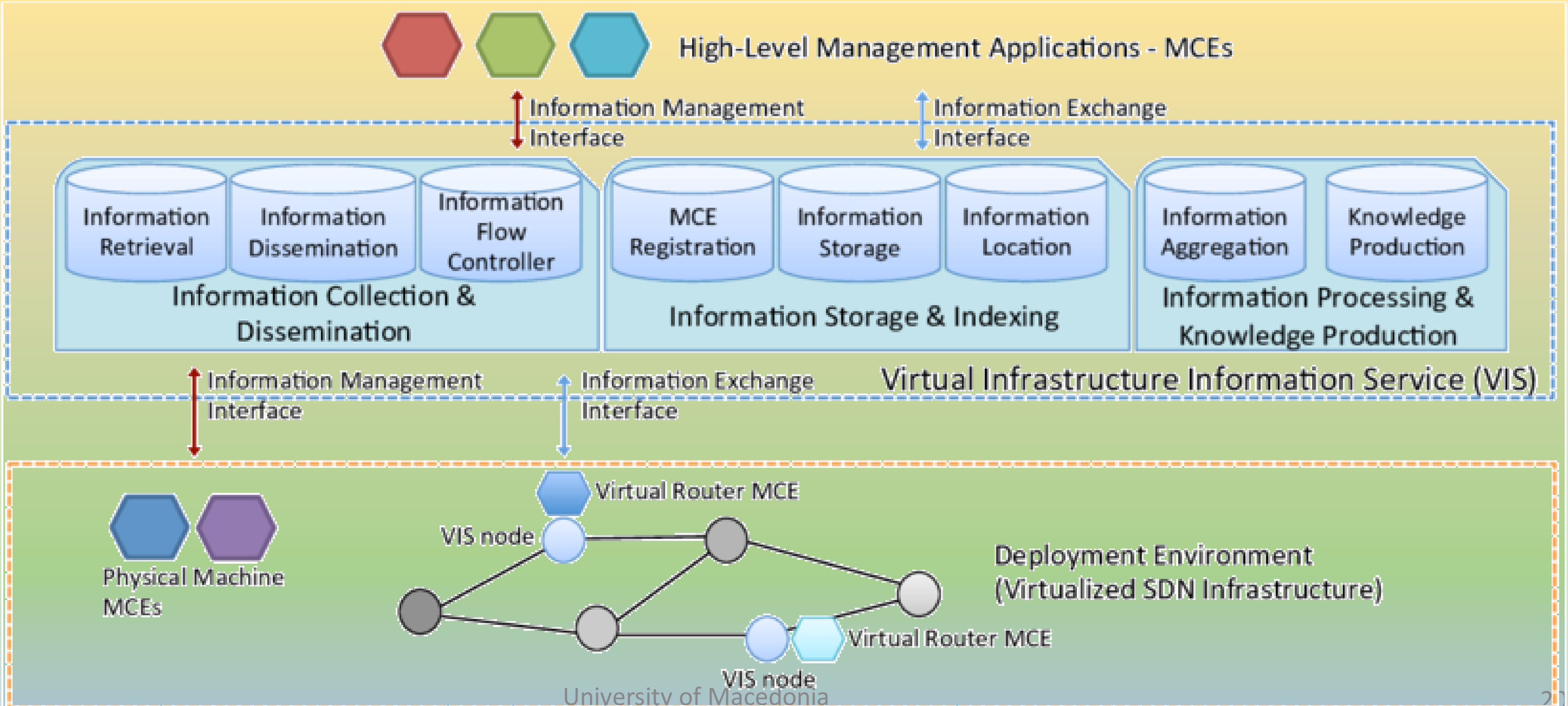
Source: Ai, Yuan, Mugen Peng, and Kecheng Zhang. "Edge cloud computing technologies for internet of things: A primer." Digital Communications and Networks (2017).

