Software-Defined Architecture for Mobile Cloud in Device-to-Device Communication

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***Abstract*—Device-to-Device (D2D) communication enables direct communication between nearby user devices using cellular or ad hoc links thereby improving the spectrum utilization, system throughput, and energy efficiency of the network. Exploiting mobile cloud based D2D communication architecture underlying LTE cellular network has a huge importance in reducing the transmission power of the UEs resulting an improved battery life. This paper proposes a novel hybrid D2D communication architecture where a centralized Software-Defined Networking (SDN) controller communicates with the cloud head (CH) in order to reduce the number of LTE communication links thereby improving energy consumption. In addition, UEs can participate and perform operations in multiple clouds simultaneously. The obtained simulation results confirm improved energy efficiency as compared to the legacy LTE network.**

***Index Terms*—Software–Defined Networking, D2D, device discovery, spectrum efficiency, energy efficiency, cellular communication**

I. Introduction

The mobile data traffic is growing exponentially and is forecasted to surpass 24.3 Exabyte/month by 2019 [1]. Mobile operators need more capacity to meet the demands of mobile users for higher data rates and lower latency. Legacy cellular communication systems often become overloaded [2], while D2D communication in mobile clouds can offer solution to improve system capacity [2].

Mobile Clouds exploit D2D communication to enable a variety of services that can be used in applications such as video streaming, public safety, rich content media offloading, online gaming and energy efficient content distribution [3]. The Mobile Clouds enable User Equipments (UEs) to share their resources/services over D2D links, while preserving connectivity to overlay network. Many aspects of mobile clouds have been separately studied in the past, in the field of ad-hoc networks.

The mobile cloud works in three different stages, *cloud formation*, *cloud operation* and *cloud maintenance* [4]. An important issue in exploring D2D communication for mobile cloud is the design of a composite architecture that accounts for dynamic characteristics of the nodes and their resources in all three stages. The architecture should be capable of establishing the rules on how resources/services are shared. In the formation of a mobile cloud, several device discovery mechanisms can be used that exist in literature, and they can be classified in two general categories: (1) centralized device discovery, where all UEs register their location for other devices to be identified, and (2) distributed device discovery, where each UE broadcasts in a periodic time interval and listens to receive other devices' identities in other time slots.

In this paper, we propose a hierarchal SDN-based (hybrid) architecture for formation and operation of mobile cloud. We propose the idea of local and global SDN controllers that make the process of cloud formation and operation scalable, reliable and energy efficient. We divide the cloud formation in two phases. One is the training phase, where a UE initiates a mobile cloud, broadcasting cloud formation request to the UEs in the proximity over Wi-Fi link. Upon successful formation, the cloud is registered to a global SDN controller. In the second phase, the mature phase, the central SDN controller will have a global view of all served clouds with the services they offer. At that point, the global controller is able to setup the clouds upon users requests.

The proposed architecture is analyzed using the following performance indexes: energy consumption of mobile device in cloud formation and operation stage and the cloud size.

The rest of the paper is organized as follows. We provide a short summary of related work in section II. System architecture and mathematical formulation is presented in section III. Section IV discusses the performance evaluation and presents the results from mathematical model. Section V is the conclusions and future directions.

II. Related Work

The Mobile Cloud represents the logical evolution of the concept of moving the distributed cloud more and more towards the user side. Satyanarayanan et al. [5] use the term cloudlets to describe resource-rich computing environment located at the edge of the network and in the proximity of mobile users. The UEs can use this environment to offload computations and execute virtualized tasks. In [6], Hassan et al. propose a D2D-based mobile cloud architecture, where mobile cloud coverage area is divided into clusters (logical regions) of UEs and comprises a primary cluster head (PCH), a secondary cluster head (SCH) and standard UEs. PCH and SCH, which are selected based on the residual energy and SINR of the UEs, multicast information to the UEs of their respective clusters.

Mass et al. [7] propose a mobile cloud system that implements device discovery based on the audio data obtained from

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the user environment. This centrally controlled cloud system follows client-server architecture, where clients (UEs) send synchronized time series recordings to the server (Amazon Cloud) that runs a clustering algorithm on the time series in order to group them based on their audio similarity. The algorithm is not energy efficient, as clients have to be continuously synchronized with the server through cellular interface.

