Clouds of Small Things: Provisioning Infrastructure-as-a-Service from within Community Networks

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Abstract—**Community networks offer a shared communication infrastructure where communities of citizens build and own open networks. While the IP connectivity of the networking devices is successfully achieved, the number of services and applications available from within the community network is typically small and the usage of the community network is often limited to providing Internet access to remote areas through wireless links. In this paper we propose to apply the principle of resource sharing of community networks, currently limited to the network bandwidth, to other computing resources, which leads to cloud computing in community networks. Towards this vision, we review some characteristics of community networks and identify potential scenarios for community clouds. We simulate a cloud computing infrastructure service and discuss different aspects of its performance in comparison to a commercial centralized cloud system. We note that in community clouds the computing resources are heterogeneous and less powerful, which affects the time needed to assign resources. Response time of the infrastructure service is high in community clouds even for a small number of resources since resources are distributed, but tends to get closer to that of a centralized cloud when the number of resources requested increases. Our initial results suggest that the performance of the community clouds highly depends on the community network conditions, but has some potential for improvement with network-aware cloud services. The main strength compared to commercial cloud services, however, is that community cloud services hosted on community-owned resources will follow the principles of community network and will be neutral and open.**

Index Terms—**community networks; cloud computing; distributed resource sharing**

I. INTRODUCTION

Community networks represent collaborative effort of community members for building ICT infrastructure in a bottom-up approach to meet demand for Internet access and services using open unlicensed wireless spectrum and off-the-shelf communication equipment. Even with wide deployment of community networks [1], the sharing in today's community networks is still limited to bandwidth only, and does not extend to sharing of computing and storage resources which is commonplace nowadays with cloud services. The community cloud we present in this paper is the vision of a cloud deployment in community networks: A cloud hosted on community-owned computing and communication resources providing services of local interest. The concept of community clouds has been introduced in its generic form before, e.g. [2], [3], 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.

Such a community cloud built in community networks inherits the challenges of community networks, and will need to cope with:

- Hardware and software diversity: The network nodes and computers are often inexpensive off-the-shelf equipment with large heterogeneity in the hardware, software and capacity.
- Decentralized management: The network infrastructure and the computers are contributed and managed by the users. They belong to the users and are shared to build the network. There is usually no (or a rather weak) central authority that is responsible for resource provisioning.
- Dynamics: The number of network and computing nodes may rapidly change when members join or leave the network, or when nodes overload or fail.

In spite of these difficulties, community networks seem to be rather successful and there are several large community networks in Europe, having from 500 to 20,000 nodes, such as FunkFeuer[1], AWMN[2], Guifi.net[3] and Freifunk[4] among many others. Providing applications and services deployed upon community clouds using local resources can further boost the usage and spread of the community network model as ICT infrastructure for society. Even though cloud computing

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[1] http://www.funkfeuer.at

[2] http://www.awmn.gr

[3] http://www.guifi.net

[4] http://www.freifunk.net

infrastructures have emerged as a cost-effective, elastic and scalable way to build and support Internet applications, issues like privacy, security, integrity and control over data and applications still need addressing [4]–[6]. Community clouds with their open, free and neutral design based on principles of community networks [7] can address these concerns by bringing control and ownership of the data and applications back to the local communities.

Our main contribution in this paper is that we identify the scenarios for implementing a community cloud keeping in view the characteristics of community networks and with simulation experiments we analyze the behaviour of applications deployed on community cloud under these scenarios. We elaborate our contribution in the rest of the paper as following. We discuss the design of community cloud considering the conditions of community networks in section II. We evaluate in simulation experiments the resource utilization behaviour of cloud infrastructures in different scenarios in section III. We relate the work of other authors with our results in section IV, and conclude our findings and indicate future work in section V.

