A CLOSE EXAMINATION OF CLOUDLET ROUTING: INVESTIGATING THE DATA LATENCY IN CLOUD COMPUTING ENVIRONMENTS

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ABSTRACT: *It is necessary for the mobile devices to function with high-performance processing tasks in comparison to the static clients along with the servers. The computational resources of a device can be limited due to weight, memory, battery life, and heat dissipation. Cloud computing is recognized as one of the best solutions to overcome limitations in mobile devices. It expresses a few issues, like long-latency and expensive roaming charges for the access of cellular radio. Cloudlets can provide benefits over the distance cloud; for example faster data transfer, efficient application processing, and reduced utilization of mobile resources. Coordinated cloudlets can assist the cloudlet environment to have faster communication affecting the cloud computing infrastructure positively. Coordinated cloudlets may even assist in other areas; like fog computing, vehicular fog computing, and vehicular networks.*

KEYWORDS: cloud computing, cloudlet, fog computing

1.INTRODUCTION

Mobile devices have become the most convenient and effective means of communication tools. The devices popularly include the modalities; like tablet PC and smartphones. Today, mobile users are accumulating a rich experience attaining through the services, provided by various mobile applications. These mobile applications include popular services from Google and iPhone that function on the devices and the remote services through wireless networking. Mobile computing is becoming a powerful trend in a prompt manner, particularly in the development of information technology and commerce. The resources for the mobile devices may indicate challenges in terms of battery life, weight, bandwidth, memory and storage. Furthermore, they may also display issues regarding security and mobility. These limitations within the resources can significantly delay the improvement in the quality of services.

The network resources can be shared via cloud technology that can provide sustained solutions and reliable alternatives to improve networking and communicating technology. Cloud technology plays a significant part in exchanging data among different users. With the rising popularity of cloud computing and outburst of mobile applications, some issues have been emerging as serious concerns like expensive roaming charges and long latency of cellular radio. The noisy neighbor is a phrase that has been used to describe the infrastructure of cloud computing, which may monopolize the bandwidth, CPU, disk I/O along with other resources. Moreover, the noisy neighbor also negatively influences the cloud performance of other users. It may also induce uneven cloud networking among the infrastructure of other virtual machines and applications.

Cloud computing is recognized as the next generation of computing infrastructure. Cloud providers function to deliver services at lower cost by infrastructure, platforms, and software. The popular cloud providers are known as Google, Amazon and Salesforce. Similarly, infrastructures include service (IaaS) like servers, networks, and storages; platforms include service (PaaS); such as middleware services and operating systems; while software may include software as a service (SaaS) like application programs. The model of cloud networking also allows users to elastically employ the resources in an on-demand manner. Consequently, it rapidly provides the mobile application to the users with minimal efforts for management and interaction between the service providers.

In order to provide efficient services to the users, cloud computing utilizes a big number of computer networking; like a software application, databases access, and file storage. These services are the usual ones that a user may receive from either the single computer or a complete server. Nonetheless, it may not be possible to detect a single device as aproviding source for the user as services emerge from the entire network within a cloud. The heavy lifting within cloud computing is performed by the computer network. The heavy lifting may include the storage of files and running the software. User needs to run the interface software only for interacting with the cloud; for example, the email. A user may use any web browser for emailing for receiving, reading, deleting, writing ND sending messages. Whereas, the actual software of the email and the shared files remained in the cloud rather than the computer.

The terminology of mobile cloud computing has been introduced soon after the model of cloud computing. Since the early days, mobile cloud computing has gained the interest of entrepreneurs for being a profitable business entity. It has been realized that mass attention can affect the modality of mobile applications in terms of development and running cost. Yet, the factor can further enhance the ability of a user to attain access to the new technology and live the rich experience of the mobile services at a lower cost. The notion has been promoted by the researchers as a potential solution for green information technology (IT).

In the era of mobile application popularity, cloud computing has acquired long term support from users in the form of diverse services. Mobile cloud computing has been introduced in the same era, with an integration of cloud computing and mobile environment. The model has provided users with new services and facilities that enable them to attain complete advantages of cloud computing.

