# Device-to-Device Assisted Mobile Cloud Framework for 5G Networks

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***Abstract*—Due to the upsurge of context-aware and proximity aware applications, device-to-device (D2D) enabled mobile cloud (MC) emerges as next step towards future 5G system. There are many applications for such MC based architecture but mobile data offloading is one of the most prominent one especially for ultra dense wireless networks. The proposed system exploits the short range links to establish a cluster based network between the nearby devices, adapts according to environment and uses various cooperation strategies to obtain efficient utilization of resources. We proposed a novel architecture of MC in which the total coverage area of a eNB is divided into several logical regions (clusters). Furthermore, UEs in the cluster are classified into Primary Cluster Head (PCH), Secondary Cluster Head (SCH) and Standard UEs (UEs). Each cluster is managed by selected PCH and SCH. An algorithm is proposed for the selection of PCH and SCH which is based on signal-to-interference-plus-noise (SINR) and residual energy of UEs. Finally each PCH and SCH distributes data in their respective regions by efficiently utilizing D2D links. Simulation results demonstrate that the proposed D2D-enabled MC based approach yields significantly better gains in terms of data rate and energy efficiency as compared to the classical cellular approach.**

## I. Introduction

The proliferation of bandwidth intensive wireless applications such as mobile video streaming and social networking has led to a tremendous increase of data demand [1]. The exponentially increasing demand for wireless capacity mandates novel cellular architectures to deliver high quality-of-service (QoS) while maintaining a cost-effective operation. In this respect, device-to-device (D2D) communication is seen as the key technique to boost the wireless capacity and offloading traffic from cellular network [2]. Recently, 3GPP LTE release 12 Proximity Services (ProSe) which has dealt with D2D communication in order to address the ever-increasing demands for upcoming 5G networks [3]. Reaping number of benefits of D2D communication by exploiting short-range links has yields increased network capacity, extended coverage, improved energy efficiency and enhanced data offload [4]. The benefits of D2D communication are accompanied with a number of technical challenges that include proximity service discovery (ProSe), resource allocation, and inter-cell interference coordination between cellular and D2D links [2].

Due to the rise of context-aware and the advent of location based applications, D2D enabled mobile cloud (MC) has gained lot of attention in the wireless industry. D2D enabled MC is a very flexible platform for sharing resources (e.g., bandwidth, energy etc.) efficiently in a wireless networks. By applying D2D enabled MC in the network, mobile data operators can see gain in threefold: a) the proximity of user equipment (UE) may allow for extremely high bit rates and low energy consumption, b) the reuse gain implies that radio resources may be simultaneously used by cellular as well as D2D links, strengthening the reuse factor so that the same spectral resource can be used multiple times within the same cell [3], c) finally, there is a gain by avoiding both an uplink and a downlink resource, as is the case when communicating via the access point in the cellular mode.

Most of the existing works related to Mobile Cloud (MC) discuss number of advantages of using MC based architecture for resource sharing and exploring challenges related to leader selection, MC management and resource allocation. In this respect, authors presented detail architectural and design aspects for the formation and management of the MC [5]. The authors in [6] discussed various physical and communications resources that had been shared in MC. The authors in [7] explored various architectures of MC and devised various algorithms based on central and hybrid scheme for the formation of MC. In [8] authors proposed a context aware algorithm for leader selection. The author in [9] showed the energy savings in MC by considering homogeneous and heterogeneous data requests. However, these works did not elaborate the detail protocol design aspects for such MC based architecture. This work is the extension of [10] where UEs and eNB together managed and controlled the data distribution inside the MC. In this work we described architectural parameters for the cloud formation and data distribution. Furthermore, the impact of energy efficiency is also examined.

This paper proposes a novel architecture of MC in which the UEs in the cluster are classified into Primary Cluster Head (PCH), Secondary Cluster Head (SCH) and Standard UEs (UEs) shown in Fig. 1. The MC coverage area is divided into several logical regions (clusters) where each cluster is managed by a PCH or SCH. The PCH/SCHs distributes the data in their respective cluster. The paper also presents an algorithm for the selection of PCH and SCH based on the residual energy and the SINR of UEs. The rest of this paper is organized as follows. In Section II, we present the system architecture including the functions of the entities in the proposed architecture. The algorithm for PCH and SCHs selection is illustrated in Section III. Simulation results are presented in Section IV. Finally conclusions are drawn in Section V.