II. Scenarios for Community Cloud

We first analyze the conditions of community networks that need to be taken into account when developing the scenarios for community cloud, and then state the two main scenarios we foresee for community cloud. Since our community cloud aims to be deployed in real community networks [8], it is a must that the design, architecture and implementation of the community cloud fits into these conditions and scenarios. We focus our explanation on the Guifi.net community network, considered the largest community network worldwide.

A community network like Guifi.net is organized into zones where a zone can be a village, a small city, a region, or districts of a larger city. Mostly, the detailed technical support is only available within the community of the zone so we identify a zone to have the highest social strength within the community network. Figure 1 shows part of a zone in a community network where some typical community nodes have a router and some server or clients attached to them. These nodes in the community network can be classified as either super nodes (SN) or ordinary nodes (ON) depending upon their capability and function. Super nodes have at least two wireless links, each to other super nodes, and provide connectivity to ordinary nodes. Most super nodes are installed in the community network participant's premises although some can be placed strategically in third party location to improve the community network's backbone. Cloud resources can also be attached to super nodes to provide services and applications. Ordinary nodes only connect to a super node, but do not route any traffic. The ratio of super nodes to ordinary nodes in a community network is usually low, for example, a study of the Guifi.net community network [9] shows that among a total of around 17,000 nodes, only 7% are super nodes.

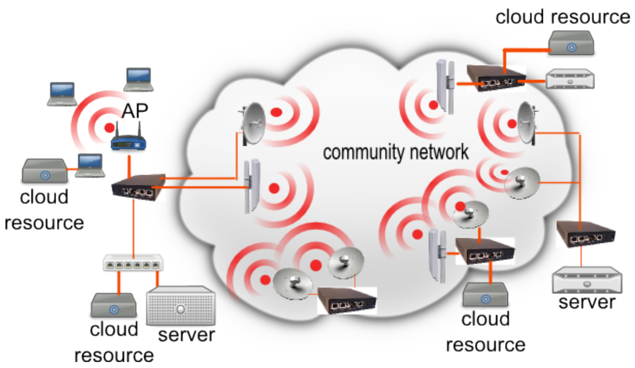

Figure 1. Nodes in a community network

A. Local Community Cloud

The scenario of the local community cloud is based on the characteristics of the social networks existing within zones and the topology of the community network. SNs with their better connectivity and high availability are made responsible for the management of a set of attached ONs contributing cloud resources. This SN runs the cloud management system software and acts as a centralized unit to manage the cloud services. This leads to a hierarchical architecture for the integration of local community cloud where responsibility is shared among nodes according to their capability.

B. Federated Community Cloud

Local community cloud can provide services for the users within its zone, however, multiple SNs from different zones in a community network can participate together in a federated community cloud [10] to support greater functionality and higher capacity. Such a federated cloud is dynamic in nature and it may grow as more local clouds merge together or break up as nodes leave the community network. When there is a sufficient number of SNs in the federated cloud, some of the more resourceful SNs can take additional responsibility for management and coordination among their neighbouring SNs.

SNs connect physically with other SNs through wireless links and logically in an overlay network to other SNs that manage local clouds. SNs coordinate among themselves for provisioning infrastructure service so the requests originating from one SN's zone can be satisfied by the resources allocated from another SN's zone. Figure 2 shows an example of a federate community cloud formed by SNs from three zones. The ONs in a given zone are directly managed by the SN in that zone but they can also consume resources from other zones because of the coordination among SNs.

C. Community Cloud Management System

The implementation of community cloud involves setting up a cloud management system tailored to community networks on a SN and we present a conceptual overview for such a system in Figure 3 which consists of the following layers.

