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ever the past few years, cloud computing has rapidly emerged as a widely accepted computing paradigm built around core concepts such as on-demand computing resources, elastic scaling, elimination of up-front capital and operational expenses, and establishing a pay-as-you-go business model for computing and information technology services. With the widespread adoption of virtualization, service-oriented architectures, and utility computing there has been a significant development in the creation of cloud support structures to deliver IT services within QoS bounds, service level agreements, and security and privacy requirements.

While cloud data centers are dominated by the server and infrastructure costs followed by networking and power, it turns out that networking and systems innovations are the key to the success of the cloud. The capital cost of networking gear for data centers is a significant portion of the cost of networking and is concentrated primarily in switches and routers, load balancers. The remaining networking costs are concentrated in wide area networking, such as peering, data center links, and regional back-haul facilities needed to reach wide area network interconnection sites [1]. The value of the wide area network is shared across the data centers, and costs vary with industry dynamics (e.g., with tariffs), and are sensitive to site selection. Clever design of peering and transit strategies combined with optimal placement of micro and mega data centers therefore have a role to play in reducing network costs which can be further reduced by optimizing the network usage through better design of the services themselves, and better partitioning of their functionality. For example, with micro centers built out close to users, the latency of response can be reduced, but under the threat of substantial increases in wide area network costs. Networking has a role in data partitioning and replication, which requires better methods for design and management of traffic across the network of data centers, as well as better algorithms to map users to data centers.

Significant advancements in virtualization technologies have led to the development of large clouds that exist today. Virtualization creates several networking challenges that arise at the data link (layer 2) and network (layer 3) layers, which must be overcome by the networking gear (switches and routers) used in creating cloud computing infrastructure. Cloud computing networks must contend with a large number of attached devices consisting of physical and virtual devices, a large number of independent subnetworks, collocated software components belonging to different applications, and automated creation, deletion, and live migration of virtual machines — all of which may possibly come from different vendors. In order to be able to create a true multivendor cloud infrastructure that supports resource pooling the standardization of components is of utmost importance.

In the Call for Papers for this feature topic we solicited contributions on “networking and communication challenges” that need to be addressed for the long-term success of cloud computing. We kept our scope wider to consider all aspects of the infrastructure, which included computing centers, data centers, the cloud network, and the supported end-user services. The challenges related to the architecture, performance, reliability, security, maintainability, and virtualization were all within the scope of this issue. From the numerous submissions we have accepted four manuscripts for this special issue.

The first article in this feature topic, “Connecting Through Clouds: Open Standards and Proprietary Protocols for Data Center Networking,” discusses the standardization protocols for switches and routers used in clouds at layers 2 and 3. It also presents a few proprietary protocols used in equipment manufactured by commercial vendors. One such standardized protocol is Spanning Tree Protocol (STP), which is a layer 2 switching protocol that creates a loop-free single-path tree structure for the entire network. STP, which works well in classical Ethernet, suffers from several limitations when deployed in the cloud such as:

• Reduction in aggregate bandwidth as a result of blocking of redundant paths.
• Scalability.
• Path isolation.
• Support for multiple applications — multiple tenancy
• The need to discover a new path if a node or a link fails on a given path adds latency of several seconds to minutes, causing disruptions to virtual machine migrations.

To overcome the limitations of STP, Multiple Spanning Tree Protocol (MSTP) and Link Aggregation Group (LAG, IEEE 802.3ad) protocols have been standardized. The extension of LAG is called multicell link aggregation (MC-LAG), which creates loop-free topology, allows dual homing, and works with existing management and multicast protocols. It has been extensively deployed. Equal Cost Multi-Pathing (ECMP) is also a standardized layer 3 protocol, which can be adapted to cloud computing due to its ability to create multiple load-balanced paths that can provide variable bandwidths depending on the needs of the applications. However, one of the limita-
appear in the literature. In addition, the authors also exam-
hybrid clouds and surveys some of the schedulers that have
Hybrid Clouds," deals with the problem of scheduling in
and hotspot mitigation.
the literature to achieve server consolidation, load balancing,
OpenFlow is a new industry standard that achieves virtualiza-
tion using software defined networking (SDN). It supports fea-
tures such as packet flows, topology change, QoS, firewalls,
statistical analysis of data streams, and network management.
Besides the standardized protocols, this article also discusses a
few proprietary protocols that are vendor specific. For example,
Cisco uses a layer two protocol called FabricPath which is
TRILL like but has a better performance when it comes to cre-
ating of a large number of virtual machines and MAC addre-
s. Similarly, Virtual Cluster Switching (VCS) and QFabric are
used by Brocade and Juniper Networks, respectively.
Without virtualization it is hard to imagine if cloud com-
puting could have emerged as a new computing paradigm.
Virtualization hinges on the management of virtual machines
(VMs) to achieve optimum utilization of cloud resources. The
second article of this special issue, "Dynamic Resource Man-
agement Using Virtual Machine Migration," discusses the
importance of VM migration in clouds. Virtual machine
migration is needed in clouds to:
• Conserve energy, memory, and bandwidth resources
• Solve load imbalance among servers to meet application
performance requirements
• Achieve server consolidation, which advocates use of a
few servers with higher loads supporting a workload than
on many lightly loaded servers
Consolidation also reduces server sprawl. One of the beauties
of VMs is that they can be migrated from one server to the
other live even while executing applications, and thus can
mit-
gate server hotspots as and when they arise.
A cloud is a very dynamic resource where new VMs are
created as jobs arrive, and old machines are removed as
jobs complete their demands. Management of resources
therefore needs to be done dynamically using heuristics-based
algorithms to decide which client tasks should be executed on
the public cloud. Performance results computed using three
different schedulers confirm the importance of available band-
width between the private and public clouds. The fourth arti-
cle of this special issue, “Toward Cloud Ready Transport
Network,” discusses the need for evolving the existing trans-
port networks to provide high-bandwidth connectivity to data
centers on demand. To be able to provision such services, the
authors propose that the transport networks must be capable
of supporting automatic network configuration, adaptive
bandwidth allocation, and multilayer network control driven
by cross-layer optimization of available resources. The article
suggests that, fortunately, several standard interfaces for con-
trol/management plane already exist. These interfaces can
facilitate cross-layer optimization to improve the utilization
of network resources, and reduction in infrastructure costs.
We would like to thank all authors who submitted manuscrip-
tis to this special issue and the reviewers for their wis-
dom in helping us select the four articles that are included here.
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