

# Distributed Computing: Utilities, Grids & Clouds

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Terms such as 'Cloud Computing' have gained a lot of attention, as they are used to describe emerging paradigms for the management of information and computing resources. This report describes the advent of new forms of distributed computing, notably grid and cloud computing, the applications that they enable, and their potential impact on future standardization.

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## Acknowledgements

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The opinions expressed in this report are those of the authors and do not necessarily reflect the views of the International Telecommunication Union or its membership.

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## Distributed Computing: Utilities, Grids & Clouds

The spread of high-speed broadband networks in developed countries, the continual increase in computing power, and the growth of the Internet have changed the way in which society manages information and information services.

Geographically distributed resources, such as storage devices, data sources, and supercomputers, are interconnected and can be exploited by users around the world as single, unified resource. To a growing extent, repetitive or resource-intensive IT tasks can be outsourced to service providers, which execute the task and often provide the results at a lower cost. A new paradigm is emerging in which computing is offered as a utility by third parties whereby the user is billed only for consumption. This service-oriented approach from organizations offering a large portfolio of services can be scalable and flexible.

This report describes the advent of new forms of distributed computing, notably grid and cloud computing, the applications that they enable, and their potential impact on future standardization. The idea of distributing resources within computer networks is not new. It dates back to remote job entry on mainframe computers and the initial use of data entry terminals. This was expanded first with minicomputers, then with personal computers (PCs) and two-tier client-server architecture. While the PC offered more autonomy on the desktop, the trend is moving back to client-server architecture with additional tiers, but now the server is not in-house.

Not only improvements in computer component technology but also in communication protocols paved the way for distributed computing. Networks based on Systems Network Architecture (SNA), created by IBM in 1974, and on ITU-T's X.25, approved in March 1976<sup>1</sup>, enabled large-scale public and private data networks. These were gradually replaced by more efficient or less complex protocols, notably TCP/IP. Broadband networks extend the geographical reach of distributed computing, as the client-server

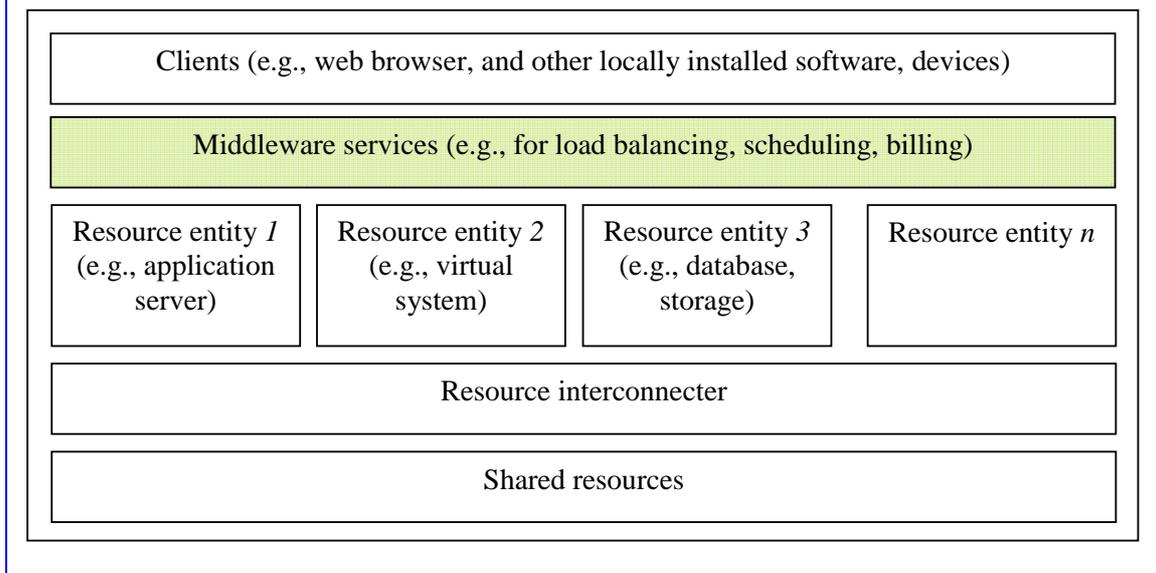
relationship can extend across borders and continents.

