Sustainable Cloud and Fog Networks

Jaafar Elmirghani,

University of Leeds, UK, j.m.h.elmirghani@leeds.ac.uk

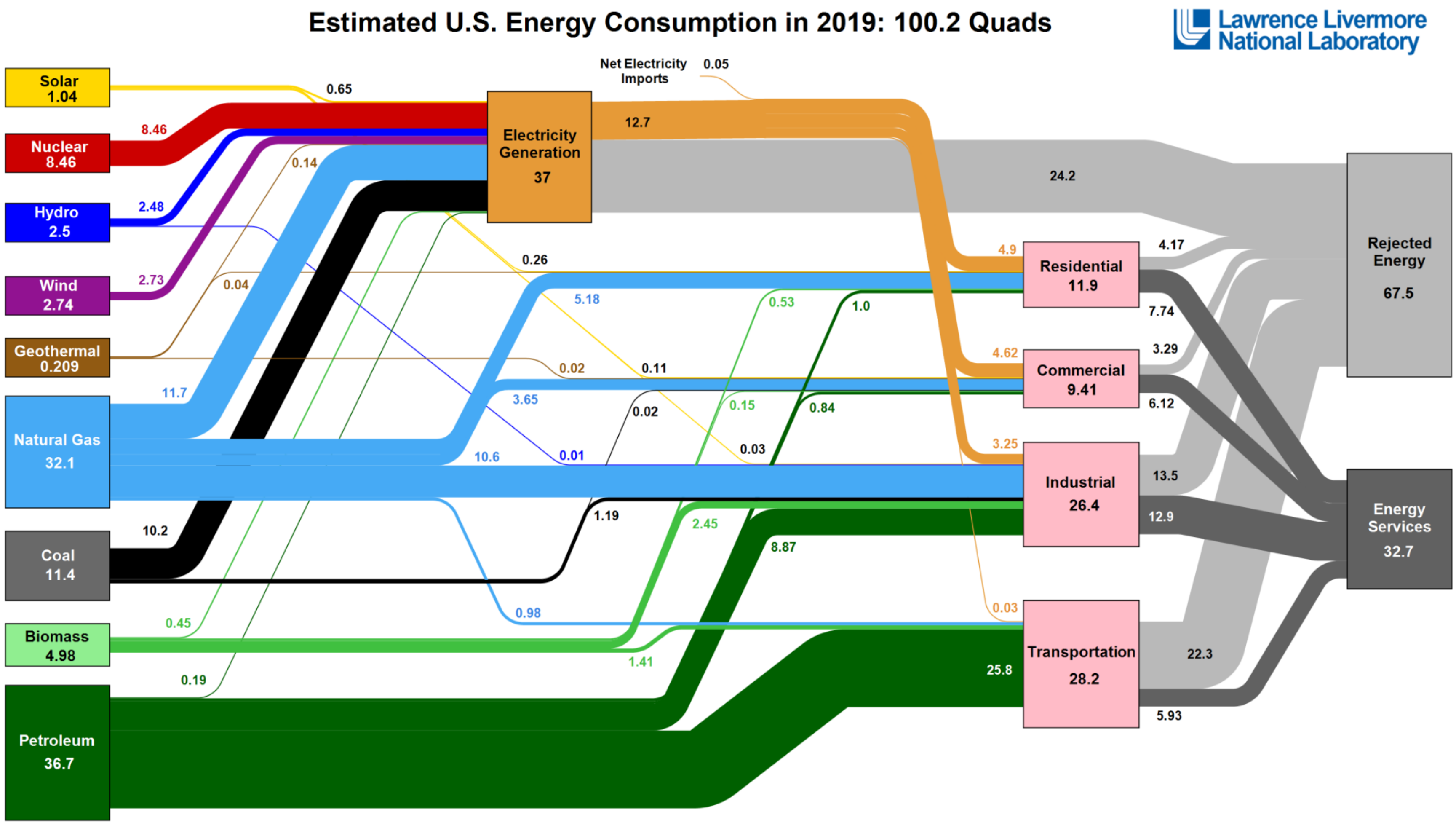
Outline

- Introduction, sustainable cloud and fog networks
  - Wireless and access networks
  - IoT networks
  - Core networks
  - Data centre networks
- Test-bed implementations
- IEEE standards
- Sustainability through ICT

Outline

- ➞ Introduction, sustainable cloud and fog networks
  - Wireless and access networks
  - IoT networks
  - Core networks
  - Data centre networks
- Test-bed implementations
- IEEE standards
- Sustainability through ICT

Energy Supply and Consumption: Most Energy is Lost



Source: LLNL March, 2020. Data is based on DOE/EIA MER (2019). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