Our approach in the MEC & NECOS H2020 Projects

- Fog Computing / MEC environments do not work well with traditional cloud environments
  - most of the VMs codebase is not required
  - just needing a web server of less than 50MB in a 20GB virtual machine
  - they are not dynamic enough
- We apply Lightweight Edge Cloud Solutions
  - the Very Lightweight Software Driven Network and Services (VLSP) (*next slide*)
  - the Unikernel lightweight cloud technology

Very Lightweight Software Driven Network and Services (VLSP)

A complete cloud facility that includes a **custom lightweight virtual router implementation** combined with virtual network connectivity and the associated network management and control features [6], [7], [8]



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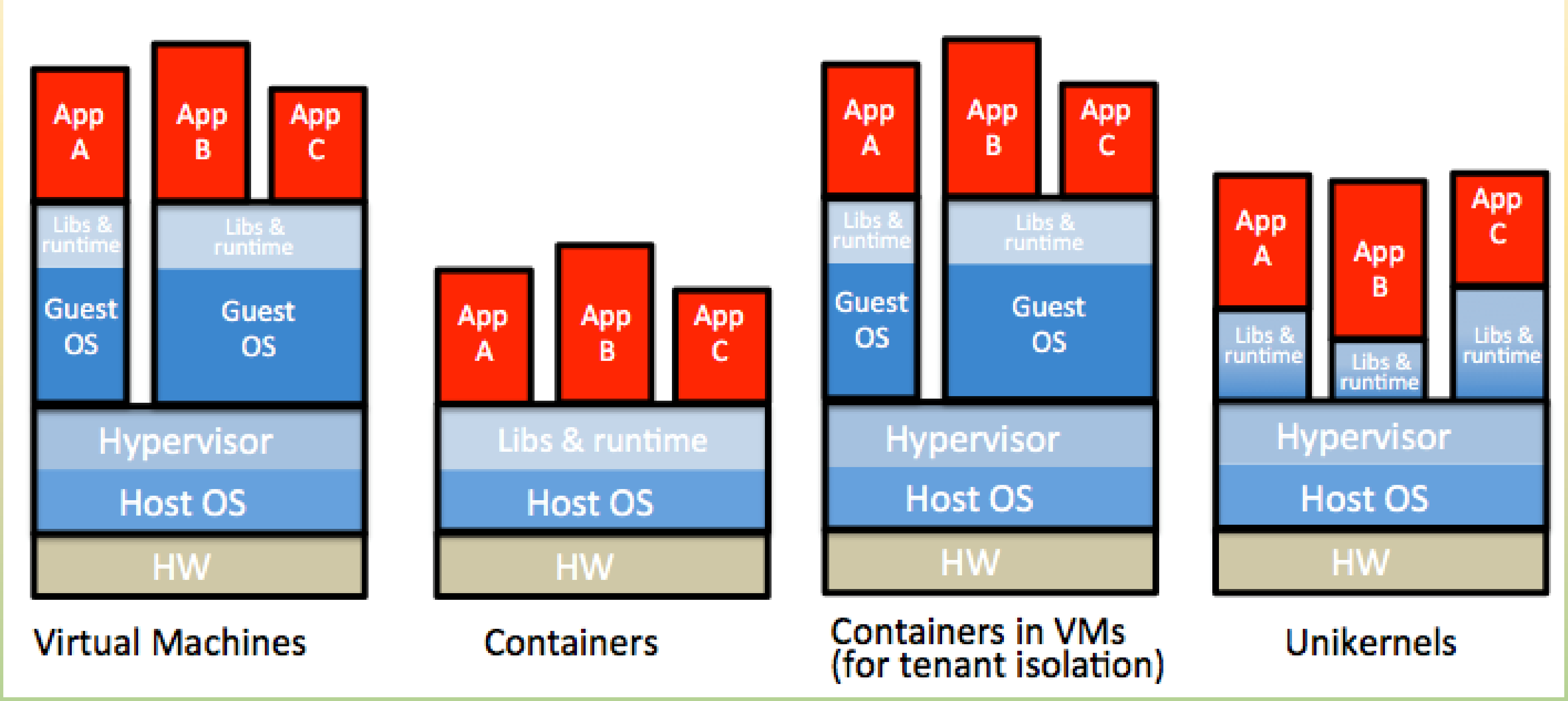
Unikernels

- **Unikernels** are single-purpose appliances:
  - specialized at compile-time into standalone kernels,
  - acting as individual SW components,
  - sealed against modification when deployed in a cloud platform.