A number of new paradigms and terms related to distributed computing have been introduced, promising to deliver IT as a service. While experts disagree on the precise boundaries between these new computing models, the following table provides a rough taxonomy.

New Computing Paradigms	New Services	New or enhanced Features
<ul style="list-style-type: none"> <li>• Cloud computing</li> <li>• Edge computing</li> <li>• Grid computing</li> <li>• Utility computing</li> </ul>	<ul style="list-style-type: none"> <li>• Software as a Service (SaaS)</li> <li>• Infrastructure as a Service (IaaS)</li> <li>• Platform as a Service (PaaS)</li> <li>• Service-Oriented Architecture (SOA)</li> </ul>	<ul style="list-style-type: none"> <li>• Ubiquitous access</li> <li>• Reliability</li> <li>• Scalability</li> <li>• Virtualization</li> <li>• Exchangeability / Location independence</li> <li>• Cost-effectiveness</li> </ul>

It is difficult to draw lines between these paradigms: Some commentators say that grid, utility and cloud computing refer to the same thing; others believe there are only subtle distinctions among them, while others would claim they refer to completely different phenomenon.<sup>2</sup> There are no clear or standard definitions, and it is likely that vendor A describes the feature set of its cloud solution differently than vendor B. The new paradigms are sometimes analogized to the electric power grid, which provides universal access to electricity and has had a dramatic impact on social and industrial development.<sup>3</sup> Electric power grids are spread over large geographical regions, but form a single entity, providing power to billions of devices and customers, in a relatively low-cost and reliable fashion.<sup>4</sup> Although owned and operated by different organizations at different geographical locations, the components of grids appear highly heterogeneous in their physical characteristics. Its users only rarely know about the details of operation,

**Figure 1: Stack of a distributed system**



or the location of the resources they are using.

In general terms, a distributed system is “is a collection of independent computers that appears to its users as a single coherent system” (Andrew S. Tanenbaum)<sup>5</sup>. A second description of distributed systems by Leslie Lamport points out the importance of considering aspects such as reliability, fault tolerance and security when going distributed: “You know you have a distributed system when the crash of a computer you’ve never heard of stops you from getting any work done.”<sup>6</sup>

Even without a clear definition for each of the distributed paradigms: clouds and grids have been hailed by some as a trillion dollar business opportunity.<sup>7</sup>

### Shared resources

The main goal of a distributed computing system is to connect users and IT resources in a transparent, open, cost-effective, reliable and scalable way.

The resources that can be shared in grids, clouds and other distributed computing systems include:

- Physical resources
  - Computational power
  - Storage devices
  - Communication capacity
- Virtual resources, which can be exchanged and are independent from its physical location; like virtual memory
  - Operating systems
  - Software and licenses
  - Tasks and applications
  - Services

Figure 1 outlines a possible composition of a distributed system. Similar system stacks have been described, e.g., specifically for clouds<sup>8</sup> and grids<sup>9</sup>, and in a simplified stack with three layers<sup>10</sup>: application layer, mediator (=resource interconnector), and connectivity layer (=shared resources).

The client layer is used to display information, receive user input, and to communicate with the other layers. A web browser, a Matlab computing client or an Oracle database client suggest some of the applications that can be addressed.

A transparent and network-independent middleware layer plays a mediating role: it connects clients with requested and provisioned resources, balances peak loads between multiple resources and customers, regulates the access to limited resources (such as processing time on a supercomputer), monitors all activities, gathers statistics, which can later be used for billing and system management. The middleware has to be reliable and always available. It provides interfaces to over- and underlying layers, which can be used by programmers to shape the system according to their needs. These interfaces enable the system to be scalable, extensible, and to handle peak loads, for instance during the holiday season (see Box 1).