World wide ICT Carbon footprint

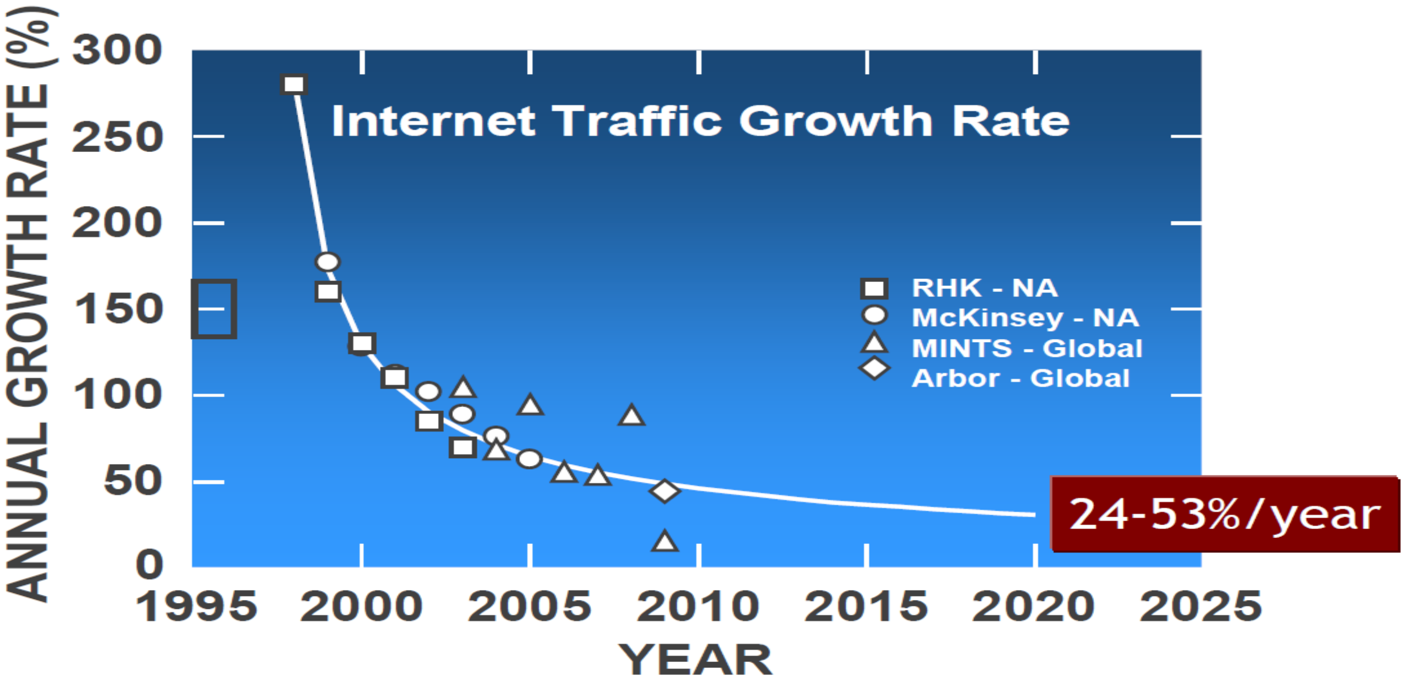
ICT emissions*

1.25 GtCO2e (1.97% of total baseline)*

A. End-user devices	B. Data Centers	C. Networks
0.59 GtCO2e	0.36 GtCO2e	0.30 GtCO2e
(47,2% of total)	(28,8% of total)	(24.0% of total)
(Smart) Phones	Servers	Wireless
Tablets	Data	Home
PCs	Computing units	Enterprise
3D printers		Data Transport
Others		

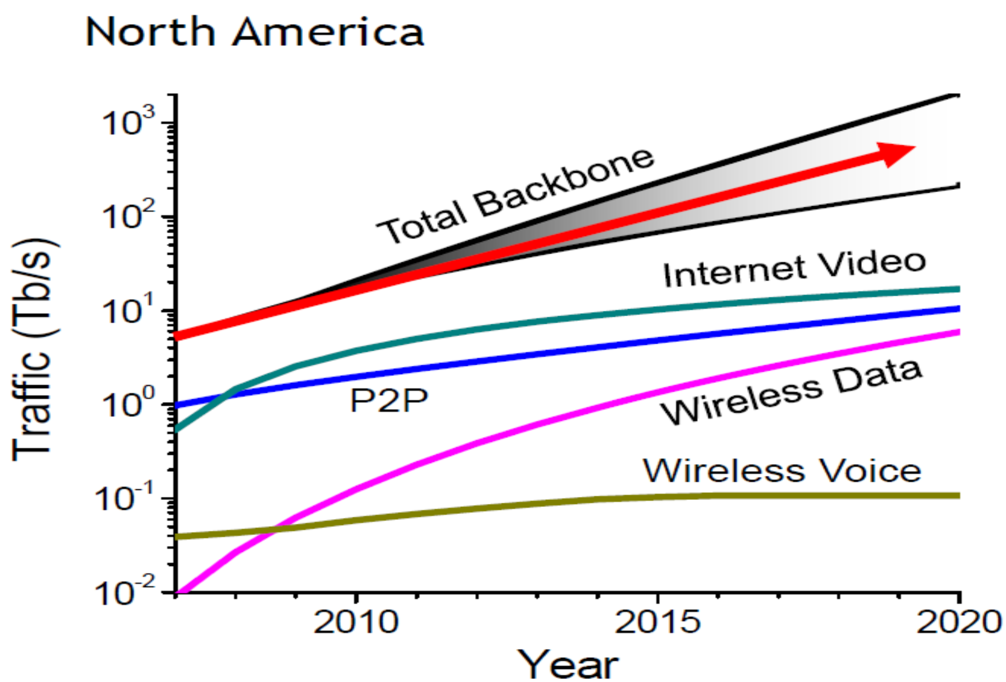
- GeSi SMARTer 2030 report

Internet Traffic Growth Rate



- Courtesy Thierry Klein, Alcatel-Lucent Bell Labs, Sources: RHK, 2004; McKinsey, JPMorgan, AT&T, 2001; MINTS, 2009; Arbor, 2009

Exponential traffic growth



Data from: RHK, McKinsey-JPMorgan, AT&T, MINTS, Arbor, ALU, and
Bell Labs Analysis: Linear regression on log(traffic growth rate) versus log(time) with Bayesian learning to compute uncertainty

Doubling every 2 years

- **40% per year**
- **30x in 10 years**
- **1000x in 20 years**

Mix of services is important from energy perspective:

- **Mobile less efficient than fiber optics**

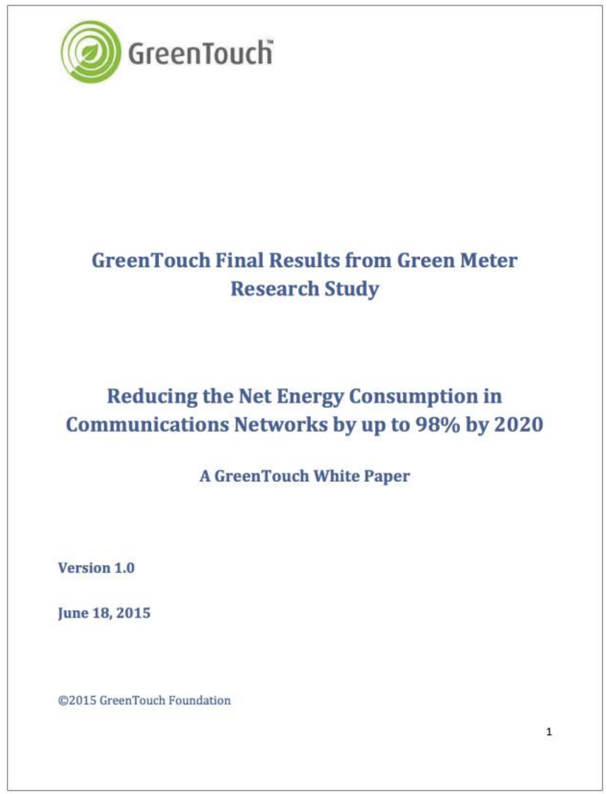
GreenTouch: Improving Energy Efficiency by a factor of 1000


GreenTouch

GreenTouch Green Meter Research Study:
Reducing the Net Energy Consumption in Communications Networks by up to 90% by 2020

A GreenTouch White Paper

Version 1.0
June 26, 2013


GreenTouch

GreenTouch Final Results from Green Meter Research Study

Reducing the Net Energy Consumption in Communications Networks by up to 98% by 2020

A GreenTouch White Paper

Version 1.0

June 18, 2015

Green Meter Results for Core Networks

Portfolio of 2020 Technologies	Efficiency Gains
Business as Usual (Moore's Law Improvement)	4.23x
GreenTouch Equipment Innovations - Optical Interconnects - Optimized Packet Processing - Link-Optimized Signal Processing in Transponders	4.73x
Deployment and Management of Protection Equipment	1.96x
Router Bypass & Sleep Modes During Off-Peak	2.13x
Dynamically Allocated Line Rates (40G, 100G, 400G, 1T)	1.21x
Optimized Network Direct Path Topology	1.43x
Optimized Distributed Cloud and Virtualisation	2.19x

