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# Adaptive Avatar Handoff in the Cloudlet Network Systems

Gandhimathi. D<sup>1</sup>, Dr. S. Chandrasekaran<sup>2</sup>

<sup>1</sup>PG Student and <sup>2</sup>Assistant Professor, Department of Computer Science and Engineering, P.S.V. College of Engineering & Technology, Krishnagiri

**Abstract:** In a traditional big data network, data streams generated by User Equipments (UEs) are uploaded to the remote cloud (for further processing) via the Internet. However, moving a huge amount of data via the Internet may lead to a long End-to-End (E2E) delay between a UE and its computing resources (in the remote cloud) as well as severe traffic jams in the Internet. To overcome this drawback, we propose a cloudlet network to bring the computing and storage resources from the cloud to the mobile edge. Each base station is attached to one cloudlet and each UE is associated with its Avatar in the cloudlet to process its data locally. Thus, the E2E delay between a UE and its computing resources in its Avatars is reduced as compared to that in the traditional big data network. However, in order to maintain the low E2E delay when UEs roam away, it is necessary to hand off Avatars accordingly—it is not practical to hand off the Avatars’ virtual disks during roaming as this will incur unbearable migration time and network congestion. We propose the Latency Aware Replica placement (LEARN) algorithm to place a number of replicas of each Avatar’s virtual disk into suitable cloudlets. Thus, the Avatar can be handed off among its cloudlets (which contain one of its replicas) without migrating its virtual disk. Simulations demonstrate that LEARN reduces the average E2E delay. Meanwhile, by considering the capacity limitation of each cloudlet, we propose the Latency aware Avatar handoff (LEAD) algorithm to place UEs’ Avatars among the cloudlets such that the average E2E delay is minimized. Simulations demonstrate that LEAD maintains the low average E2E delay.

## I. INTRODUCTION

Portable User Equipments (UEs), such as smart phones, tablets, smart watches and smart glasses, come with a rich set of embedded sensors already built-in. By utilizing these intelligent UEs, the location (e.g., GPS information), activity(e.g., walking, speaking, sitting, etc.), mood (e.g., happy, calm, alert, etc.),health information (e.g., blood pressure, heartbeat rate, body temperature, etc.), and the ambient environment information of each human being can be monitored and recorded. Thus, UEs are considered as data stream generators producing massive amounts of data, and analyzing these data is not only extremely valuable for market applications, but also has an incredible potential to benefit society as a whole. For instance, analyzing the videos and photos captured by UEs is crucial to localize lost children or terrorists, and analyzing the users’ activities, possible events and historical traffic statistics can accurately forecast the traffic condition to help drivers selecting optimal driving directions. However, the value of the big data decreases as time passes by (for instance, it is important to identify the terrorists from the recent photos/videos quickly). Therefore, analyzing the big data in realtime is critical. In a traditional big data network, all the data generated by UEs are transmitted to a data center (for further analysis) via the Internet because the data center can provision efficient distributed computing architecture (such as MapReduce, Dryad, and Storm) as well as flexible resource allocation. However, transmitting the big data from UEs to the data center through the Internet leads to long network latency and drains the network resources. Thus, the existing big data networking platform is not suitable for real-time big data analysis.

