# x-cloud challenges

Jakub Krzywda
Dept. of Computing Science
Umeå University
SE-901 87 Umeå, Sweden
Email: jakub@cs.umu.se

William Tärneberg
Dept. of Electrical and Information Technology
Lund University
Ole Römers väg 3, 223 63 Lund, Sweden
Email: william.tarneberg@eit.lth.se

***Abstract*—The abstract goes here.**

## I. Introduction

Services accessed from mobile devices is increasingly provided hosted in the cloud. Migrating services to the cloud compliments and virtualizes a mobile devices resources. Nevertheless, the delay as a result of executing code or storing resources fully or partially in the cloud introduces and unwanted delay that can disrupt the desired seamless user experience.

Cloud services are traditionally hosted in aggregated data centres scattered throughout the globe. Theirs ability to cost effectively host services is in general fundamentally derived by their size and energy efficient.

The delay introduced when externalising a service to a data centre is a product of the geographic distance to the data centre, the congestion on the intermediate core network, the mobile access network, and the performance of the data centre.

As the number of cloud service increase and the number of devices rely on cloud services increase so will the congestion in the access network and thus also delay. Moreover, as more traditional hardware or device local service are virtualized to the cloud, the demand to low latency response will increase. Conceivably, storage can be fully virtualized, critical control processes can be migrated to the cloud. In the advent of the emergence the internet of things, data from an vast number of sensors, actuators, and peripheral interaction points will flood the internet with traffic, ranging as vastly in size and QoS needs.

In order to be able to reduce latency and be able to formulate relevant SLAs the service hosting nodes will need to reduce their geographic proximity to the consumption device or process.

We refer to proposed paradigm of migrating cloud service hosting and execution closer to the consumption device as the x-cloud . The distribution of cloud data centre hardware and the virtualizetion of resources can proposedly coexist with future virtualized mobile networks.

## II. Related research

Geo-distributed cloud [11]

## III. The case for the x-cloud

The motivations for the adoption of the x-cloud are multi-dimensional. ...

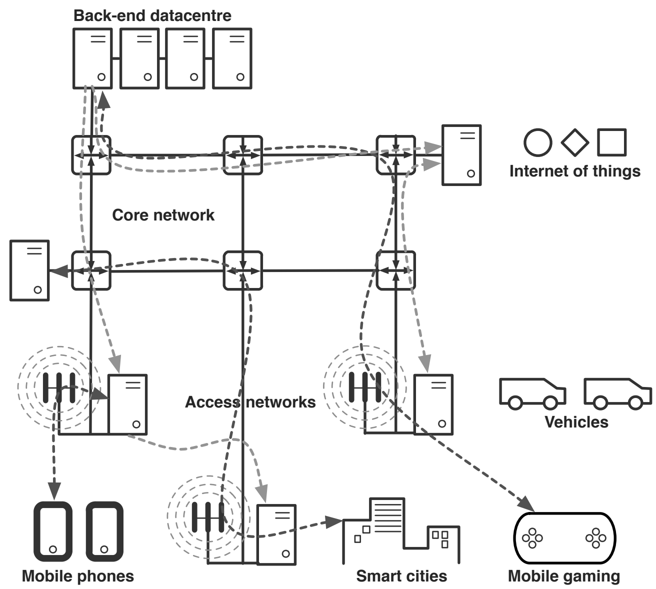


Fig. 1: x-cloud

The geographic distance separating the device and the host introduces a propagation delay. The intra-continental propagation delay is in order of 20-30 ms, which conceivably constitutes a concious geographic placement of the data centre to minimize the propagation delay, on the scale of hundreds of kilometres. ...

The number of devices accessing a service in a geographic area contributes to congestion on the access links. More and more devices will access the internet and so also cloud services the wireless medium. As a result, the access links will be suffer from an increasing level of congestion. ...

The forthcoming mobile networks are protectedly distributed with virtualized centralized resources. The scale of which is proportional to the acceptable distance between the antenna and the aggregated centralized resources. ...

All of the above factors provide just as many data centre placement possibilities. It is the purpose of our our research to ...