2010
360 nJ/bit

315 x gain

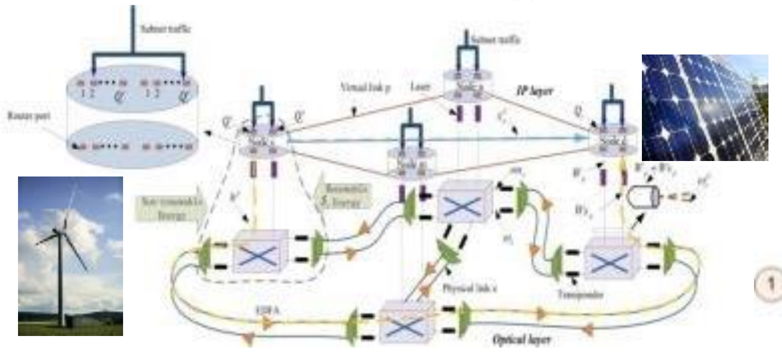
2020
1.14 nJ/bit

Enabling a 96% Decrease in Net Energy Consumption in Future Core Networks

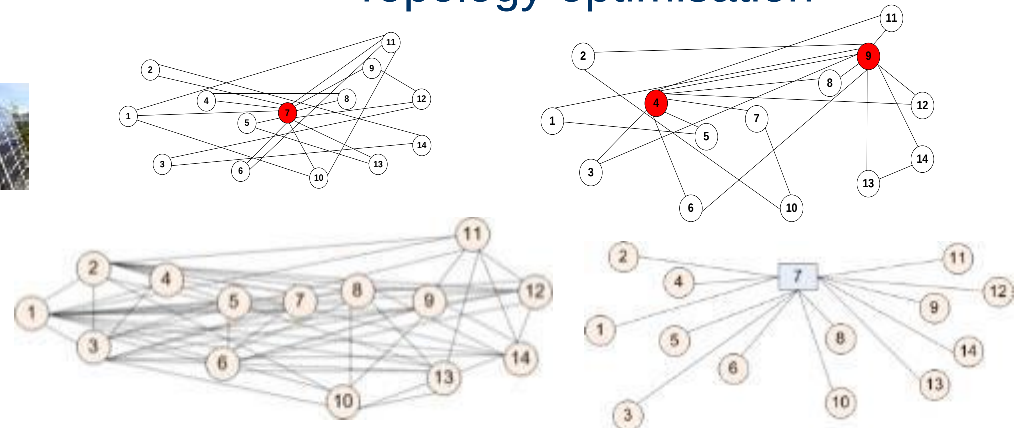
EPSRC Intelligent Energy aware Networks (INTERNET) PG, £6m, 2010-16