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## II. System Model

Consider the *downlink* transmission of a macro-cellular network underlaid by $B$ eNBs. Let $\mathcal{B} = \{1, ...B\}$ and $\mathcal{M} = \{1, \ldots, M\}$ be the sets of eNBs and UEs, respectively. Let $\mathcal{M}_b$ be the set of UEs under the coverage of eNB $b \in \mathcal{B}$. In order to explore D2D links, a UE is selected as a PCH or SCH to serve other UEs within its physical proximity. The rationale and selection criterion for PCH and SCHs is described in subsequent section. Let $n \in \mathcal{M}_b$ represents a PCH node for the given D2D enabled MC. We let $\mathcal{S}_b = \{1, \ldots, |\mathcal{S}_b|\}, \mathcal{S}_b \in \mathcal{M}_b, \mathcal{S}_b \neq n$ be the set of SCHs under the coverage of $b$ eNB. Here a PCH $n$ and a SCH $(s \in \mathcal{S}_b)$ is defined as an anchor node[1] for D2D communication in the given MC. We let $\mathcal{A}_b = \{1, \ldots, |\mathcal{A}_b|\}$ be the set of anchor nodes, which can be either PCH or SCH under the coverage of eNB $b$, i.e., $\mathcal{A}_b = n \cup \mathcal{S}_b$. Moreover, we also consider that physical area of MC is divided into $|\mathcal{A}_b|$ logical regions, served by PCH or SCH. We denote region $\mathcal{L}_a$ as the set of UEs served by an anchor node $a \in \mathcal{A}_b$ and region $\mathcal{L}_b = \{\mathcal{M} - \sum_{\forall a \in \mathcal{A}_b} \mathcal{L}_a\}$ be the set of nodes (anchor nodes and UEs which are out of coverage of PCH and SCH) serviced by the eNB $b$. We assume that the total bandwidth $W$ is divided into two equal parts cellular bandwidth $W^{(C)}$ and D2D bandwidth $W^{(D)}$. The considered network model for the D2D enabled MC is shown in the Fig. 1. The achievable rate for cellular link between eNB $b$ and UE $m \in \{\mathcal{A}_b \cup \mathcal{L}_b\}$ is given by:

$$R_{b,m}^{(C)} = \frac{W^{(C)}}{|\mathcal{L}_b|} \cdot \log_2 (1 + \gamma_{b,m}), \tag{1}$$

where $W^{(C)}$ is the cellular bandwidth and $\gamma_{b,m}$ is the signal-to-interference-plus-noise (SINR) at UE $m \in \{\mathcal{A}_b \cup \mathcal{L}_b\}$ when serviced by eNB $b$ which is given by:

$$\gamma_{b,m}^{(C)} = \frac{p_b h_{b,m} d_{b,m}^{-\beta}}{\sum_{b' \in \mathcal{B} \setminus \{b\}} p_{b'} h_{b',m} d_{b,m}^{-\beta} + N_0}, \tag{2}$$

where $p_b$ is the transmission power of eNB $b$, $\beta$ is the path loss coefficient, $d_{b,m}$ is the physical distance and $h_{b,m}$ is the channel gain from eNB $b$ to UE $m$, respectively, while $N_0$ is the variance of the additive white Gaussian noise (AWGN). The interference term in the denominator represents the aggregate interference at UE $m$ caused by the transmissions of other eNBs $b' \in \mathcal{B} \setminus \{b\}$. For D2D transmission, interference comes from other anchor nodes (same cell and other cells), hence the rate for D2D link between anchor node $a \in \mathcal{A}_b$ and UE $m \in \mathcal{L}_a$ is:

$$R_{a,m}^{(D)} = \frac{W^{(D)}}{|\mathcal{L}_a|} \cdot \log_2 (1 + \gamma_{a,m}), \tag{3}$$

where $W^{(D)}$ is the short-range D2D bandwidth $\gamma_{a,m}$ is the signal-to-interference-plus-noise (SINR) at node $m \in \mathcal{L}_a$ when serviced by an anchor node $a$ which is given by:

$$\gamma_{a,m}^{(D)} = \frac{p_a h_{a,m} d_{a,m}^{-\beta}}{I_{\mathcal{A}_b} + I_{\mathcal{A}_{b'}} + N_0}. \tag{4}$$

