Current Trends and Future Directions in Community Edge Clouds

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***Abstract*—Cloud computing promises access to computing resources that is cost-effective, elastic and easily scalable. With few key cloud providers in the field, despite the benefits, there are issues like vendor lock-in, privacy and control over data. In this paper we focus on alternative models of cloud computing, like the community clouds at the edge which are built collaboratively using the resources contributed by the users, either through solely relying on users' machines, or using them to augment existing cloud infrastructures. We study community network clouds in the context of other initiatives in community cloud computing, mobile cloud computing, social cloud computing, and volunteer computing, and analyse how the context of community networks can support the community clouds.**

***Index Terms*—cloud computing; community clouds**

I. Introduction

Cloud computing has emerged as a cost-effective, elastic and scalable way to build and support Internet applications, but issues like privacy, security, control over data and applications, performance, reliability, availability and access to specific cloud services have led to different cloud deployment models. Among these deployment models, the public cloud offers services of generic interest over the Internet, available to anybody who signs in with its credentials. On the other side, the private cloud model aims to provide cloud services to only a specific user group, such as a company, and the cloud infrastructure is isolated by firewalls avoiding public access. Finally, when a private cloud is combined with the public cloud, for instance some functionality of the cloud is provided by the public cloud and some remains in the private cloud, this is referred to as hybrid cloud.

The community cloud bridges in different aspects the gap between the public cloud, the general purpose cloud available to all users, and the private cloud, available to only one cloud user with user-specific services. The concept of community cloud computing has been introduced in its generic form before, e.g. [1], as a cloud deployment model in which a cloud infrastructure is built and provisioned for an exclusive use by a specific community of consumers with shared concerns and interests, owned and managed by the community or by a third party or a combination of both. Just as cloud computing can involve variety of definitions depending upon how the services are provisioned and consumed, community cloud computing can have different interpretations depending upon the specific requirements and characteristics of the community, and how the infrastructures are deployed and services are provisioned. In this paper, our focus is on the collaborative model of provisioning community cloud services based on volunteer computing paradigm as laid out in [2]. We study the existing work and analyse the current trends and the future research directions of this collaboration based community cloud computing model. We then explore this in the context of community networks which are a successful case of collaboratively built communication infrastructure, and we see community cloud services as the logical next step in the evolution of community networks.

II. Community Cloud Initiatives

The community cloud systems are designed with the requirements of the community of the users they are to serve, so as to encourage contribution and participation by the community members. This shows that besides the technical challenges, community clouds require a strong value proposition in the specific social and economic context of the targeted communities to ensure uptake and sustainability of the proposed cloud solution among the community. There have been quite a few community cloud ideas and implementations investigated in different contexts, as we discuss in detail below.

A. Volunteer Cloud Computing

The idea of building cloud infrastructure using resources contributed by a community of users [2], follows on from earlier volunteer distributed computing platforms like SETI@Home [3] and PlanetLab [4] among many others, and in the same vein, Seattle [5] project focuses on providing a cloud computing environment for educational purposes. Seattle project provides a Python based toolkit that allows the participants to share their computing resources with the community, and use the interfaces provided by the toolkit to design applications in Python taking advantage of the distributed resources of the Seattle platform.

B. Edge Cloud Computing

The idea behind edge computing is to utilise users' contributed edge resources connected through Internet to provide infrastructure for community cloud services. There are a few such research prototypes for community clouds at the edge. The Cloud@Home [6] project aims to harvest resources from the community for meeting the peaks in demand, working with public, private and hybrid clouds to form cloud federations. The P2PCS [7] project has built a prototype implementation of a decentralized peer-to-peer cloud system, with basic support for creating and managing VMs using Java JRMI technology. The Clouds@home [8] project focuses on providing guaranteed performance and ensuring quality of service even when using volatile volunteered resources connected by Internet.

C. Social Cloud Computing

Social cloud computing [9], [10] takes advantage of the trust relationships between members of the online social networks to motivate sharing of storage and computation resources, by integrating with the programming interfaces (API) of the social network services which facilitates the establishment of mutual trust and resource sharing agreements. Users can trade their excess capacity to earn virtual currency and credits that they can utilize later, and consumers submit feedback about the providers after each transaction which is used to maintain reputation of each user.

D. Mobile Cloud Computing

The work in mobile cloud computing [11] can be generally divided into two categories. The first and the most prevalent one is termed as *application offloading*, where most of the processing is done on the servers in the cloud, and the results are delivered to the mobile device, since computing and memory demands of the applications are not met by the resources on the local device. The other model is of *crowd computing*, where the aim is to employ the mobile devices both as providers and consumers of the cloud services. In this case, the computing and storage resources for the cloud infrastructure are aggregated from the mobile devices of the users [12]. This model closely matches the idea of community cloud computing, where issues like high mobility and limited capacity introduce additional constraints to the problem.