NFV, SDN Control and Software-isation

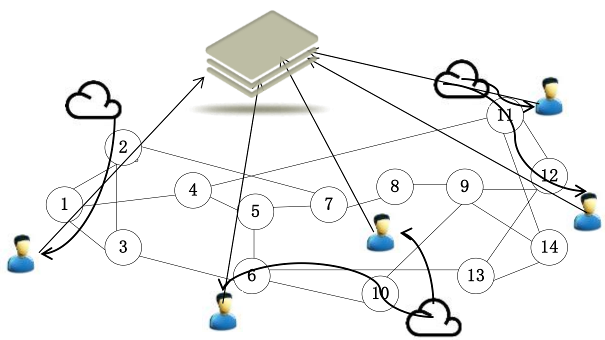
Renewable energy



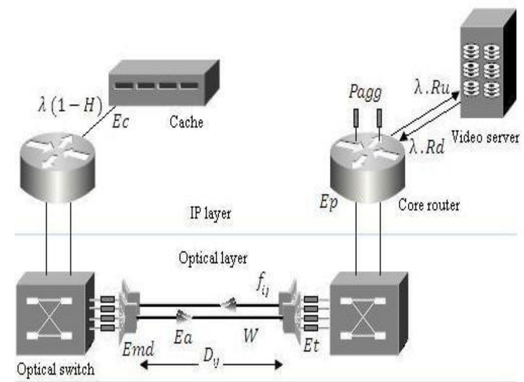
Topology optimisation



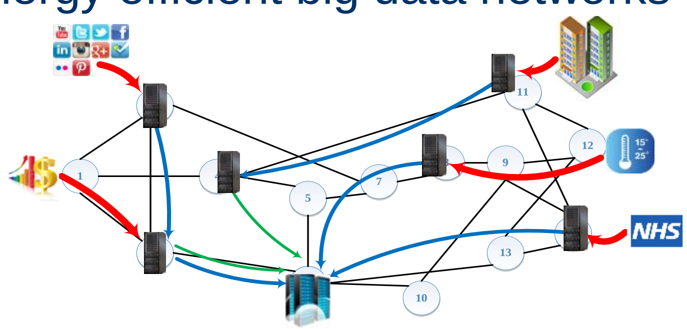
Cloud content distribution



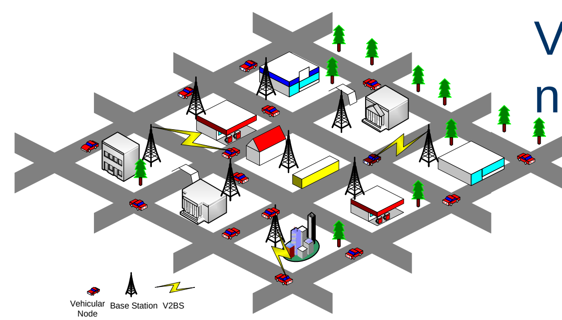
Content caching



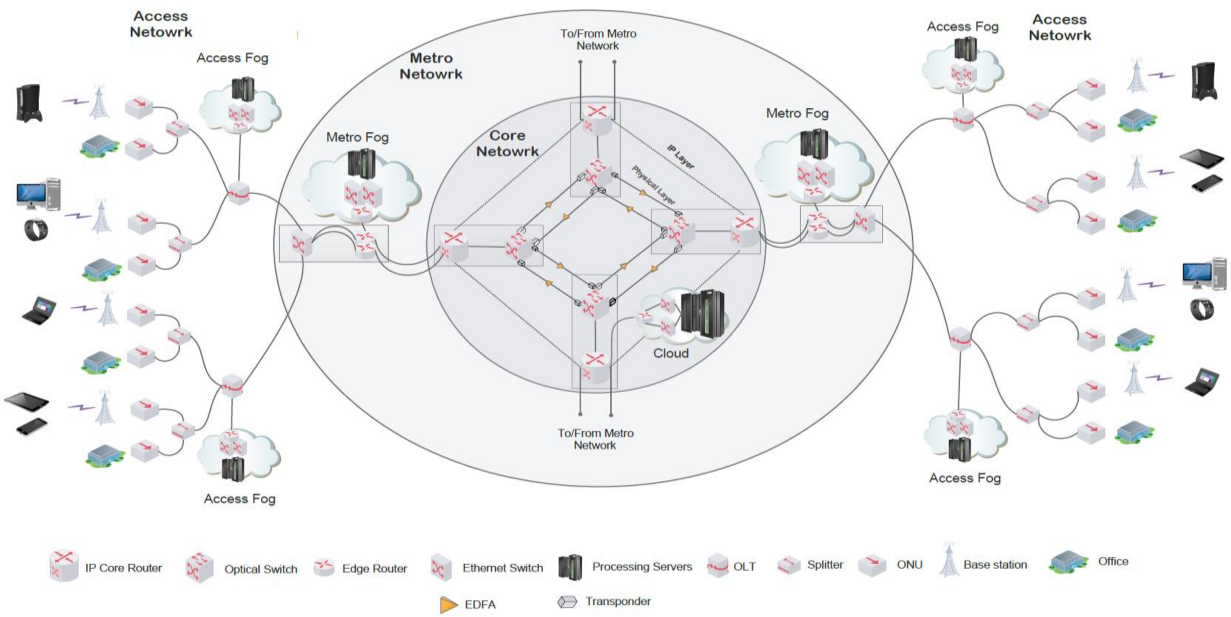
Energy efficient big data networks

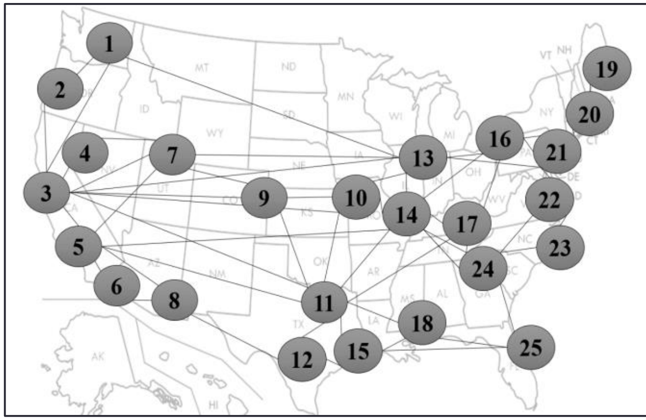


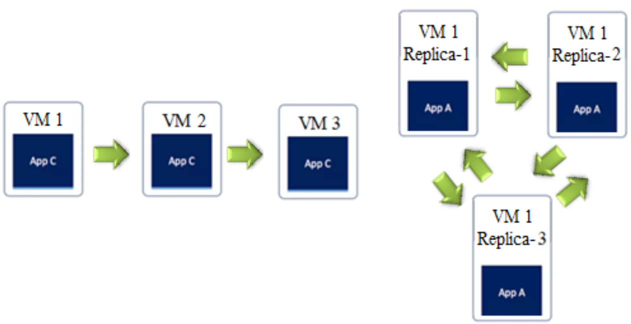
Vehicular networks



Case study 2: VM placement and migration

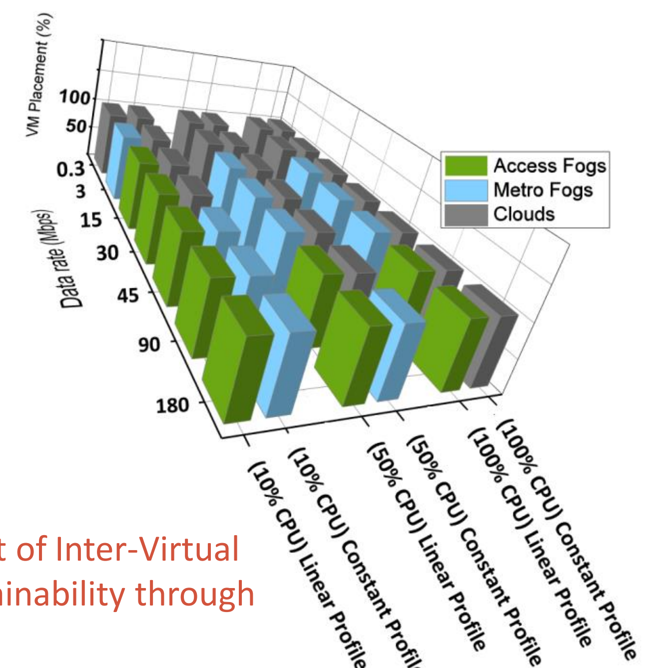






(a) (b)

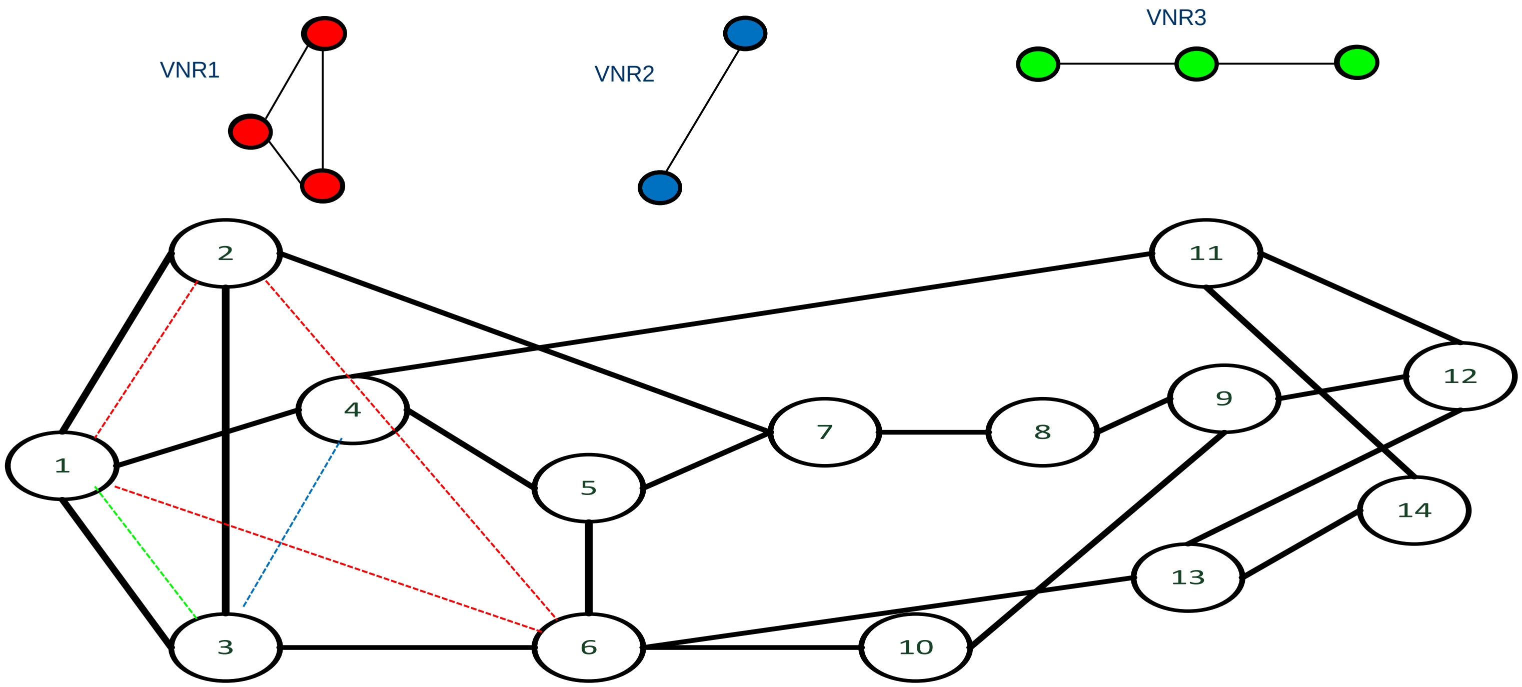
(a) VM Cooperation traffic
(b) VM Synchronisation traffic



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.