### A. *The bandwidth case for x-cloud*

- Internet structure, latency, and bandwidth: [36]

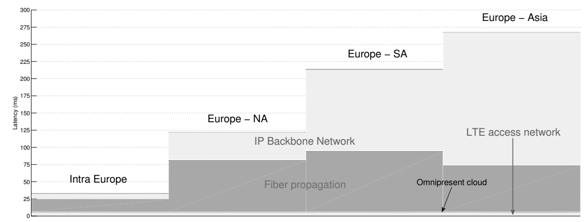


Fig. 2: IP Internet latency in western Europe [10] over LTE [15]

### B. The latency case for x-cloud

The intermediate latency between a client and a data centre is a product of propagation, modulation, and network routing and traffic shaping. Propagation is a clear physical obstacle to reducing latency, and there is very little evidence to suggest that information will propagate faster than $\frac{2}{3}$ of the speed of light, at scale, in the near future. Furthermore, the delay in the backbone network is incurred to the most part by routing. A full point to point network where the propagation speed is the only limit, is not economically viable and would dissolve the fabric of the Internet. As such, we can always expect a certain amount of network contributed latency and jitter. At best, an LTE mobile access network adds about 5 ms of latency [15]. Radio access network latency can be expected to diminish over the next few generations of mobile networks.

Moving the cloud data centres closer to the IP backbone networks eliminates some of the additive latency on one side of the connection. Doing so, not only eliminate the propagation delay, but will over time, add more complexity to peripheries of the backbone as more severs nodes make their home there.

The x-cloud remedies this latency challenge in a more sustainable way. By moving compute resources to the mobile networks, IP backbone network propagation and routing delays are eliminate without disrupting the Internet topology. The resulting distributed infrastructure is capable of delivering content and services at latencies less than 10 ms.

The x-cloud will thus enable latency-sensitive services to be migrated to the cloud, such as, gaming, financial trading, process control, and most real-time human-machine interaction process.

### C. The infrastructure case for x-cloud

Distributed virtualized mobile networks will rely on centralized compute nodes for higher level link management. One node will proposedly host multiple base stations, to which they connect over a network link, much like the Ericsson Radio Dot System [**?**], but at a larger scale. The size of these virtualization resource nodes is proportional to the maximum distance they can reside from the radio nodes, given the induced propagation delay. Supposedly these virtualization resource nodes will the placed in the vicinity of the core IP network. The virtualization resource nodes can be seen as to define geographic areas whos boundaries are defined by the reach of the mobile network which it serves. Depending on the level of desired provision and load balancing flexibility, these geographic domains will overlap to varying degrees.

The virtualization resource nodes are conceivably constructed of generic x86 or ARM servers, hosting VMs or containers within which the virtualized mobile network infrastructure is executed. Given the placement of the virtualization resource node, any free or designually excess capacity can be used hist other services.

The topology is designed to optimize the use of radio resources, the geographic domains which the virtualization resource nodes constitute do not necessarily overlap or map the demographic area which x-cloud services operate.

### D. Services in the x-cloud

Placing capacity in the capillaries of the network does not necessarily have to be a means to reduce latency and congestion, but also a vessel within which localized services can be hosted. Localized services can exists purely in the x-cloud , serve only one user and geographically migrate with the user, be fully of partially hosted in the x-cloud . Different tiers can proposedly by hosted at distributed, depending on the users mobility behaviour. Conceivably, such services could range from compute offloading, game rendering, emergency services, sensor and traffic monitoring, low-latency process control, such as surgical robotics.

## IV. Desiard model

The below models are intended to cater for all research topics.

- no sociogeographic model, however the model will acknowledge the primes of service sociogeographic domain, and will thus be geographically bounded appropriately.
  ...

## V. Proposed research topics

### A. Size of edge data centres (number of CPU, memory, etc.)

Ericsson

*1) Proposed research:* The size of an edge data center is primarily bounded by two factors: the costs of infrastructure and maintenance as well as the availability of power supply. On the one hand, the economy of scale indicates the minimum size. Creating many tiny edge data centers is simply unprofitable. To set up even the smallest data center one has to provide computing resources, power supply, network connection, cooling system, building, etc. On the other hand, the maximum size of the edge data center is determined by the available power supply. Data centers need a lot of energy which is mostly consumed by cooling system. However, nowadays antennas and base stations can be localized in places where providing such power supply is difficult (e.g. roofs of residential blocks or towers of historical buildings).