Mobile cloud computing, in its simplest form, represents an infrastructure that accommodates the data processing and storing, occurring outside the device. The applications of mobile cloud interchange computer power along with the data storage from mobile phones to the cloud. The model brings applications and mobile computation to smartphones and a broad range of mobile subscription. Mobile cloud computing can also be elaborated as a new paradigm for mobile applications. The processing of data and storage is further moved to the centralized platforms of computation located within the clouds. The centralized applications are accessed through the wireless connection that is mainly based on thin native client or a web browser available on the mobile device [1].

2. CLOUDLETS INFRASTRUCTURE AND VIRTUALIZATION

Cloudlet is an emerging element of architectural nature, which has been developed from the convergence that involved both the mobile and cloud computation. It belongs to the middle tier of three-tier hierarchy that includes Mobile Device – Cloudlet – Cloud. A cloudlet expresses the goal of "bring the cloud closer" as it is perceived as a "data center in a box" [2]. A study presented the notion of cloudlets as the trusted and resourceful computers within the vicinity of the user that can be collocated with or near the wireless access point [3]. Cloudlets have been originally driven by narrow considerations identified from the end to end latency. Eventually, it enables the cloudlets to play a foundational part for the mobile computation in a hostile environment. As the middle tier of a three-tier hierarchy, a cloudlet can be observed in the form of surrogate or a proxy of the real cloud [4]. Moreover, cloudlet can also be elaborated as a small cloud that is primarily located near the mobile users. The modality can be connected with the clouds in the faraway location via LAN network [5]. A face recognition application has been exhibited in a study along with its design as well as the implementation. It has been presented with the use of mobile-cloudlet-cloud architecture termed as MOCHA with the results of the initial performance. Figure 1 displays the MOCHA architecture where mobile device interacts with the cloudlet and cloud through multiple links. The model utilizes dynamic partitioning for achieving the quality in the services such as cost and latency [6].

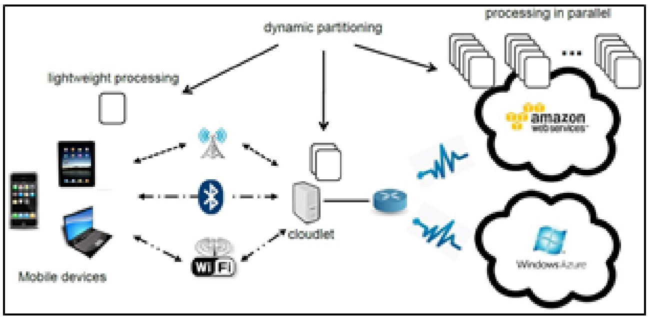

Figure 1. The architecture of the MOCHA [6]

The utilization of a cloudlet simplifies the challenges that may occur while satisfying the demands for peak bandwidth from the multiple users. The model interactively generates and receives media that may include high definition images and videos. Cloudlet can reduce the cost of equipment as it can avoid a large degree of expensive access points. The approach ensures network coverage as the points of wireless termination that are maintained to be as light as possible. It decreases the latency of access as it places the networking and applications near to the ends users. A flexible and simplified network can be managed as cloudlet that can be self – managed and may not require professional assistance. It can further reduce the CAPEX as well as OPEX by disposing off expensive middleboxes and the management complexities. The complications can be avoided by network function virtualization, targeted services on the basis of the location, and its geography. Moreover, the software can be provided remotely with the services to install new hardware, without the need of visiting sites [7].

Even though there are a number of studies that have been conducted in the domain of cloud computation, there is still a lack of researches that can emphasize the significance among the cloudlets. Thus, the aim of the paper has been developed to gather the research material on cloud computation and cloudlets to identify the strengths and flaws of the contemporary methods and proposed approaches. It has been presumed to be helpful in developing and improving the concepts and techniques for the cloudlets coordination environment and their better performance and security.

Coordinated cloudlets refer to small clouds connected to each other and close to the users. They are installed on discoverable, localized, stateless servers running one or more virtual machines (VMs) on which mobile devices can offload expensive computations. Also, they are well-connected to the internet and available for use by nearby mobile devices. The basic cloud infrastructure is located far from the mobile user. For example, Amazon's EC2 infrastructure is located only in 16 geographic regions around the world [1]. When the client tries to reach one of these sites from the mobile device, its "end to end" path includes many network segments. High WAN latencies make this approach of direct connection insufficient for the real-time applications of mobile users, in some cases. Cloudlet based mobile computing is also referred to as fog computing that may facilitate the operation of computing, storing and networking services between mobile devices and remote clouds. It also aims to reduce access latency [8].