- The hardware layer consists of the SNs and ONs of the community network where the hardware resources are

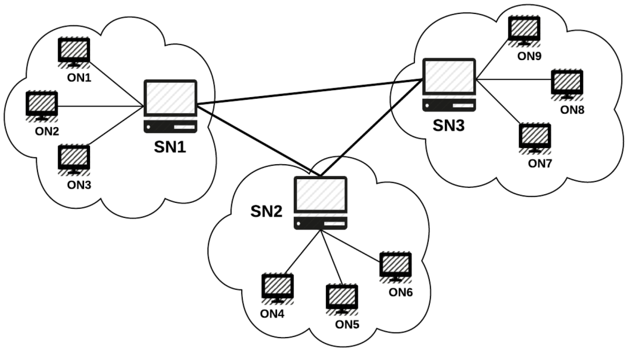

Figure 2. Super and ordinary nodes in federated community cloud

allocated to the users isolated as instances of the virtual machines (VMs).

- The core layer consists of the components needed for instantiating, scheduling and managing VMs on ONs and is installed on the SN.
- The cloud coordinator is responsible for the federation of the cloud resources which are independently managed by different local clouds. The cloud coordinator components in different SNs connect with each other in a decentralized manner to exchange relevant information about managing the available resources.
- The front end layer provides the mechanism for accessing resources from the cloud as Infrastructure-as-a-Service (IaaS), through graphical (GUI), command-line (CLI) or application programming (API) interfaces.

There are a few cloud management systems available to manage public and private clouds, for example OpenNebula[5], OpenStack[6], CloudStack[7], Eucalyptus[8], Nimbus[9] and Aeolus[10]. Such cloud management systems can be extended for community networks by implementing the cloud coordinator and its services on top of the existing functionality to address the particular conditions of community networks. For example, incentive mechanisms inspired by the social nature of community networks can be built into resource regulation component to encourage users to contribute resources [11]–[13].

III. EVALUATION

For our simulation experiments, we have used CloudSim simulation toolkit [14] which supports analysing the behaviour of cloud computing environments under various experimental conditions [15]. CloudSim is an event-based simulator that models cloud infrastructures as data centres characterized by the number of physical nodes and the scheduling policy for assigning users' requests to the nodes. The nodes in CloudSim are defined by their processing capacity given in millions of instructions per second (MIPS), memory, storage, bandwidth, the number of VMs and the policy for distributing resources among VMs. The requests from users are termed as *cloudlets* in CloudSim and dynamic behaviour of applications with respect to resource requirements can be programmed by extending the code for cloudlets. Both VMs and cloudlets have attributes like processing capacity, memory, storage and bandwidth and these attributes are used by the *broker* process which manages the instantiation and allocation of VMs to map cloudlets to VMs. CloudSim also supports federated cloud architectures by providing a *cloud coordinator* entity which distributes the users' requests among multiple data centres.

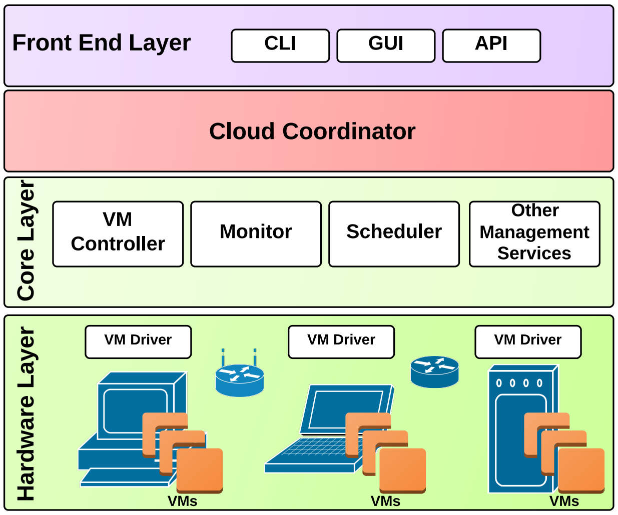

Figure 3. Conceptual overview of the community cloud management system

We have modelled commercial centralized clouds as a single data centre and community clouds as a cloud coordinator with multiple data centres in CloudSim. SN in a community network is assumed to be the broker in data centre while ONs in a community network are the nodes hosting VMs. Our goal is to analyse the behaviour of community clouds and compare its profile with commercial clouds and in our preliminary experiments, we have focused on the resource utilization in terms of processing capacity (CPU), memory (RAM), network bandwidth and the quality of service in terms of average response time for users' requests.