In our research we would like to determine the optimal size of edge data centers. We will take into account such factors as:

- costs of infrastructure and maintenance

- demography
- available power supply

*2) Related research:* Current research focuses on the cost of running big data centers with particular emphasis on network [22], cooling [31]. There are also cost models for planning, development and operation of a data center available [33]. According to our knowledge there is no research about the optimal size of edge data centers.

### *B. How mobility of user affects network and cloud computing?* Lund

*1) Proposed research:* The traffic generated by

*2) Related research:*

### *C. How many devices can be handle by the current infrastructure (latency/bandwidth limits or other requirements)* Umeå

*1) Proposed research:* In our research we would like to simulate the current network infrastructure (mobile network, core network, remote/big data centers) and show the limits of it.

- What will happen when the number of connected devices increases by order(s) of magnitude? The influence on a core network (connection between a base station and a big/remote data center).
- How many connected devices can be handeled by the current infrastructure (depending on a latency limits)?

*2) Related research:* Research about limitations of current network infrastructure?

### *D. Placement of edge data centres* Ericsson

*1) Proposed research:* There are no clear directions as to what degree the coming mobile networks will be virtualized. The degree of virtualization will determine the distribution of compute resources in the network, bounded by properties such as propagation delay, and cell resource provisioning.

The geographic domain in which users move, the location and size of the x-cloud hosting entity defines the bounds in which the service can perform optimally.

We propose a service performance study into the placement of the x-cloud resources. The study will contrast the service delay performance with the placement of the x-cloud resources ranging from the radio bases station to the adjacent core network, where there the x-cloud node caters for multiple base stations.

The service delay will be determined by the additive latency in the mobile network, the level of congestion in the x-cloud node, and the resource shift instigated by user mobility.

We propose to contract the latency experienced by the user with the additional load imposed on the x-cloud infrastructure, as a form of utility.

*2) Related research:*

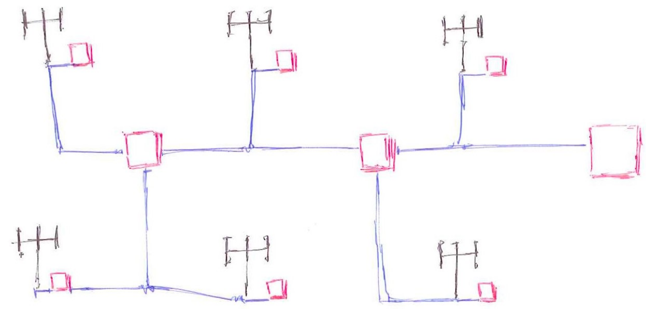

Fig. 3: x-cloud placement

### *E. Topology of mobile network (antennas detached from BTS) CRAN* Lund

*1) Proposed research:* Based on the conclusions drawn in paper VII-E

*2) Related research:*

### *F. VM placement and migration decisions* Umeå

*1) Proposed research:* In the x-cloud a service will either exists only locally or distributed, but purposely serves a geographically and demographically bounded populous. The units on which the service is hosted are of limited capacity and cannot he universally virtualized as a traditional data center, with relatively unlimited capacity over time. Give the load on each of the nodes and their geographic relevance to the demographic populous they server, services will conceivably need to be mobile, migrating, dispersing, and contracting to minimize such properties as cost, load, and traffic, also taking into account the cost of the migration itself.

