

Sustainable Intelligent Communication and Computing Systems

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Outline

- The Team and the Lab
- EPSRC INTERNET Programme Grant, GreenTouch
- Network Energy Efficiency, case studies
 - Data centres and renewable energy
 - Joint cloud and network virtualisation
 - Content placement and VM migration
 - Big data networks
 - Data centre networks
- Sustainable Intelligent Communication and Computing Systems

Team: Current team: 2 academics, 5 postdocs, 19 PhD students (11 in Energy efficiency); 21 completed PhDs in Energy Efficiency related topics

	Name	PhD Project Energy Efficiency (completed)
1	Dong	Green optical networks, 2009-2012
2	Idjmayyel	Energy Efficient Vehicular Networks, 2009-2013
3	Osman	Energy efficiency in content delivery networks, 10-14
4	Lawey	Energy efficiency of peer to peer and distributed cloud networks, 2011-2015
5	Audu	Motorway Vehicular Networks with Renewable Energy Powered Access Points, 2012-2016
6	Nonde	Energy Efficient Core Networks with Clouds, 2012-2016
7	Igder	Green Vehicular Content Distribution Network, 2012-2016
8	Musa	Energy Efficiency in IP over WDM Networks Using Network Coding, 2012-2016
9	Hammadi	Future PON Data Centre Networks, 2013-2017
10	Ali	Energy efficient resource provisioning in data centers, 13-17
11	Nasralla	Disaster resilient networks, 2013-2017
12	Al-Salim	Energy efficiency in big data networking, 2014-2018
13	Al-Azez	Optimized Green IoT Network Architectures, 2014-2018
14	Al-Quzweeni	Energy Efficient Network Function Virtualization in 5G Networks, 2014-2018
15	Al-Shammari	Service embedding in IoT networks, 2015-2019
16	Alharbi	Energy Efficient Cloud-Fog Networks Architecture, 2015-2019
17	Mohamed	Optimisation of cloud data centers, 2015-2019
18	Yosuf	Energy Efficient Distributed Processing for IoT, 2015-2019

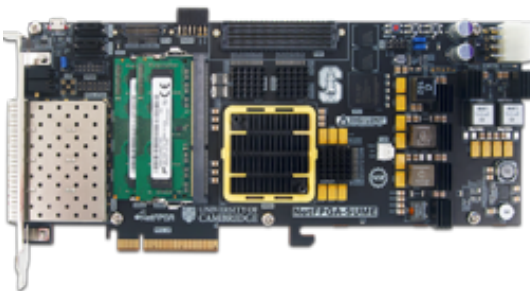
	Name	PhD Project Energy Efficiency (completed)
19	Isa	Energy Efficient Internet of Things Networks, 2015-2019
20	Hadi	Network Optimisation Using Big Data Analytics, 2015-2019
21	Alahmadi	Green Network Topologies and Architectures, 2016-2020

	Name	PhD Project Energy Efficiency (current)
1	Behbehani	Energy Efficient Vehicular Networks, 2016-2020
2	Alani	Virtualisation of PON Data Centres Networks, 2016-2020
3	Elterifi	MAC protocols for optical Data Centres, 2016-2020
4	Ajibola	Data centre network topologies, 2017-2021
5	Alenazi,	Energy efficiency in 5G networks, 2018-2022
6	Alqahtani,	Fog architecture in 5G mobile networks , 2018-2022
7	Ma	Opportunistic Vehicular Clouds, 2019-2023
8	Fadlelmula	Fog processing in Microgrid-Powered Environments, 2019-2023
9	Alharthi	Energy Efficient Optical Data Centre Networks, 2020 - 2024
10	Hamid	Resilient software defined smart grid networks, 2020 - 2024
11	Ncube	Energy efficient fog networks, 2020 - 2024

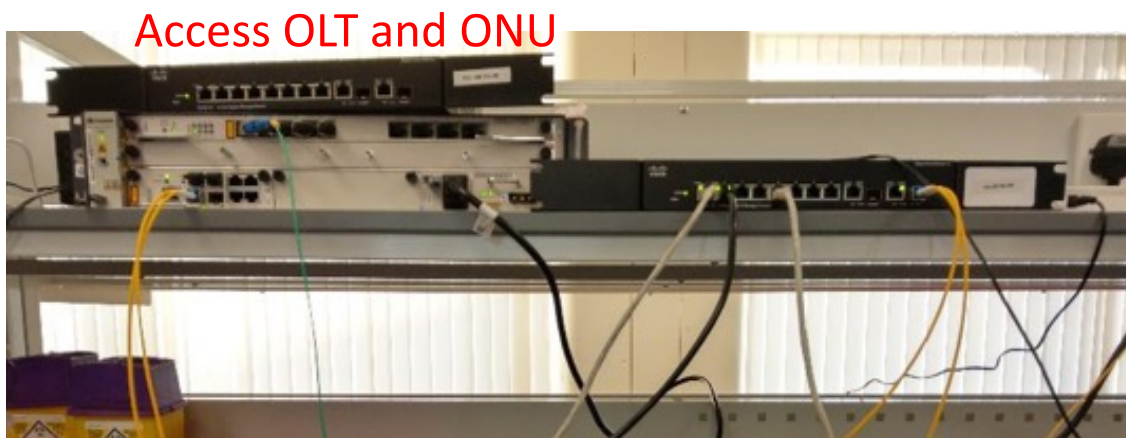
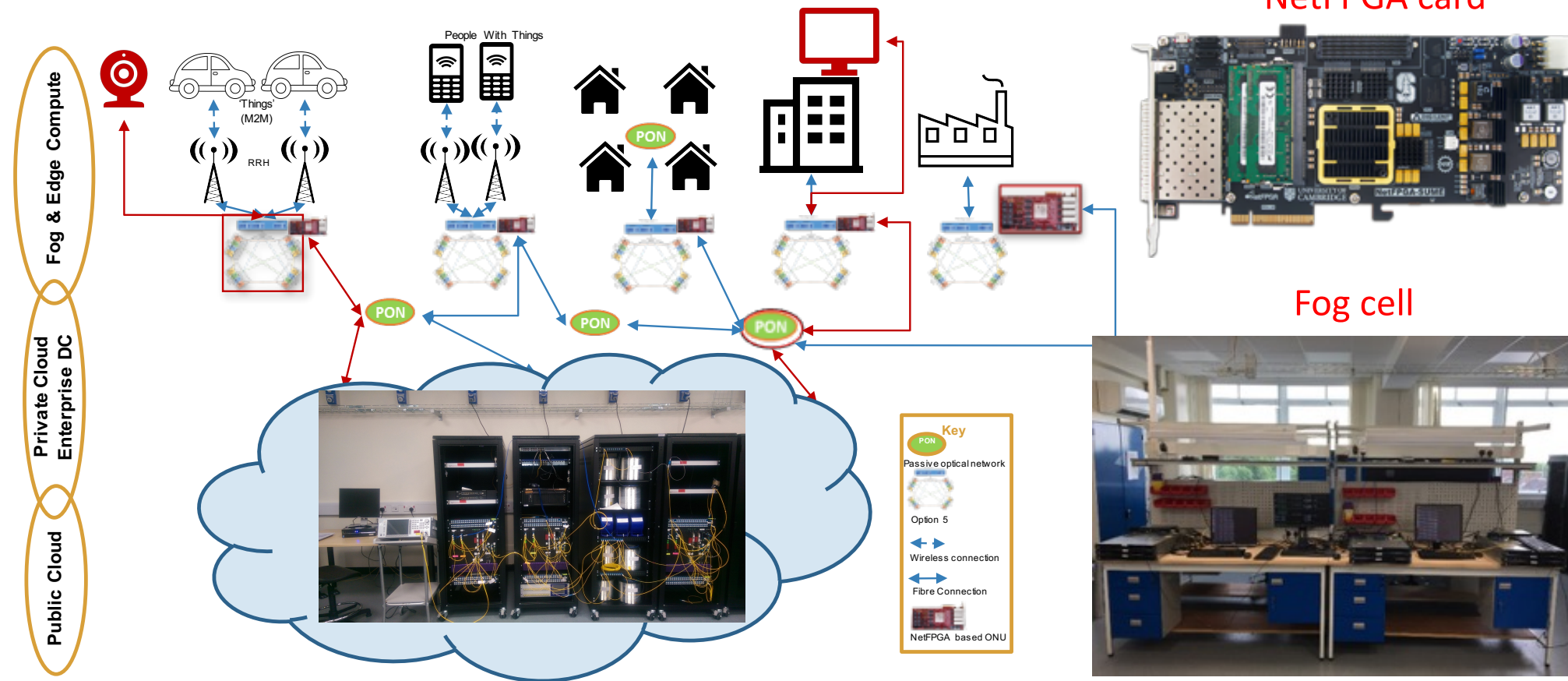
Fog, cloud, access, core, IoT testbed