- Minimum required OS support / libraries are compiled together with the application and configuration code
  - to build sealed, fixed-purpose images (unikernels) which run directly on a **hypervisor** (e.g. XEN)
  - no other OS (e.g. Linux) is needed

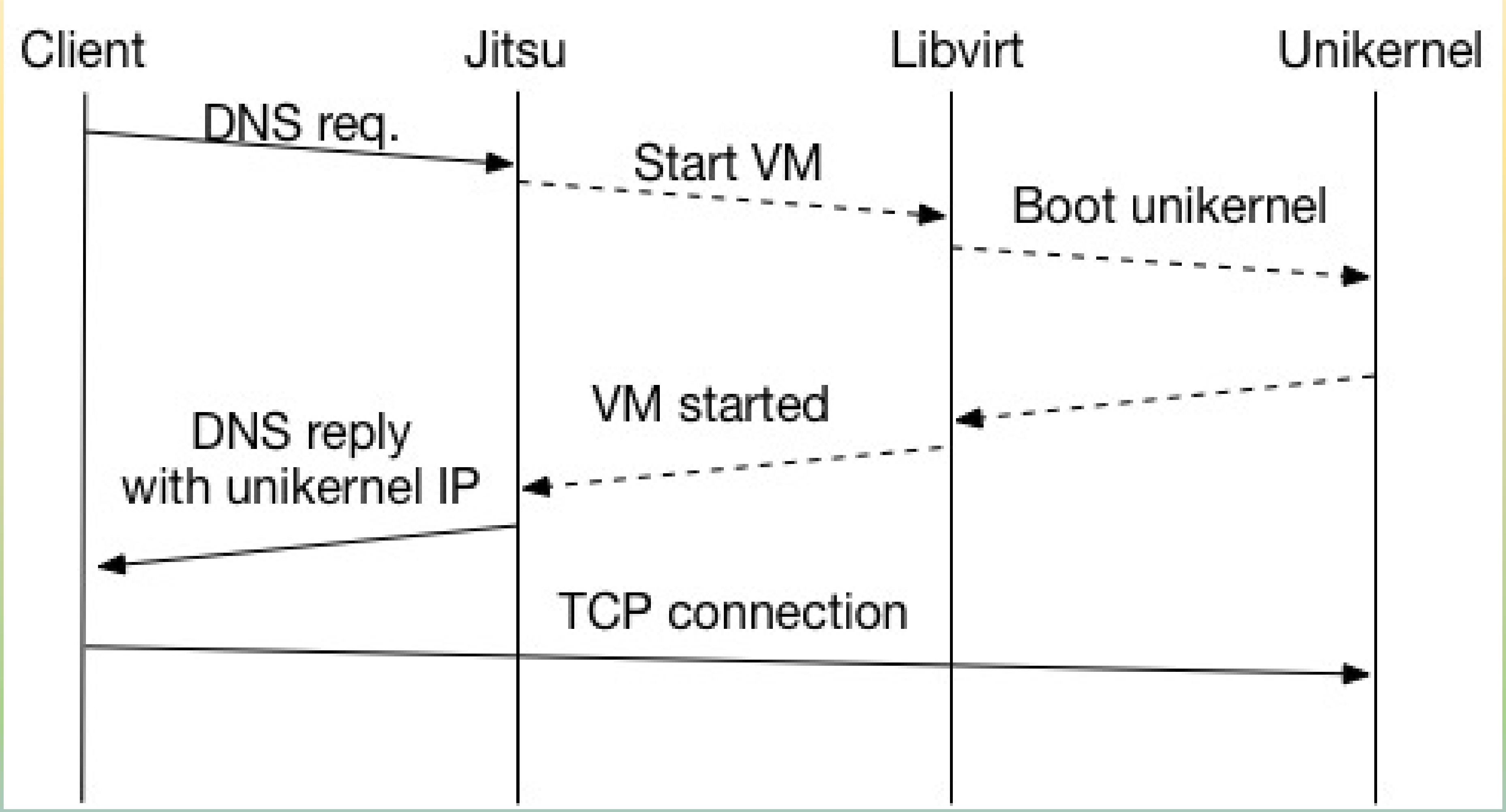
Unikernels


App A
App B
App C
Libs & runtime
Libs & runtime
Guest OS
Guest OS
Hypervisor
Host OS
HW
Virtual Machines
App A
App B
App C
Libs & runtime
Host OS
HW
Containers
App A
App B
App C
Libs & runtime
Libs & runtime
Guest OS
Guest OS
Hypervisor
Host OS
HW
Containers in VMs (for tenant isolation)
App A
App B
App C
Libs & runtime
Libs & runtime
Libs & runtime
Hypervisor
Host OS
HW
Unikernels