Different resources can be geographically dispersed or hosted in the same data center. Furthermore, they can be interconnected. Regardless of the architecture of the resources, they appear to the user/client as one entity. Resources can be formed into

## Box 1: Amazon.com holiday sales 2002-2008

	2002	2003	2004	2005	2006	2007	2008
Number of items ordered on peak day	1.7m	2.1m	2.8m	3.6m	4m	5.4m	6.3m
Average number of items ordered per second on peak day	20	24	32	41	46	62.5	72.9

Amazon.com, one of the world's largest online retailers, announced that 6.3 million items were ordered on the peak day of the holiday season on 15 December 2008 – a multiple of the items sold on an ordinary business day. This is 72.9 items per second on average.

Source: Amazon.com press releases, 2002-2008

virtual organizations, which again can make use of other resources.

Provided that the service meets the technical specifications defined in a Service Level Agreement, for some users the location of the data is not an issue. However, the users of distributed systems need to consider legal aspects, questions of liability and data security, before outsourcing data and processes. These issues are addressed later in this report.

### Grid computing

Grid computing enables the sharing, selection, and aggregation by users of a wide variety of geographically distributed resources owned by different organizations and is well-suited for solving IT resource-intensive problems in science, engineering and commerce.

Grids are very large-scale virtualized, distributed computing systems. They cover multiple administrative domains and enable virtual organizations.<sup>11</sup> Such organizations can share their resources collectively to create an even larger grid.

For instance, 80,000 CPU cores are shared within EGEE (Enabling Grids for E-science), one of the largest multi-disciplinary grid infrastructure in the world. This brings together more than 10,000 users in 140 institutions (300 sites in 50 countries) to produce a reliable and scalable computing resource available to the European and global research community.<sup>12</sup> High-energy physics (HEP) is one of the pilot application domains in EGEE, and is the largest user of the grid infrastructure. The four Large Hadron Collider (LHC) experiments at CERN<sup>13</sup>, Europe's central organization for

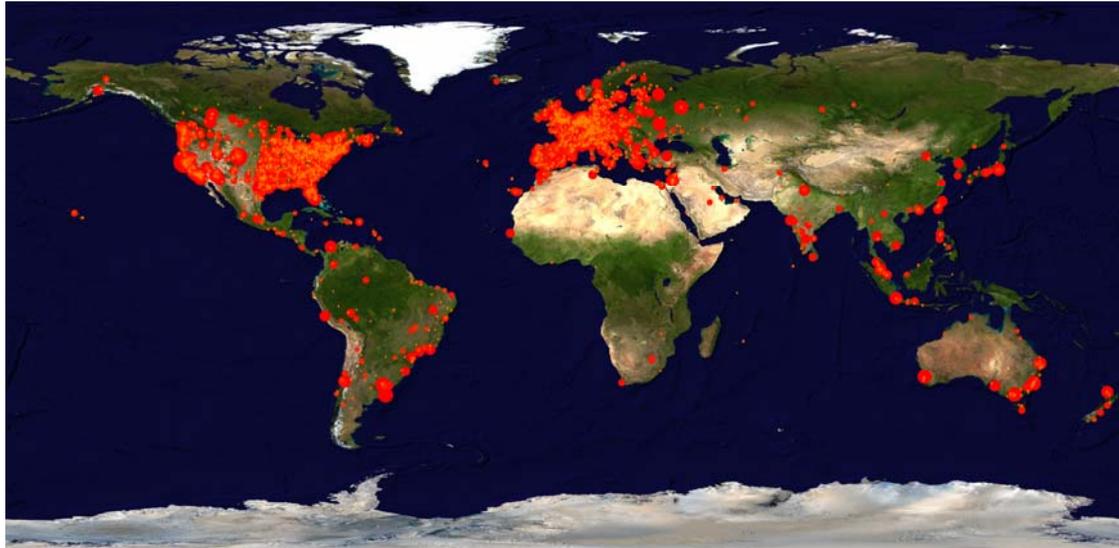
nuclear research, have a production which involves more than 150,000 daily jobs sent to the EGEE infrastructure and generates hundreds of terabytes of data per year. This is done in collaboration with the Open Science Grid (OSG<sup>14</sup>) project in the USA and the Nordic Data Grid Facility (NDGF<sup>15</sup>).