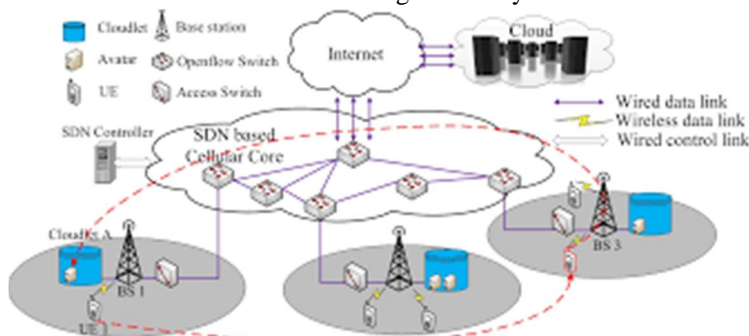


Fig. 1.1 Big data analysis

## II. AVATAR HANDOFF

UEs are roaming among BSs over time and so the E2E delay between UEs and their Avatars may become worse if the Avatars remain in their original cloudlets. For instance, if UE 1 roams from BS 1's coverage area into BS 3's coverage area and its Avatar still resides in Cloudlet A, the communications path between UE 1 and its Avatar should traverse the SDN based cellular core, which may increase the E2E delay as well as the traffic load of the SDN based cellular core. Note that the E2E delay between a UE and its Avatar comprises three parts: first, the E2E delay between a UE and its serving BS; second, the E2E delay between the BS and the cloudlet which contains the UE's Avatar; third, the E2E delay within the cloudlet. Normally, the E2E delay between the BS and the cloudlet is the main factor to determine the overall E2E delay when UE roams away. Thus, we refer to the E2E delay between a UE and its Avatar as the E2E delay between the BS (which serves the UE) and the cloudlet (which contains the UE's Avatar) in the rest of the paper. Long E2E delay can significantly degrade the performance of the big data analysis as well as the MCC applications. Obviously, spending less time for uploading the data streams to Avatars will benefit real-time big data analysis to produce more valuable results. Meanwhile, the E2E delay is critical for MCC applications. It is reported that augmented reality applications require an E2E delay of less than 16 ms and the cloud-based virtual desktop applications require an E2E delay of less than 60 ms. Thus, it is critical to preserve the low E2E delay between a UE and its Avatar by migrating the Avatar among cloudlets when the UE roams away. An Avatar is considered as a private VM, which comprises isolated vCPUs, memory, and virtual disks, and so migrating an Avatar between cloudlets is to conduct live VM migration between cloudlets over the SDN based cellular core. We refer to the Avatar migration process as the Avatar handoff in the rest of the paper. The Avatar handoff process needs to migrate the whole Avatar (which includes the memory, the virtual disk1, and the dirty blocks of the memory and the virtual disk generated during the migration process) from the source into the destination cloudlet. The total Avatar handoff time determines the performance of the Avatar handoff [10]. This is because, first, the degraded E2E delay between a UE and its Avatar persists until the Avatar handoff process is finished, and so shorter handoff time will produce lower E2E delay; second, the Avatar handoff process consumes extra resources of the Avatar (especially the bandwidth resource), and thus degrades the performance of applications currently running in the Avatar. Therefore, short handoff time will improve the performance of the applications.

## III. AVATAR REPLICA PLACEMENT

Migrating the whole virtual disk of an Avatar during the Avatar handoff process incurs unbearable handoff time and increases the traffic load of the SDN-based cellular core significantly. Thus, in order to avoid the virtual disk migration during the Avatar handoff process, we pre-deploy a number of the Avatar's replicas among the cloudlets. A cloudlet, which contains one of an Avatar's replicas, is defined as the Avatar's Available cloudlet. Thus, an Avatar can only be migrated to its available cloudlets.

Note that it is unnecessary and inefficient to place the Avatar's replicas in all the cloudlets in the network because increasing the number of replicas for each Avatar increases the capital expenditure (CAPEX) of the cloudlet provider (by implementing more storage space in the cloudlets) as well as the synchronization traffic in the SDN based cellular core. Meanwhile, placing the Avatar's replicas in the cloudlets, which are never visited by the UE, cannot benefit the communications between the UE and its Avatar. Therefore, it is important to optimally place a limited number of replicas for each Avatar among the cloudlets so that the average E2E delay (during a period  $\Delta T$ , e.g., one day) between the UE and its Avatar can be minimized (by utilizing Avatar handoff) when the UE roams in the network. Therefore, we conclude that the value of  $p_{ij}$  is not the only determinant to affect the performance of the Avatar replica placement. The E2E delay between different BSCs can also affect the performance of Avatar replica placement.