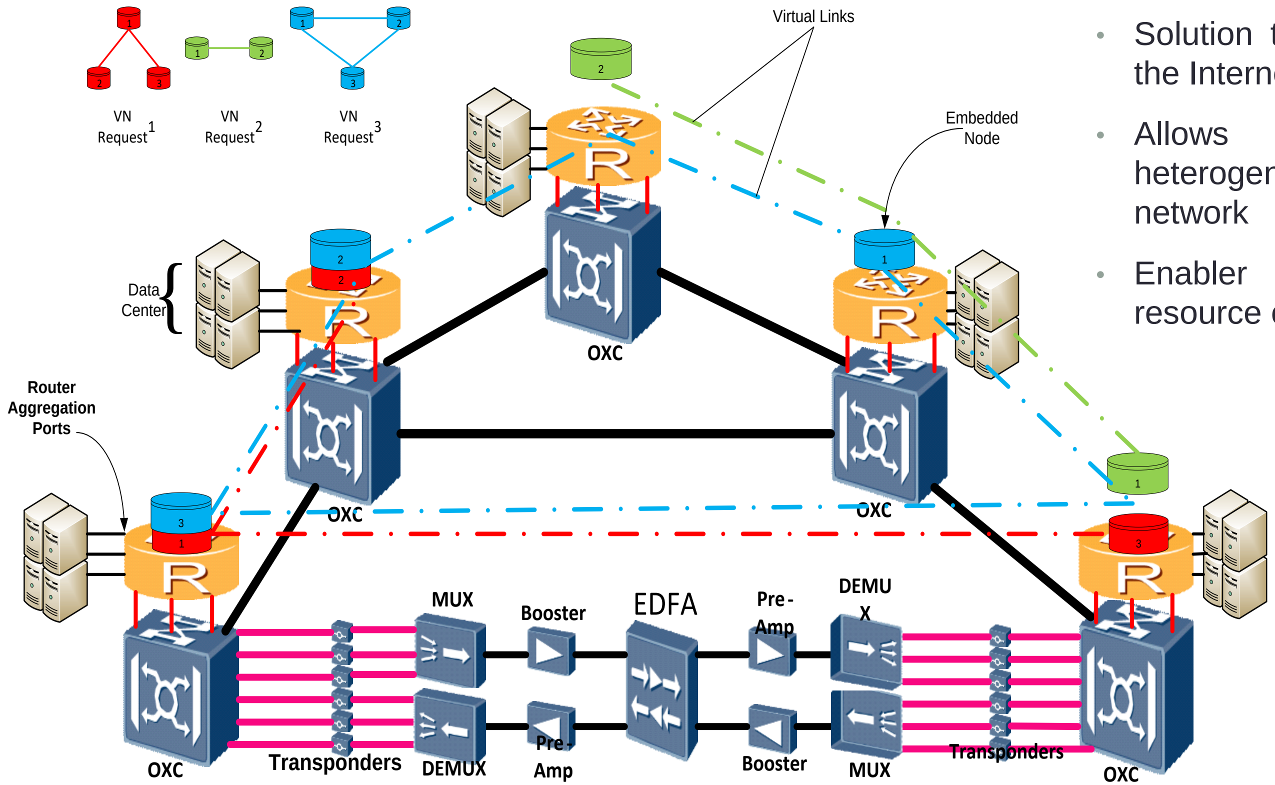
Use case 5: Joint core network and cloud virtualisation

Resource Allocation



- Enterprise clients requests for network resources
- A resource allocation framework (RAF) assigns these resources
- Optimization is on the RAF to achieve energy and cost efficiencies

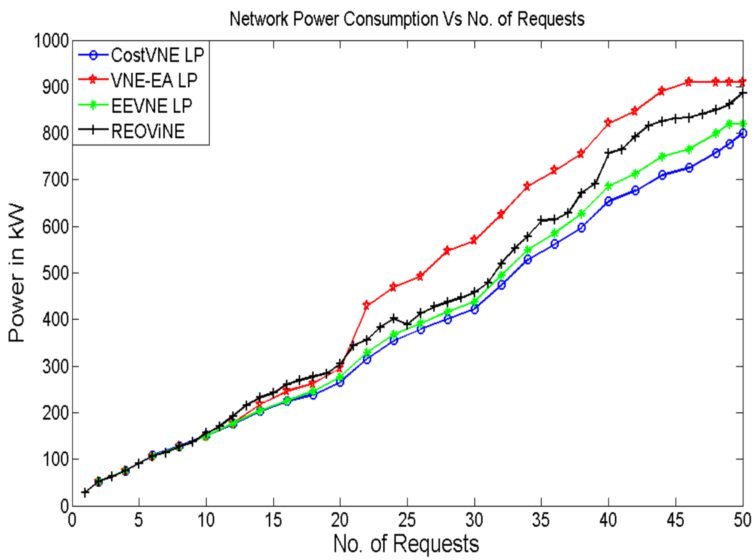
Core Network Virtualization with clouds



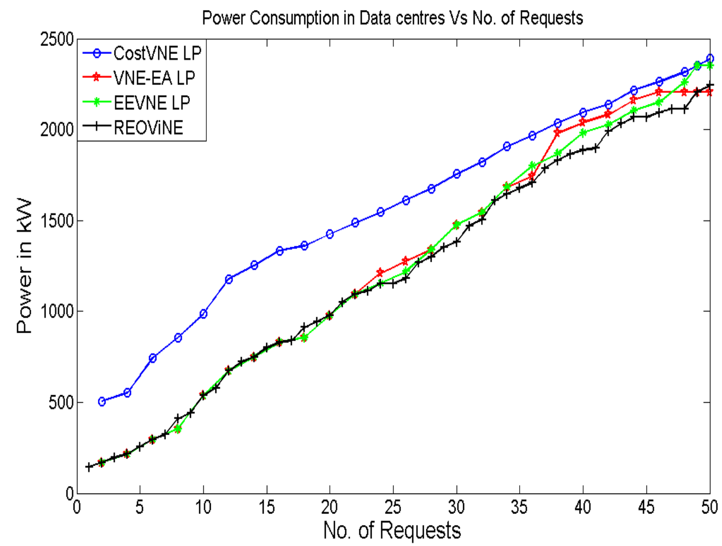
- Solution to the current ossifying forces of the Internet
- Allows the existence of several heterogeneous networks in one physical network
- Enabler of Energy Savings through resource consolidation

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.