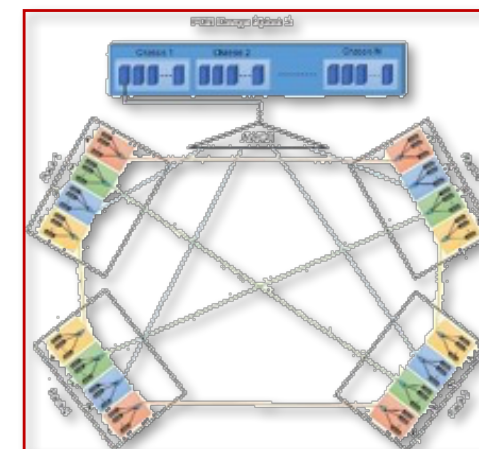
NetFPGA, 100 Gb/s



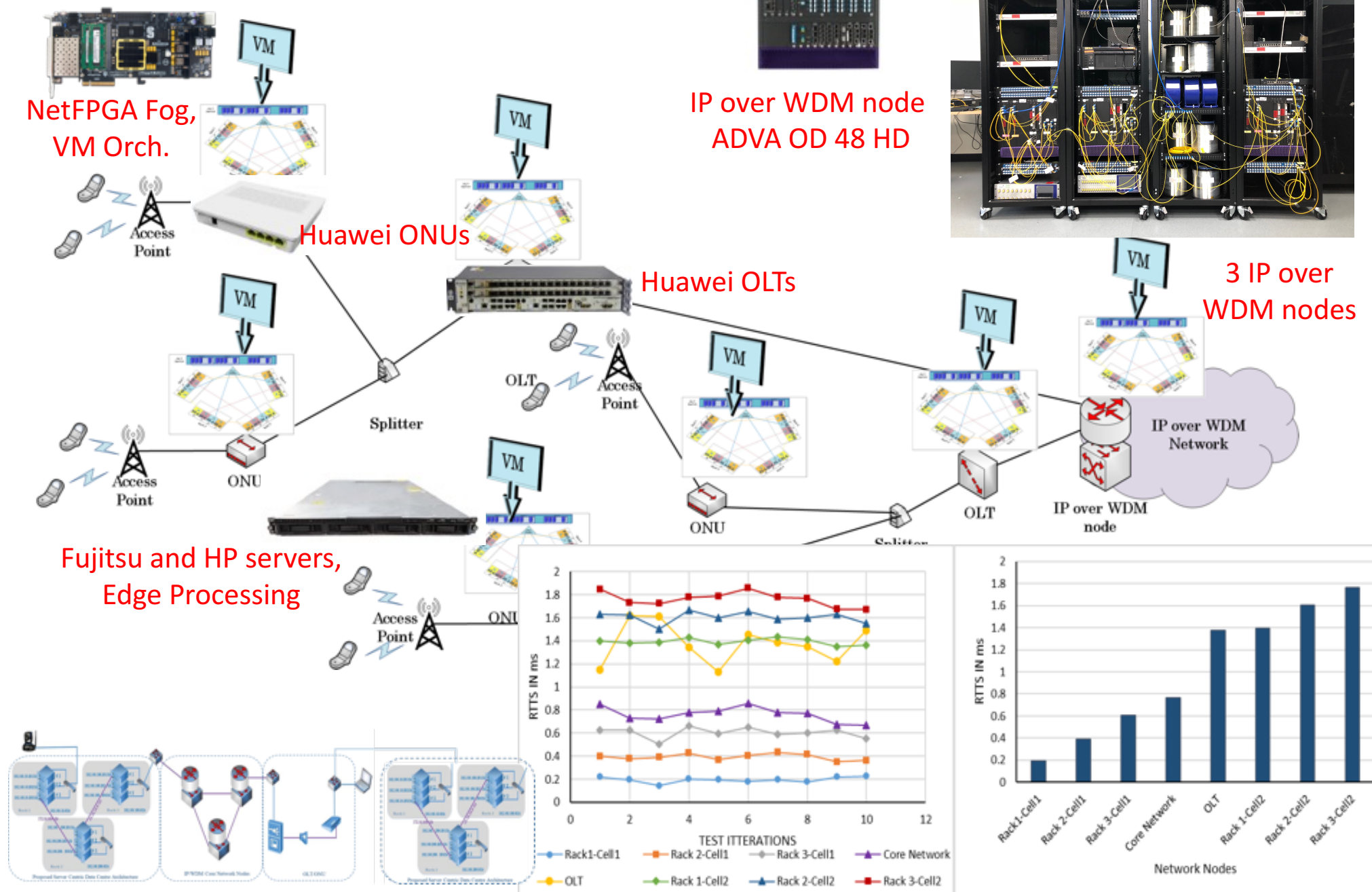
1. Elmirghani, J.M.H., Klein, T., Hinton, K., Nonde, L., Lawey, A.Q., El-Gorashi, T.E.H., Musa, M.O.I., and Dong, X., "GreenTouch GreenMeter Core Network Energy Efficiency Improvement Measures and Optimization [Invited]," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 10, No. 2, pp. 250-269, 2018.
2. Musa, M., El-Gorashi, T.E. and Elmirghani, J.M.H., "Bounds on GreenTouch GreenMeter Network Energy Efficiency," *IEEE/OSA Journal of Lightwave Technology*, vol. 36, No. 23, pp. 5395-5405, 2018.
3. Elterifi, A., Elgorashi, T.E.H., and Elmirghani, J.M.H., "Experimental evaluation of passive optical network based data cen-tre architecture," *Proc IEEE ICTON*, 2018.
4. Elterifi, A., Musa, M.O.I., Al-Quzweeni, A., and Elmirghani, J.M.H., "Experimental evaluation of server centric passive optical network based data centre architectur,e" *Proc ICTON*, Angers, France, 9-13 July 2019.