A. Experiment Setup

We simulate three scenarios in our experiments with different distribution of nodes among data centres. Table I shows the number of data centres and the number of nodes at each data centre for different values of n which is the total number of available nodes across all data centres.

1) Centralized Cloud: Centralized Cloud represents commercial clouds where all the nodes are present in a single data centre.

2) Federated Cloud: Federated Cloud depicts the common scenario in community networks where a super node provides the cloud management system and manages the VMs on the ordinary nodes linked to it. In this case, the nodes are evenly

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[5] http://www.opennebula.org

[6] http://www.openstack.org

[7] http://cloudstack.apache.org

[8] http://www.eucalyptus.com

[9] http://www.nimbusproject.org

[10] http://www.aeolusproject.org

Table I
SCENARIOS FOR PROVIDING INFRASTRUCTURE SERVICE WITH n NODES

Scenario	Data Centres	Nodes per Data Centre
Centralized Cloud	1	n
Federated Cloud	$\approx \sqrt{n}$	$\approx \sqrt{n}$
Decentralized Cloud	n	1

Table II
CHARACTERISTICS OF NODES IN DATA CENTRES

Attribute	Value
Architecture	x86
Operating System	Linux
Hypervisor	Xen
CPU	2,400 MIPS per VM
RAM	8 GB
Storage	80 GB
Bandwidth	100 Mbps
Hosted VMs	4
VM Scheduling	Time Shared
VM Migration	Not Allowed

Table III
CHARACTERISTICS OF VMS REQUESTED BY USERS

Attribute	Value
CPU Time	1,000 MI
Number of Cores	1
RAM	512 MB
Bandwidth	100 Mbps
VM Image Size	1 GB
Scheduling Policy	Dynamic Workload
Number of Requests	50 requests per minute

Table IV
PERCENTAGE OF RESOURCES UTILIZED

Nodes	Data Centres	Nodes/Centre	CPU	RAM	Bandwidth
100	1	100	48.51	49.3	49.08
100	10	10	49.13	49.43	49.09
100	100	1	49.27	49.52	49.35
400	1	400	50.22	48.83	48.56
400	20	20	49.46	49.27	49.72
400	400	1	49.36	48.29	50.31
1000	1	1000	49.50	49.43	49.50
1000	30	30–35	49.41	49.36	49.57
1000	1000	1	50.12	48.94	48.42

distributed between the data centres and the number of data centres equals the number of nodes at each data centre. For example, the federated cloud in Figure 2 has total 9 ONs so $n = 9$, and we can view it as consisting of 3 data centres where each data centre has 3 nodes.

3) Decentralized Cloud: Decentralized Cloud depicts the scenario where all the nodes act as independent service providers. This is taken as an extreme case of federated community cloud when there is no hierarchy among nodes and all the nodes act as individual local clouds, albeit consisting of just one node. This is modelled as multiple data centres each with only a single node in CloudSim.

The hardware profile of nodes, as shown in Table II, is same across all the three scenarios and is comparable to the configurations used in other recent experiments involving CloudSim [15]. The profile of VMs requested by users, as shown in Table III, is also identical in all the three scenarios. We have not considered the effect of network topology in these experiments, so bandwidth between all data centres is assumed to be identical.

B. Results

We present here the results from our simulation experiments. We have run each experiment ten times, and plotted the average values in the following graphs.

