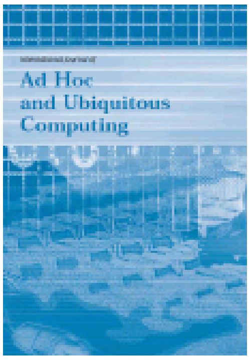

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Energy aware handoff management for cluster-based D2D communications

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Abstract: In device-to-device (D2D) multicasting, network service continuity can be disrupted due to the mobility of multicasting users, potentially resulting in a lower multicasting rate and increased energy dissipation by the serving cluster heads (CHs). To ensure seamless communication for mobile multicasting users, this paper addresses an energy-efficient handoff strategy for 5G D2D multicasting. The proposed approach identifies victim users based on the energy dissipation of their current CH and determines the target destination accordingly. An integer programming-based mathematical model is presented, along with a suitable greedy algorithm. The proposed handoff technique demonstrates over 90% service coverage with a high fairness index, and achieves more than double the energy savings compared to other methods. A detailed quantitative and qualitative performance evaluation is provided, demonstrating that our approach results in minimal energy dissipation of 0.3 Joules and achieves a higher multicasting rate of 8 Mbps, even under conditions of high user density.

Keywords: 5G D2D; cluster head; energy efficiency; handoff management.

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1 Introduction

Device-to-device (D2D) communication has evolved as a promising communication paradigm of fifth-generation (5G) cellular network to facilitate high-speed direct communication among two user equipment (UEs) of close proximity. Effective D2D communications can also lead to a reduction in load on the base station (BS) of the existing cellular network. With the unprecedented growth in the number of wireless communication traffic the demand for high-speed network access, spectrum efficiency, energy-efficient communications, and service continuity also increases proportionally. Service continuity is a prime concern of mobile users. This is because a mobile user may lose its potential coverage under the current service provider while it roams across the network. In such cases, appropriate handoff management is an essential concern which is one of the major aspects of this study. Service continuity may also become disrupted due to the high energy consumption of the battery-operated device as it directly influences the device's lifetime. This essentially raises the need for energy efficient communication which is another major aspect of this study.

Cluster-based D2D communication, also known as D2D multicasting is a suitable mean to provide energy efficient D2D communication. In D2D multicasting, a group of users can access the communication services through a common device known as cluster head (CH). On behalf of the cluster members, the CH receives the content from the BS and transmits it to them through what known as multicasting. However, energy dissipation takes place in both of receiving the content and transmitting the same. There are multiple parameters including the number of cluster members and the rate at which they are associated to the CH influence the consumed energy of the CH. Communication becomes disrupted if the energy dissipation of the battery-operated device, acting as CH is high. Therefore, the design of an energy-efficient D2D multicasting is highly desirable.

Communication quality becomes degraded if a cluster-based mobile user loses its potential coverage from its currently associating CH during its roaming across the network. This is because the obtained data rate becomes weaker and that also has a significant impact on the multicasting rate of the concern cluster. Such weak data rate has a negative impact on the consumed energy of the CH. Thus in both cases, there is a chance to the loss of service continuity. In such a context, suitable handoff management is a prime concern that needs much attention in order to maintain the quality of services (QoS). Handoff management includes identifying the set of mobile users of each cluster that are going to trigger handoff and finding a suitable target CH for them. In both cases, the consumed energy of the CHs acting as source and destination respectively are influenced. Therefore, energy-efficient handoff management for cluster-based D2D users is of utmost importance which is the prime concern of this article.

This paper addresses an energy-efficient handoff management for cluster-based D2D users. The main motivation is to identify the set of mobile users under handoff that access network services from their associating CHs and suitably assigns them to the selected target CHs. The objective is to maintain the QoS through appropriate data rate and to limit the dissipated energy of the CH to the battery capacity of the device. More formally the specific contributions of the manuscript are as follows:

- We first describe the need for an energy aware handoff management for D2D multicasting and address the framework of the proposed handoff model. The proposed model addresses the parameters concerned with identifying the cluster-based mobile users under handoff and selecting their suitable target CH.
- We have developed a mathematical formulation of the proposed energy aware handoff management through an integer linear programming (ILP).
- An elegant greedy algorithm has been developed to solve the problem of energy aware handoff for D2D multicasting. We validate our approach with extensive simulations and a comparative study with the existing approach.

Different notations used in this manuscript are represented in Table 1. The rest of the paper is organised as follows. Section 2 describes the related works of the manuscript. Section 3 addresses the System model. Section 4, addresses the motivation behind the work and the proposed handoff model. The ILP formulation of the problem is represented in Section 5 and the proposed algorithm is presented in Section 6. We represent the performance evaluation of the proposed approach in Sections 7 and 8 concludes the manuscript.

Table 1 Mathematical notations

Notations	*Illustration*
M_{CH}	Set of cluster heads
N_{DU}	Set of cluster-based mobile users
r_{ij}	Obtained data rate of user DU_i from CH_j
$\mathcal{R}_j$	Set of data rates by CH_j
m_j	Number of cluster members of CH_j
L	Payload
ρ_j	Multicasting factor of CH_j
η_j^{BS}	Content receiving energy of CH_j
$\eta_j^{T_x}$	Content transmitting energy of CH_j
$\mathcal{A}$	User association matrix
r_{th}	Threshold data rate for approaching handoff
η_{th}	Threshold battery capacity of a device

2 Related works

D2D communications have evolved as one of the most efficient communication paradigms of future wireless communications (March and BecVar, 2022). Considering D2D communications in 5G networks, handoff management is an important research concern (Li et al., 2018). In Li et al. (2018), a combined approach of mobility-aware handoff and cluster-based D2D communication are presented. Investigating the impact of user mobility on the performance of the network is an interesting research concern. This is because the users' locations may change during the ongoing D2D communications. Existing research works reveal that several studies have been done on mobile

D2D users (Sumathi et al., 2022; Waqas et al., 2020). Mobility management for D2D enabled heterogeneous networks has been addressed in (Xu et al., 2021). Ouali et al. (2017) have proposed a group handover mechanism for underlay inband D2D communication by using different mode selection algorithms to reduce network overheads. This work is further extended in Ouali et al. (2020), where the authors have presented their experiments by incorporating a software-defined network (SDN) in 5G. A detailed survey on SDN-based D2D handover has been addressed in Valiveti and Duggineni (2021). In Lai et al. (2020) have proposed a D2D handover solution in 5G networks where each pair of D2D users choose their target eNB according to their mobility and also by measuring their RSS from the target eNB. The authors have also addressed the reductions of the unnecessary handoff caused by the ping pong effect. To provide seamless services a new idea of half handover and half handover timer has been proposed in Balaji et al. (2019), where the handoff decisions are taken dynamically for a couple of D2D users not only by measuring their SINR threshold but also observing their mobility approaches towards the new BS. Mobile users are also considered in Seifhashemi et al. (2019) towards content sharing for relay-based D2D communications. All these works except in Li et al. (2018), address the issue of mobility management in the context of D2D communications only and did not focus on cluster-based D2D communications. Cluster-based D2D communications is one of the promising approaches towards efficient content sharing and network offloading (Mukherjee and De, 2021). In cluster-based D2D communications, a mobile user may often lose its potential association from its current cluster while roam across the networks. In such a scenario, efficient handoff management is required to maintain the service continuity which is main focus of this study. Unlike the work described in Narmanlioglu and Zeydan (2018) where a machine learning-based approach to handle intra-cluster mobility is addressed, our present work addresses inter-cluster mobility management from the perspective of service continuity and energy efficiency.