Advantages of Unikernels

- Possible to deploy hundreds of Unikernels in a single (virtual) machine with a full web server (7MB without webpages)
- Decrease surface attack, improve security
- Fast response to incoming requests, "*just in time*"
- Fast boot time (tens of msec to a few seconds)
- Reduce the complexity of the modern OS
- Restrain only necessary computational resources (22MB of memory, less than 2% processor usage)

Can boot up with a DNS request



Unikernels

Alternative unikernel approaches:

- **MirageOS**: focuses on safety and security
- **Osv:** on compatibility with legacy software
- **ClickOS**: on performance, e.g., booting-up of under 30ms
- **Rumpkernels** balance well compatibility with legacy software with performance

Rumpkernels

- **Rumpkernels** enable you to build the software stack you need with driver-like components
- **Rumpkernels** provide free, reusable, componentized, kernel quality drivers such as file systems, POSIX system calls, PCI device drivers and TCP/IP and SCSI protocol stacks

Download: https://github.com/rumpkernel

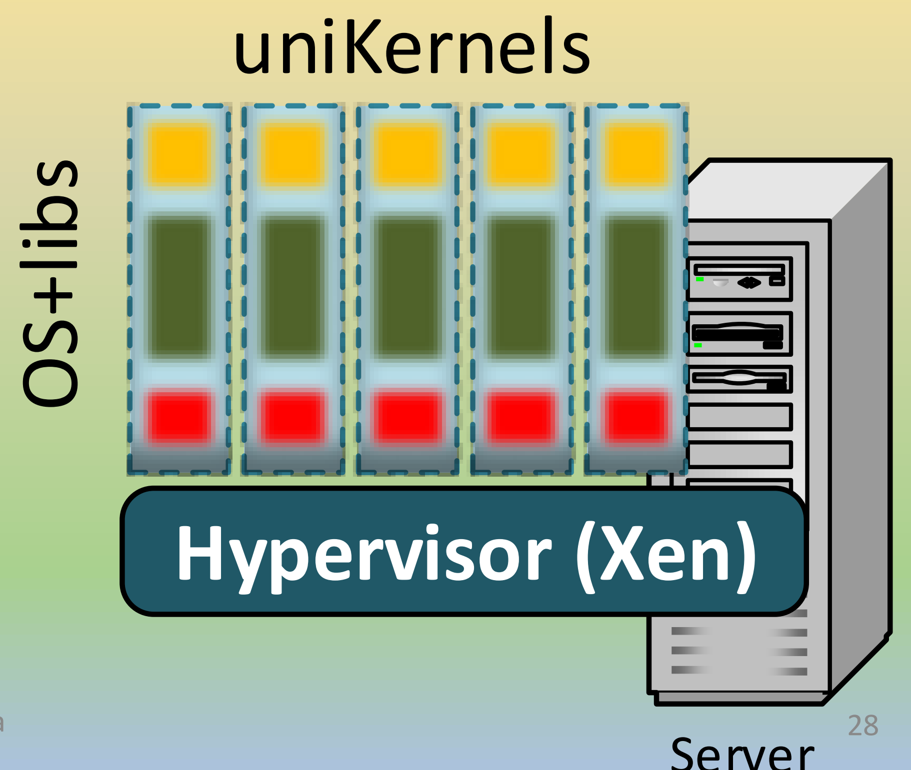
Unikernel References

- Unikernels - Rethinking Cloud Infrastructure [WWW Document], 2015. URL http://unikernel.org/ (accessed 11.5.17)
- Unikernels: Rise of the Virtual Library Operating System - ACM Queue [WWW Document], 2015. URL http://queue.acm.org/detail.cfm?id=2566628 (accessed 11.5.17)

Hands-on 2-1 tutorial

Basic components used

- Xen-project (A hypervisor)
- Rumpkernel unikernels (A single purpose lightweight operating system) hosted to the above Hypervisor
- Testbed in University of Macedonia, Greece
    - 9 mini-PC with Ubuntu 16 OS
    - 9 IoT devices (zolertia) connected to the above PCs
- Puttty (for windows) or ssh (for Linux) fro remote access



Why Lightweight Edge Cloud Solutions

- **Implementation of novel services at the network edge** (VNFs), Service Function Chaining combined with the wireless/mobile resources run on lightweight virtual machines
- **Uniform Orchestration, Network Management, and Control** with integrated capabilities handling the efficient inter-operation of lightweight edge cloud, wireless and mobile resources, using NFV, SDN
- **Handling Heterogeneous Resource Abstractions and Federation** with appropriate abstractions and open interfaces, edge cloud, wireless and mobile technologies, allowing full end-to-end interactions

MEC enabled by SDN/NFV advantages

- **Latency:** operators can offer new value added services with latency requirements
- **Resiliency**: Load can be distributed on virtual NEs at many DC sites, hence node failures is not an issue
- **Reduced backbone traffic:** Caching content and hosting applications closer to the edge can reduce the cost of transporting
- **Elastic provisioning and intelligent routing:** NFV and SDN, allow traffic to be dynamically redistributed across servers and DC sites in response to fluctuations (demand, failure, etc.)