We propose research into an appropriate centralized or distributed, load balancing cost function, taking into account :

- Incurred migration load on host and receiver
- Incurred migration induced network congestion
- Network congestion
- Delay RTT to client to aggregate client base. In other words, minimize delay to aggregate delay/latency to all its served clients. *Perhaps separate research topic preceding this one*
- Client mobility

A property such as energy consumption is perhaps irrelevant to a topology of small data centres as domain of movement is fairly limited and bounded by the demographic service, the rate of which a service migrates is to some extent bounded by the mobility of its users. Nevertheless, energy can become a relevant parameter if the service is allowed to migrate between the x-cloud and a traditional data centre or if the energy profiles of the local x-cloud hosts, is heterogeneous. As the serviced domain is bounds each service by its sociogeographic profile and the fact that latency gains are fairly small accounting for thermal emissions and reuse would be counter productive, and should be dealt with optimally by each node independently.

When optimizing for latency, inherent thermal efficiency will conceivably seldom correlate with the service sociogeographic domain.

*2) Related research:* Existing research in this area is mainly focuses on load balancing and provisioning between larger distributed data centres with static users.

## VI. SIMULATION

### A. Constituent models

*1) Data Centre:* Cloud model : [23] Web serve model : [17] VM migration model : [12], [24], [38], [40]

*2) Radio access network:* Because the mobile access network is a service access qualifier, the mechanisms of the network is relatively irrelevant to the primary research topics. The network can appropriately be modelled with a series of delays.

It is a constituent objective of our research to determine relevant X-Cloud/NGN [1] symbiotic topologies. These topolgies will be feed into the simulation model and will conceivably encompass, resource placement and dimension, cell sizes, and radio resource provisioning [25], [35], [37].

Alternatively we can deploy a full scale LTE system simulation tool such as LTE-Sim [34]. However, such a solution would leave us with a skewed level of detail across the entire model set. The core and mobile networks would have a proportionally greater level of detail than the serve model. The granularity of the model might be incompatible with

Our basic research topics will require a homogeneous, equidistant, and equirange cell topology. Although it is reasonable to assume that future networks hosting an X-Cloud will be distributed.

*3) Base station:* The base station can conceivably be modelled with a queue and a delay proportional to its propagation distance to its associated "C-RAN" node.

*4) Core network:* The essential property of the core network is bandwidth and delay. Both of which can be modelled with queues.

- Latency
  - "Point-to-Point" core network delay model [19]
  - "One-hop" core network router queue delay model [32]

*5) Mobility:* A smooth random walk, unobstructed, bounded, edge-aware mobility model will provide a uniformly distributed dispersion of users across the simulation domain [14]. The model is two-dimensional and provides pedestrian, bicycle, and auto mobile mobility modes. The model is uniform and does thus not take into account any socio-demographic variations, and local clusters. Nevertheless, exploring specific demographic and urban settings is beyond the scope of our basic research topics. Furthermore, in the absence of a socio-demographic and urban scenarios, an aggregate mobility mode will be deployed.

[1] Next Generation Network

*6) Service:* There is a multitude of appropriate service models.

- Light weight 1-tiere web service model from 1998 [13]
- Modern light weight 1-tiere web service model [26]
- YouTube workload generator [21]
- 3-tiered open-loop web service model [29]
- Web browsing behaviour : [28]
- Cloud service usage patterns : [41]

### B. Simulation framework

Below are the candidate simulation tools and frameworks proposed during the third Cloud Control Workshop. [42]

*1) SimJava:*

*2) SimPy:* Python and SimPy has the ability to run powerful statistical analyses with R [8], interact with a MATLAB workspace [7], and bind NS-3 modules [6]. Nevertheless, not able to confirm weather or not you can call uncompiled MATLAB SimEvent modules.

*3) LTE-Sim:* LTE-Sim [34] provides a modular event-driven simulation framework that allows you to model and LTE mobile access network, including:

- eNB
- Radio channel
- PHY/MAC
- Propagation
- IP backbone
- UE

The above models are included in a relatively high detail, however, simplifications are not supplied. The simulation framework is accesible in C++, and allows for you to build custom modules to enable replacing existig and adding components. The framework enables sending packets addressed to a specific node. The framwork by default also includes two exchangable mobility models.

What remains to be determined is:

- Output analysis?
- Interoperabilty with other frameworks, such as NS-3, matlab etc?

Although flexible, the framework is ridigd to LTE and cannot easily be modified to other standards. On the other hand, if your chnages are incremental to LTE then the framework will provide fast means to deploy your experiments.