Energy efficient D2D multicasting has a significant importance for efficient D2D communications specially for battery operated network devices (Mukherjee and De, 2023a,b). Here, the important aspect is to design energy aware cluster formation so that the cluster-based energy consumption should be minimum to increase the lifetime of battery operated devices. An energy efficient D2D multicasting has been proposed in Abbasi-Verki et al. (2022) where resource allocation and power control are two different aspects that are addressed. Power and channel allocation have been jointly addressed in Du et al. (2021). Raziah et al. (2019) have addressed a cooperative D2D communication with adaptive relay node selection to reduce the energy consumption. Yin et al. (2019) have addressed energy efficient clustering using k-means approach. Energy efficiency in the context of appropriate CH selection has been addressed in Ren et al. (2018) however, the authors did not consider the mobility aspect of the users.

A comparative study between relay-based D2D communications and direct link in terms of energy efficiency has been presented in Vargas Anamuro et al. (2018). The issue of resource allocation has also been addressed in the context of energy efficiency by many different researchers. Energy efficiency together with resource allocation has been addressed in Hmila et al. (2019), Feng et al. (2018), Huang et al. (2020) and Zuo et al. (2019).

An extensive review of various existing studies is summarised in Table 2. From this thorough survey, we observe that previous research has not addressed the challenge of seamless communication in the context of D2D multicasting. In this manuscript, we argue that network service continuity may be compromised due to the mobility of the cluster-based users. To address this issue we propose an energy aware D2D multicasting in 5G networks. Unlike the works described in Sumathi et al. (2022), Lai et al. (2020), Waqas et al. (2020) and Ouali et al. (2017, 2020), we have considered inter-cluster mobility management instead of unicast D2D communications. In this perspective, the proposed approach considers the associated energy consumption of devices acting as CHs for maintaining service continuity.

3 The system model

3.1 Network environment

We have considered a D2D enabled 5G cellular network controlled by a BS, where cluster-based D2D communication takes place. There exists a set of users, present under the weak signal coverage of the BS served through D2D multicasting by a set of CHs. Such users are identified as D2D users (DUs). A particular CH and its associated DUs forms a cluster. It is considered that the cluster members of a cluster should obtain a data rate greater than a minimum rate denoted by r_{th} to maintain appropriate QoS. Furthermore, the dissipated energy of a CH to serve its members must be limited by the battery capacity of the device denoted as η_{th}. Let the DUs roam across the network and while roaming they may loose connectivity from the current CH and may join to other CH for maintaining service continuity. In this context, we have considered random way point mobility model. Let, m number of CHs are active and they are represented by CH_j, $j \in \{1, 2, ..., m\}$. Let n number of DUs are served by these CHs and each represented as DU_i, $i \in \{1, 2, ..., n\}$. The obtained data rate of DU_i from CH_j is represented as r_{ij}.

Table 2 A comprehensive summary of related works

S. no.	*Authors*	*Problem descriptions and findings*	*Limitations*
1	Li et al. (2018)	A speed-conscious handoff mechanism has been introduced for D2D clustering. Also, the received SNR has been used as a criterion of the handoff decision.	Only the impact of the velocity has been investigated. The authors did not address the other useful parameters like available RBs, consumed energy, etc.
2	Sumathi et al. (2022) and Lai et al. (2020)	Handoff to reduce the ping-pong effect has been addressed.	The authors did not consider the issue of D2D multicasting when the devices are in motion.
3	Waqas et al. (2020) and Ouali et al. (2017, 2020)	User mobility on D2D communications.	Challenges on mobility aware unicast D2D communications have been addressed.
4	Xu et al. (2021) and Balaji et al. (2019)	Mobility management of D2D communications in heterogeneous networks has been investigated.	Performance constraints related to operating RBs of the involved networks are not addressed.
5	Seifhashemi et al. (2019)	Content sharing for mobile D2D communications using relay node has been addressed.	Operating RB of the relay node may have a negative impact on the network performance.
6	Mukherjee and De (2021)	Content sharing for multicasting users based on user locations has been addressed.	Inter-cluster mobility has not been considered.
7	Narmanlioglu and Zeydan (2018)	Inter-cluster mobility using machine learning model.	Emphasis is only on cluster formation of the users ignoring the other network performance parameters.
8	Mukherjee and De (2023a, 2023b)	Clustering of the users based on minimum energy consumption.	User mobility has not been addressed.
9	Mukherjee and De (2023a, 2023b)	Clustering of the users based on minimum energy consumption.	User mobility has not been addressed.
10	Abbasi-Verki et al. (2022) and Du et al. (2021)	Resource allocation and energy efficiency has been jointly addressed in D2D multicasting.	Cluster formation, considering power and resource are considered as only parameters.
11	Raziah et al. (2019) and Vargas Anamuro et al. (2018)	Energy minimisation using relay node.	Limited spectrum efficiency due to single D2D communications.
12	Ren et al. (2018), Li et al. (2016), Hmila et al. (2019), Feng et al. (2018), Huang et al. (2020) and Zuo et al. (2019)	Energy efficient cluster-based D2D communications.	Handoff management is not addressed.