Fog cell



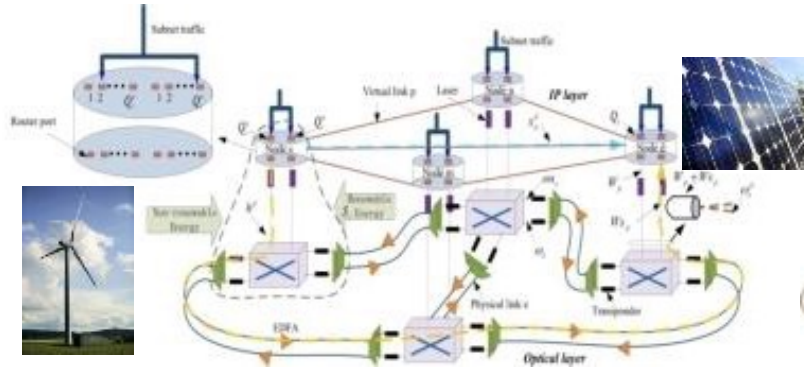
VM Orchestration in Test-bed



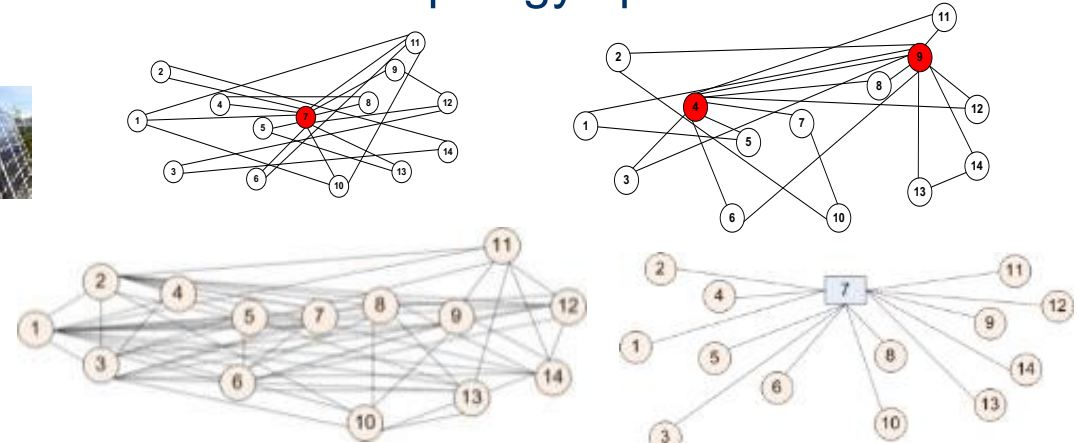
EPSRC Intelligent Energy aware Networks (INTERNET) PG, £6m, 2010-16

Renewables, Energy Storage, NfV, SDN Control

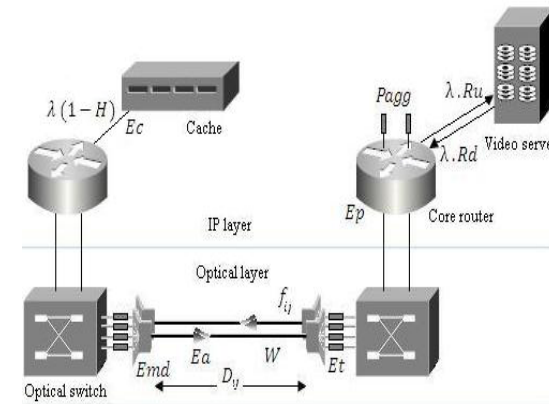
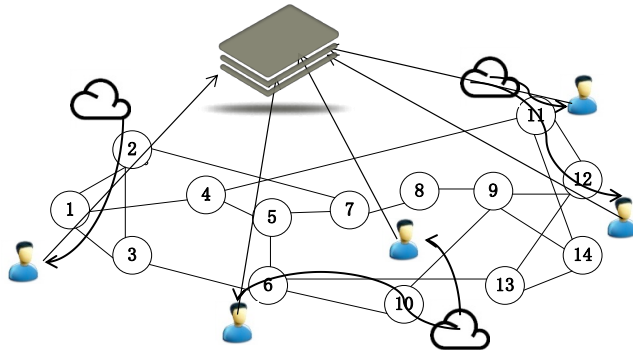
Renewable energy



Topology optimisation

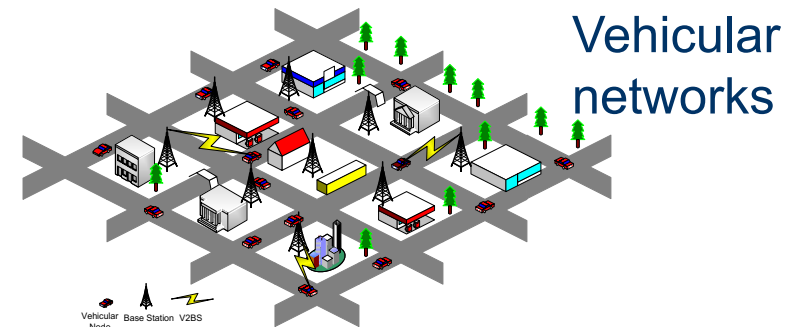
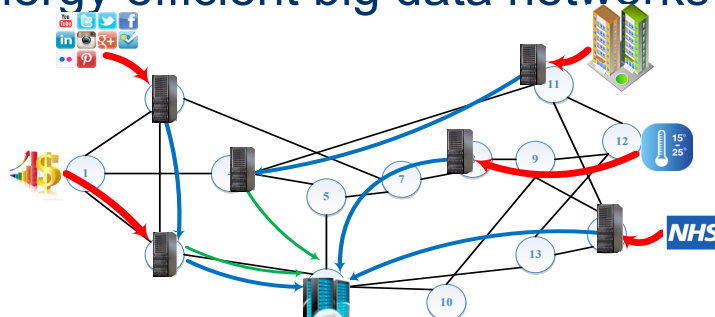