*4) CloudSim:* [1]

CloudSim adaptations:

- NetworkCloudSim [20]
- CloudAnalyst [39]

*5) GreenCloud:* [3]

*6) iCanCloud:* [4]

*7) MDCSim:* [27]

*8) SimGrid:* [9]

- [18]
- [16]

*9) CoolSim:* [2]

*10) ns-3:* [5]

*11) Matlab+SimEvent:* (and TrueTime)

## VII. Papers

### A. Comparison of existing simulators from the perspective of x-cloud

A survey of existing simulators with comparison of their capabilities (and limitations) to simulate x-cloud .

Simulators of:

- Data centers,
- BTS,
- Network (BTS — DC),
- Mobile network,
- Mobile devices,
- Users (mobility).

What is different in operation/simulation of x-cloud ?

### B. Network bottlenecks and latency in the x-cloud

Simulate the current infrastructure (mobile network + remote/big data centers) and show the limits of it.

- What will happen when the number of mobile devices increases by order(s) of magnitude? The influence on a network connection between a base station and a big/remote data center.
- How many mobile devices can be handeled by the current infrastructure (depending on a latency limits)?

*1) The setup/structure of x-cloud , paper VII-B1:* The x-cloud consists of antennas, small (edge) data centers and big (remote) data centers. Small data centers are located close to the antennas and can host both virtualized base station software and VMs with applications. Big data centrs are located far away from users. Small data centers have smaller amount of resources than big ones (maybe also performance is lower) and running applications there is more expensive. However, latency is is much lower than in a case of big (remote) data centers.

Questions about the setup/structure of x-cloud :

- how many antennas should be associated with one small (local) data center? (probably this will be limited by the latency between an antenna and a small data center)
- how big should small (local) data centers be (#CPUs etc)?

### C. Virtual Machine placement and migration in x-cloud

Regarding placement of Virtual Machines (VMs) in the edge data centers:

- Should a VM that serves all users (even these outside of the range of the directly connected antennas) be placed in an edge data cener or should it be rather an additional instance that serves users that are in the close proximity (duplicating a VM in a big data center)?
- When a VM should be placed/duplicated in a small data center?
- While users are moving from one antenna to another when VM should be migrated from one edge data center to another one?

### D. x-cloud model

### E. Performance and mobility, paper VII-E

| Conference | Date | Loc. | Deadline | Pages |
|---|---|---|---|---|
| CloudCom | Dec 15-18 | SG | Jul 31 | 8 |
| BDCS | Jan 26-27 | SG | Aug 29 | 10 |
| 6th CCW | Dec 8-11 | LDN | Jul 25 | 8 |

*1) Abstract:* In an x-cloud topology the resources are dispersed throughout the network. Given that services strictly migrate with the user from, depending on the placement of the service hosts, user mobility will affect the performance perceived performance of the service. The model takes into account the effort of migrating a service and the service performance degradation it introduces.

This paper determines the fundamental service performance issues in system of mobile users with disperead data centres, in relation to the placement of the x-cloud host nodes and explores the user and provider utility of subscribing to an x-cloud node at a certain network depth.

*2) Related research:* In addition to my first paper we need to find more on

*3) Desired model:* As the the topology of the x-cloud and future mobile networks is yet to be determined, and due to the fact that we want to research the effects of mobility without a socio-economic model, the network

*4) Simulation:* Multiple runs for each DC/x-cloud placement mode.

Service: The traffic generated by and the usage pattern of a simple web application is characteristic of any smaller mobile application. The HTTP traffic model in [30] provides a small scale closed loop traffic model that is representative of light mobile traffic.

Mobility: The 2 dimensional, multi model, mobility model [**?**] will provide the uniform mobile network with an relevant distribution of users.

Mobile Access Network: Provided by Williams SIMJava framework. Handover are instantanious and move

Core network: No delay, no routeing

Server The server provides VM and DC models that encompass, inucrred VM migration performance degredation in DC and in VM, resulting in a different service time.

Possible service hosting schemes:
- One service model, one VM is empolyed to host that service for each user.
- One service model, each VM hosts multiple but each number of users, behaving as multiple services while still being compatible.