3. RELATED STUDIES AND DEVELOPMENT

The number of mobile phone users, connected to the internet, tends to rise in a constant manner. Mobile hardware significantly appears to be poor in resource in relation to the static client and hardware of the server. Mobile devices display more setbacks in limiting the computational resources as compared to static clients and servers. The limiting factors may include weight, memory, battery life and dissipation of heat from the devices. Mobile users can access the virtual machines on the cloudlet by running the software in a thin client manner through the cloudlet.

Jemma, Pujolle, and Pariente displayed an architecture for WLAN networks with carrier management. The model leverages the concepts of network virtualization along with the virtualization as a general entity. The study has used two virtual machines with the running of FreeBSD OS and Xubuntu OS. The delay in performance has been tested in three cases:

- The delay between the video server and the user's device.
- Measurement of round trip time for the architectures that have been referenced and proposed between the user’s device and gateway.

4. DELAY BETWEEN THE POINTS OF WIRELESS TERMINATION AND GATEWAY

The study provided a conclusion that the solution form WLAN cloudlet provides numerous advantages in regard to the cost, agility, and flexibility of the model. The study also showed a cloudlet-based WLAN architecture and stated some of cloudlet-based WLAN benefits, such as reduced equipment cost, reducing CAPEX and OPEX, decreasing access latency, more flexible and simplified network management, increased speed of time to market and faster configuration of new services, the possibility of introducing targeted services based on geography or venue type and encouraging openness and more innovation to bring new services and new revenue streams quickly at much lower risk (fig. 2).

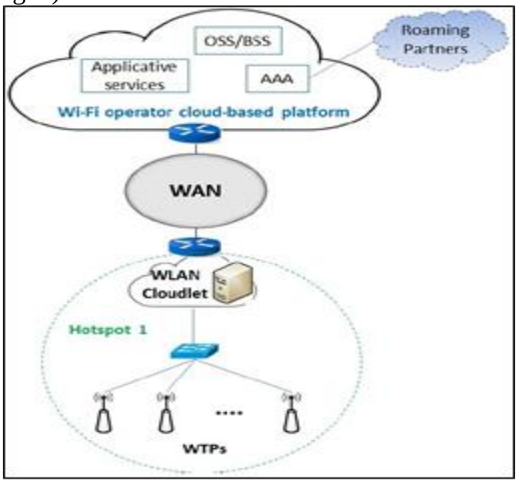

Figure 2. The architecture of Cloudlet-Based WLAN [7]

The concept of cloudlet properties has been introduced by Li and Wang [9]. The properties included the reachable time, lifetime, and size of the modality. The study further explored the field of mobile cloudlet within mobile cloud computing. The evaluation involved the study on the properties and performance of the cloudlets. It presented a number of nodes within a network, its frequency to meet, and a number of devices that are rich in resources. These devices tend to be active as an initiator that can interlink the computing services. In a delay-tolerant task, an intermittent connection marks a less negative impact on the optimal function of a mobile cloudlet. Upper and lower bounds within a computing capacity along with the long term computational speed of a mobile cloudlet were also derived from this study. An initiator can choose to upload tasks to remote clouds and use mobile cloudlets near to the source by using the derived bounds. Li and Wang [9] highlighted that they planned to design and execute the mobile application on the system of a mobile cloudlet for instigating the viability and functioning capabilities of a mobile cloudlet computational model.

A cloudlet based architecture for the data security protocol has been proposed by Jindal and Dave [10]. They utilized the property of perfect forward secrecy to integrate the cloudlet and a base station. The model protected the data from the reach of unauthorized users and also prevented the data from exposing to the cloud. The protocol of data security consisted of four components that are as follows:

- Cloud
- Cloudlet
- Data owner: User of the mobile device who uploads encrypted files on the cloud
- Data sharer: User of the mobile deice who accesses the uploaded files on the cloud

Cloudlets have acted as an intermediary entity between the cloud and the mobile devices. In the presented model, each cloudlet serves around a hundred mobile devices. The modality exhibited the following assumptions:

- Cloudlets can be trusted
- Cloudlet can maintain the cache of files that are accessed frequently
- Data owners can maintain the list that is authorized by the sharers
- Clouds servers can be assumed to have an abundance of storing capacity as well as computational power; they are presumed to be in a continuous online status
- Each file holds a unique identity
- Ne session key can be generated for every file that has to be uploaded

The exhibited solution eventually offloaded all the intensive tasks, related to the computation on the cloudlet. It also enabled the lightweight wireless devices to store and retrieve data within a cloud, in a secure manner. Security analysis of the model showed that the protocol can protect the stored data on the cloud from the access of illegal entities.