The CERN grid is also used to support research communities outside the field of HEP. In 2006, the ITU-R Regional Radio Conference (RRC06<sup>16</sup>) established a new frequency plan for the introduction of digital broadcasting in the VHF (174-230 MHz) and UHF (470-862 MHz) bands. The complex calculations involved required non-trivial dependable computing capability. The tight schedule at the RRC06 imposed very stringent time constraints for performing a full set of calculations (less than 12 hours for an estimate of 1000 CPU/hours on a 3 GHz PC).

The ITU-R developed and deployed a client-server distributed system consisting of 100 high speed (3.6 GHz) hyper-thread PCs, capable of running 200 parallel jobs. To complement the local cluster and to provide additional flexibility and reliability to the planning system it agreed with CERN to use resources from the EGEE grid infrastructure (located at CERN and other institutions in Germany, Russia, Italy, France and Spain).

UNOSAT<sup>17</sup> is a humanitarian initiative delivering satellite solutions to relief and development organizations within and outside the UN system for crisis response, early recovery and vulnerability reduction. UNOSAT uses the grid to convert uncompressed satellite images into JPEG2000 ECW<sup>18</sup> files. UNOSAT has already been involved in a number of joint activities

**Box 2: Folding@home: What is protein folding and how is folding linked to disease?**



Proteins are biology's workhorses, its "nanomachines." Before proteins can carry out these important functions, they assemble themselves, or "fold." The process of protein folding, while critical and fundamental to virtually all of biology, in many ways remains a mystery. Moreover, when proteins do not fold correctly (i.e. "misfold"), there can be serious consequences, including many well known diseases, such as Alzheimer's, Mad Cow (BSE/CJD), Huntington's, Parkinson's, and many cancers.

Folding@home uses distributed computing to simulate problems millions of times more challenging than previously achieved, by interconnecting idle computer resources of individuals from throughout the world, represented as red dots in the Figure above (May 2008). More than 400,000 CPUs are active, corresponding to a performance of 4.5 PFLOPS.

Source: <http://folding.stanford.edu/>

with ITU, particularly in providing satellite imagery for humanitarian work<sup>19</sup>.

In volunteer computing, individuals donate unused or idle resources of their computers to distributed computing projects such as SETI@home<sup>20</sup>, Folding@home<sup>21</sup> (see Box 2) and LHC@home<sup>22</sup>. A similar mechanism has also been implemented by ITU-R utilizing idle PCs of ITU's staff to carry out the monthly compatibility analysis of HF broadcasting schedules at nighttime.

The resources of hundreds and thousands PCs are organized with the help of middleware systems. The Berkeley Open Infrastructure for Network Computing (BOINC<sup>23</sup>) is the most widely-used middleware in volunteer computing made available to researchers and their projects.

Grid technology has emerged from the scientific and academic communities and entered the commercial world. For instance, the world's largest company and banking group<sup>24</sup> HSBC uses a grid with more than

3,500 CPUs operating in its data centers in four countries to carry out derivative trades, which rely on making numerous calculations based on future events, and risk analysis, which also looks to the future, calculating risks based on available information<sup>25</sup>. The German shipyard FSG<sup>26</sup> uses high performance computing resources to solve complex and CPU-intensive calculations to create individual ship designs in a short time. On-demand access to resources, which are not available locally or which are only needed temporarily, reduces cost of ownership and reduces technical and financial risks in the ship design. By increasing the availability of computing resources and helping to integrate data, grid computing enables organizations to address problems that were previously too large or too complex for them to handle alone. Other commercial applications of grid computing can be found in logistics, engineering, pharmaceuticals and the ICT sector.<sup>27</sup>

### Utility computing

The shift from using grids for non-commercial scientific applications to using them in processing-intensive commercial applications led to also using distributed systems for less challenging and resource-demanding tasks.