Energy Inefficient Data Centre

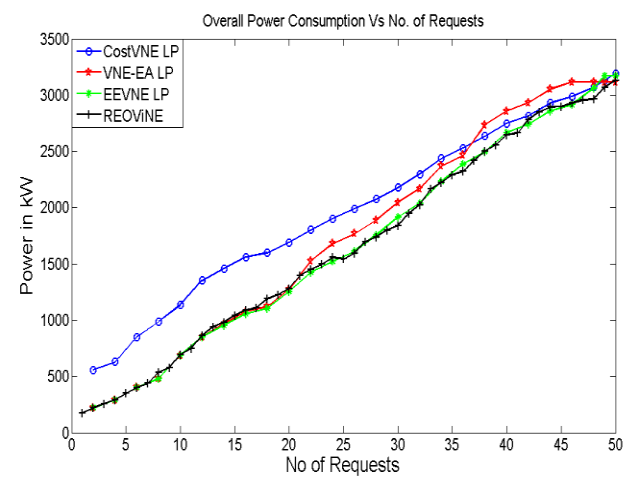


Network Power Consumption



Data Centres Power Consumption

- The EEVNE model saves 60% (Maximum) of the overall power consumption compared to the CostVNE model (20% Average).
- The EEVNE model saves 9% (Maximum) of the overall power consumption compared to the VNE-EA (3% Average).
- The REOViNE heuristic approaches the EE-VNE model in terms of the network power consumption.



Overall Power Consumption

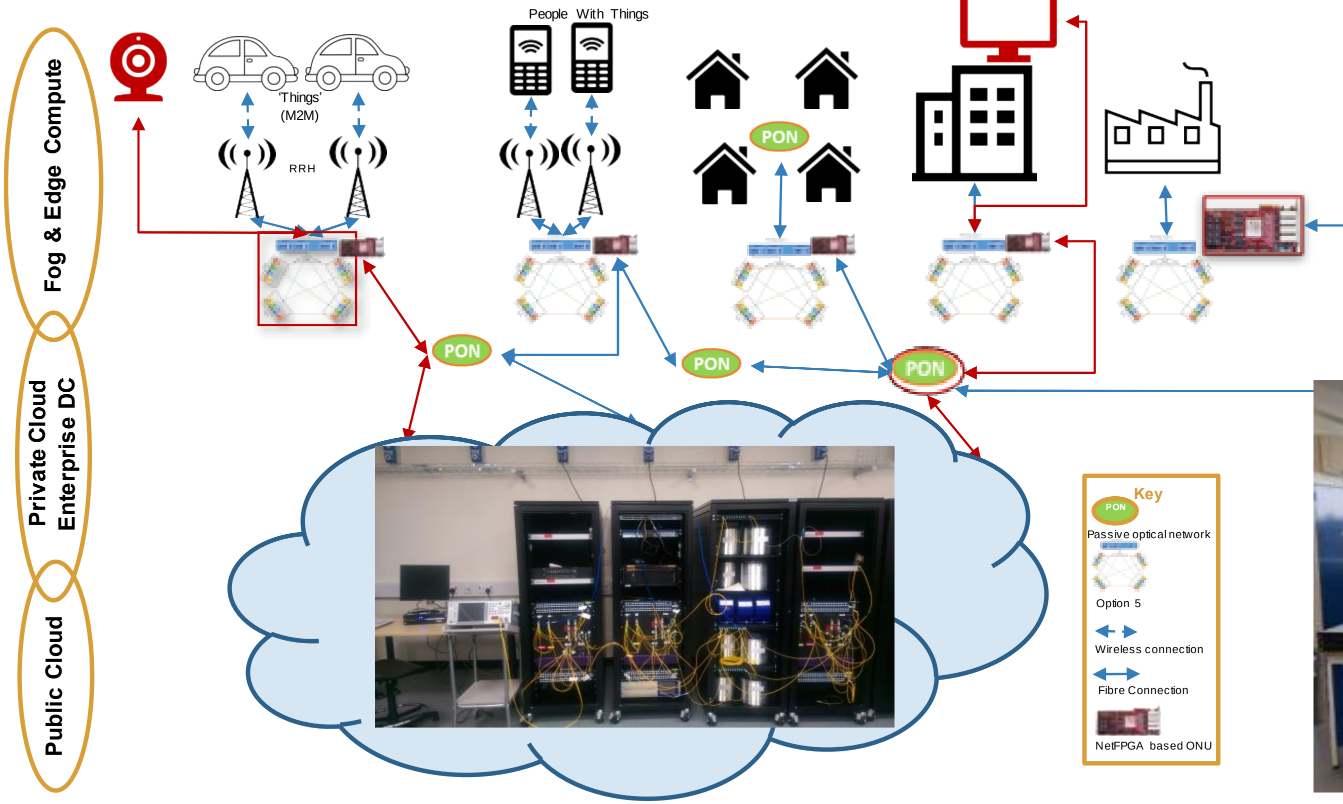
Outline

- Introduction, sustainable cloud and fog networks
  - Wireless and access networks
  - IoT networks
  - Core networks
  - Data centre networks
- ➞ Test-bed implementations
- ➞ IEEE standards
- ➞ Sustainability through ICT

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 centre 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 architecture" *Proc ICTON*, Angers, France, 9-13 July 2019.