Open Research Issues

- NFV Orchestration for IoT environments
- Optimized VM deployment / migration, i.e., quick, live migration
- Heterogeneity
- Mobile IoTs

Resource Orchestration for IoTs

Optimally provisioning resources in the MEC and associating users with serving DCs to service the maximal end-user demand

- **Example mechanism:** minimum-cost MEC resource allocation problem as a Mixed Integer Linear Program (MILP)
- **Network slicing** aspect

VM Placement/Migration Problem

- VM Placement is the process of selection the suitable host-node for each given VM
- Optimization Approaches:
  - ✓ Mono-Objective Approach (MOP)
  - ✓ Multi-Objective solved as Mono-Objective Approach (MAM):
    - Weighted Sum Method
    - Consider other objective function as constraint
  - ✓ Pure Multi-Objective Approach (PMO)

Optimization Criteria

Plethora of criteria can be considered for the solution of Virtual Machine Placement problem:

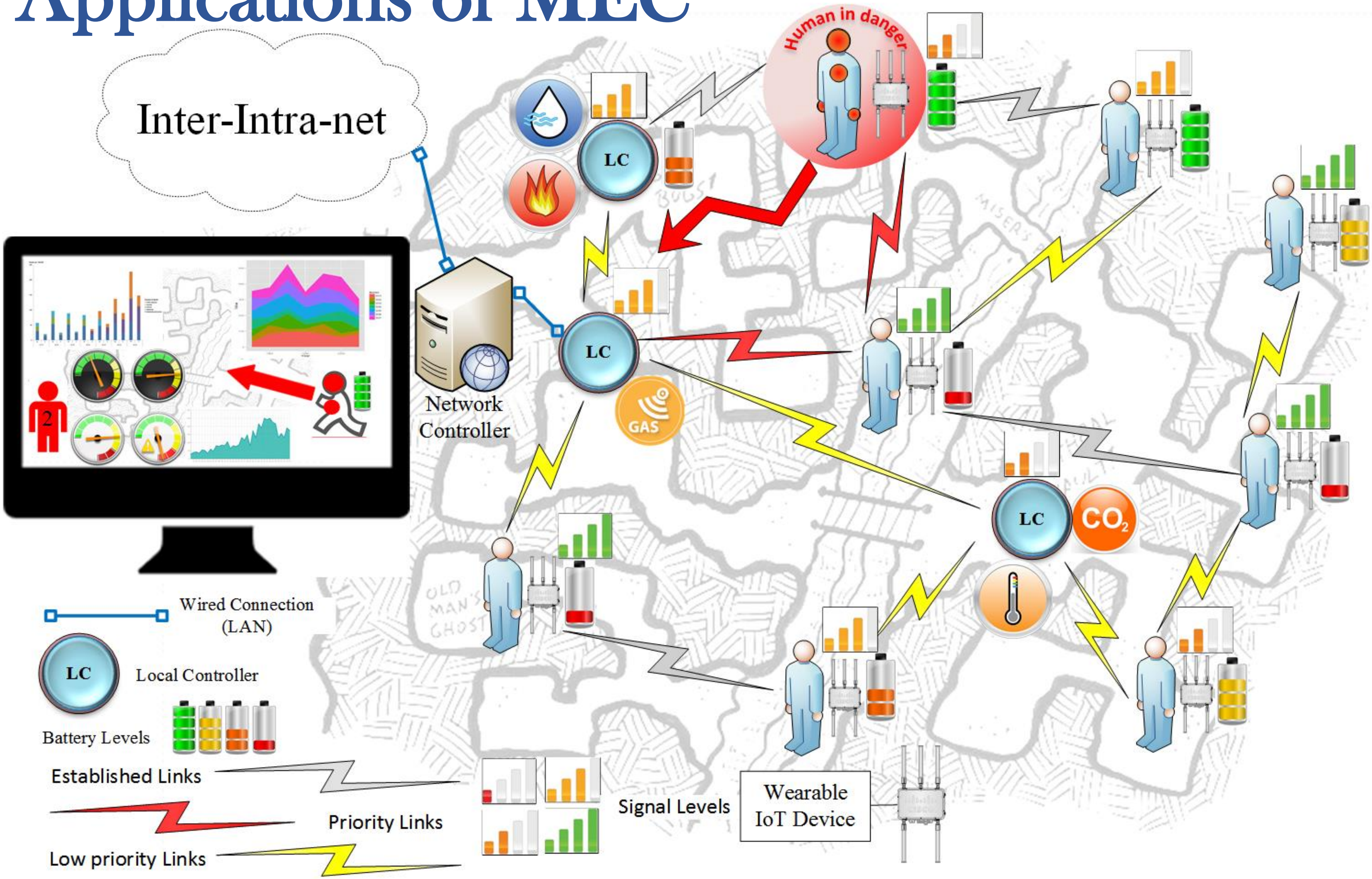
- Energy Consumption
- Network Traffic
- Economical Costs
- Performance
- Resource Utilization