Doppler et al. [8] propose a distributed device beaconing scheme that exchanges small data packets and works with the assistance of cellular network. The devices transmit their beacons using Orthogonal Frequency-Division Multiple Access (OFDMA), based on the Long Term Evolution (LTE) beacon structure. The mobile cloud formation is not on demand rather a background network is formed based on beacon messages irrespective of the will of the devices to share resources/services.

Wu et al. [9] propose FlashLinQ, a synchronous OFDM based system, to perform device discovery, channel allocation and link scheduling in the licensed spectrum. The distributed channel allocation in licensed spectrum is claimed to give significant gain over conventional 802.11 systems.

In the proposed system, we use distributed device discovery mechanism exploiting Wi-Fi links of the UEs with partial assistance from cellular network. The relative large bandwidth of an IEEE 802.11 cell and large coverage area of the cellular network makes the proposed cloud architecture reliable and energy efficient.

III. Software-Defined Hierarchical Mobile Clouds

This section describes architecture and mathematical foundation of the proposed system.

A. System Architecture

We propose a hierarchal SDN architecture where each UE has an SDN application for cooperation in the mobile clouds. The formation of a mobile cloud is on demand and the SDN application uses a hybrid approach to create a mobile cloud for the demanded service. The central SDN controller, which resides in the Internet, has a global view of all mobile clouds exist in its range (see Fig. 1). We have central SDN controller for each 3 or 4 eNBs.

The SDN controller maintains a database of all mobile clouds, saving identity of each UE with all the services it can share with others. In case of resource sharing services, the details of resources are also stored in the SDN database. Once the database is matured, the central controller, to save energy in the device and service discovery phase, performs the cloud formation without involving local controller. Any service change of a UE will be updated to SDN controller over LTE interface.

The initiator broadcasts a request of cloud formation over Wi-Fi interface. All mobile devices in the vicinity, interested in sharing that service, respond with their resources/services. SDN application in each mobile device maintains a database of all services and resources that a mobile user is willing to share. Once a request for a cloud formation for a particular service, is received from an initiating UE, all interested UEs share the complete database with the initiator. The initiator shares this database with the central SDN controller. The SDN controller registers the mobile cloud and assigns an authentication key to the cloud. The initiator then unicasts the authentication key to each UE, securing it from any malicious attack. The complete signaling procedure for cloud formation and operation is shown in Fig. 2.

Our architecture enables a UE to participate in a multiple Mobile Clouds providing different resources/services. This raises two important issues that needs to be considered:

- The operations belonging to different Mobile Clouds should be performed in a complete isolation (one of the goals of *virtualization*), i.e., to avoid collisions between the operations.
- There should be a proper *allocation of resources* based on the Quality of Service (QoS) requirement of different services (operations). For example, let us consider that one of the Mobile Clouds provides services for file transfer and the other for video conferencing. In such situations, we need to deploy a dynamic resource allocation scheme that will take into account the service requirements with the final goal of achieving an improved network performance in terms of better spectrum utilization and/or a better network throughput.

There are several studies concerning the design and implementation of controllers (e.g., centralized, distributed, hierarchical, etc.), where each has its merits and disadvantages. However, the hierarchal architecture better fits our need in a way that it helps to address the problem of scalability and efficient resource utilization by lowering the communication (i.e., scarce LTE spectrum) load with the central controller. The distribution of different functionalities to different levels of the controllers (i.e., local and central) helps to reduce unnecessary communication with the higher-level controllers, which use scarce radio resources (i.e., LTE spectrum). For example, the local controller (initiator/cloud head) can independently make and break clouds without involving the central-controller. In addition, the hierarchical architecture is very convenient for scalability. The number of devices participating in a cloud could increase as far as the processing capacity of the Cloud Head (CH) has not been reached. The Channel Quality Information (CQI) of the UE determines the selection of the CH, i.e., the UE should be in better signal condition. Moreover, the flexibility of having local decisions carried out by local-controller enables each cloud to work in a distributed manner.