*5) Measurements:* At all placement modes:

- Measure RTT for all packetc at UE
- Measure DC load
- Measure ratio of requests generated vs. processed in x-cloud node
- Identify the incurred VM migration load

*6) Future research:*

- Optimal service/VM migration/placement in relevant topology
- Performance in LTE newtork topology using LTE-SIM [34]

### F. Other thoughts

- Different workload patterns?
- How to perform monitoring? (System is very distributed)
- Maybe new metrics to monitor (eg. distance from antenna, velocity, direction, etc.)
- Changes in the architecture of mobile applications

## References


[1] Cloudsim. Available online at http://www.cloudbus.org/cloudsim/.

[2] Coolsim. Available online at http://www.coolsimsoftware.com/.

[3] Greencloud. Available online at https://greencloud.gforge.uni.lu/.

[4] icancloud. Available online at http://www.arcos.inf.uc3m.es/~icancloud/Home.html.

[5] Ns-3. Available online at http://www.nsnam.org/.

[6] Ns-3 python interaction. Available online at http://www.nsnam.org/docs/manual/html/python.html.

[7] pymatlab. Available online at https://pypi.python.org/pypi/pymatlab.

[8] R project. Available online at http://www.r-project.org/.

[9] Simgird. Available online at http://simgrid.gforge.inria.fr/.

[10] Monthly network summary, 05 2014.

[11] Sharad Agarwal, John Dunagan, Navendu Jain, Stefan Saroiu, Alec Wolman, and Harbinder Bhogan. Volley: Automated data placement for geo-distributed cloud services. In *NSDI*, pages 17–32, 2010.

[12] S. Akoush, R. Sohan, A. Rice, A.W. Moore, and A. Hopper. Predicting the performance of virtual machine migration. In *Modeling, Analysis Simulation of Computer and Telecommunication Systems (MASCOTS), 2010 IEEE International Symposium on*, pages 37–46, Aug 2010.

[13] Paul Barford and Mark Crovella. Generating representative web workloads for network and server performance evaluation. *ACM SIGMETRICS Performance Evaluation Review*, 26(1):151–160, 1998.

[14] Christian Bettstetter. Smooth is better than sharp: A random mobility model for simulation of wireless networks. In *Proceedings of the 4th ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, MSWIM '01, pages 19–27, New York, NY, USA, 2001. ACM.

[15] T Blajić, D Nogulić, and M Družijanić. Latency improvements in 3g long term evolution. *Mipro CTI, svibanj*, 2006.

[16] Laurent Bobelin, Arnaud Legrand, David A González Márquez, Pierre Navarro, Martin Quinson, Frédéric Suter, and Christophe Thiéry. Scalable multi-purpose network representation for large scale distributed system simulation. In *Proceedings of the 2012 12th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (ccgrid 2012)*, pages 220–227. IEEE Computer Society, 2012.

[17] Jianhua Cao, M. Andersson, C. Nyberg, and M. Kihl. Web server performance modeling using an m/g/1/k*ps queue. In *Telecommunications, 2003. ICT 2003. 10th International Conference on*, volume 2, pages 1501–1506 vol.2, Feb 2003.

[18] H. Casanova, A. Legrand, and M. Quinson. Simgrid: A generic framework for large-scale distributed experiments. In *Computer Modeling and Simulation, 2008. UKSIM 2008. Tenth International Conference on*, pages 126–131, April 2008.

[19] Baek-Young Choi, Sue Moon, Zhi-Li Zhang, Konstantina Papagiannaki, and Christophe Diot. Analysis of point-to-point packet delay in an operational network. *Computer networks*, 51(13):3812–3827, 2007.

[20] S.K. Garg and R. Buyya. Networkcloudsim: Modelling parallel applications in cloud simulations. In *Utility and Cloud Computing (UCC), 2011 Fourth IEEE International Conference on*, pages 105–113, Dec 2011.

[21] Phillipa Gill, Martin Arlitt, Zongpeng Li, and Anirban Mahanti. Youtube traffic characterization: A view from the edge. In *Proceedings of the 7th ACM SIGCOMM Conference on Internet Measurement*, IMC '07, pages 15–28, New York, NY, USA, 2007. ACM.