Cloud content distribution



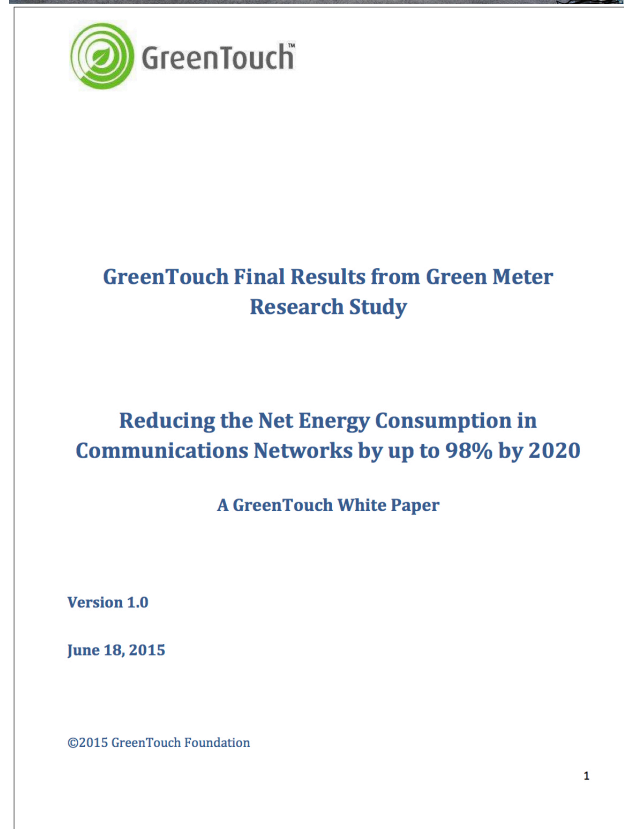
Content caching

Energy efficient big data networks



Vehicular networks

GreenTouch: Improving Energy Efficiency by a factor of 1000

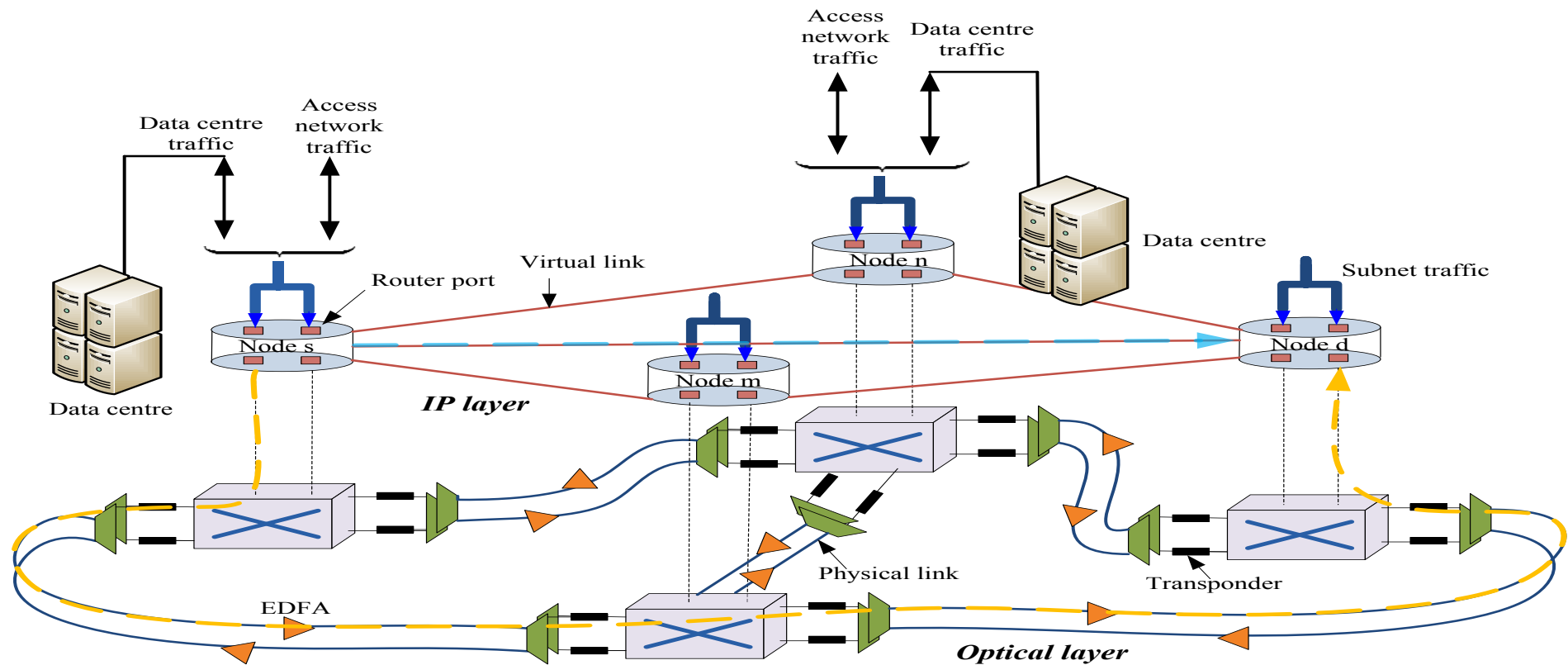


Delivery highlights



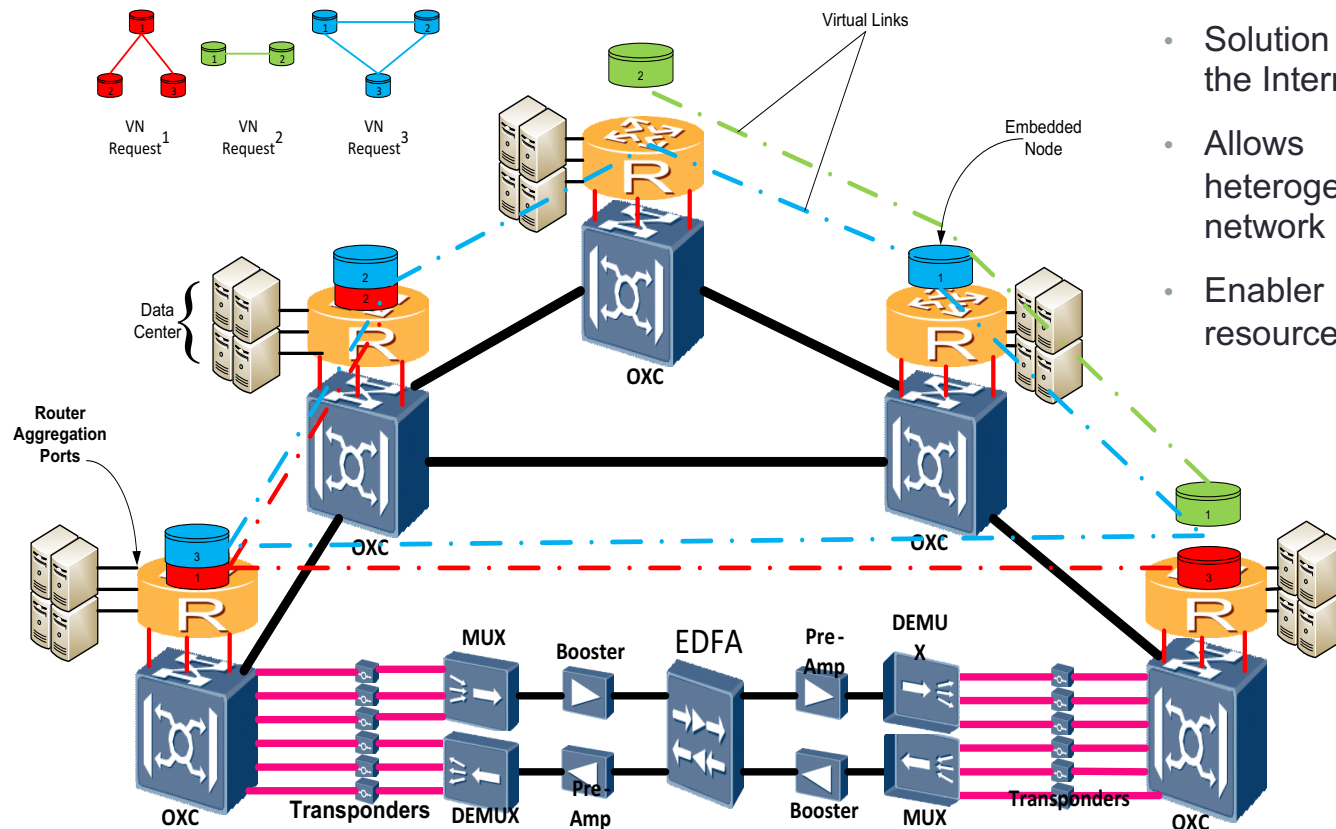
- 9 new IEEE Standards, building on the work of the 50+ GreenTouch industrial and academic members
 - IEEE P1922.1 Standard for a Method Calculating Anticipated Emissions Caused by Virtual Machine Migration and Placement
 - (Approved) IEEE P1922.2 Standard for a Method to Calculate Near Real-time Emissions of Information and Communications Technology Infrastructure P1923.1 Standard for computation of energy efficiency upper bound for apparatus processing communication signal waveforms
 - P1924.1 Recommended practice for developing energy efficient power-proportional digital architectures
 - IEEE P1925.1 Standard for Energy Efficient Dynamic Line Rate Transmission System.
 - IEEE P1926.1 Standard for a Functional Architecture of Distributed Energy Efficient Big Data Processing.