Shi and Hwang presented another cloudlet mesh architecture for the purpose of security. The security enforcement aimed to develop a mobile cloud computation with truth by specifying the authentication sequence, encryption protocols among the mobile devices, distance clouds and cloudlet servers for securing communication [11]. The aim has been to improve the aspects that included:

- Structured security architecture based on a hierarchy: Trust chain is established between mobile devices, the cloudlet mesh, and remote cloud platforms.
- Predictive security analytics: Processing at the backend cloud for virus signature scanning and updating with automated virus/spam filtering and removal.
- Real-time filtering or removal of malicious attacks or fast response to intrusions with the help of trusted remote clouds.
- The study further suggested the use of multiple cloudlets within the mesh for the following purposes:
- Increase in the wireless coverage in order to serve mobile devices with their cloudlets enabled with the Wi-Fi.
- Defense coordination between the mesh cloudlets that may shield and alert all the mobile users.
- Off-loading tasks for the cloud with caching and load balancing within the cloudlets.

An advantage of utilizing the composite mesh of three cloudlets over the intrusion detection by the individual cloudlet has been shown in the study. It has been noted that the performance of composite intrusion detection system (IDS) remains still at 10 ~ 20%, that is higher than the individual performance of IDS, when the rate of false-positive is kept high by 0.006, at the extreme right. A study [12] identified the key challenges in the dynamic allocation, orchestration, and migration from the virtual machines within the wide areas of interlinked networks. Two multicore servers were equipped with Linux Cent OS distribution that has been running the Virtual Box as VM hypervisor. Two virtual single-core Linux boxes were implemented into the study where one acted as the video server while other as the access router that connected the user to the server. The migration latency has been kept as small as possible by dimensioning the two VMs with the minimum memory of 512 Mbytes for both along with the disc space of 7.2 GB for the video server and 1.3 GB for the router access. The whole network infrastructure underwent live migration via the function of VM teleporting as available in the Virtual Box. The two servers, hosting and emulating the two remote data centers, were connected through an ad hoc link between the interfaces. The interfaces are kept separated from the interface in use for communication by the user. It has been concluded that the network infrastructures will consist of numerous virtual resources that may include computing, storing and networking I/O. These resources will be dynamically controlled by the user according to the demands, QoS, objectives of the business and other conditions. Thus, advances in standard hardware and the emergence of paradigms like SDN and NFv are presumed to enable the disruption within the current networks. The cloudlet network design problem for mobile access networks was investigated by Ceselli and his team [13]. The virtual machines in the model were connected to the mobile users who were allocated the cloudlets. The study compared the bulk and live migration as the function for service requirements of the mobile cloud. It determined that high preference must be attributed to the bulk migration for delay-stringent services, like augmented reality support. On the other hand, it suggested that live migration may appear largely preferable for the applications that may have less stringent delay requirements. The objective of the model has been to find:

- Design of an optimal network design, which may include cloudlet placement and assignment of base stations to cloudlets
- Optimal routing of the traffic to and from the cloudlets
- The main aim has been to provide strategic acuities for the policies of optimal designs rather than the planning to operate.

A comprehensive design framework of cloudlet networking has been provided for the mobile access of the metropolitan networks. The problem has been known to include a planning mode that may remain unaware of the user and mobility of virtual machine. It is defined as a mode in consideration to the bulk migrations and another to the live migrations. Planning options for the scenario, developed over the datasets of real cellular networks, were extensively compared. The comparison has been carried out in terms of the enabled number of cloudlets and volume of the migration. The observations were made taken from various traffic engineering and goals for performances in reference to the services by the mobile cloud. High gain derivation with the consideration of user and mobility of virtual equipment within the network planning has also been highlighted in the study. Moreover, it has also determined the planning approach for the most appropriate services of the mobile cloud with regard to the migrated traffic volume.