E. Scientific Research Community

Scientific research benefits from pooling in cloud computing resources across the organisations, similar to earlier Grid systems, and from contribution of resources by the users, similar to volunteer computing like PlanetLab [4]. For example, IEEE InterCloud Testbed project [13] explores federating cloud infrastructures from multiple providers.

F. ICT Services Providers

Community cloud has applications for ICT services providers through either taking advantage of customer-premises equipment (CPE) or network edge devices, for improving delivery of services and better utilisation of provider's facilities. For instance, Telefónica ClubWiFi project [14] pools together Wi-Fi connections of different customers to provide higher bandwidth, an idea that can be extended to providing other services like video-on-demand. This shows that interesting applications can be developed in future making use of the federation of large number of smaller cloud installations set up either at service providers' or consumers' end.

III. Community Network Clouds

Community networking [15] is a shared communication infrastructure in which citizens build and own open communication networks, using mostly wireless but also optical fibre links. Community networks are already based on the principle of sharing, though only of bandwidth, but the social aspects and community nature makes it easier to extend this sharing to other computing resources [16]. The strong sense of community and technical knowledge of participants of such networks are some strong points which are conducive to building cloud applications tailored to local needs built on infrastructure provided by the community members. For example, Guifi.net community network has deployed community edge cloud using their Debian-based Cloudy distribution [17].

The community network clouds need to address the conditions of community networks and satisfy their requirements. We look at the different aspects of designing community cloud systems and the challenges involved below.

A. Requirements and Challenges

A community cloud is a cloud infrastructure which is run and managed independently by various community members. In community clouds, resource distribution is very different from the existing commercial public clouds which are deployed on data centres using clusters of mostly homogeneous computers. It is also different from private and hybrid clouds where resources, though not as abundant as data centres, are still consolidated into larger entities.

1) Key Requirements: We consider the following requirements to be a foundation and guideline for the design of the community cloud system, and we believe that, if addressed, among other challenges, these requirements can largely provide a cloud system that is deployed and adopted successfully by the community.

- Autonomy
- Security
- Self-Management
- Utility
- Ease of Use
- Incentives for Contribution
- Social and Economic Mechanisms
- Support for Heterogeneity
- Standard Middleware Interfaces
- QoS and SLA Guarantees

2) Vision and Proposal: Marinos et al. [2] is one of the first work to offer a detailed vision for community cloud computing which they see as coming together of fields like green computing, volunteer computing, cloud computing and digital ecosystems.

3) Architecture and Design: Khan et al. [18] propose a collaborative distributed architecture for building a community cloud system that employs resources contributed by the members of the community network for provisioning infrastructure and software services. Such architecture needs to be tailored to the specific social, economic and technical characteristics of the community networks for community clouds to be successful and sustainable. Gall et al. [19] have explored how an InterCloud architecture [13] can be adapted to community clouds.

4) Economic Models for Resource Allocation: Community clouds need fair and efficient economic mechanisms for resource allocation and regulation for sustaining users' participation, for instance Zhao et al. [20] explore efficient and fair resource sharing among the participants in community-based cloud systems. Other recent work has also addressed different issues in efficient and optimal resource allocation [10].

5) Incentive Mechanisms: To ensure sustainability and growth of the community cloud, incentive mechanisms are needed that encourage members to contribute with their hardware, effort and time. Khan et al. [16] suggest an effort-based incentive mechanism for community cloud where effort is defined as contribution relative to the capacity of the users. Social cloud [9], [10] employs virtual currency based mechanisms to encourage users to participate for gaining credits that they can use later to request resources from the system.

6) Security, Privacy and Trust: Security and privacy gain added significance in community clouds since users are contributing with their own resources to the system, and moreover, their data and applications are placed in other contributors' machines [21].

IV. Outlook & Conclusion

Cloud computing with its success in providing virtualized resources on demand has transformed the technology landscape, revolutionising how Internet applications are developed and delivered to the users. Peer-to-peer and edge computing models have been explored in the past decade, but other than a few success stories they do not seem to make it big in the mainstream. Perhaps now is the right opportunity to take full advantage of the virtualization model of the cloud computing to design the killer applications for the community cloud. On the technical side, this allows for sophisticated applications and services that were not possible with the simple process-level isolation approaches of earlier efforts like SETI@Home or Seattle. The challenge is to provide developer tools and middleware services that streamline the process of programming and deploying the community cloud applications. At the same time, killer applications are needed that by satisfying users' critical needs and problem scenarios succeed in engaging the community for the long-term. This requires that the user experience in installing, managing and interacting with these applications is as smooth and seamless as possible, for the promise of today's cloud computing model is not just the virtually unlimited resources available instantly but also the ease with which they can be acquired and integrated.

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