Heterogeneity in MEC

is the existence of diverse hardware, architectures, infrastructures, and technologies related to mobile devices, clouds, and wireless networks

Target (Open Issue): Collaboration among these heterogeneous environments toward efficient mobile computing with novel services at the network edge

Applications of MEC



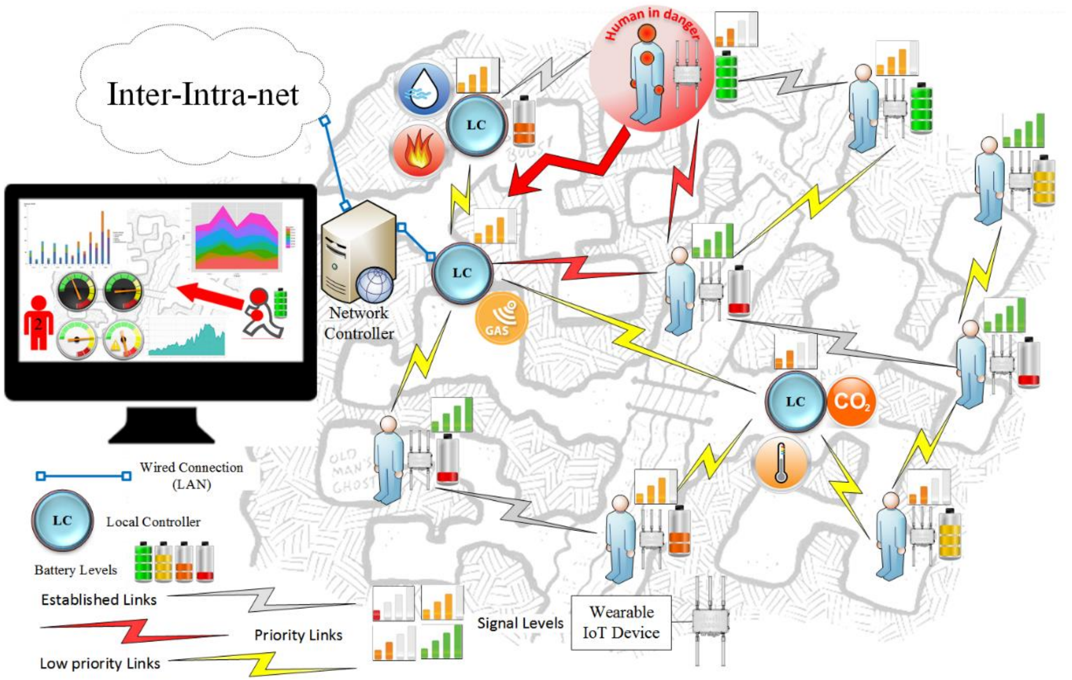
Intelligent flow control, mobility models, topology manager, measurements aggregator, information handling and monitoring features, VM migration algorithms

Applications of MEC (2)

- Each worker with IoT energy-constrained sensors monitors
  - (heartbeat, blood pressure etc.) & sensors (e.g. CO_2 levels)
- measurements have to be uploaded, aggregated and analyzed ideally in real time
- Lightweight are allowing resource offloading

Basic challenges:

- resource constraints
- intermittent connectivity
- mobility behavior
- signal propagation issues
- security and safety issues



Applications of MEC (3)

Smart City

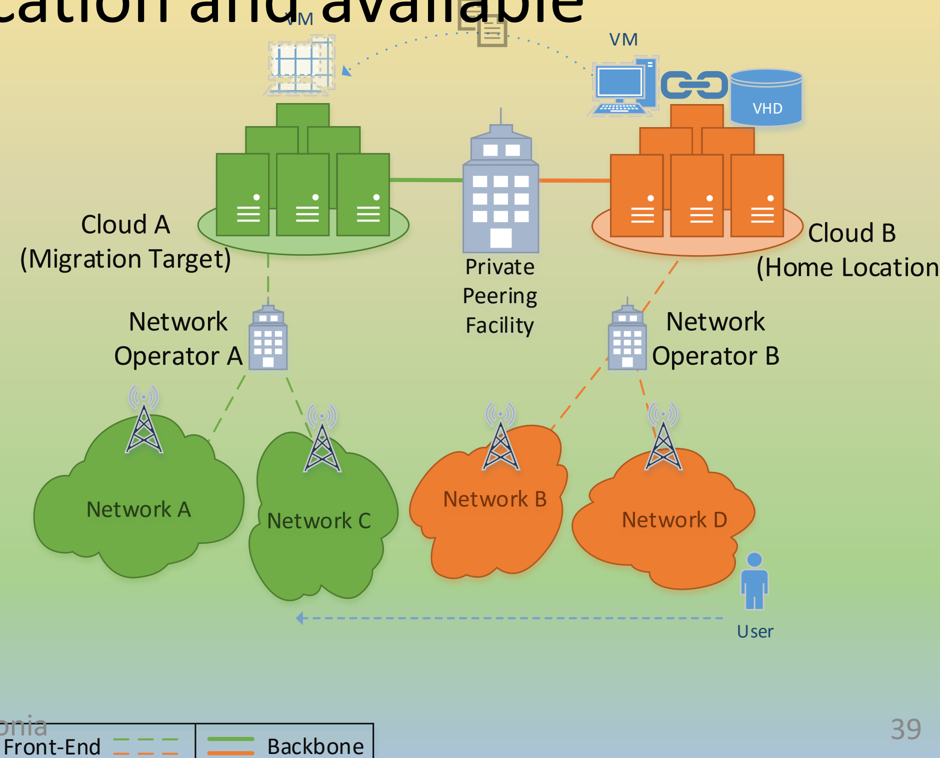
Open Issues:

- Mobility models
- opportunistic communication algorithms
- knowledge building components
- behavioral inference modules