In order to reduce the communication overhead between CH and SDN controller, the CH sends periodic updates to the SDN controller after a preset time, informing all the changes (i.e., users leaving or joining the cluster) that happened during this time interval. This significantly reduces the Ping-Pong effect of users joining and leaving the cluster, resulting in an improved performance of the network in terms of delay and overheads. The database residing in the CHs reduces the possible delay incurred in retrieving information from the SDN

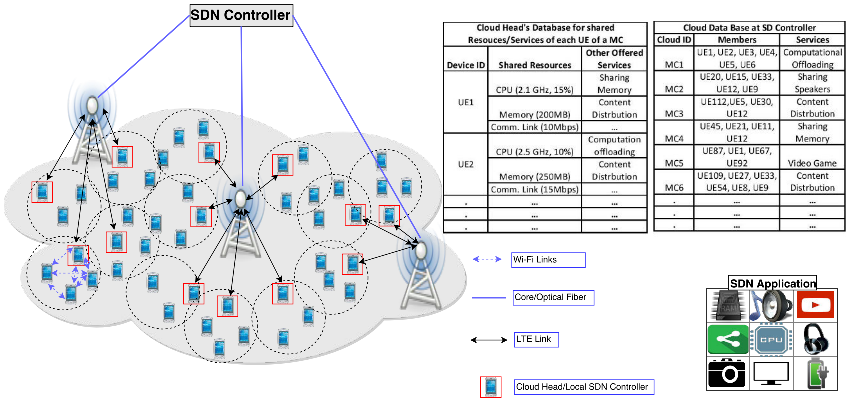

Fig. 1: The proposed system architecture of SDN D2D communication

controller.

B. Energy Model

Besides the improvements in bit rate and spectral efficiency, D2D communication also offers better UE battery life. LTE uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink instead of OFDM, which suffers from poor power efficiency [10]. In addition, Discontinuous Reception (DRX) technique is employed in order to reduce the UE power consumption as defined in the standard. Due to the boom in data services, several applications need a higher computational power in UEs leading to higher energy consumption. D2D communication offers a promising improvement in power saving by reducing the number of LTE communication links, which needs more power as a result of the longer distance between the base stations (i.e., in LTE eNBs) and the UEs.

In this paper, we propose a mathematical formulation for energy consumption of UEs, while communicating through mobile cloud or through LTE links over cellular network. We compare the energy consumption in both cases and found that we can save significant amount of energy if D2D links are exploited. Let we have M clouds each having N_i UEs for $i = \{1, 2, 3, ...M\}$. Then following relation represents the number Wi-Fi links in the system.

$$N^{WiFi} = \sum_{i=1}^{M-1} N_i \ , \tag{1}$$

whereas M is the number of cloud heads that communicate with cellular network over LTE link (i.e., the communication between the CH and the SDN controller). Thus number of LTE links will be M in this case. Let n_i is the number of UEs participating in multiple Mobile Clouds.

$$n_i = \rho_i \times N_i \ ; 0 \leq \rho_i \leq 1 \tag{2}$$

where ρ_i is the percentage of UEs that belong to multiple Mobile Clouds. Based on above model the energy consumption of a UE for transmission on a communication link is given by the following expression.

$$E_{Tx} = P_{Tx} \times t \ , \tag{3}$$

where P_{Tx} is the power consumption during transmission and t is transmission time of a UE. The average energy consumption for M LTE links can be given by following expression.

$$E_{avg}^{LTE_M} = \sum_{i=1}^{M} E_{Tx_i}^{LTE} \ , \tag{4}$$

Similarly, the average energy consumption for all Wi-Fi links is given the following expression.

$$E_{avg}^{WiFi} = \sum_{i=1}^{M} \left[\sum_{j=1}^{N_i - n_i} E_{Tx_j}^{WiFi} + 2 \sum_{j=1}^{n_i} E_{Tx_j}^{WiFi} \right] \ , \tag{5}$$