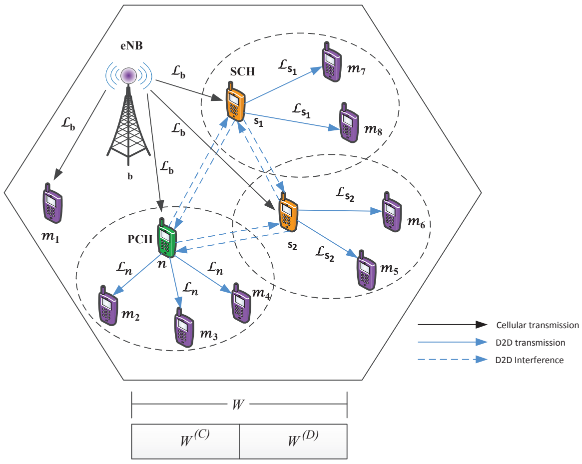


Fig. 1. System model for D2D-enabled MC

The interference term in the denominator represents the aggregate interference at UE $m$ caused by the transmissions of anchor nodes in the same cell $I_{\mathcal{A}_b} = \sum_{a' \in \mathcal{A}_b \setminus \{a\}} p_{a'} h_{a',m} d_{a',m}^{-\beta}$ and anchor nodes of other cells $I_{\mathcal{A}_{b'}} = \sum_{\forall b' \in \mathcal{B} \setminus \{b\}} \sum_{\forall \hat{a} \in \mathcal{A}_{b'}} h_{\hat{a},m} d_{\hat{a},m}^{-\beta}$, where $p_a$ is the transmission power of anchor node $a$, $h_{a,m}$ is the channel gain from anchor node $a$ to UE $m \in \mathcal{L}_a$, respectively, while $N_0$ is the variance of the additive white Gaussian noise (AWGN). A UE is aware of their neighbors through a neighbor discovery [11]. The list of potential UEs for PCH and SCHs is created based on the residual energy and SINR over cellular and D2D links. The selection criterion for the PCH and SCH is detailed in Section III.

### A. Functions of the entities

In order to describe the proposed architecture, different entities such as PCH and SCH have been considered. Each entity has specific roles with respect to their designated logical region. Here, a PCH is defined as important entity for data distribution and management in its allocated logical region. The PCH has several roles in the network; 1) PCH exchanges data with other SCHs 2) It mitigates interference in the MC through power control mechanisms, 3) performs radio resource (time and frequency resources) management of MC, and 4) PCH also performs medium access control functions within the MC such as error control and retransmissions. The basic functions of SCH is to distribute the data locally as well as exchange the data with other SCH's/PCH in MC. Moreover, it also performs error control in its logical region.

### B. Benefits of Devised Architecture

Consider a content distribution scenario among the UEs, where every UE is seeking for the same content. In the classical mobile communication scenario, each UE requests directly to the network for the desired information. By employing the classical method of content delivery in such network where UEs are requesting the same content leads to to following problem:

[1]The term PCH, SCH and anchor node are used interchangeably

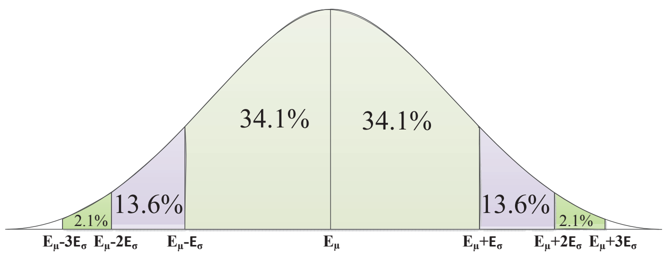


Fig. 2. Energy distribution in Mobile Cloud

- Energy consumption is high when compared to classical mobile communication, since the energy consumption depends on the power and distance.
- Every UE is assigned individual segment of the spectrum which leads to capacity problem, in case of dense UEs deployment.

In our proposed solution, we address the above problems, by taking into account the UE residual energy and rate. In this respect, we proposed D2D assisted MC architecture in which eNB transmit data only to PCH and SCHs. In order to deliver requested data to UEs, every PCH and SCHs use multicast instead of broadcast in their respective region with the help of short-range D2D links.