The concept of utility computing is simple: rather than operating servers in-house, organizations subscribe to an external utility computing service provider and pay only for the hardware and software resources they use. Utility computing relies heavily on the principle of consolidation, where physical resources are shared by a number of applications and users. The principal resources offered include, but are not limited to, virtual computing environments (paid per hour and data transfer), and storage capacity (paid per GB or TB used).

It is assumed that in-house data centers are idle most of the time due to over-provisioning. Over-provisioning is essential to be sure they can handle peak loads (e.g., opening of the trading day or during holiday shopping seasons), including unanticipated surges in demand. Utility computing allows companies to pay only for the computing resources they need, when they need them.<sup>28</sup> It also creates markets for resource owners to sell excess capacities, and therefore make their data centers (and business) more profitable. The example of online retailer Amazon was mentioned in Box 1. To increase efficiency, one Amazon server can host, in addition to a system managing the company's e-commerce services, multiple other isolated computing environments used by its customers. These virtual machines are software implementations of 'real' computers that can be customized according to the customers' needs: processing power, storage capacity, operating system (e.g., Linux, MS Windows), software, etc.

With the increasing availability of broadband networks in many countries, some computer utility providers do not necessarily need to be geographically distributed or in close proximity to clients: providers tend to build their data centers in areas with the lowest costs, e.g., for electricity, real estate, etc. and with access to renewable energy (e.g. hydroelectric).

However, in many cases it proves useful to employ data centers close to the customer, for example to ensure low rates of latency and packet loss in content delivery applications. For example, content delivery providers such as Akamai<sup>29</sup> or Limelight Networks<sup>30</sup> built their networks of data centers around the globe, and interconnect them with high-speed fiber-optic backbones. These are directly connected to user access networks, in order to deliver to a maximum of users simultaneously, while minimizing the path between the user and the desired content.

### Cloud computing

Over the years, technology and Internet companies such as Google, Amazon, Microsoft and others, have acquired a considerable expertise in operating large data centers, which are the backbone of their businesses. Their know-how extends beyond physical infrastructure and includes experience with software, e.g., office suites, applications for process management and business intelligence, and best practices in a range of other domains, such as Internet search, maps, email and other communications applications. In cloud computing, these services are hosted in a data center and commercialized, so that a wide range of software applications are offered by the provider as a billable service (Software as a Service, SaaS) and no longer need to be installed on the user's PC.<sup>31</sup> For example, instead of Outlook stored on the PC hard drive, Gmail offers a similar service, but the data is stored on the providers' servers and accessed via a web browser.

For small and medium-sized enterprises, the ability to outsource IT services and applications not only offers the potential to reduce overall costs, but also can lower the barriers to entry for many processing-intensive activities, since it eliminates the need for up-front capital investment and the necessity of maintaining dedicated infrastructure. Cloud providers gain an additional source of revenue and are able to commercialize their expertise in managing large data centers.

One main assumption in cloud computing consists of infinite computing resources available on demand and delivered via broadband. However that is not always the

case. Problems faced by users in developing countries include the high cost of software and hardware, a poor power infrastructure, and limited access to broadband. Low-cost computing devices<sup>32</sup> equipped with free and open source software might provide a solution for the first problem. Although the number of broadband Internet subscribers has grown rapidly worldwide, developed economies still dominate subscriptions, and the gap in terms of penetration in developed and developing countries is widening<sup>33</sup>. Internet users without broadband access are disadvantaged with respect to broadband users, as they are unable to use certain applications, e.g., video and audio streaming, online backup of photos and other data. Ubiquitous and unmetered access to broadband Internet is one of the most important requirements for the success of cloud computing.

Applications available in the cloud include software suites that were traditionally installed on the desktop and can now be found in the cloud, accessible via a web browser (e.g., for word processing, communication, email, business intelligence applications, or customer relationship management). This paradigm may save license fees, costs for maintenance and software updates, which makes it attractive to small businesses and individuals. Even some large companies have adopted cloud solutions with the growing capacities, capabilities and success of the service providers. Forrester Research suggests that cloud-based email solutions would be less expensive than on-premise solutions for up to 15,000 email accounts.<sup>34</sup> Another approach is to outsource certain tasks to the cloud, e.g., spam and virus filtering, and to keep other tasks in the corporate data center, e.g., the storage of the mailbox.