3.2 Data rate and energy computation

In order to compute the obtained data rate of DU_i from CH_j, we have considered free space propagation model where the received signal to noise ratio (SNR) obtained by DU_i from CH_j is given by Tewari and Ghosh (2022):

$$\gamma_{ji} = \frac{P_j.G_{ji}}{\sigma^2}. \tag{1}$$

The transmitting power and the noise are represented by P_j and σ^2 respectively. Considering the intermediate distance as d_{ij}, α as the path loss coefficient, g is power gain factor, h_0 ($\in (0, 1)$) as a complex Gaussian variable representing Rayleigh fading and ξ as log normal distribution representing shadow fading, the gain is represented as follows (Tewari and Ghosh, 2022):

$$G_{ji} = g.d_{ij}^{-\alpha}.|h_0|^2\xi. \tag{2}$$

Using Shanon capacity formula, if B represents the channel bandwidth, the obtained data rate is given by:

$$r_{ij} = B\log_2(1 + \gamma_{ji}). \tag{3}$$

In cluster-based D2D communication the CH has to receive the content from the BS and to transmit it to the cluster members. This causes energy dissipation of the device acting as CH. Considering P_j^R as the received power drained from CH_j for receiving the content from the BS at rate r_0, the dissipated energy of CH_j for a payload L can be measured by Li et al. (2016) and Mukherjee and De (2023a):

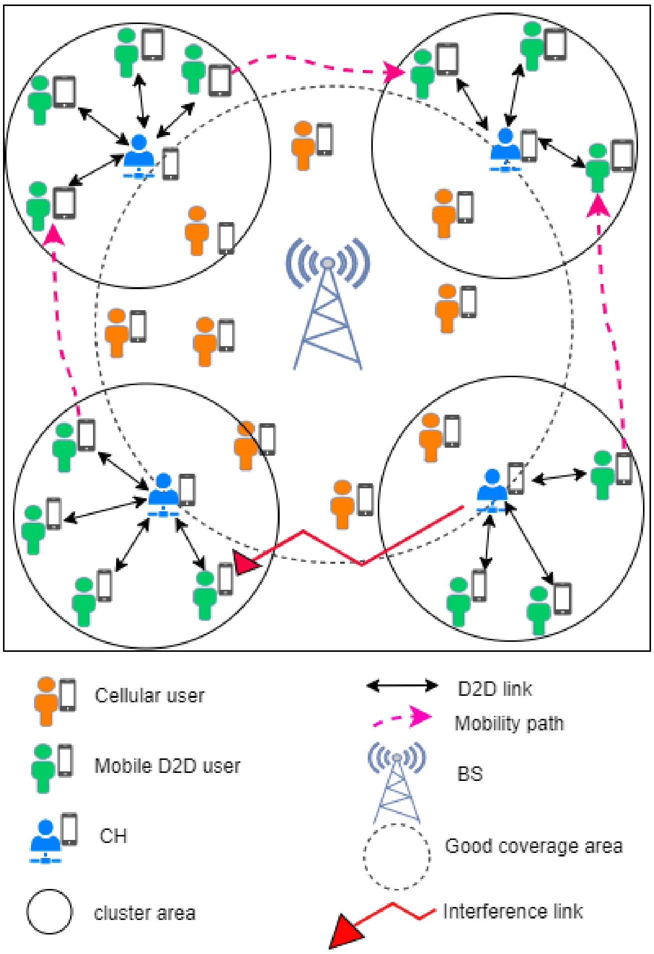
$$\eta_j^{BS} = \frac{L.P_j^R}{r_0}. \tag{4}$$

If m_j number of cluster members are served by CH_j at rate r_{ij}, the consumed energy of CH_j can be represented as:

$$\eta_j^{Tx} = \sum_{i=1}^{m_j} \frac{L.\rho_j.P_j^{Tx}}{r_{ij}} \tag{5}$$

where $\rho_j = \frac{1}{m_j - 1}$ represents the multicasting factor (Li et al., 2016; Mukherjee and De, 2023a).

Figure 1 Proposed model (see online version for colours)



4 Motivation and proposed handoff model

Cluster-based D2D communications allow a group of users to be served by a selected CH. In such communications, both the power consumption of the device acting as CH and the rate at which the concerned CH multicasts the data to its associating members are performance-influencing parameters. The network access services can no longer be fruitful if the transmitting energy of the CH becomes higher than that of the initial battery capacity of the device. Service continuity may also become disrupted when a mobile user loses its potential coverage from the current association. While roaming across the network, the cluster-based mobile users may witness poor signal coverage from its current service providing CH thereby affecting the communication quality and the dissipated energy of the CH as well. Therefore, it is required to design a suitable handoff strategy for the cluster-based mobile users so that they can select the appropriate target CH maintaining both service continuity and QoS. The main motivation is to design an energy efficient handoff strategy that identifies the cluster-based mobile users under handoff and their suitable target CH. The framework of the proposed model describing the networking scenario is illustrated in Figure 1. Our proposed handoff model is based on the following important parameters.

- Users approaching towards handoff: If m_j^k number of users are accessing services from CH_j at a rate $r_k \in \mathcal{R}_j$, where $\mathcal{R}_j$ is set of data rates of all users served by CH_j. The multicasting rate for CH_j is given by $r_{min} = arg\min_k(r_k)$. Now, one or more members of CH_j trigger handoff if $m_j \times \frac{L.\rho_j.P_j^{Tx}}{r_{\min}} < \eta_{th}$ [using equation (5)]. All such users i $(i \in \{1, 2, ..., m_j^k\})$ are approaching handoff for which $r_{ij} < r_{th}$.
- The set of victim users: The set of users that are disassociated from CH_j to maintain $\eta_j < \eta_{th}$ are the victim users of the cluster controlled by CH_j.
- Selecting the target CH: If Q is the list of victim users, for a user $DU_i \in Q$ with its current association CH_j, it selects k' number of possible target CHs such that $\forall j' \in \{1, 2, ..., k'\}$ $r_{ij'} > r_{th}$ and $\eta_{j'} < \eta_{th}$. Among this, it selects $CH_{j''}$ as target CH such that $\eta_{j''} = arg\min_{j'}(\eta_{j'})$.

5 Problem formulation

Given a set of cluster-based mobile users N_{DU} and a set of serving CHs as M_{CH}, the problem is to identify the set of victim mobile users that trigger handoff and suitably assign them to a selected target CH such that the dissipated transmission energy of the selected target CH is minimum and within the battery capacity of the device.

We define the following binary variables for all $j \in M_{CH}$, $i \in N_{DU}$:

$$x_{ij} = \begin{cases} 1 & \text{if a mobile user } DU_i \text{ switches to } CH_j \\ 0 & \text{otherwise.} \end{cases}$$

$$s_j = \begin{cases} 1 & \text{if } CH_j \text{ is selected as target CH} \\ 0 & \text{otherwise.} \end{cases}$$

Along with these binary variables, we also consider an association matrix $\mathcal{A}$, such that $\mathcal{A} = (a_{ij})$ for which $a_{ij} = 1$, if DU_i is served by CH_j and 0 otherwise. We represent the problem of energy aware handoff by the following integer programming where the objective is to minimise the consumed energy of the target CH. For a given payload L, the objective function can be formulated as follows:

$$Minimise\ m_j.\frac{L.\rho_j.P_j^{Tx}.s_j}{r_{\min}} \tag{6}$$

subject to the following constraints:

$$\sum_{j \in M_{CH}} x_{ij} \le 1\ \forall i \in N_{DU} \tag{7}$$

$$x_{ij} \le s_j\ \forall i \in N_{DU}, j \in M_{CH} \tag{8}$$

$$m_j = \sum_{i \in N_{DU}} a_{ij}.s_j \; \forall j \in M_{CH} \tag{9}$$

$$r_{\min} = \text{argmin}_i(r_{ij}.a_{ij}) \; \forall j \in M_{CH} \tag{10}$$

$$\sum_{j \in M_{CH}} r_{ij} x_{ij} \geq r_{th} \sum_{j \in M_{CH}} x_{ij} \; \forall i \in N_{DU} \tag{11}$$

$$\sum_{j \in M_{CH}} \eta_j s_j \leq \eta_{th} \sum_{j \in M_{CH}} s_j \; \forall i \in N_{DU} \tag{12}$$