## III. Selection Description

This section describes the procedure for selecting PCH and SCHs. The selection is based on residual energy of UEs and SINR. The selection process comprises of two steps:

- The first step selects the UEs which have residual energy greater than a threshold value.
- The second step determines a metric based on residual energy and SINR of UEs.

### A. Thresholds Selection

As described in Section II, UEs are randomly distributed within the MC. The eNB calculates the mean value ($E_\mu$), variance ($E_{\sigma^2}$) and standard deviation ($E_\sigma = \sqrt{E_{\sigma^2}}$) according to the following equations:

$$E_\mu = \frac{1}{M}\sum_{m=1}^{M} E_m \tag{5}$$

$$E_{\sigma^2} = \frac{1}{M}\sum_{m=1}^{M} E_m^2 - E_\mu^2 \tag{6}$$

The energy distribution is shown in Fig. 2. From the statistical properties of normal distribution (3-sigma rule), it is known that $68.2\%$ of the UEs have residual energy within $E_\mu \pm E_\sigma$ while $95\%$ UEs have residual energy within $E_\mu \pm 2E_\sigma$ as shown in Fig. 2. In this way, the error function can be defined which gives the information about the UE's having residual energy outside the confidence interval. This is described by the given equation:

$$Err\_fun = F(E_\mu + \alpha E_\sigma) - F(E_\mu - \alpha E_\sigma) \tag{7}$$

$$= \phi(\alpha) - \phi(-\alpha) = \frac{erf(\alpha)}{\sqrt{(2)}}, \quad \alpha \geq 1 \tag{8}$$

where $\alpha$ is the tunable parameter. From (7), we calculate thresholds values for PCH $n$ and SCH $s$ selection, which are given by:

$$\Gamma_n = E_\mu + \sqrt{2}erf^{-1}(\alpha_n)E_\sigma, \quad 0 < \alpha_n < 1 \tag{9}$$

$$\Gamma_s = E_\mu - \sqrt{2}erf^{-1}(\alpha_s)E_\sigma, \quad 0 < \alpha_s < 1 \tag{10}$$

where $\alpha_n$ and $\alpha_s$ are the tuning parameters for PCH and SCH, respectively. The set of UEs, having residual energy greater than $\Gamma_n$, competes for PCH. Similarly, UEs having residual energy greater than $\Gamma_s$, participates in SCH selection. Moreover, a high value of the tuning parameter results in making the selection criteria too strict that does not give optimized network performance. Meanwhile, a lower value results in high probability of a UE not having the maximum residual energy. Thus, it is essential to select the feasible values for tuning parameters for the selection of PCH and SCH.

### B. Metric Computation

In this step, a metric is defined for PCH and SCHs selection. The metric depends on residual energy, power used for transmission, reception and processing and SINR. A high metric value increases the probability of a UE to select as PCH or SCH. The metric $z_m$ for a UE $m \in \mathcal{M}$ is defined as:

$$z_m = \frac{E_m}{E_m^{(C)} + E_m^{(D)}} \tag{11}$$

where $E_m$ is the residual energy of $m^{th}$ UE, and $E_m^{(C/S)}$ is the consumed energy per bit for cellular and D2D communications, respectively. The energy consumed per bit to serve UE $m$ is the ratio between the power consumed per bit $p_x^{(C/S)}, x \in \{\mathcal{B} \cup \mathcal{A}\}$ to the bit rate of the link $R_{x,m}^{(C/S)}$ for cellular and D2D short-range links, given by:

$$E_m^{(C/D)} = \frac{p_x^{(C/D)}}{R_{x,m}^{(C/D)}} \tag{12}$$

By inserting the values of (1, 3 and 12) in (11) we get:

$$z_m = \frac{E_m R_{x,m}^{(C)} R_{x,m}^{(D)}}{R_{x,m}^{(D)} p_x^{(C)} + R_{x,m}^{(C)} p_m^{(D)}} \tag{13}$$

Moreover, the energy efficiency (EE) is defined as the ratio of the total transmitted bits per unit energy consumption (unit: bits/Joule) is given by [14]:

$$EE^{(C/D)} = \frac{R_{x,m}^{(C/D)}}{p_x^{(C/D)}} \tag{14}$$

Our objective is to increase the number of bits in a given transmitted power from the $x$ node. It also implies that energy efficiency increase as a result of higher data rates due to D2D links.