Other typical services offered include web services for search, payment, identification and mapping.

## Utility and cloud providers

The list of providers of utility and cloud computing services is growing steadily. Beside many smaller providers specialized cloud and grid services, such as 3tera<sup>35</sup>, FlexiScale<sup>36</sup>, Morph Labs<sup>37</sup>, RightScale<sup>38</sup>, are some of the best known names in web and enterprise computing, of which three (still) have their core activities in other areas (online retail, Internet search, software) are:<sup>39</sup>

- Amazon Web Services (AWS) provide companies of all sizes with an infrastructure platform in the cloud, which includes computational power, storage, and other infrastructure services.<sup>40</sup> The AWS product range includes EC2 (Elastic Compute Cloud), a web service that provides computing capacity in the cloud, and S3 (Simple Storage Service), a scalable storage for the Internet, that can be used to store and retrieve any amount of data, at any time, from anywhere on the web.
- Google App Engine is a platform for building and hosting web applications on infrastructure operated by Google. The service is currently in "preview", allowing developers to sign up for free and to use up to 500MB of persistent storage and enough CPU and bandwidth for about 5 million page views a month.<sup>41</sup>
- Salesforce.com is a vendor of Customer Relationship Management (CRM) solutions, which it delivers using the software as a service model. CRM solutions include applications for sales, service and support, and marketing. Force.com is a Platform-as-a-Service product of the same vendor that allows external developers to create add-on applications that integrate into the CRM applications and to host them on the vendor's infrastructure.<sup>42</sup>
- The Azure Services Platform (Azure) is a cloud services platform hosted in Microsoft data centers, which provides an operating system and a set of developer services that can be used individually or together. After completing its "Community Technology Preview" launched in October 2008, the services will be priced and licensed through a consumption-based model.<sup>43</sup>

While there are different pricing models, so-called consumption-based models, sometimes referred to as "Pay As You Go" (PAYG), are quite popular and measure the resources used to determine charges, e.g.,

- Computing time, measured in machine hours
- Transmissions to and from the data center, measured in GB
- Storage capacity, measured in GB
- Transactions, measured as application requests

In these types of arrangements, customers are not tied to monthly subscription rates, or other advance payments; they pay only for what they use.

### Cloud computing and information policy

While the main focus of this report is on the impact of distributed computing on future standards work, it should be noted that the continued and successful deployment of computing as a utility presents other challenges, including issues of privacy, security, liability, access, and regulation. Distributed computing paradigms operate across borders, and raise jurisdiction and law enforcement issues similarly to those of the Internet itself. These issues are briefly described below.

**Reliability and liability:** As with any other telecommunications service, users will expect the cloud to be a reliable resource, especially if a cloud provider takes over the task of running “mission-critical” applications, and will expect clear delineation of liability if serious problems occur. Although service disruptions will become increasingly rare, they cannot be excluded. Data integrity and the correctness of results are other facets of reliability. Erroneous results, data lost or altered due to service disruptions can have a negative impact on the business of the cloud user. The matters of reliability, liability and QoS can be determined in service-level agreements.

**Security, privacy, anonymity:** It may be the case that the levels of privacy and anonymity available to the user of a cloud will be lower than the user of desktop applications.<sup>44</sup> To protect the privacy of cloud users, care must be taken to guard the users’ data and applications for manipulating that data. Organizations may be concerned about the security of client data and proprietary algorithms; researchers may be concerned about unintended release of discoveries; individuals may fear the misuse of sensitive personal information. Since the physical infrastructure in a distributed computing environment is shared among its users, any doubts about data security have to be overcome.

**Access and usage restrictions:** In addition to privacy concerns, the possibility of storing and sharing data in clouds raises concerns about copyright, licenses, and intellectual property. Clouds can be accessed at any time, by any user with an Internet connection, from any place. Licensing, usage agreements and intellectual property rights may vary in different participating countries, but the cloud hides these differences, which can cause problems.