 - IEEE P1927.1 Standard for Services Provided by the Energy-efficient Orchestration and Management of Virtualized Distributed Data Centers Interconnected by a Virtualized Network.
 - IEEE P1928.1 Standard for a Mechanism for Energy Efficient Virtual Machine Placement.
 - 9 ➤ IEEE P1929.1 An Architectural Framework for Energy Efficient Content Distribution.

Case study 1: Data centres and renewable energy



1. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "IP Over WDM Networks Employing Renewable Energy Sources," *IEEE/OSA Journal of Lightwave Technology*, vol. 27, No. 1, pp. 3-14, 2011.
2. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Green IP over WDM Networks with Data Centres," *IEEE/OSA Journal of Lightwave Technology*, vol. 27, No. 12, pp. 1861 - 1880, 2011.
3. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "On the Energy Efficiency of Physical Topology Design for IP over WDM Networks," *IEEE/OSA Journal of Lightwave Technology*, vol. 30, pp.1931-1942, 2012.

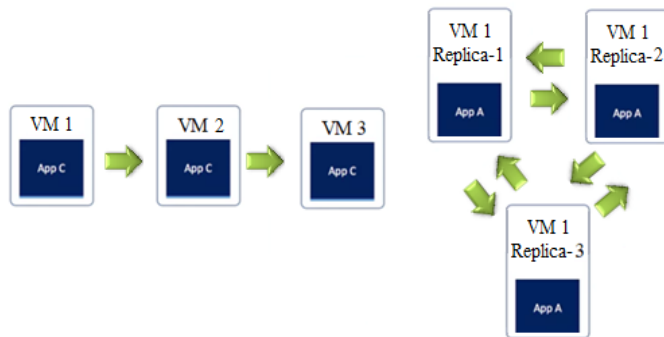
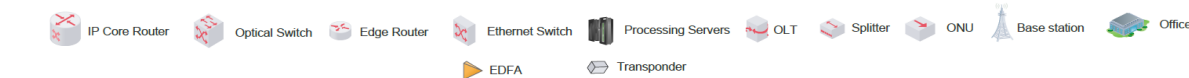
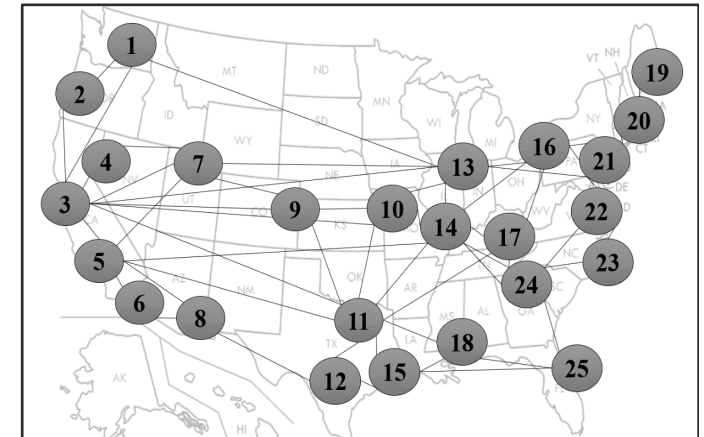
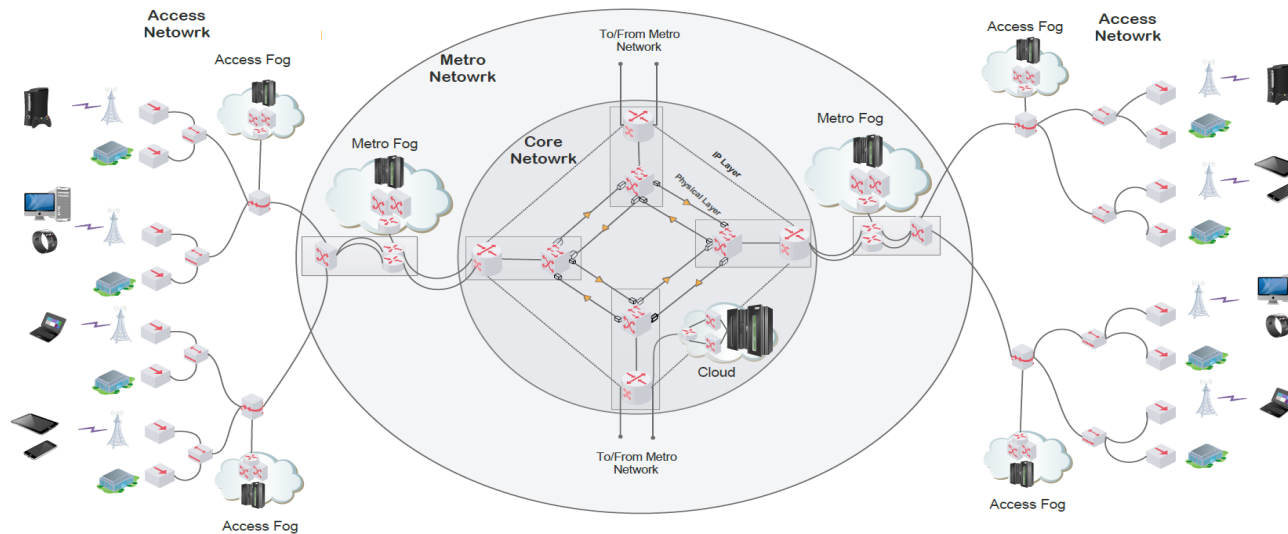
Case study 2: Joint core network and cloud virtualisation