## IV. Simulations and Performance Evaluation

We consider a single macro-cell with single sector hexagonal structure in which UEs are uniformly distributed over the area of interest. We assume that there is no power control and thus the power is uniformly divided between UEs. For simulations, we assume only one PCH and multiple SCH

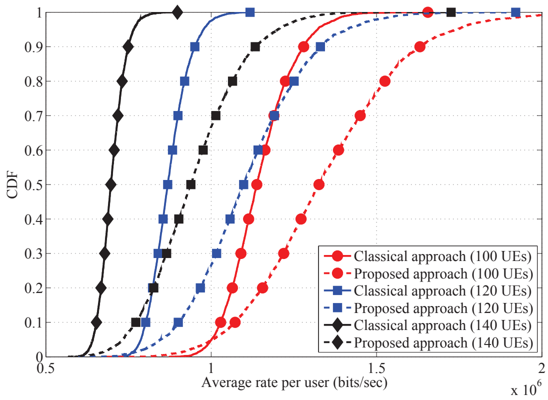


Fig. 3. Data rate comparison for cellular and proposed scheme

nodes in the network. Each UE determine its neighbors based on the cluster radius. The simulation parameters are chosen according to [10], such that residual energy $E_m$ varies from $10\% - 100\%$, tunable parameters $\alpha_n$ and $\alpha_s$ are set to 0.6 and 0.8, respectively. The UEs are assumed to follow random walk model with speed of $2km/h$ [14]. Furthermore, all statistical results are averaged over a 2000 number of independent runs with different densities of UEs 100 to 150 UEs in the system.

For the classical cellular baseline scheme, the bandwidth is equally divided among the UEs. In the proposed scheme, the bandwidth is divided into two equal parts. The first part of the bandwidth is used for cellular communication which is further divided equally between the PCH and SCHs. The PCH and SCHs utilize remaining bandwidth locally by dividing it equally between UEs in their respective regions. In the proposed scheme, to calculate the SINR from eNB to CH, the useful signal is assumed only from eNB to CH while the interference is considered from the other anchor nodes. While in case of SINR for a UE, the useful signal is only computed from CH to the respective UE and interference is considered from the other anchor nodes and eNB.

Fig. 3 shows the cumulative density function of UE's data rate for different number of UEs. It can be shown from the figure that there is an increase in the UE data rate relative to the classical approach. It is observed that the gain for proposed D2D enabled MC in terms of data rate per UE is almost two times to the classical approach. This is due to the short-range D2D links between UEs in the proximity. Fig. 4 shows the

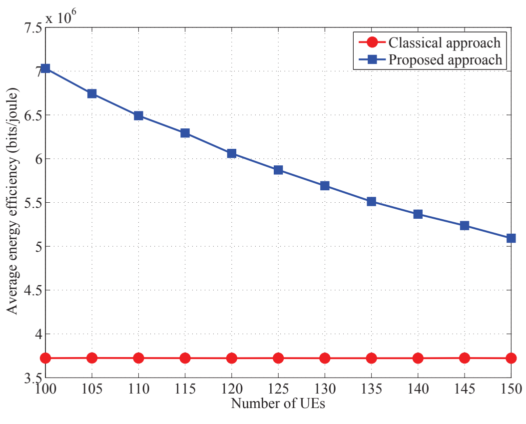


Fig. 4. Energy efficiency comparison for cellular and proposed scheme

energy efficiency as per (14) of proposed D2D-enabled MC with classical cellular approach. In order to show the impact of the density of UEs over the energy efficiency, different load (i.e. number of UEs) are simulated. In case of the proposed approach average energy efficiency decreases as the number of UEs increases as compared to classical approach which is almost static for all values of number of UEs. We can see that, for 100 and 150 UEs, our proposed approach outperforms the classical approach by up to $81\%$ and $78\%$ respectively. Thus, the proposed D2D-enabled MC is more energy efficient than classical cellular communication. This is due to the fact, that the short range D2D links consumed less energy as compared to long cellular links.

## V. Conclusions

In this paper, we proposed a novel approach for data distribution in D2D assisted mobile cloud wireless network. To manage the resources in the network, UEs are assigned different roles such as PCH, SCH and simple UEs. In this respect, we have proposed a method for the selection of primary and secondary cluster heads in the network based on residual energy and SINR. Simulation results have shown that, the proposed D2D enabled MC based approach provides considerable gains in terms of data rates, and energy with respect to classical cellular approach.

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