Constraint (7) ensures that a mobile user under handoff switches to at most one CH. Before a handover from one CH to another CH is executed by a mobile user, the target CH must be selected is ensured by constraint (8). Constraint (9) computes the number of cluster members served by a CH. Constraint (10) is the computation of multicasting rate of a CH. Constraint (11) ensures that a cluster-based mobile user switches to a target CH only when its obtained data rate is greater than that of some threshold value. Constraint (12) ensures that the dissipated energy of the CHs must be limited to a threshold value.

Algorithm 1 Energy aware handoff algorithm for cluster-based D2D users

Input: List of CHs M_{CH} and the set of cluster members N_{DU}, initial association $\mathcal{A}$, r_{th}, η_{th}
Output: Final association after handoff $\mathcal{A}'$, consumed energy of each CH, obtained rate of each cluster member and list of successful handoff

1 **for** *all* $CH_j \in M_{CH}$ **do**
2   Identify cluster member DU_i such that $r_{ij} < r_{th}$ and mark them as weak user;
3   Find out the set of weak users W_j in the order of lower to higher data rate and their count as C_j;
4   Compute η_j;
5 For all $CH_j \in M_{CH}$, find out those for which $\eta_j > \eta_{th}$ and arrange them on descending value of C_j;
6 Denote this new set as M'_{CH};
7 **for** *all* $CH_{j'} \in M'_{CH}$ **do**
8   Remove each user from $W_{j'}$ and add in FIFO queue Q until $\eta_j < \eta_{th}$;
9 **for** *all* $DU_{i'} \in Q$ **do**
10   From the set of CHs M_{CH} find out a set of target CHs M''_{CH}, such that $r_{i'j} \geq r_{th}$ and $\eta_j < \eta_{th}$, $\forall j \in M_{CH}$;
11   **if** *found* **then**
12   Select the target CH, $CH_{j''}$ such that $arg\min_{j''}(\eta_{j''})$, $\forall j'' \in M''_{CH}$;
13   Make the handoff for $DU_{i'}$ to $CH_{j''}$ and compute $\eta_{j''}$ and $r_{i'j''}$;
14   **else**
15   Handoff for $DU_{i'}$ is unsuccessful;
16 return;

6 The proposed energy aware handoff algorithm

In order to address the handoff problem in cluster-based D2D multicasting, we propose a greedy solution. The objective is to identify the set of victim DUs from different clusters that actually require handoff and then to select appropriate target CHs for them. The outcome of the algorithm is to have formulated clusters with minimum energy after satisfying the handoff requirements of the victim users. Let r_{th} be a threshold data rate to identify a user which is approaching towards handoff and η_{th} be the maximum consumed energy allowed per cluster. For all the CHs the list of DUs that falls below r_{th} are identified. For each such CH, CH_j, $j \in \{1, 2, ..., m\}$ the set of weak users are identified and arranged in an order such as user with lowest data rate appears first. Now the CHs are sorted in descending order of the value of count on number of weak DUs approaching handoff. Let the arranged set of CHs is represented by the set M'_{CH}. For each such $CH_{j'} \in M'_{CH}$ the actual victim user is found and added to the handoff queue list q, which will be processed in first in first out (FIFO) basis. The actual victim user for each CH, $CH_{j'}$ is identified by opting out the weak DUs one by one from lowest data rate and checking whether the consumed energy $\eta_{j'} < \eta_{th}$. This process is repeated for all the CHs to have the complete list q. After this step, the victim DUs from list q is considered one by one. For each $DU_i \in q$ the list of target CHs found in descending value of the consumed energy with obtained data rate $r_{ij'} > r_{th}$ and $\eta_{j'} < \eta_{th}$. Based on these DU_i selects the target CH with minimum value of consumed energy. Note that while computing the consumed energy of the possible target CHs, it does not consider the DU in list q if any and takes care of its own association. For a victim user if no such CH is found then the handoff is unsuccessful for that user. More formally, the algorithm is described in Algorithm 1 and the proposed methodology is diagrammatically represented in Figure 2.