- Solution to the current ossifying forces of the Internet
- Allows the existence of several heterogeneous networks in one physical network
- Enabler of Energy Savings through resource consolidation

1. Nonde, L., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Energy Efficient Virtual Network Embedding for Cloud Networks," *IEEE/OSA Journal of Lightwave Technology*, vol. 33, No. 9, pp. 1828-1849, 2015.
2. Elmirghani, J.M.H., Klein, T., Hinton, K., Nonde, L., Lawey, A.Q., El-Gorashi, T.E.H., Musa, M.O.I., and Dong, X., "GreenTouch GreenMeter Core Network Energy Efficiency Improvement Measures and Optimization [Invited]," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 10, No. 2, pp. 250-269, 2018.
3. Al-Salim, A.M., Lawey, A., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Energy Efficient Big Data Networks: Impact of Volume and Variety," *IEEE Transactions on Network and Service Management*, vol. 15, No. 1, pp. 458 - 474, 2018.

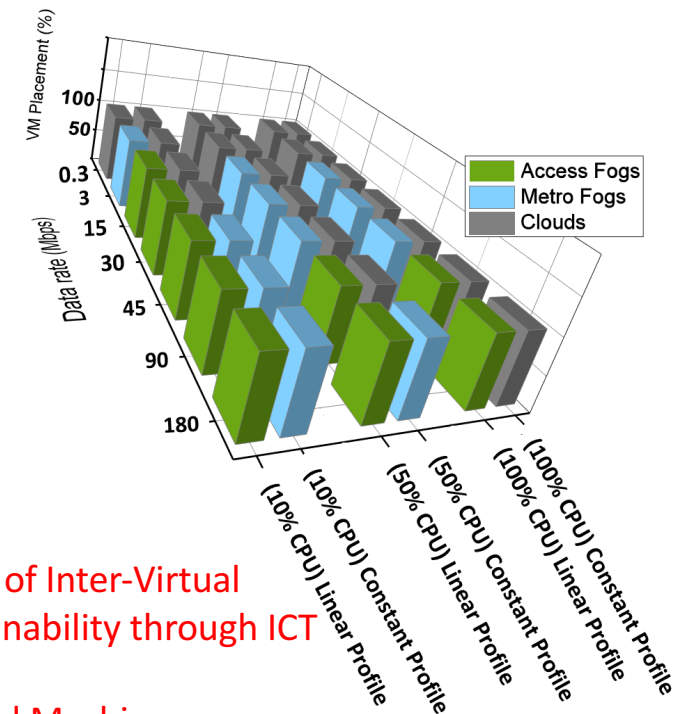
Case study 3: VM placement and migration



(a)

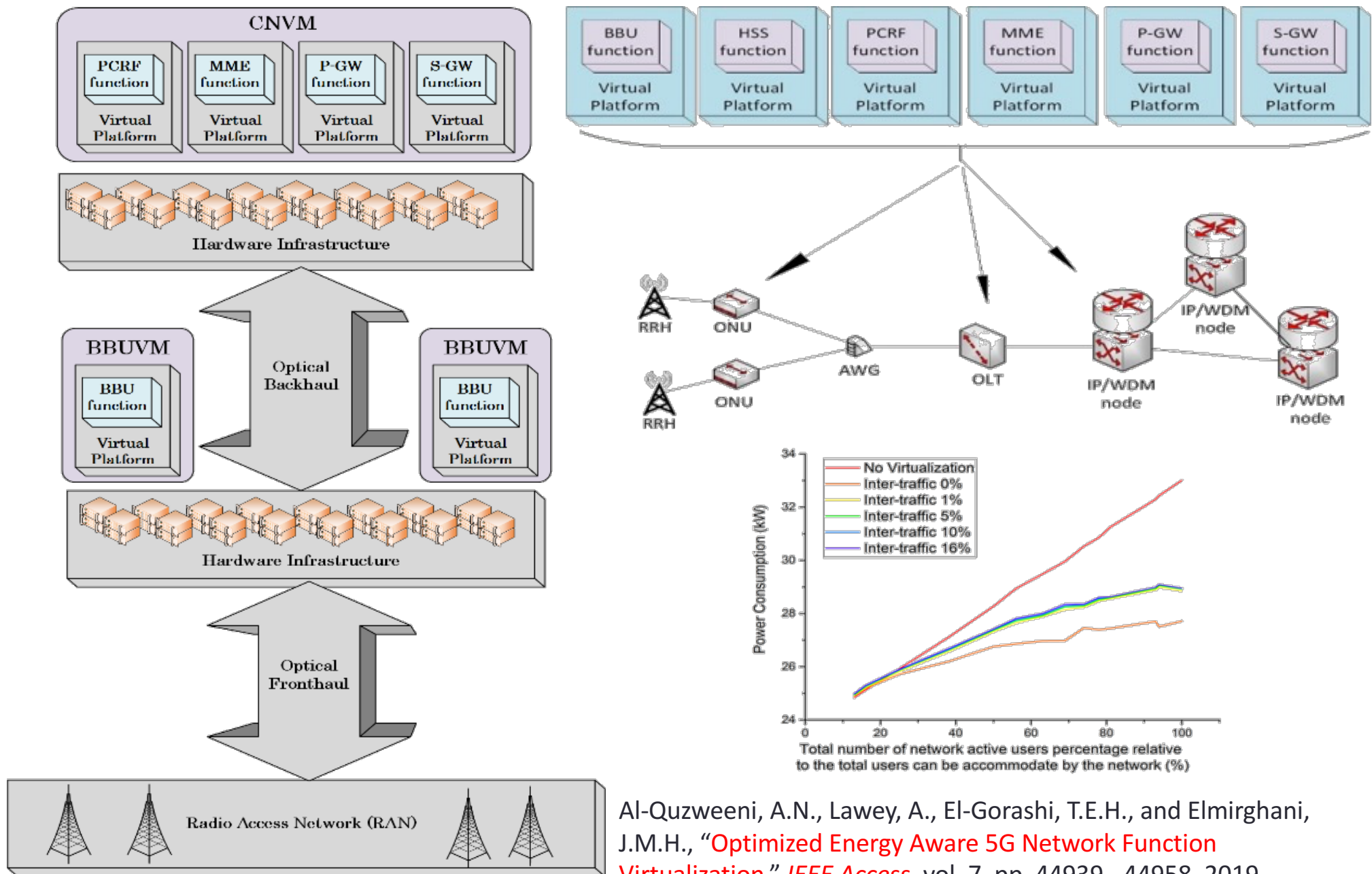
(b)