[22] Albert Greenberg, James Hamilton, David A. Maltz, and Parveen Patel. The cost of a cloud: Research problems in data center networks. *SIGCOMM Comput. Commun. Rev.*, 39(1):68–73, December 2008.

[23] H. Khazaei, J. Misic, and V.B. Misic. Performance analysis of cloud computing centers using m/g/m/m+r queuing systems. *Parallel and Distributed Systems, IEEE Transactions on*, 23(5):936–943, May 2012.

[24] S. Kikuchi and Y. Matsumoto. Performance modeling of concurrent live migration operations in cloud computing systems using prism probabilistic model checker. In *Cloud Computing (CLOUD), 2011 IEEE International Conference on*, pages 49–56, July 2011.

[25] Raymond Kwan, Rob Arnott, Robert Paterson, Riccardo Trivisonno, and Mitsuhiro Kubota. On mobility load balancing for lte systems. In *Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd*, pages 1–5. IEEE, 2010.

[26] Jeongeun Julie Lee and Maruti Gupta. A new traffic model for current user web browsing behavior. *Intel Corporation*, 2007.

[27] Seung-Hwan Lim, B. Sharma, Gunwoo Nam, Eun Kyoung Kim, and C.R. Das. Mdcsim: A multi-tier data center simulation, platform. In *Cluster Computing and Workshops, 2009. CLUSTER '09. IEEE International Conference on*, pages 1–9, Aug 2009.

[28] Chao Liu, Ryen W White, and Susan Dumais. Understanding web browsing behaviors through weibull analysis of dwell time. In *Proceedings of the 33rd international ACM SIGIR conference on Research and development in information retrieval*, pages 379–386. ACM, 2010.

[29] Xue Liu, J. Heo, and Lui Sha. Modeling 3-tiered web applications. In *Modeling, Analysis, and Simulation of Computer and Telecommunication Systems, 2005. 13th IEEE International Symposium on*, pages 307–310, Sept 2005.

[30] Zhen Liu, Nicolas Niclausse, and César Jalpa-Villanueva. Traffic model and performance evaluation of web servers. *Performance Evaluation*, 46(2):77–100, 2001.

[31] Ehsan Pakbaznia and Massoud Pedram. Minimizing data center cooling and server power costs. In *Proceedings of the 14th ACM/IEEE International Symposium on Low Power Electronics and Design*, ISLPED '09, pages 145–150, New York, NY, USA, 2009. ACM.

[32] Konstantina Papagiannaki, Sue Moon, Chuck Fraleigh, Patrick Thiran, and Christophe Diot. Measurement and analysis of single-hop delay

on an ip backbone network. *Selected Areas in Communications, IEEE Journal on*, 21(6):908–921, 2003.

[33] Chandrakant D Patel and Amip J Shah. Cost model for planning, development and operation of a data center, 2005.

[34] G. Piro, L.A. Grieco, G. Boggia, F. Capozzi, and P. Camarda. Simulating lte cellular systems: An open-source framework. *Vehicular Technology, IEEE Transactions on*, 60(2):498–513, Feb 2011.

[35] Andras Racz, Andras Temesvary, and Norbert Reider. Handover performance in 3gpp long term evolution (lte) systems. In *Mobile and Wireless Communications Summit, 2007. 16th IST*, pages 1–5. IEEE, 2007.

[36] Venugopalan Ramasubramanian, Dahlia Malkhi, Fabian Kuhn, Mahesh Balakrishnan, Archit Gupta, and Aditya Akella. On the treeness of internet latency and bandwidth. *SIGMETRICS Perform. Eval. Rev.*, 37(1):61–72, June 2009.

[37] J Salo, M Nur-Alam, and K Chang. Practical introduction to lte radio planning. *A white paper on basics of radio planning for 3GPP LTE in interference limited and coverage limited scenarios, European Communications Engineering (ECE) Ltd, Espoo, Finland*, 2010.