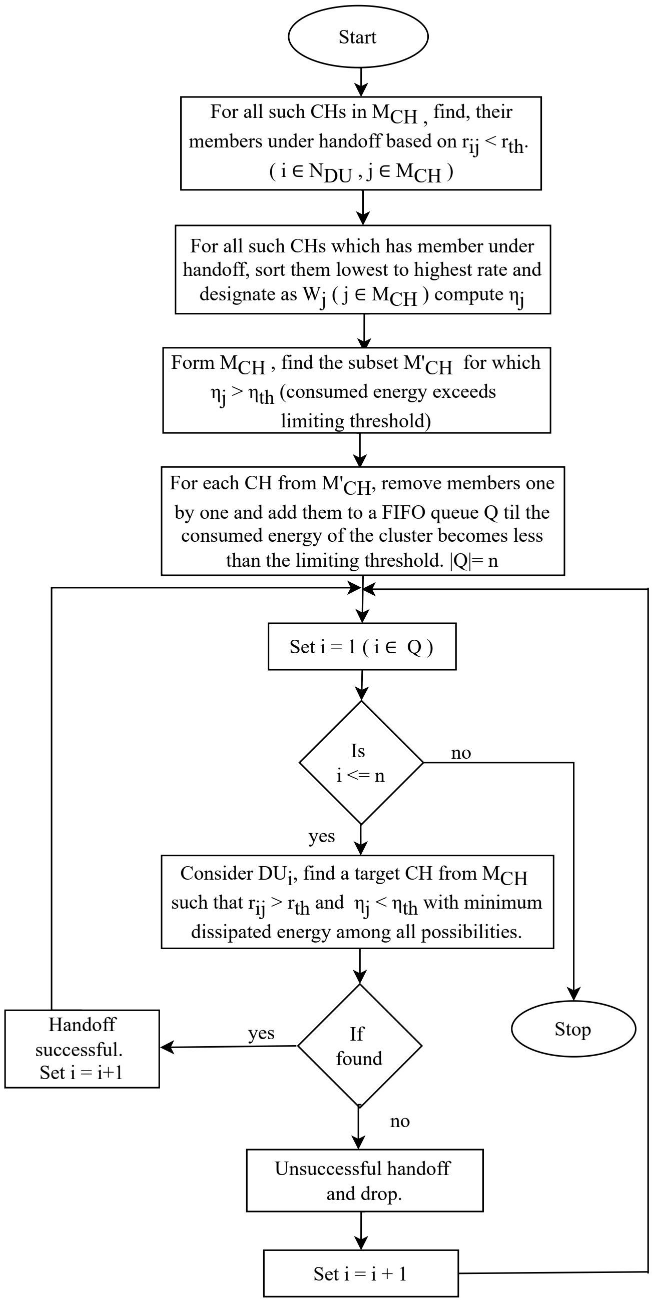
6.1 Complexity analysis

Let us consider, n number of DUs are served by m number of CHs. For m number of CHs and n number of DUs, steps 1–4 of the algorithm requires time complexity of $O(mn)$ in worst case. Step 5 of the algorithm needs $O(\log m)$ time, and step 7 has time complexity of $O(m)$. Finally, the for loop of step 9 has time complexity of $O(m)$. So, the overall worst case time complexity of the algorithm is $O(mn)$.

7 Performance analysis

In this section, we validate the performance of the proposed approach through extensive simulations. Note that, the performance evaluation is done in two folds: first, we evaluate the proposed approach based on several network metrics considering the different network parameters like user density, velocity of the mobile users and energy threshold and secondly, we did a comparative study with the existing approach namely speed aware handoff described in Li et al. (2018).

Figure 2 Flowchart of the proposed methodology



7.1 Simulation environment

We have performed the entire simulations in network simulator 2 (NS2), where we have realistically modelled the standard networking environment. The list of parameters which are considered in the simulations are listed in Table 3. The users are distributed randomly in an area of 500 × 500 square meters. The users with poor signal coverage from the existing BS are considered as target users, served by the selected CHs in their formulated clusters. In this context, the user density is chosen as the number of users from 100 to 350 in a step of 50. Among this, for each set of users, we identify only those users served through different formulated clusters and we have mentioned them as cluster-based users in the current manuscript. Furthermore, in our simulations, we assign mobility with a certain velocity on all the cluster-based users.

Table 3 Parameter list

Parameters	*Value*
Cellular layout	Single cell
File size	1 Mbits
System bandwidth	5 MHz
Threshold data rate for handoff	9 Mbps
Users velocity	10–50 metres/sec
Power gains factor	–33.58 dB
Noise power σ^2	–107 dBm
Path loss exponent α	4
Shadow fading standard deviation	4 dB
BS transmit power	46 dBm
D2D radius	25 metres
Circuit power (P_0)	850 mW
Content receiving power ($P_j^{R_x}$)	925 mW
Content transmitting power ($P_j^{T_x}$)	1.425 Joules/s
Content receiving power from BS	1.8 Joules/s
Threshold energy	1–5 Joules

7.2 Simulation results for performance evaluation of the proposed approach

The performance of the proposed approach is evaluated on the following performance metrics:

- Number of requesting handoff and number of successful handoff.
- Number of failure handoff.
- Average consumed energy of the CHs of the clusters.
- Obtained throughput.

Based on these metrics, we have investigated how our proposed approach performs with several networking parameters like user density, velocity of the mobile users or the required energy threshold of the battery operated device acting as CH.

7.2.1 Impact of user density

Considering a constant velocity of 20 metres/sec with the minimum required data rate of 9 Mbps, we observed how the performance of the proposed approach is influenced by varying user density. For this, we vary the user density from low to high, considering the number of users as 100 to 350 in a step of 50. We have identified the number of cluster-based mobile users and plot them in x axes of Figures 3, 4 and 5. We measure the performance of the proposed approach on several metrics.

In Figure 3, we measure the number of requesting handoffs, successful handoffs, and failure handoffs for varying user density. It is observed in Figure 3, that there exists an increasing trend on all three metrics for the increase in user density. This is due to the increase in the number of cluster-based accommodated users. However, interesting to note that the number of successful handoffs is quite comparable with the number of requesting handoffs. The number of failure handoffs are also much controlled even in higher user density.

Figure 3 Requesting, successful and failure handoff vs. cluster-based mobile users (see online version for colours)

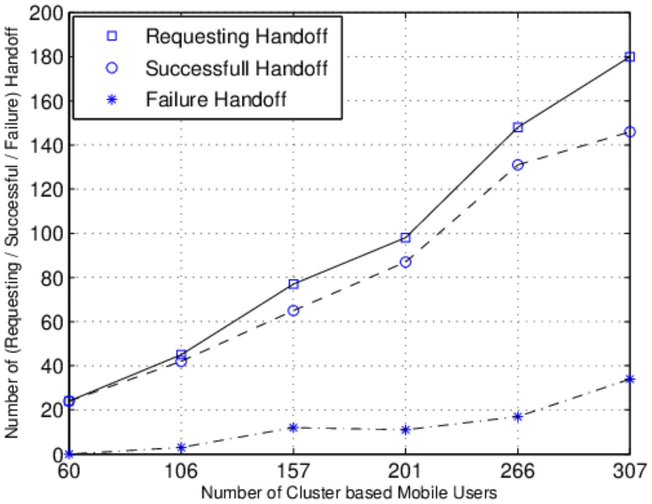
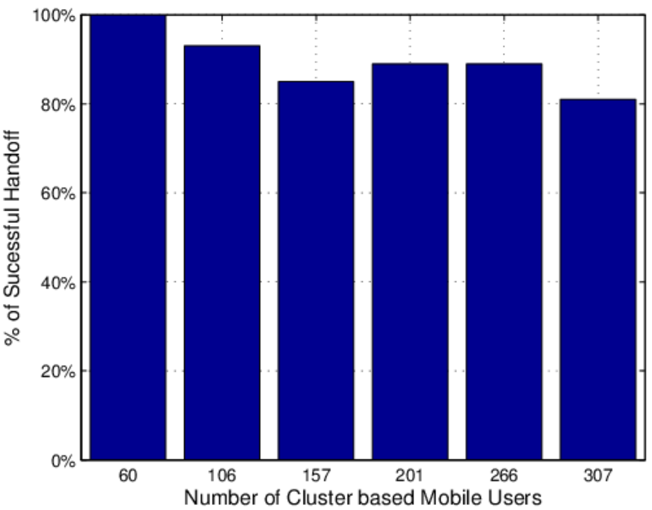


Figure 4 Percentage of successful handoff vs. cluster-based mobile users (see online version for colours)



In Figure 4, we plot the percentage of successful handoff against different user density. We note that at low load, almost all the mobile users are able to successfully find out their target CH, hence leading to either 100% successful handoff or close to 100%. At all load, more than 80% successful handoff is achieved. Interestingly, the percentage of successful handoffs is not always increasing or decreasing with increased user density. The reason is that the objective of the proposed approach is not to increase the number of satisfied users rather to judiciously select the target CH, maintaining the appropriate data rate and taking care of the consumed energy of the battery-operated devices which act as CH.