1) Resource Utilization: We first consider the overall resource utilization in our experiments, as shown in Table IV. Our first observation is that the values are similar across all the scenarios. This is because the number and capability of the nodes, and the number of requests made by the users are identical in the three scenarios. In addition, we are not considering the network delays and state of the links between different nodes. In reality, the hardware of the nodes in a community network will differ in capacity and the network bandwidth will also be limited, so we need to extend our simulations to take this heterogeneity into account for community cloud. The other point is that utilization is almost 50% in all the cases, which shows that there are not sufficient number of requests to keep the available resources in data centres busy all the time and so the nodes are idle almost half of the time while the experiment is running. In the future work, we need to evaluate the behaviour of the system including the level of resource utilization under different load conditions.

2) Response Time: We consider the average response time in order to analyse the quality of service provided by the infrastructure service. This is the difference between the time when a request is submitted to the system and when a VM is allocated for that request. Figure 4 shows the average response time across all requests as the number of nodes increases in the system for the three scenarios. We find that for limited number of nodes, centralized cloud provides better service because resources are consolidated at one data centre. However, in the case of federated and decentralized scenarios, resources are distributed between multiple data centres and are not sufficient to meet the requests forwarded to the data centres. However, as the number of nodes increases along with the rise in the volume of requests, the overheads for centralized data centre become significant since the requests remain in the queue relatively longer waiting for resources to become available.

We also studied how the rise in demand affected the quality

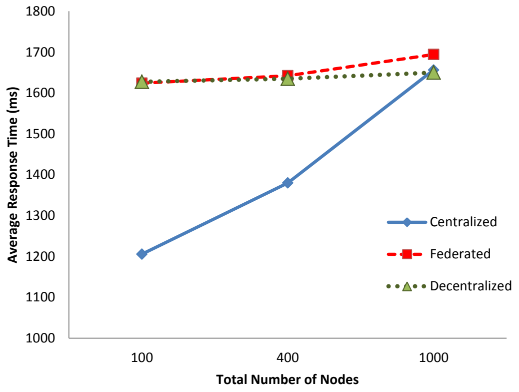

Figure 4. Average response time as number of nodes increases

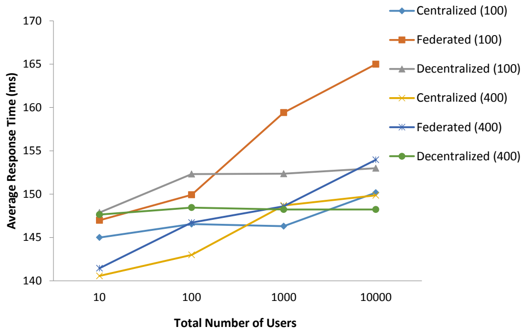

Figure 5. Average response time as the number of users increases

of service. Figure 5 shows the response time as the number of users increases in the system for the three scenarios with 100 and 400 nodes. We find that for federated scenario in the case of 100 nodes, where only 10 ONs are assigned to each SN, the system is not able to cope well with the increase in number of users and the performance degrades sharply as compared to the other scenarios. We notice that in addition to the availability and distribution of resources, another factor that could affect the performance is the implementation of cloud coordinator and the broker processes as they may act as a bottleneck under very high load, so we also plan to explore their impact on the system in the future work.

3) Requests Completion Time: In addition to the response time, Figure 6 shows the finish time when a request is completed and is released back to the system. We find that the behaviour is similar in all the three scenarios, which is due to the fact that the total number of resources available in the system remain the same for each scenario. Moreover, as the duration of requests is relatively short and does not vary much, there are not any significant delays in the system at any point. It would be interesting to model requests that have different resource requirements and see how they affect the overall quality of service of the system.