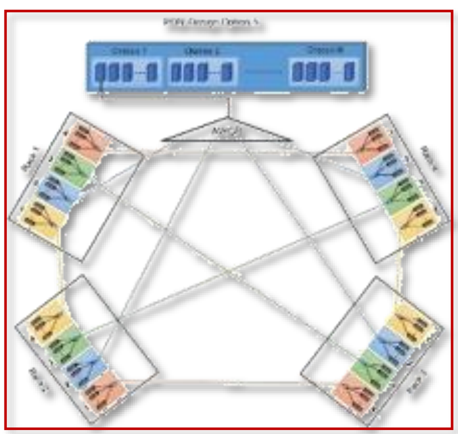


NetFPGA card

Fog cell

Access OLT and ONU

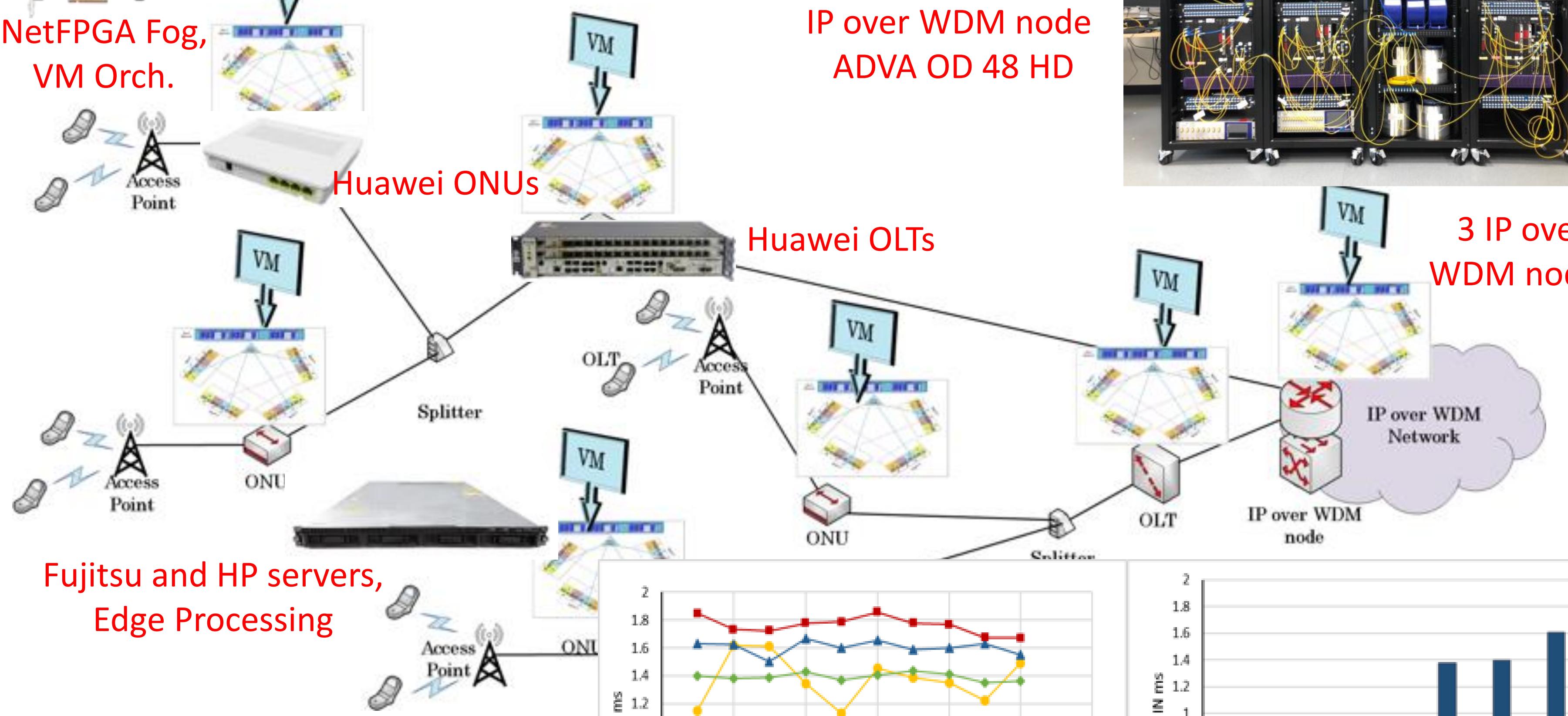
Fog cell



VM Orchestration in Test-bed

NetFPGA Fog, VM Orch.

IP over WDM node ADVA OD 48 HD

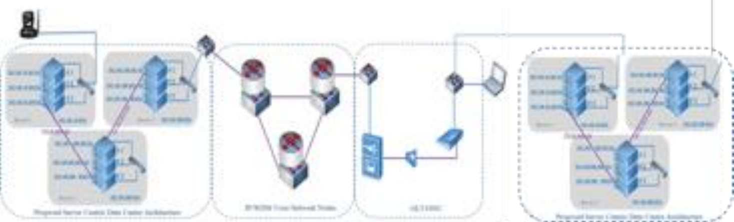


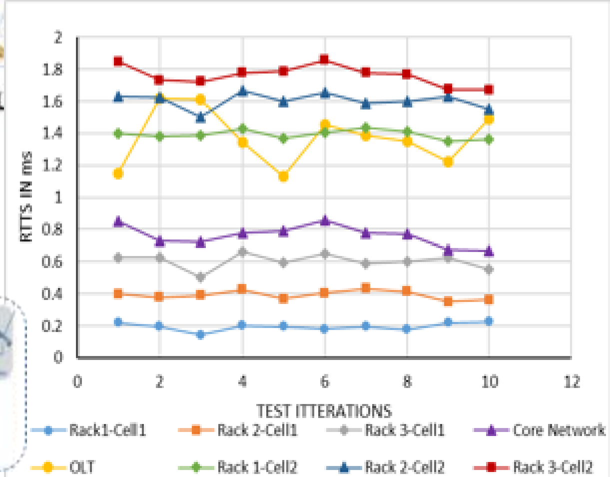
Huawei ONUs

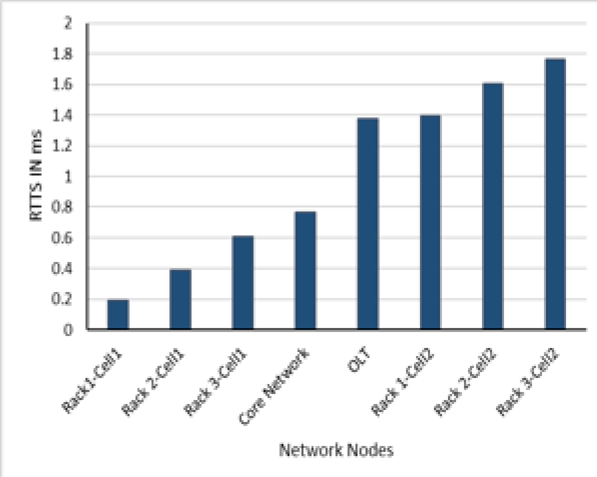
Huawei OLTs

3 IP over WDM nodes

Fujitsu and HP servers, Edge Processing







IEEE SUSTAINABLEICT™

Mission:
to build a holistic approach to sustainability through ICT by incorporating green metrics throughout IEEE technical domains.

Interactions among multiple IEEE societies and initiatives to implement energy-sustainable:
- Metrics
- Hardware design Methods
- Energy-aware algorithms
- Power-proportional computing designs

Actions:
- Standards
- Conferences and events
- Publications
- Education

Deliveries
- 9 standards, PARs approved 2017
  - 3 IEEE Comsoc, SA working groups
- Sustainable ICT Summit, 2017, 2019
- White papers
- Publications
  - IEEE Trans on Green Communications and Networking
  - IEEE Magazine "Sustainability and ICT"
- Education
  - 7 Short courses