### A. System Model

Let  $I$ ,  $J$  and  $K$  be the set of UEs, BSs and cloudlets, respectively. Denote  $x_{ik}$  as a binary variable indicating one replica of UE  $i$ 's Avatar ( $i \in I$ ) is located in cloudlet  $k$  (i.e., BSC combination indicates that a BS is attached to a dedicated cloudlet.  $x_{ik} = 1$ , where  $k \in K$ ) or not (i.e.,  $x_{ik} = 0$ ). Meanwhile, let  $t_{jk}$  be the average E2E delay between BS  $j$  and cloudlet  $k$ . The value of  $t_{jk}$  ( $j \neq k$ ) can be measured and recorded by the SDN controller. Note that if  $j = k$ , we say that cloudlet  $k$  is BS  $j$ 's attached cloudlet. Moreover, denote  $y_{ijk}$  as a binary variable indicating UE  $i$ 's Avatar is located in cloudlet  $k$  (i.e.,  $y_{ijk} = 1$ ) or not (i.e.,  $y_{ijk} = 0$ ) when UE  $i$  is in BS  $j$ 's coverage area. Let  $_{ij}$  be the average E2E delay between UE  $i$  and its Avatar when UE  $i$  is in the BS  $j$ 's coverage area, then we have:

$$_{ij} = \sum_{k \in K} t_{jk} y_{ijk} \quad (1)$$

Denote  $_{ij}$  as the average E2E delay between UE  $i$  and its Avatar during the period  $\Delta T$  (e.g., one day); meanwhile, let  $p_{ij}$  be the predicted occurrence probability of UE  $i$  in BS  $j$ 's coverage area during the period  $\Delta T$ ; then, we have:

$$_{ij} = \sum_{j \in J} p_{ij} _{ij} = \sum_{j \in J} \sum_{k \in K} p_{ij} t_{jk} y_{ijk} \quad (2)$$

#### IV. ADAPTIVE AVATAR HANDOFF

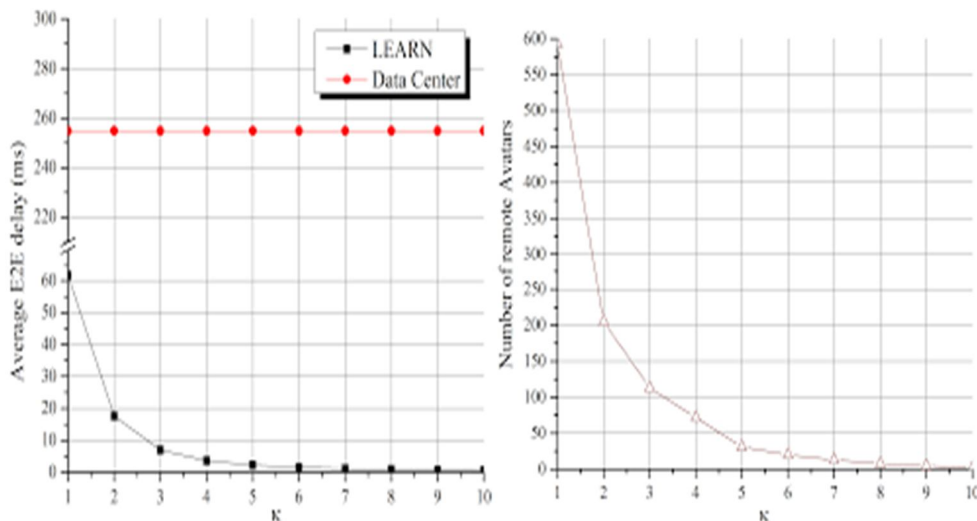
After the replicas of each UE's Avatar being deployed among cloudlets, the Avatar can be handed off among its available cloudlets based on its UE's location. Optimally, the Avatar will be handed off to the available cloudlet, which incurs the lowest E2E among its available cloudlets, when the UE roams into a new location. However, each cloudlet has its CPU and memory capacity, and so the Avatar may not be handed off to the optimal cloudlet because the optimal cloudlet may not have enough residual capacity to host the Avatar. Therefore, it is necessary to design an adaptive Avatar handoff strategy to determine the location of each UE's Avatar in each time slot in order to minimize the average E2E delay between all the UEs and their Avatars during the time slot by jointly considering the capacity limitation of each cloudlet. Note that different from the Avatar replica placement problem (which tries to generate the replica placement solution for each UE's Avatar based on the statistics for a long time period (e.g., one day)), the adaptive Avatar handoff problem tries to obtain the location of each UE's Avatar (rather the Avatar's replicas) based on real time information (e.g., the current locations of all the UEs) and the problem should be solved in real time.