For simplicity we consider that a UE can participate in maximum of two clouds. The first term in (5) represents the energy consumption for the users participating in a single cloud and the second term represents the consumptions for UEs participating in two clouds. Thus the total energy consumption in D2D case will be:

$$E_{Tot}^{D2D} = E_{avg}^{LTE_M} + E_{avg}^{WiFi} \ , \tag{6}$$

Now we consider the case when there is no D2D communication and all devices have to communicate through eNB only. The average energy consumption in this case will be:

$$E_{Tot}^{LTE} = \sum_{i=1}^{M} \sum_{j=1}^{N_i} E_{Tx_j}^{LTE} \ , \tag{7}$$

where E_{Tot}^{LTE} and E_{Tot}^{D2D} are the average energy consumptions of UEs in the operation of mobile clouds.

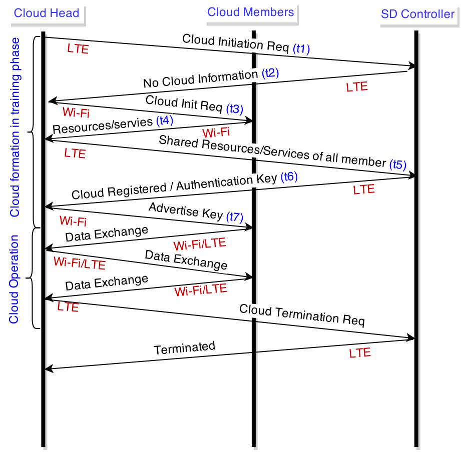

Fig. 2: Description of signaling for cloud formation

We can estimate the energy overhead due the time the UEs consume in cloud formation phase. During the training period, the time spent in the cloud formation phase is the summation of times from t_1 to t_7 (see Fig. 2). Once the SDN controllers database is mature enough to make the clouds and assign the cloud head, the time consumed to make a cloud will be reduced. The following relation estimates the average energy consumption in the cloud formation phase.

$$E^{Training}_{C.F.} = P^{LTE}_{Tx_j} \times t^{LTE}_{Training} + P^{WiFi}_{Tx_j} \times t^{WiFi}_{Training} \text{ ,} \quad (8)$$

where $E^{Training}_{C.F.}$ is the average energy consumption of a UE in training phase of cloud formation, P^{LTE}_{Tx} is the power consumption of a UE for transmission on an LTE interface during cloud formation, $t^{LTE}_{Training}$ is the time spent in transmission on LTE links, P^{WiFi}_{Tx} is the power consumption of a UE for transmission on an WiFi interface during cloud formation and $t^{WiFi}_{Training}$ is the time spent in transmission on WiFi Links.

Similarly the following relation gives the energy consumption of a UE in the mature phase of cloud formation.

$$E^{Mature}_{C.F.} = P^{LTE}_{Tx_j} \times t^{LTE}_{Mature} + P^{WiFi}_{Tx_j} \times t^{WiFi}_{Mature} \text{ ,} \quad (9)$$

IV. Performance Evaluation

The above model estimates the energy consumption of UEs in transmitting on D2D links and LTE links both in cloud formation and operation phase. In Fig. 3 we compare the energy consumption of UEs for different percentages of ρ. To estimate the transmission time over Wi-Fi and LTE links we use the model presented in [11]. Table I presents the values of different parameters [11]; we used to estimate the energy consumption of UEs in cloud formation and operation phase. We consider a simple scenario where each UE has to upload a $20MB$ data to the eNB using D2D (Wi-Fi) and LTE links. For Wi-Fi links we randomly generated the data rates between the range of $7.2Mbit/s$ to $72.2Mbit/s$ (maximum achievable

TABLE I: Numerical Parameters

Parameter	Value
Backoff time (Wi-Fi)	0.1554 [s]
Size of Packet (Wi-Fi)	1500 [Bytes]
Modulation and Coding Scheme (Wi-Fi)	24.10^{-6} [s]
Minimum Data rate (LTE)	5.2 [Mbps]
Maximum Data rate (LTE)	25.5 [Mbps]
Minimum Data rate (Wi-Fi)	7.2 [Mbps]
Maximum Data rate (Wi-Fi)	72.2 [Mbps]