Governments will need to carefully consider the appropriate polices and levels of regulation or legislation to provide adequate safeguards for distributed computing, e.g. by mandating greater precision in contracts and service agreements between users and providers, with a possible view to establishing some minimal levels of protection. These may include:

- Basic thresholds for reliability;
- Assignment of liability for loss or other violation of data;
- Expectations for data security;
- Privacy protection;
- Expectations for anonymity;
- Access and usage rights.

Gartner summarizes seven issues cloud customers should address before migrating from in-house infrastructure to external resources: privileged user access, regulatory compliance, data location, data segregation, data recovery, investigative support, and long-term viability.<sup>45</sup>

While different users (e.g., individuals, organizations, researchers) may have different expectations for any of these points when they “outsource” their data and processes to a cloud or grid, it is necessary that both providers and policy makers address these issues in order to foster user trust and to handle eventual events of damage or loss.

### Future standardization work

Parallels can be drawn between the current state of distributed computing and the early days of networking: independent islands of systems with little interoperability, only few standards and proprietary management interfaces:

“The problem is that there’s no standard to move things around. I

think it's the biggest hurdle that cloud computing has to face today. How do we create an open environment between clouds, so that I can have some things reside in my cloud and some things in other people's data center? A lot of work needs to be done." Padmasree Warrior, CTO, Cisco<sup>46</sup>

The key to realizing the full benefits of cloud and grid computing may well lie in standardization, particularly in the middleware layer and the area of resource interconnection.

In addition to the questions about reliability, liability, trust, etc., discussed above, the users of distributed computing infrastructure also are likely to be concerned about portability and interoperability.

Portability, the freedom to migrate data on and off the clouds of different providers, without significant effort and switching costs, should be a major focus of attention in standardization. Furthermore, standardized solutions for automation, monitoring, provisioning and configuration of cloud and grid applications need to be found, in order to provide interoperability. Users may want to employ infrastructure and services from different providers at the same time.

Today's services include both proprietary and open source solutions. Many of them provide their own APIs (application programming interfaces) that improve interoperability by allowing users to adapt their code and applications according to the requirements of the service. However, the APIs are essentially proprietary and have not been subject of standardization, which means that users cannot easily extract their data and code from one site to run on another. Instead they need to repeat adaptation efforts for each cloud service used. Global standards could allow services of different vendors to interoperate. Standardized interfaces would allow users to use the same code on different distributed computing solutions, which could additionally decrease the risk of a total loss of data.

On the provider side, there could be an interest in standards for distributed network management, memory management and load balancing, identity management and security, and standards that allow for

scalability and extensibility of their infrastructure. Standards work in these areas will need to be aware of those who contend that such efforts are premature and could impede innovation.<sup>47</sup>

### Other SDOs

Among the bodies engaged in the standardization of distributed computing concepts are:

Common Component Architecture Forum (CCA)	<a href="http://www.cca-forum.org">http://www.cca-forum.org</a>
Distributed Management Task Force (DMTF)	<a href="http://www.dmtf.org">http://www.dmtf.org</a>
Globus Alliance	<a href="http://www.globus.org">http://www.globus.org</a>
Organization for the Advancement of Structured Information Standards (OASIS)	<a href="http://www.oasis-open.org">http://www.oasis-open.org</a>
Open Grid Forum (OGF)	<a href="http://www.ogf.org">http://www.ogf.org</a>
Optical Internetworking Forum (OIF)	<a href="http://www.oiforum.com">http://www.oiforum.com</a>
TeleManagement Forum (TMF)	<a href="http://www.tmforum.org">http://www.tmforum.org</a>

The objective of the Common Component Architecture (CCA) Forum, formed by members of the academic high-performance computing community, is to define standards interfaces that a framework has to provide to components, and can expect from them, in order to allow disparate components to be interconnected. Such standards would promote interoperability between components developed by different teams across different institutions.