Figure 5 Average CH energy vs. cluster-based mobile users (see online version for colours)

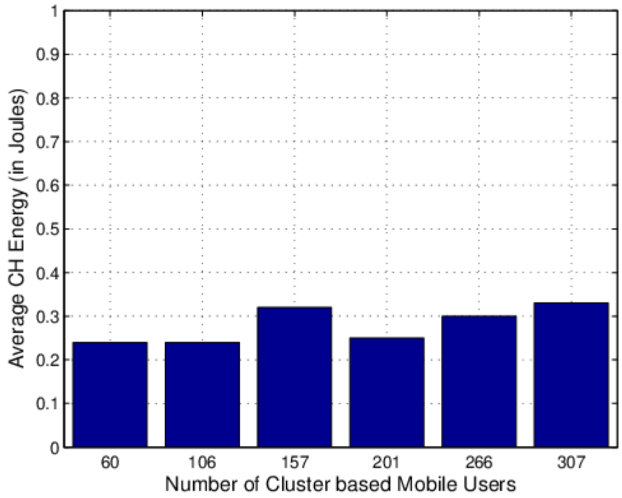
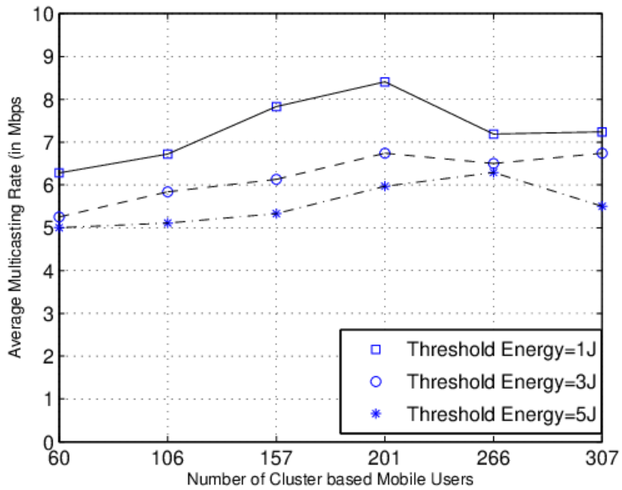


Figure 6 Average multicasting rate vs. cluster-based mobile users (see online version for colours)



The lifetime of a battery-operated device depends on the consumed energy. The proposed approach selects the target CH of the requesting users under handoff such that the consumed energy is as minimum as possible and within the limit of the battery capacity. In Figure 5, we plot the average energy consumed by the CHs with increase in user density. From this figure, we conclude two important facts. Firstly, as evident, the average consumed energy of the CHs for different user density is quite uniform and not always increasing with the increase in user density. Secondly, the average consumed energy of the CHs is much less than the threshold battery capacity of the device which has been considered 1 Joule for this simulation. This happens because, the proposed approach takes care of the consumed CH energy while associating the users under handoff.

The proposed approach considers not only the energy parameter but also the signal quality of the target CH before switching. To validate the same, we plot the average multicasting rate of the CHs for different user density considering three different energy threshold of 1 Joule, 2 Joule and 3 Joule respectively. As observed in Figure 6, the trend of the curve for the average multicasting rate against increasing user density is not always increasing because it altogether depends on the weakest link rate of a formulated cluster. However, in all cases it is found that the average multicasting rate is more than 5 Mbps which is quite satisfactory. Interesting to note that, for a fixed user density there is a decreasing trend of multicasting rate with increasing energy threshold. This is due to the accommodation of more number of users with increased energy threshold.

Figure 7 Successful handoff vs. velocity of mobile users (see online version for colours)

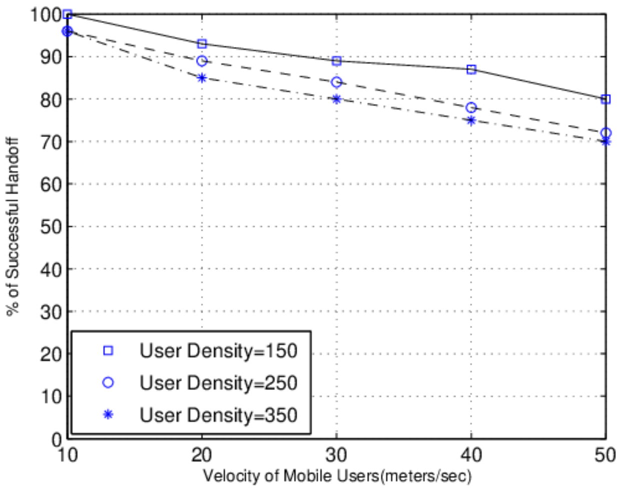
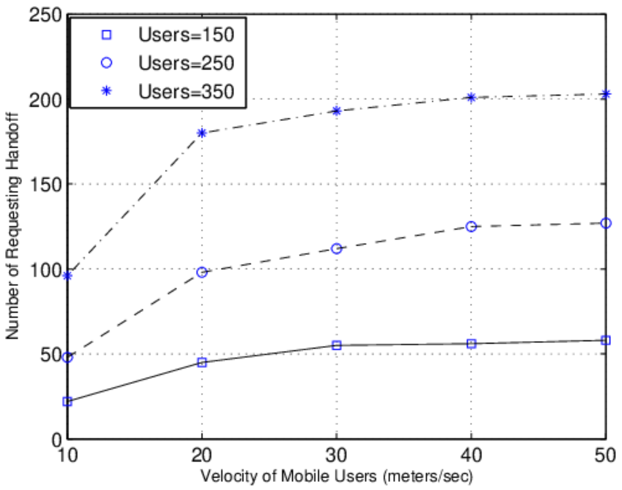


Figure 8 Requesting handoff vs. velocity of mobile users (see online version for colours)



7.2.2 Impact of velocity

We observe how the performance of the proposed approach is influenced by the varying velocity of the cluster-based users. The mobility speed of the devices acting as cluster-based users are considered from low to high as 10 metre/sec to 50 metre/sec respectively. For this, we have considered three different user density such as 150, 250 and 350 with a constant energy threshold of 1 Joule and minimum data rate of 9 Mbps. We measure the percentage of successful handoff, number of requesting handoff and the average consumed CH energy represented in Figures 7, 8 and 9 respectively.