(a) VM Cooperation traffic
(b) VM Synchronisation traffic



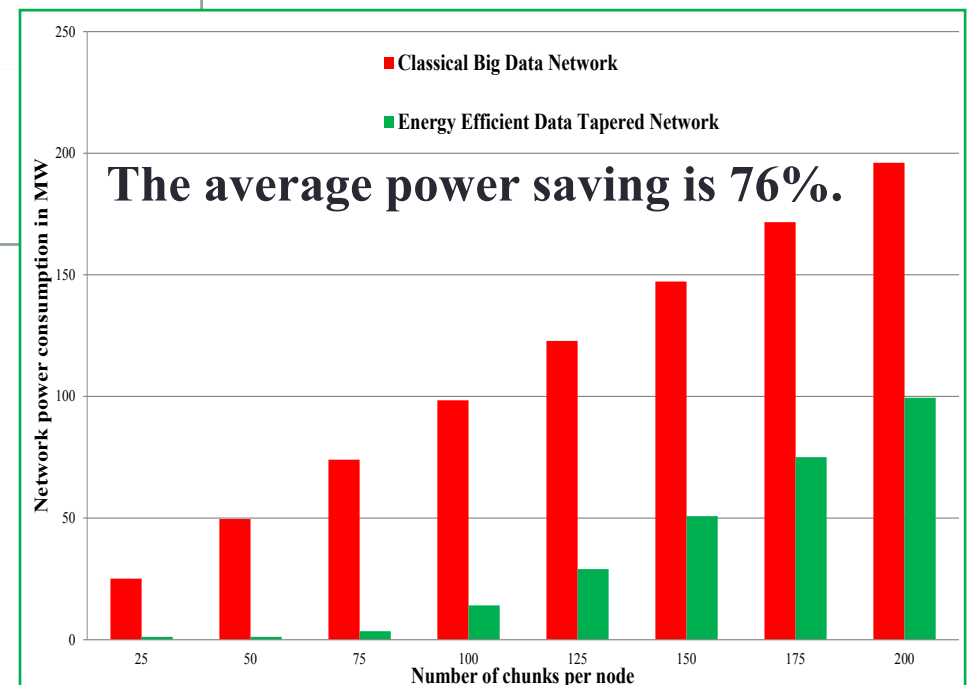
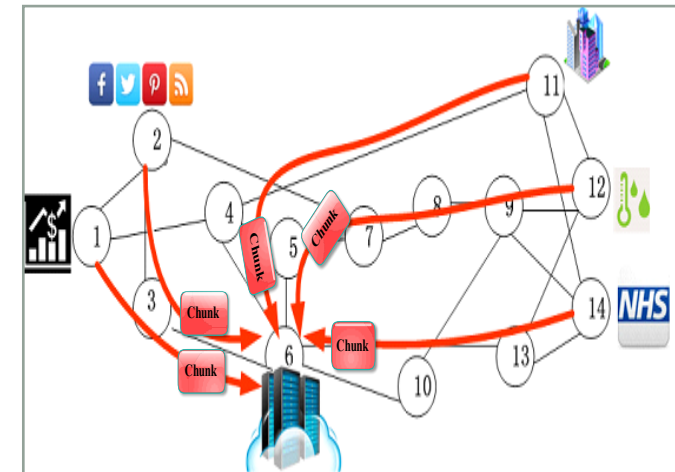
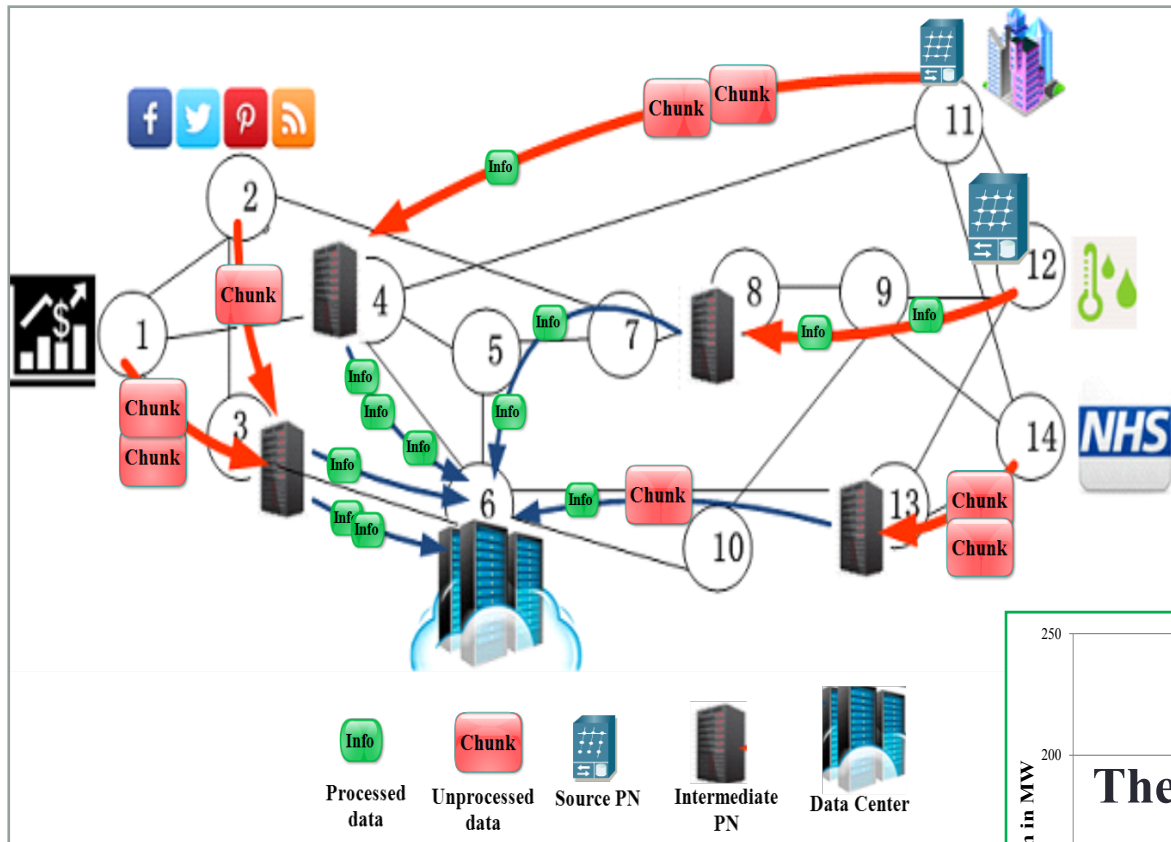
1. Alharbi, H., El-Gorashi, T.E.H., Lawey, A. and Elmirghani, J.M.H., "The Impact of Inter-Virtual Machine Traffic on Energy Efficient Virtual Machines Placement," *IEEE Sustainability through ICT Summit*, Montreal, 18-19 June 2019.
2. Alharbi, H., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Energy Efficient Virtual Machines Placement over Cloud-Fog Network Architecture," *IEEE Access*, vol. 8, pp. 94697 - 94718, 2020.