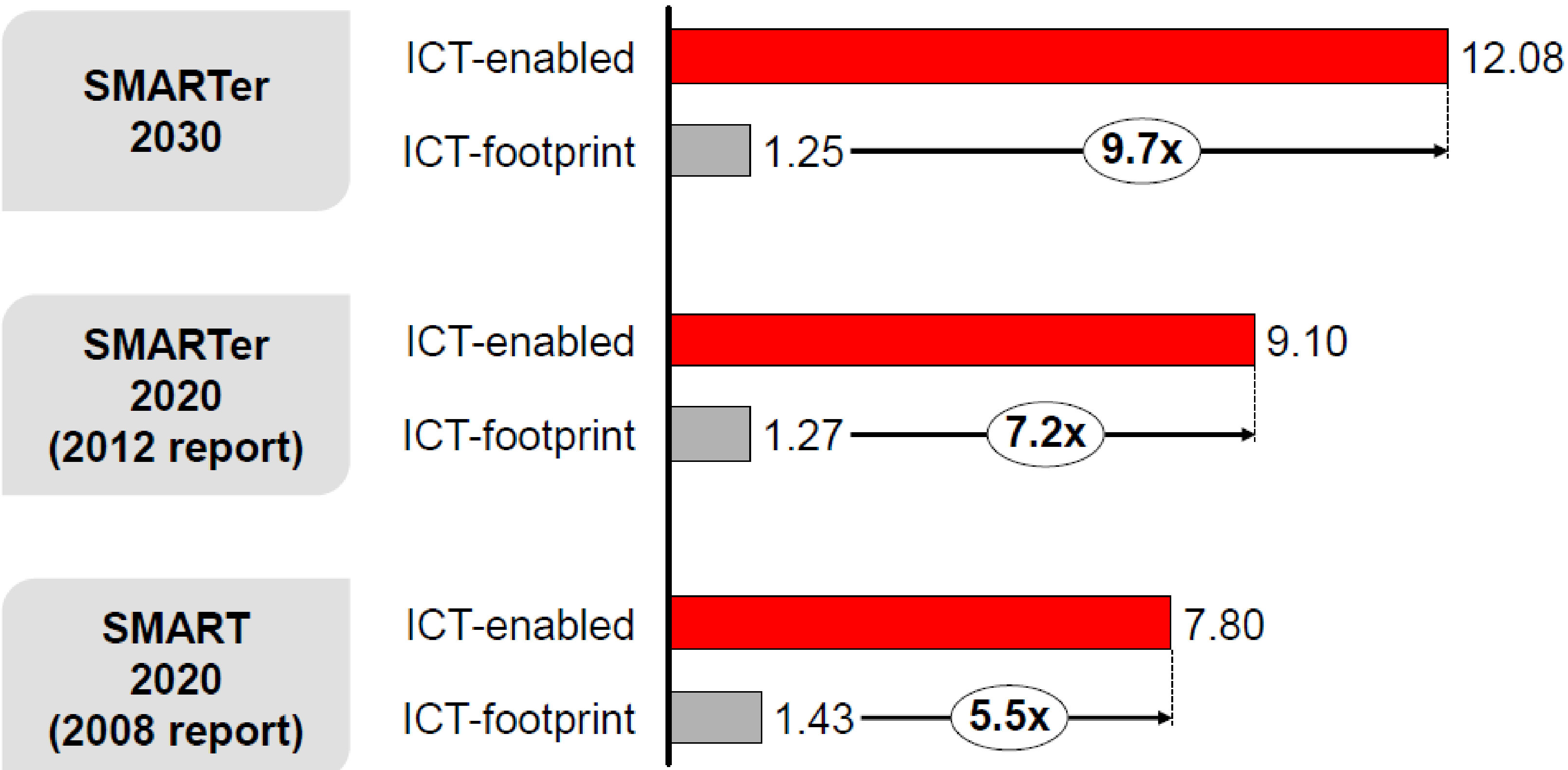
9 New IEEE Standards

IEEE SUSTAINABLEICT™

- 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
  - ***(Ballot successful)*** 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.
  - IEEE P1929.1 An Architectural Framework for Energy Efficient Content Distribution.

SMARTer 2030

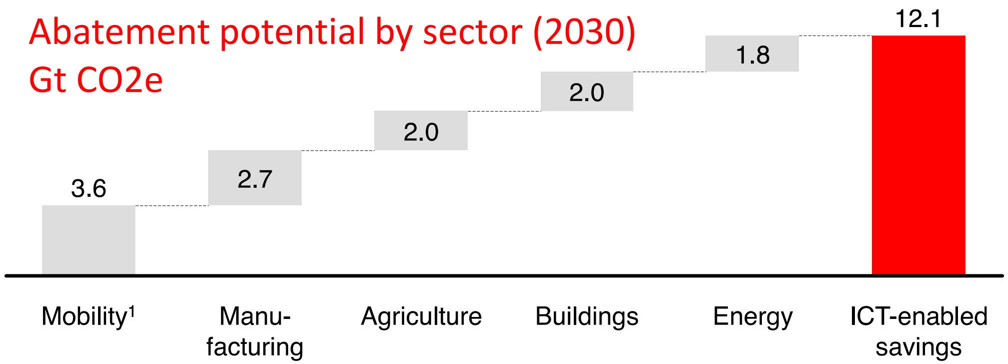


Source: Source: WRI, IPCC, GeSI, SMARTer2020, Accenture analysis & CO2 models

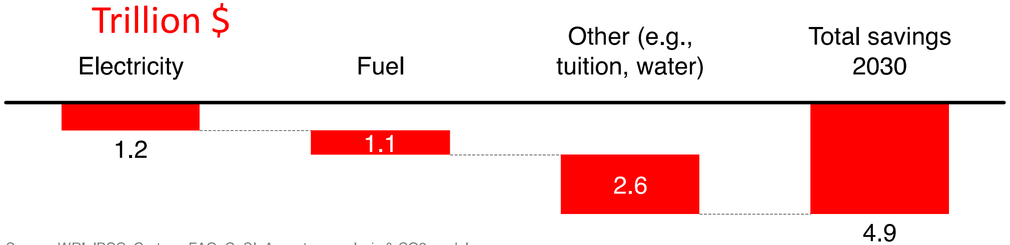
SMARTer 2030 report

Sustainability through ICT

Abatement potential by sector (2030)
Gt CO2e



ICT-enabled cost saving opportunities (2030)
Trillion $



Source: WRI, IPCC, Gartner, FAO, GeSI, Accenture analysis & CO2 models

	Use Case stakeholders	ICT sector
E-Health	Health private sector additional revenues **208.8Bn US.$**	ICT revenues from wearable devices **63.4Bn US.$**
E-Learning	E-Learning institutions **412.9Bn US.$**	ICT revenues from E-Learning platforms **75.3Bn US.$**
Smart Energy	Renewable energy companies **811.3Bn US.$**	ICT revenues from smart grid sensors **2.1Bn US.$**
Smart Home	Revenues from smart home system installations **184.9Bn US.$**	ICT revenues from smart home connectivity **199.7Bn US.$**
Smart Agriculture	Farmers additional revenues **1.8Tr US.$**	ICT revenues from soil sensors **53.1Bn US.$**
Smart Logistics	Logistic sector cost savings **174.3Bn US.$**	ICT revenues from fleet management tools **59.5Bn US.$**
E-Work	Office space saved **501.2Bn US.$**	ICT revenues from E-Work platforms **536.5Bn US.$**
Smart Manu-facturing	Industry cost savings **11.9Bn US.$**	ICT revenues from smart industrial machinery **3Bn US.$**

SMARTer 2030 report