Figure 9 Average CH energy vs. velocity of mobile users (see online version for colours)

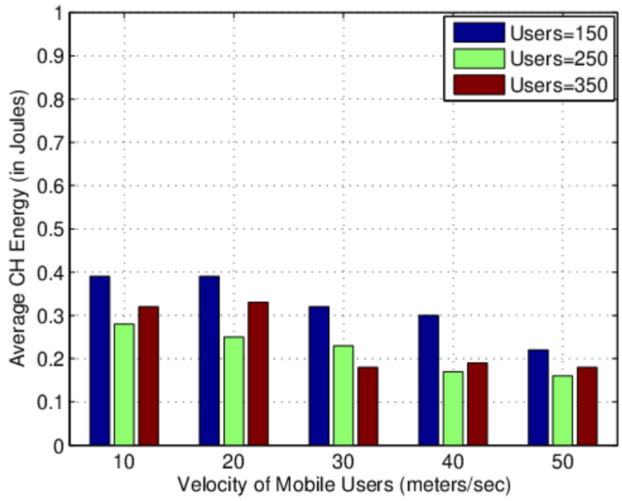
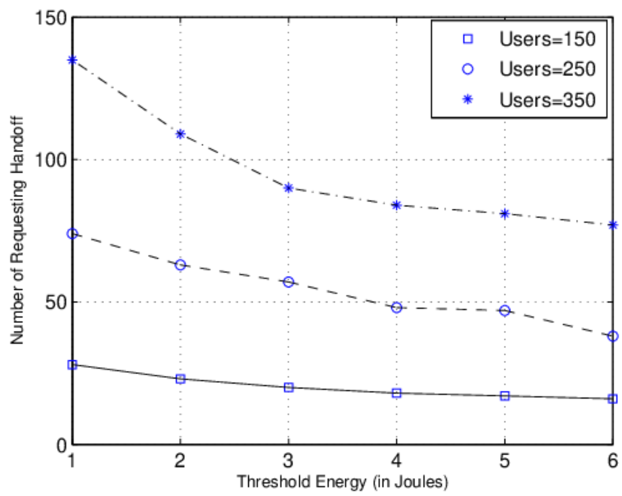


Figure 10 Number of requesting handoff vs. threshold energy (see online version for colours)



We observe in Figure 7, that the percentage of successful handoff decreases with the increase in velocity. This is due to the fact that the increased velocity causes more mobile users to be in the region of weak data rate of the current clusters which proportionally affect the consumed CH energy and hence an increase in the number of required handoff also noted in Figure 8. This also causes an increase in number of failure handoff and hence decreases the percentage of successful handoff as noted in Figure 7. However, in proposed approach, judicious selection of the target CH during handoff results in more that 80% successful handoff at low user density of 150 and more than 70% success in high user density of 350 even in high velocity of 50 metres/sec.

Figure 11 Average multicasting rate vs. threshold energy (see online version for colours)

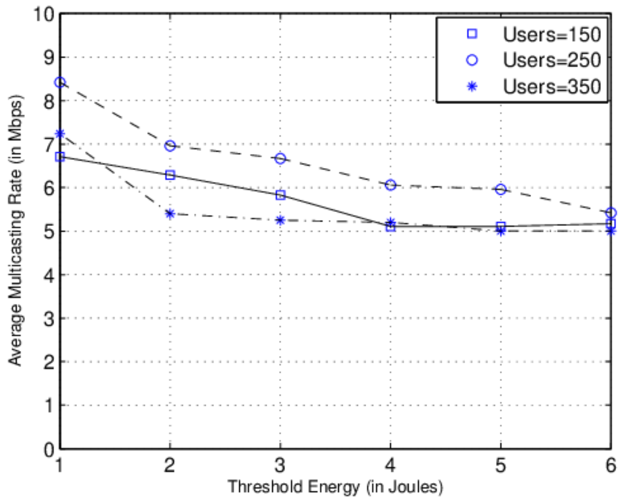


Figure 12 Number of failure handoff vs. threshold energy (see online version for colours)

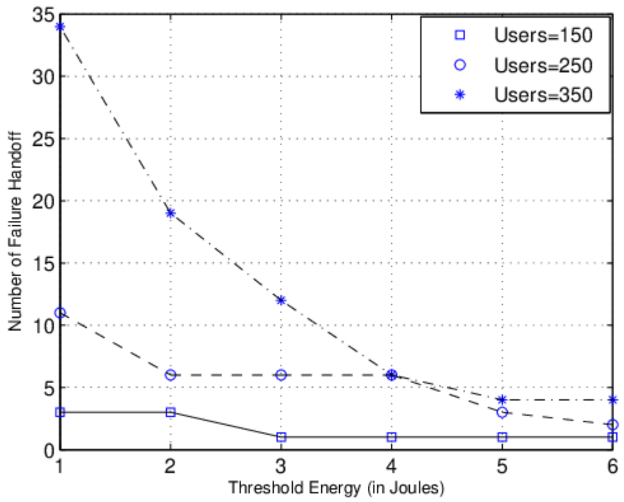


Figure 13 Number of successful handoff vs. threshold energy (see online version for colours)

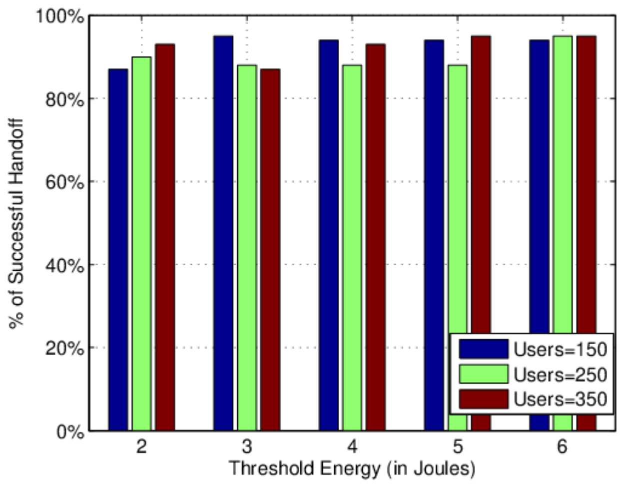


Figure 9, demonstrates the average consumed CH energy with the increase in velocity from 10 metres/sec to 50 metres/sec. It is noted that for a fixed user density, the average consumed energy is decreasing with the increased velocity. This happens due to decreasing number of successful handoff with increasing velocity which results in less number of admitted members in a given cluster. However, it is interesting to note that in all cases, the average consumed energy of the CH is limited by the battery capacity of the device which is considered as 1 Joule in this simulation even in the case of low user density and low velocity when the admitted handoff is more. Also note, for a given velocity there is no uniform trend in average consumed CH energy with varying velocity for different users. This reveals that the objective of the proposed approach is to consider all relevant parameters that influences the consumed CH energy while maintaining appropriate coverage and QoS.

7.2.3 Impact of threshold energy

The initial battery capacity of a device plays a vital role in determining its lifetime. If the consumed energy is more then the communication becomes disrupted. The proposed approach suitably designs a handoff strategy that takes care of the initial battery capacity of the device designated as threshold energy. So, in our proposed model the threshold energy is an influencing parameter and we investigate its influence on the performance of the proposed approach in Figures 10, 11, 12 and 13 respectively by considering three different user densities and keeping a constant velocity of 20 metres/sec.