Case study 4: Network virtualisation, energy efficiency



Al-Quzweeni, A.N., Lawey, A., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Optimized Energy Aware 5G Network Function Virtualization," *IEEE Access*, vol. 7, pp. 44939 - 44958, 2019.

Case study 5: Big Data Networks



1. Al-Salim, A.M., Lawey, A., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Energy Efficient Big Data Networks: Impact of Volume and Variety," *IEEE Transactions on Network and Service Management*, vol. 15, No. 1, pp. 458 - 474, 2018.
2. Al-Salim, A.M., El-Gorashi, T.E.H., Lawey, A., and Elmirghani, J.M.H., "Greening big data networks: velocity impact," *IET Optoelectronics*, vol. 12, No. 3, pp. 126-135, 2018.

Sustainable Intelligent Communication and Computing Systems

- The Internet traffic is currently continuing to increase at **30% to 40% per year**, thus doubling every two years, and leading to expectations of traffic growth by 30x in 10 years and by 1000x in 20 years.
- A corresponding growth in communication and computing power consumption is clearly **not sustainable**.
- In addition, we have recently witnessed significant **growth in data collection using IoT devices and systems**, as well as growth in data from a wide range of sources including **social media, medical, financial and industrial data**.

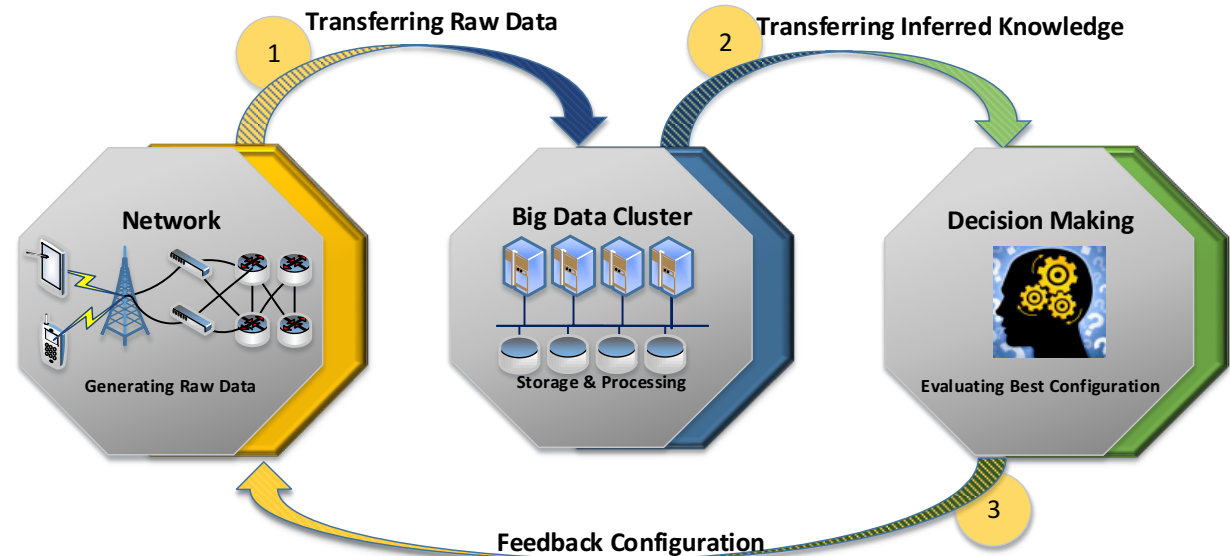
Sustainable Intelligent Communication and Computing Systems

- Machine learning and AI have helped introduce intelligence in networks and in computing systems.
- They are expected to continue to help extract value from this huge data, leading to significant increase in computational requirements.
- There is therefore a need to re-examine the fundamentals of intelligent communication and computing from a sustainability point of view including
 - hardware design,
 - network architecture,
 - software and cloud and fog computing systems.

Sustainable big data analytics for wireless networks

- The main steps in **optimizing networks using big data analytics** are:

1. **Collect raw data** from network entities, **transfer** it to a big data analytics engine for storage and processing to extract trends & correlations.
2. Transfer refined info **to decision making** platforms.
3. A new decision is sent as a **feedback for network reconfiguration**.



1. Hadi, M.S., Lawey, A., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Patient-Centric Cellular Networks Optimization using Big Data Analytics," *IEEE Access*, vol. 7, pp. 49279 - 49296, 2019.
2. Hadi, M.S., Lawey, A., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Using Machine Learning and Big Data Analytics to Prioritize OutPatients in HetNets," *IEEE INFOCOM 2019 Workshop on Sustainable networking through Machine Learning and Internet of things (SMILING 2019)*, invited paper, 2019.
3. Hadi, M.S., Lawey, A.Q., El-Gorashi, T.E.H., and Elmirghani, J.M.H. "Big Data Analytics for Wireless and Wired Network Design: A Survey, *Elsevier Computer Networks*, vol. 132, No. 2, pp. 180-199, 2018.
4. Hadi, M.S., Lawey, A., El-Gorashi, T.E.H., and Elmirghani, J.M.H., "Patient-centric HetNets Powered by Machine Learning and Big Data Analytics for 6G Networks," *IEEE Access*, vol. 8, pp. 85639-85655, 2020.