[38] William Voorsluys, James Broberg, Srikumar Venugopal, and Rajkumar Buyya. Cost of virtual machine live migration in clouds: A performance evaluation. In *Cloud Computing*, pages 254–265. Springer, 2009.

[39] Bhathiya Wickremasinghe, Rodrigo N Calheiros, and Rajkumar Buyya. Cloudanalyst: A cloudsim-based visual modeller for analysing cloud computing environments and applications. In *Advanced Information Networking and Applications (AINA), 2010 24th IEEE International Conference on*, pages 446–452. IEEE, 2010.

[40] Yangyang Wu and Ming Zhao. Performance modeling of virtual machine live migration. In *Cloud Computing (CLOUD), 2011 IEEE International Conference on*, pages 492–499, July 2011.

[41] Gansen Zhao, Jiale Liu, Yong Tang, Wei Sun, Feng Zhang, Xiaoping Ye, and Na Tang. Cloud computing: A statistics aspect of users. In *Cloud Computing*, pages 347–358. Springer, 2009.

[42] Wei Zhao, Yong Peng, Feng Xie, and Zhonghua Dai. Modeling and simulation of cloud computing: A review. In *Cloud Computing Congress (APCloudCC), 2012 IEEE Asia Pacific*, pages 20–24. IEEE, 2012.

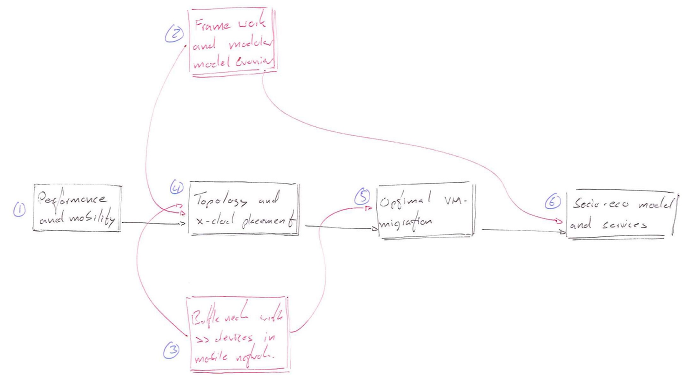


Fig. 4: Proposed sequence of papers

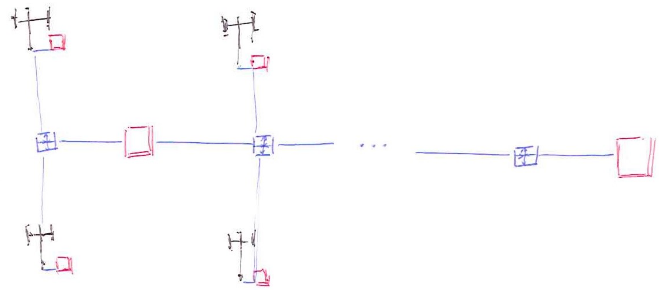

Fig. 5: Network model

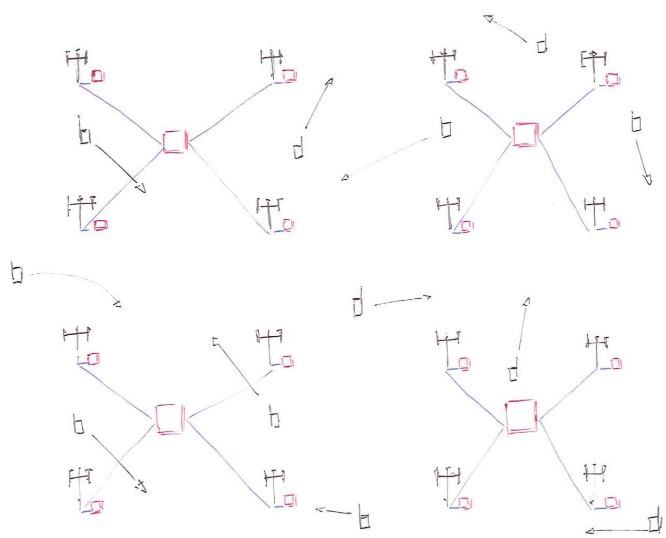

Fig. 6: Performance model