IV. RELATED WORK

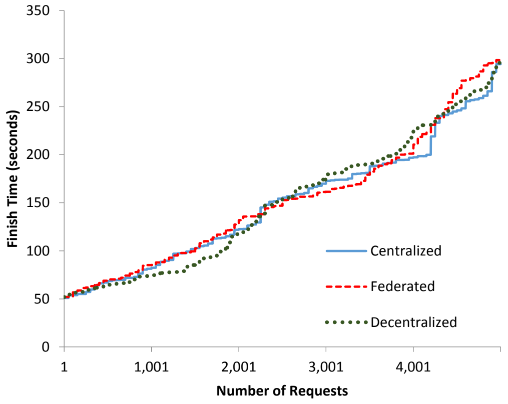

Figure 6. Finish time of requests for the three scenarios with 400 nodes

The wide adoption of commercial clouds has led to increasing interest in building cloud infrastructure using resources contributed by communities of users [3]. This follows on from earlier distributed voluntary computing platforms like BOINC [16], HTCondor [17], Seattle [18] and PlanetLab [19]. There are a few research prototypes for community cloud computing [3], for example the Cloud@Home[11] [20] project has similar goals to harvest in resources from the community for meeting peaks in the demand. The aim is to work with open, commercial and hybrid clouds to form cloud federations and ensure quality of service using a rewards and credit system. Skadsem et al. [21] provide applications for communities by using local cloud services. Their context is similar to ours and they assume that the social mechanisms like trust in a small community do not require additional mechanisms for incentives. They have built distributed storage in P2P systems, and they want to extend that to the community cloud by incorporating virtualization. CuteCloud [22] is an ongoing project that plans to use idle resources form users' commodity machines in addition to dedicated servers, so high-demanding jobs are assigned to the dedicated servers while the excess demand is met from the commodity machines. The Clouds@home[12] [23] project focuses on providing guaranteed performance and ensuring quality of service even when using volatile volunteered resources connected by Internet. The P2PCS[13] [24] project has built a prototype implementation of a decentralized peer-to-peer cloud system. It uses Java JRMI technology and builds an IaaS system that provides very basic support for creating and managing VMs. It manages VM information in a decentralized manner using gossip protocols, however the system is not completely implemented and integrated. Social Cloud[14] project [25] takes advantage of online relationships between users of social networks to motivate contribution towards a cloud storage service. From the review of the related work it can be seen that the socio-technical challenges that we find in community networks are not addressed comprehensively by the related work. In the

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[11] http://cloudathome.unime.it
[12] http://clouds.gforge.inria.fr
[13] https://code.google.com/p/cloudsystem
[14] http://www.ksri.kit.edu/SocialCloud

community cloud system that we propose, we aim to take into account several of the important factors that characterize community networks, for example the scenarios we identified from the conditions of community networks, to come up with cloud services which are tailored for community networks.

V. CONCLUSION AND FUTURE WORK

Community networks have the potential to offer applications to users through open and neutral cloud services hosted on community-owned resources. This paper introduces the vision of a community cloud-based infrastructure service. First some characteristics of community networks are revised in order to identify potential scenarios for cloud computing systems. These scenarios help in obtaining through simulations a preliminary characterization of the behaviour of an infrastructure service in community clouds. It is observed that for community clouds the distribution and capability of resources, which are less powerful than those in commercial centralized clouds, will impact the response time and the resource assignment. Network-aware cloud services, however, seem to have some potential to improve the performance of infrastructure service by reducing its dependency on the conditions of community network. Achieving a reasonable quality of user experience with community clouds will be needed to sufficiently motivate the members of community network to extend the current collective management at the network level to that of cloud services. Once this level of technical performance is assured, community clouds may outperform commercial clouds in their social aspects by offering open and neutral cloud services provided from within the community network. Our future work aims at refining the topological network model for simulations of community clouds by integrating both the results from statistical network measurement and from a concrete community cloud prototype deployment. With such simulations we expect to obtain a better understanding of the potential and the design of network-aware infrastructure services for community clouds.

ACKNOWLEDGEMENT

This work was supported by the European Commission through FP7 FIRE Initiative projects CONFINE, FP7-288535, and CLOMMUNITY, FP7-317879, and by the Universitat Politècnica de Catalunya and the Spanish Government through the Delfin project, TIN2010-20140-C03-01.

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