##### A. Problem Formulation

Let  $l_{ij}$  be a binary indicator to identify UE  $i$  in BS  $j$ 's coverage area (i.e.,  $l_{ij} = 1$ ) or not ( $l_{ij} = 0$ ) in the current time slot. Meanwhile, let  $z_{ik}$  be a binary variable to indicate whether UE  $i$ 's Avatar is in cloudlet  $k$  ( $z_{ik} = 1$ ) or not ( $z_{ik} = 0$ ) in the current time slot.  $X_{opt}$

$X_{opt} = \{x_{optik} \mid k \in \mathbf{K}\}$ , which is

generated by the LEARN algorithm, is the optimal replica placement vector for UE  $i$ . In order to avoid the virtual disk migration, UE  $i$ 's Avatar can only be allocated to its available cloudlet  $k$  (i.e.,  $z_{ik}$  could equal to 1 iff  $k \in \mathbf{K}^i$ , where  $\mathbf{K}^i = \{k \mid l_{ik} = 1; k \in \mathbf{K}\}$ ).



##### B. Latency aware Avatar handoff (LEAD)

The optimal solution of  $P4$  generates the optimal cloudlet (which incurs the minimum weighted E2E delay among the cloudlets) for each Avatar. However, it may not be the feasible solution of the original Avatar handoff problem, i.e., the total number of Avatars that are hosted by some cloudlets may exceed their capacity. Denote these set of cloudlets.

#### V. SIMULATION RESULTS

In order to evaluate our proposed replica placement algorithm and Avatar handoff algorithm, we have obtained data traces of more than 13,000 UEs and extracted their mobility in one day in Heilongjiang province in China. The whole area contains 5,962 BSs and each UE's location is monitored during

one day period. Specifically, each packet that is transmitted to/from a UE is monitored, and the packet analyzer extracts the BS information (i.e., the BS's ID and location) from each packet and considers the BS's location to be the current location of this UE (for instance, if a packet from the UE contains the information of BS-A, then we say the UE is currently associated with BS-A and the current location of the UE is BS-A's location).

## VI. RELATED WORKS

Recently, telecommunications vendors have shown the great interest on the concept of mobile edge computing (MEC). European Telecommunications Standards Institute (ETSI) created an industry initiative on MEC to standardize the MEC platform by utilizing the concept of cloudlet. Also, in the academic area, many works [35]–[39] have proposed to utilize the cloudlet to reduce the E2E delay between users and computing resources, and thus improve the performance of MCC applications as well as big data networking. Chen *et al.* implemented a cognitive assistance application (which

*cloudlet utilization* = *Total number of Avatars hosted by the cloudlet*

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*The cloudlet capacity*

provides step-by-step visual guidance for users to implement a complex task) running in a wearable device (such as Google Glass) with the help of cloudlet processing. The cloudlet is deployed one wireless hop away to guarantee the stringent E2E delay required by the applications.

## VII. CONCLUSION

In this paper, we have proposed the cloudlet network architecture to facilitate big data networking as well as mobile cloud computing. Specifically, each UE can access its own Avatar, which is considered as private computing and storage resources for the UE, with the low E2E delay. In order to maintain the low E2E delay when UEs roam away, their Avatars should be handed off among cloudlets accordingly. However, migrating the high volume of the Avatar's virtual disk during the handoff process incurs unbearable handoff time, which may significantly degrade the E2E delay as well as the performance of the Avatar. Also, migrating the Avatar's virtual disk during the handoff process may tremendously increase the traffic in the SDN based cellular core. Thus, in order to avoid the virtual disk migration during the handoff process, we have proposed to place a number of replicas of the Avatar's virtual disk among the cloudlets so that the Avatar can be handed off among its available cloudlets (which contain one of the Avatar's replicas) based on its UE's location. We have designed the LEARN algorithm to optimally place the replicas among the cloudlets for each Avatar so that the average E2E delay between the Avatar and its UE is minimized during the day. Moreover, after optimally deploying the replicas for each Avatar, we have designed the LEAD algorithm to determine the locations of all the Avatars in each time slot so that the average E2E delay between all the UEs and their Avatars is minimized in each time slot, while the capacity of the each cloudlet is not violated.



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