The Distributed Management Task Force (DMTF) is a group of 160 member companies and organizations that develops and maintains standards for systems management of IT environments in enterprises and the Internet. These standards enable management interoperability among multi-vendor systems, tools, and solutions within the enterprise in a platform-independent and technology-neutral way. DMTF standards include:

- Common Information Model (CIM). Defines how managed elements in an IT environment are represented as a common set of objects and relationships

between them. This is intended to allow consistent management of these elements, and to interconnect them, independent of their manufacturer or provider.

- Web-Based Enterprise Management (WBEM) is a set of standardized system management technologies for the remote management of heterogeneous distributed hardware and software devices.
- Open Virtualization Format (OVF) is an open standard used in the resource layer for packaging and distributing virtual appliances or more generally software to be run in virtual machines.

The OGF is an open community committed to driving the rapid evolution and adoption of applied distributed computing. This is critical to developing new, innovative and scalable applications and infrastructures that are seen as essential to productivity in the enterprise and the scientific community. Recommendations developed by the OGF cover middleware and resource interconnection layers and include

- Open Grid Services Architecture (OGSA), which describes a service-oriented grid computing environment for business and scientific use.
- Distributed Resource Management Application API (DRMAA), a high-level specification for the submission and control of jobs to one or more Distributed Resource Management Systems (DRMS) within a grid architecture.
- Configuration Description, Deployment, and Lifecycle Management (CDDL) Specification, a standard for the management, deployment and configuration of grid service lifecycles or inter-organization resources.

The Globus Alliance is a community of organizations and individuals developing fundamental technologies for the grid. The Globus Toolkit is an open source grid middleware component that provides a standard platform for services to build upon. The toolkit includes software for security, information infrastructure, resource management, data management, communication, fault detection, and portability.

The TeleManagement Forum (TMF) is an industry association focused on transforming business processes, operations and systems for managing and economizing online information, communications and entertainment services. Existing Internet standards, such as HTTP, XML, SSL/TLS, developed at W3C, IETF, etc. play an important role in the communication between client and middleware.

### ITU-T

The ITU-T has approved a number of Recommendations that indirectly impact on distributed computing.

These concern technical aspects, for instance the work on multimedia coding in Study Group 16, or on telecommunication security in Study Group 17, as well as operational aspects, accounting principles and QoS, treated in Study Groups 2, 3 and 12.

ITU-T Study Groups 13 and 15<sup>48</sup> have liaisons with the Optical Internetworking Forum (OIF), which provides interoperability agreements (IAs) that standardize interfaces for the underlying communication infrastructure to enable the resources to be dynamically interconnected.

ITU-T Recommendations of the E-Series ("Overall network operation, telephone service, service operation and human factors") address some of these points and provide, *inter alia*, definitions related to QoS (E.800) and propose a framework of a Service Level Agreement (E.860).

Recommendations in the ITU-T M.3000 series describe the Telecommunication Management Network protocol model, which provides a framework for achieving interconnectivity and communication across heterogeneous operation systems and telecommunication networks. The TMF multi-technology network management solution is referenced in ITU-T Recommendation M.3170.0 ff.

### Conclusion

This Report describes different paradigms for distributed computing, namely grid, utility and cloud computing. The spread of communication networks, and in particular the growth of affordable broadband in developed countries, has enabled

organizations to share their computational resources. What originally started as grid computing, temporarily using remote supercomputers or clusters of mainframes to address scientific problems too large or too complex to be solved on in-house infrastructures, has evolved into service-oriented business models that offer physical and virtual resources on a pay as you go basis – as an alternative to often idle, in-house data centers and stringent license agreements.

The user can choose from a huge array of different solutions according to its needs. Each provider offers its own way of accessing the data, often in the form of APIs. That complicates the process of moving from one provider to another, or to interconnect different cloud platforms. Increased focus on standards for interfaces, and other areas suggested in the report, would enable clouds and grids to be commoditized and would ensure interoperability.

## Notes, sources and further reading

- <sup>1</sup> <http://www.itu.int/ITU-T/studygroups/com17/history.html>
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