A study conducted by Quwaider and Jararweh [14] exhibited Body Area Networks (BANs) system on a large scale with the cloudlet based data collection. The aim of the study has been to use of cloudlet based system to reduce the cost of the end-to-end packet by the dynamic preference of data collection incorporated to the cloud. In addition, the delay in the end-to-end packet has been also minimized by the operational preference of a neighboring cloudlet. Quwaider and Jararweh further extended the execution of CloudSim, a simulator tool, [15] in the form of TeachCloud [16]. It has been used to realize the cloudlet-based model of BANs. The implementation supported the multi-core technology, by the assigning of virtual machines to the part of hardware resources available that may range from one CPU to a complete set. A cloudlet system has also been equipped with sufficient memory capacity per physical server. It was provided with a storage capacity of a moderate size that may extend to the scale of Terabytes. These transceivers were capable to receive and send data packets to and from the users of BAN. Transmission power and delay of a packet are the two primary metrics that have been used to evaluate the performance of cloudlet-based BAN data collection. The two metrics are basically the direct measures of the communication energy long with the delay expenditure that may rise from a PDA device and be transferred to the cloudlet or the cloud system. It has been concluded that an increase in the number of VCs can reduce the average power of a transmission packet or a delay. It can occur in response to the increase in the coverage area of Wi-Fi technology.

The impacts of user's experience with the cloudlets, on the location of application, have been explored by Clinch [17]. The study emulated the mobile device with a 2 GHz Intel Core Duo, Mac Mini, with a RAM of 1 GB. The model has been running on the networking of Ubuntu 9.10 over wireless (802.11). The measurement of task performance has been carried out with the help of a mobile device. The display has been exhibited on a 2.26 GHz Intel Core 2 Duo, Mac Mini, with a RAM of 4 GB that has been running a wired LAN and Mac OS X 10.5. An open-source VNC client has been used for connecting the cloud or cloudlet VM. The open-source has been the chicken of the VNC. The team also developed a series of seven servers that included physical cloudlet machines (3) and cloud VM instance (4). Mac OS X 10.4 and VirtualBox 3.0.12 has been running with an Ubuntu 9.10 guest VM, which has been allocated 1 CPU, 395 MB RAM and 8 GB disk. The model has been functioning by the cloudlet of a Mac Mini of 1.83 GHz Intel Core Duo with a 2 GB RAM. Vino VNC server along with a Python 2.6 has been running by a VM by a network bridge with the Ethernet of the host. Further, the cloud instances have been running on the EC21 or Amazon Elastic Compute Cloud with a single Compute Unit of 32-bit Ubuntu 9.10 Server with 1.7 GB RAM and 160 GB storage. These instances have been processing Python 2.6 and a vnc4server. The implementation has been performed in the US, UK and EU. A significant difference has been discovered between the US and UK, which suggested that the extended latency from UK or EU may have impacts on the gameplay. The outcomes of the experiments assisted in the choices for the placements and architectural domains. It has been determined that the placement of application have significant impacts on the performance and experience of the user along with the intuition that may improve the user's experience.

Satyanarayanan [18] has described the constraints set, intrinsic to mobile computing. He also examined the impacts of the constraints on the distribution system's design. In the study, it was summarized the outcomes of Coda and Odyssey systems. He further described the opportunities in research in five essential topics related to mobile computing. The five relevant themes have been the:

- Caching metrics,
- Semantic callbacks and validators,
- Resource revocation,
- Analysis of adaptation, and
- Global estimation from local observations.

Zhang, Xiong and Lou [19] presented a community clinic solution. The solution integrated the group of cloudlets in between the mobile users and cloud. The integration decreased the cost that has been introduced by the enormous deployment of the data centers. It also saved the battery power that has been consumed by mobile devices.

Li and Wang [20] also carried out an examination on the probability of cloudlet access, the success rate of the task, and the execution speed of the task. The evaluation has measured the impact of mobility. Mean connection time and mean inter-connection time concerning the mobile device, and the cloudlet has been used to determine the probability of the cloudlet access. It has been discovered that the rate of task speed and speed of the execution depends upon the demand of computational task and speed of the cloudlet computing along with the probability of cloudlet access.

