Research infrastructures for a cloudy future Internet

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Goal of the talk

• OpenFlow
  – Enabling technology for the future Internet
  – Power of innovation, architectural implications, ...
• New packet forwarding paradigms
  – LIPSIN: Line-Speed Publish/Subscribe Inter-Networking
  – SiBF: Data center networking with in-packet Bloom filters
• Experimental Research on the Future Internet
Message

- The Cloud is here to stay,
  - but how will it evolve and impact the Internet from an architectural point of view?
- The inter-networking requirements of the Cloud
  - main driving force shaping the so-called future Internet
- Develop Inter-Cloud use cases in the national infrastructures for Future Internet R&D
  - Towards a planet-scale, federated CloudLab
Disclaimer

This presentation contains a mix of hype and speculation.
Cloud Computing
Ash  Cloud Computing
• Interoperability
• Open market
• Low entry barrier
• Incentives for innovation at all layers
• Sustainable
• Provider lock-in
• Performance hauls
• Security
• Privacy
• ...
What is the Inter-Cloud?

- A marketing term?
- If the Internet is the network of networks, the Inter-Cloud is the cloud of clouds

- A federation of clouds i.e., an agreement to cooperate for the mutual benefit ($$$)
"The Cloud represents a new layer in the Internet architecture and, like the many layers that have been invented before, it is an open opportunity to add functionality to an increasingly global network" - Vint Cerf, 2009

Cloud Initiatives that have an analogue in the Internet’s past:

1. The rising importance of *academia*.
2. Increasing interest in *interoperability* among cloud vendors.
   - Today’s clouds like network islands before IP
3. *Carrier* interest in new service opportunities.

The Inter-Cloud as an Utility

• Learn from other utilities (energy, water, transport) and anticipate the emergence of an utility-driven Cloud resource market
  – Utility-Oriented Federation of Cloud Computing Environments
• What is the role of the (inter-)networking substrate?
The emergence of a Cloud market

[Buyya et al. InterCloud: Utility-Oriented Federation of Cloud Computing Environments for Scaling of Application Services]
• It is all about *context* (again, i.e., like mobility), but strongly driven by business (aka BGP but on a higher level)
Networking the Inter-Cloud

Re-examination of cost/control trade-offs & adoption incentives:
• Mature protocols (VPN, IPv6, IP Multicast, Sec BGP, DNSsec, ...)
• Novel routing mechanisms (e.g., LISP, energy-aware protocols, or even XML routing)
• Radical information-centric architectures (e.g., CCN, PSIRP).
• Virtual flash networks, Bandwidth-on-Demand, WAN acceleration (compression, packet deduplication), etc.
Isolated Clouds over IP

naming DNS
routing BGP
addressing IP
Cloud-oriented connectivity?

Tim Bernes-Lee work on semantic web, raw data and linked data

Inter-Cloud & Cloud-Client connectivity

naming
routing
addressing

DNS'
BGP'
IP'

IP

User

IP
# Towards a CloudLab

## Table 2. Comparison of cloud computing testbeds.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Open Cirrus</th>
<th>Google/IBM cluster</th>
<th>TeraGrid</th>
<th>PlanetLab</th>
<th>Emulab</th>
<th>Open Cloud Testbed</th>
<th>Amazon EC2</th>
<th>LANL cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of research</td>
<td>Systems and services</td>
<td>Data-intensive applications</td>
<td>Scientific applications</td>
<td>Systems and services</td>
<td>Systems</td>
<td>Interoperability across clouds using open APIs</td>
<td>Commercial use</td>
<td>Systems</td>
</tr>
<tr>
<td>Approach</td>
<td>Federation of heterogeneous data centers</td>
<td>Cluster supported by Google and IBM</td>
<td>Multisite heterogeneous clusters for supercomputing</td>
<td>Nodes hosted by research institution</td>
<td>Single-site cluster with flexible control</td>
<td>Multisite heterogeneous clusters</td>
<td>Raw access to virtual machines</td>
<td>Reuse of LANL's retiring clusters</td>
</tr>
<tr>
<td>Participants</td>
<td>CMU, ETRI, HP, Intel, IDA, KIT, MIMOS, RAS, UIUC, Yahoo!</td>
<td>Google, IBM, MIT, Stanford Univ., Univ. of Washington</td>
<td>Many universities and organizations</td>
<td>Many universities and organizations</td>
<td>Univ. of Utah</td>
<td>Four centers</td>
<td>Amazon</td>
<td>CMU, LANL, NSF</td>
</tr>
<tr>
<td>Distribution</td>
<td>10 sites</td>
<td>Centralized—one data center in Atlanta</td>
<td>11 partners in US</td>
<td>More than 700 nodes worldwide</td>
<td>More than 300 machines</td>
<td>480 cores distributed in four locations</td>
<td>Several unified data centers</td>
<td>Thousands of older but still useful nodes at one site</td>
</tr>
</tbody>
</table>

GENICloud

[Source: http://groups.geni.net/geni/attachment/wiki/GENICloud/GEC7Poster.pdf]
Thank you!

Questions?

Answers???
Thank you!

Questions?

Answers???
Impacts of the cloud data center footprint on the Future Internet?

THE INTER-CLOUD
Emergence of data-centric architectures

Data naming / Linked data

IP: Bootstrapping and control plane

Overlays
Virtualization
Evolution

Data-Centric Future Internet Architectures

PSIRP
CCN
Impacts of the Inter-Cloud?

Flattering of the Internet topology

[Core image adapted from A. Greenberg SIGMETRICS 09 Tutorial]
The role of Cloud brokers
Cost-Aware Internet Routing

savings of a cloud computing installation’s power usage by dynamically re-routing service requests to wherever electricity prices are lowest on a particular day, or perhaps even where the data center is cooler.

From “Follow the energy price! “ to “Follow the wind, the sun or the moon!”

[Qureshi et al, “Cutting the Electric Bill for Internet-Scale Systems”, SIGCOMM´09]
Cloud Standards

- VM image formats and metadata
- API to storage, DB, etc.
- Naming
- Security
- ...

[Source: http://www.opencloudmanifesto.org/Cloud_Computing_Use_Cases_Whitepaper-2_0.pdf]

- Open Source developments (Eucalyptus, Ubuntu Enterprise Cloud) and de facto APIs (e.g., Amazon EC2 and S3)
Cloud Standards

[Source: http://www.opencloudmanifesto.org/Cloud_Computing_Use_Cases_Whitepaper-2_0.pdf]
Inter-Cloud

Network economics & Future Internet

• **Data Centers are like Factories**
  – Number 1 Goal: Maximize useful work per dollar spent

• **And the future network of networks?**
  – Incentives for re-architecturing the Internet? DC-driven incentives???

• **Think like an economist/industrial engineer as well as a computer scientist**
  – Understand where the dollar costs come from
  – Use computer science to reduce/eliminate the costs / complexity

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1 cf. Greenberg SIGMETRICS tutorial
2 Preliminary data [Nikander’09]