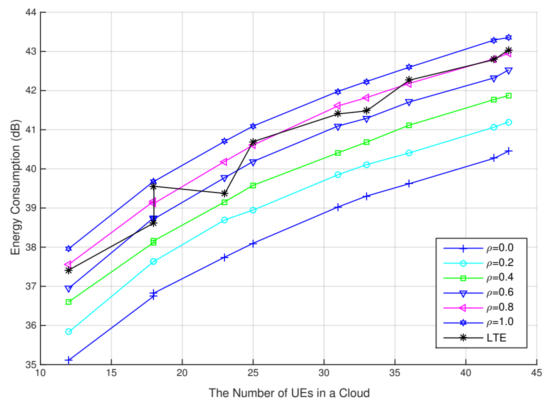

Fig. 3: Comparison of energy consumption in operation stage of mobile cloud

data rate for single spatial stream). Similarly, for LTE links, we define the range from $5.2Mbit/sec$ to $25.5Mbit/sec$ [11] for UEs belonging to category 1 and 2 according to 3GPP release 8.

We find that for $\rho < 80\%$, the D2D communication always consume less energy than LTE. In case of D2D communication on multiple clouds, the UE has to maintain multiple Wi-Fi links and it consumes more energy. To communicate on two Mobile Clouds the energy consumption will be doubled. We can notice from the Fig. 3 that if no UE is participating in multiple clouds then the energy saving can go up to 45.9% and we can still save 3.5% energy even if 70% of the UEs are participating in multiple clouds. Moreover, in our analysis we did not consider the case to use the cooperation capabilities of D2D communication where UEs can cooperate with each other and partition the data into small chunks to send it to CH. In this case the energy consumption will be reduced further as each UE will transfer a small portion of the data.

In the proposed architecture, the average cloud formation time in mature phase is reduced to the time the cloud head or SDN Controller takes to authenticate the request and assign resources. Fig. 4 shows the energy footprints of a single UE in training and mature phase during the process of cloud formation. The graphs are plotted using Eq. 8 and 9 of section III. The results show that we can save up to 96.96% energy, consumed in training phase otherwise.

In Fig. 4 we consider the case of single cloud that can be generalized to multiple clouds with increased training period.

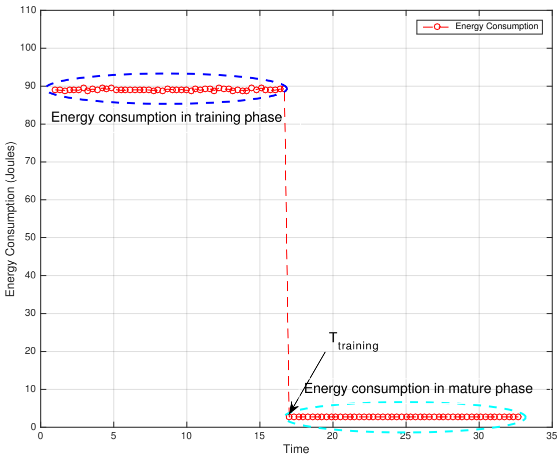

Fig. 4: Comparison of energy consumption during training and mature phase

During training phase, the cloud formation energy fluctuates around $90J$ while during mature phase it is reduced to just $3J$. It is because of the reason that in mature phase the number of communications with LTE and with other peers is reduced. In mature phase the database of services and resources of proximity users at the cloud head tends to become more mature and cloud head does not need to communicate with SDN controller to make a cloud. It can rather just inform the SDN controller about the cloud formation and uses its own database to perform the operation. In this way we can save significant amount of energy and almost no energy is wasted in device and service discovery.

V. Conclusions

In this paper, we presented a novel hybrid D2D communication architecture. The central SDN-controller has a global view of the network and consistently handles management of UEs belonging to different clouds. The simulation results show that our architecture improves the energy efficiency of the network as compared to the legacy LTE network. We are currently working towards quantifying the improvement in spectral efficiency and analyzing computational complexities incurred by the cloud heads.

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