A cloudlet concept has been proposed by Verbelen, *et al.* [21]. The concept managed the applications on the component level rather than transferring a whole virtual machine from cloud to the cloudlet. The model for cloudlet architecture has been exhibited in Figure 3. The proposed model expressed the capabilities and advantages of a mobile real-time augmented reality application.

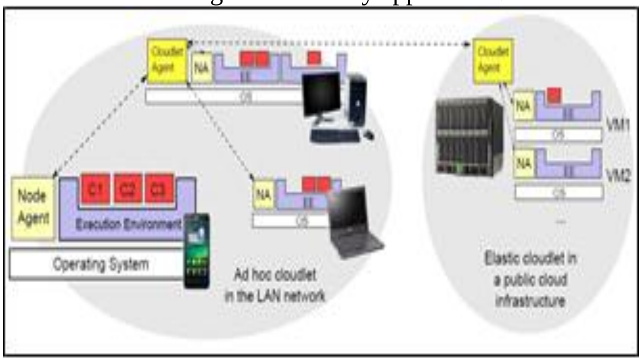

Figure 3. The proposed architecture of the cloudlet [21]

5. SOFTWARE DESIGN

In accordance with the main objective of this study, the communication between the cloud servers and clients via cloudlets has been observed. Cloudlets function as in intermediary between the clients and cloud distance servers. Clean separation has been enabled by utilizing the cloudlets of the virtual machine. The model can assist in avoiding the problems associated with the configuring software on a cloudlet. It can also help in eradicating simple issues like rapid delivery of precise pre-configured VM to the cloudlet. It has been commended that a transient guest software environment can easily be encapsulated and separated from a permanent host software environment, present within the cloudlet infrastructure. A stable interface among the host and guest can help to promote the compatibility of a cloudlet with the mobile devices [5].

In order to simulate a real cloud environment and to obtain as accurate results as possible, the implementation deployed 5 virtual machines (1 cloud VM server, 3 VM cloudlets and 1 cloud VM client) over a public network between USA, Italy and Saudi Arabia. The remote cloud VM server was installed in Seattle (USA) with IP address of 67.161.106.95. The model possessed following characteristics: 2.67 GHz Intel Core i5, 1 GB RAM and 20 GB disk, and ran Windows Web Server 2008 and VMware Workstation 9.0. 3 VM cloudlets were installed in Florence, Italy, with a shared IP address (79.52.120.186). They had the following characteristics: 1.70 GHz Intel Core i3-4005U, 512 RAM and 10 GB disk, and running Windows Web Server 2008 and VMware Workstation 9.0. The VM client was installed in Medina, Saudi Arabia, with IP address of 95.187.39.3. It had the characteristics of 2.93 GHz Intel Core 2 Duo CPU, 512 RAM and 5 GB disk, and ran Windows 7 and VMware Workstation 9.0. The generalized experiment architecture has been displayed in figure 4.

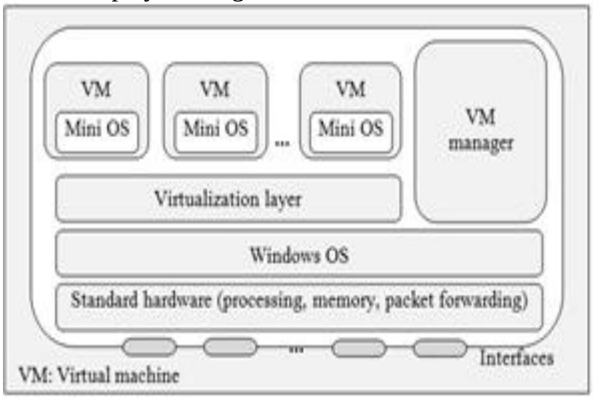

Figure 4. The architecture of Generalized Experiment

6. IMPLEMENTATION DETAILS

The work has explored the details of implementation for an in-depth study of the model. The remote cloud server has been established within a specific machine and at a specific port. The cloudlets have been started in the position where each cloudlet was aware of the location and port of the remote cloud server. Likewise, cloudlets were also aware of the port and location of the other cloudlets. The proposed architecture for the cloudlet has been displayed in figure 5.