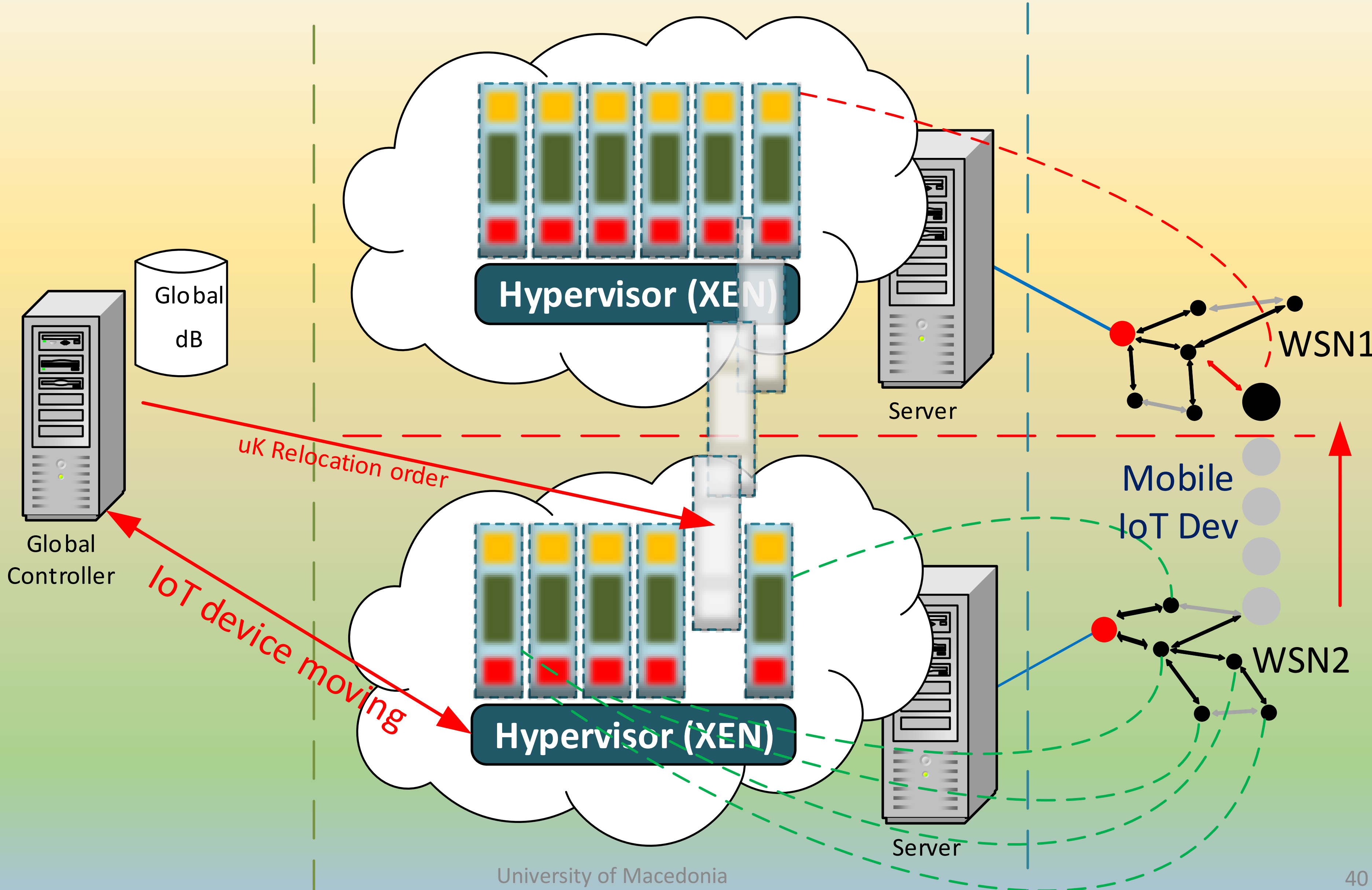
Applications of MEC (4)

Mobile Edge Computing - Video Analytics

- mobile thin-clients in a metropolitan network. Computing and storage capabilities of each client reside in a personal VM in the Cloud
- mobile clients move, the network point of attachment changes according to their location and available networks in the area.
- A client moves to an area served by a different base station or attaches to a Wi-Fi with stronger signal



Our Research - MEC



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[1] I. Farris, T. Taleb, A. Iera, and H. Flinck, “Lightweight Service Replication for Ultra-Short Latency Applications in Mobile Edge Networks,” 2017.

[2] R. Ford, A. Sridharan, R. Margolies, R. Jana, and S. Rangan, “Provisioning Low Latency, Resilient Mobile Edge Clouds for 5G,” *ArXiv Prepr. ArXiv170310915*, 2017.

[3] M. Patel *et al.*, “Mobile-Edge Computing Introductory Technical White Paper,” *White Pap. Mob.-Edge Comput. MEC Ind. Initiat.*, 2014.

[4] S. Taylor, A. Young, N. Kumar, and J. Macaulay, “Mobile Consumers Reach for the Clouds,” *Cisco Internet Bus. Solut. Group San Jose*, 2011.

[5] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, “Fog computing and its role in the internet of things,” in *Proceedings of the first edition of the MCC workshop on Mobile cloud computing*, 2012, pp. 13–16.

[6] Stuart Clayman, Lefteris Mamatas, and Alex Galis, “Energy-efficiency Enablers and Operations in Software-Defined Environments,” presented at the IEEE/IFIP Network Operations and Management Symposium (Demo Paper), Istanbul, Turkey, 2016.

[7] S. Clayman, L. Mamatas, and A. Galis, “Experimenting with Control Operations in Software-Defined Infrastructures,” in *IEEE Workshop on Open-Source Software Networking (OSSN)*.

[8] L. Mamatas, S. Clayman, and A. Galis, “A service-aware virtualized software-defined infrastructure,” *Commun. Mag. IEEE*, vol. 53, no. 4, pp. 166–174, 2015.

Hands On 2.2

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Fog Computing Scenario: Lightweight Clouds using unikernels supporting IoT devices at the Network Edge