The work has tested the routes between cloudlets and the remote cloud server. It compared the elapsed times and selected the fastest route. The model performed in the following manner:

- The client asks the cloudlet 1 for the route for some files
- If the cloudlet 1 has that file, it returns the route (cloudlet 1 IP address)
- If it does not have that file, the cloudlet 1 tries to download the file from many other cloudlets, compares and sends the fastest path to the clien
- If the cloudlet 2 has that file, it sends the file to the cloudlet
- Then, the cloudlet 1 returns the route "(cloudlet 1 IP address), (cloudlet 2 IP address)" to the client.
- If cloudlet 1 asks the remote cloud server, and it is the fastest route, then the remote cloud server sends that file to the cloudlet 1 and the cloudlet 1 returns route for the

client "(cloudlet 1 IP address), (remote cloud server IP address)"

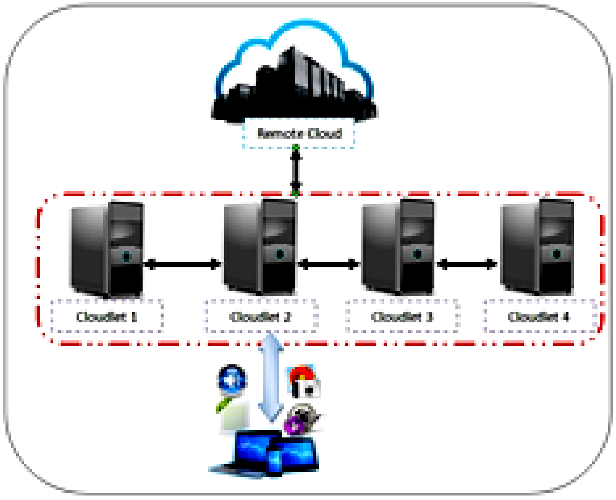

Figure 5. Proposed Cloudlet Architecture

7. EXPERIMENTAL RESULTS

The results were collected from 5 virtual machines: 1 as a remote cloud server, 3 as cloudlets, and 1 as a client. Screenshot of the fastest available route to the client has been obtained for the observation, which has been displayed in figure 6.

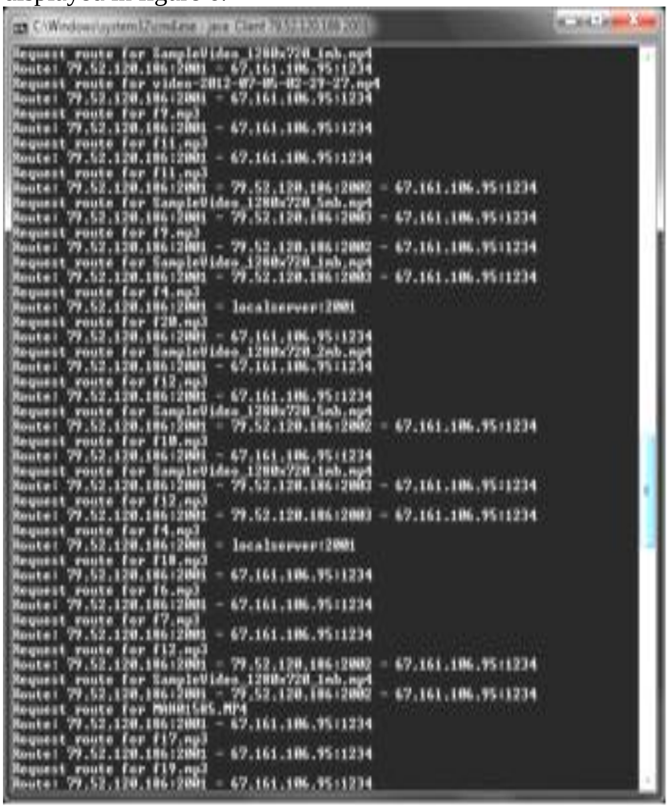

Figure 6. The capture of a Client Session, Getting the Fastest Route

8. CONCLUSION AND FUTURE WORK

The paper has examined the routes among cloudlets in the cloud computing environment. It has been concluded that the combination of cloudlets can provide significant support to the cloud computing infrastructure environment. It can further enable the model to have access to more reliable and faster connections that may also suggest new routes for faster and more efficient data transfer. It has been recommended and planned to examine the benefits of cloudlets in the internet field.

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