Figure 10 demonstrates a decreased number of requesting handoff with the increase in energy threshold for all three user densities. The proposed approach not only considers the link rate but also the energy threshold of the associating CH to define the handoff criterion. Hence if the limiting battery capacity is higher, more number of cluster members continue to accept services from their current association so long they maintain a good link rate and hence reduced number of requesting handoff as represented in Figure 10.

In Figure 11, we plot the average multicasting rate with the increasing energy threshold. The proposed approach not only takes care of the battery capacity of the device to frame the handoff criterion but also it takes care of the obtained link rate. From Figure 11, two interesting observations are found. First, there is a decreasing trend of multicasting rate with the increase in energy threshold for all three user variations. Second, the multicasting rate in all cases is above 5 Mbps which is quite standard for multimedia data streaming. Increasing the energy threshold causes the users with a distant location from a target CH become served. The multicasting rate is determined with the minimum data rate of the cluster-member which causes a decreasing trend of average multicasting rate with the increasing energy threshold. Since the average rate is higher than that of 5 Mbps, so it justifies that the proposed approach suitably maintains service continuity with QoS. Also important to note, for a constant energy threshold the trend of average rate with variation of users might not be uniform as it altogether depends on the location of the users case to case.

We observe how the number of failure handoffs varies with varying values of energy thresholds. In Figure 12, we observe mostly a decreasing trend with increased energy threshold. This is because when the threshold value of energy is higher the users under handoff have more options to find out the target CH and hence less failure in handoff. Interestingly when we have a tight constraint of the threshold value of the energy, the difference in the number of users fail in handoff is more for three different variations of user densities. Such a difference is gradually relaxed when we relax this constraint by having more energy thresholds as expected.

In Figure 13, we demonstrate the percentage of successful handoff against different energy thresholds for all three user densities. It is observed that against all the variations of the energy threshold, the success rate of handoff is uniform for three different user densities, and in all cases, more than 85% of users are able to find their target CH which surely justifies the novelty of the proposed approach.

7.3 Comparative study with existing approaches

We have conducted a thorough comparative study using some of the existing approaches from the literature.

- Speed aware handoff: In Li et al. (2018), a speed aware handoff approach has been proposed for D2D clustering. In this study, the handover decision is based on measuring the received signal strength (RSS) of the device under a certain threshold from its current association. If the RSS of the neighboring cell is higher then it switches to the neighboring cell. Note that, we have considered similar parameters consideration for a fair comparison. In this context, the threshold energy for our approach is considered as 2 Joule. The threshold for link interruption in the speed aware approach is considered as –6 dB however in our case, we have considered a data rate of 9 Mbps to identify a user that approaches handoff.
- Physical and social-based approach: The proposed energy aware handoff management is compared with the existing physical and social-based approach of cluster formation also described in Shirvani Moghaddam and Ghasemi (2018). In this approach, the cluster is formed based on the distance between its members and the received SNR. In this framework, both social traits like the number of neighbors, and physical traits such as data and files are taken into account. This method relies on the physical and social attributes of the cluster members and we call this as physical and social-based approach.
- Relay-based approach: The relay-based approach is described in Raziah et al. (2019). In this method of cluster formation, the authors have used an adaptive relay-based cooperative D2D communications. Note that, the selection of the relay node is based on the received SNR.

The listed methodologies are compared with the proposed energy aware handoff strategy based on the metrics like percentage of successful handoff, average multicasting rate, average consumed energy and the Jain's fairness index.

Figure 14 Comparison on percentage of successful handoff (see online version for colours)

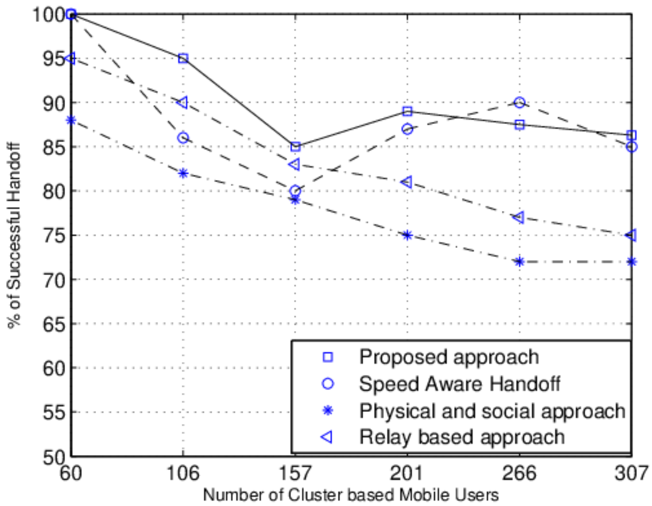


Figure 15 Comparison on multicasting rate (see online version for colours)

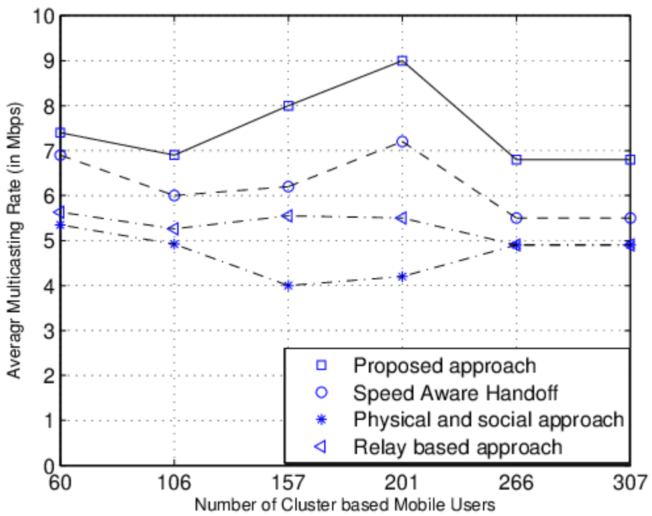


Figure 14 demonstrates the percentage of successful handoffs for different approaches considering different user densities. Interestingly to note, the proposed energy aware handoff and the speed aware approach do not result in always a decreasing trend of successful handoff with the increased number of mobile users. This indicates that the proposed approach suitably formulates the clusters for the users under handoff keeping the energy constraint at an acceptable amount. Furthermore, an obvious notice is that when the user density is much higher there are no significant variations in the percentage of successful handoff alongside the proposed approach resulting in more than 90% handoff rate in an average case. Additionally, the percentage of successful handoff is reduced in comparison to the proposed approach for physical and social approach and relay-based approach. This is because the physical and social-based approach has to consider the physical and social characteristics to form the cluster for the target users and hence a reduced handoff rate. As a final note, the proposed approach provides a considerably comparable performance in terms of successful handoff.

Figure 16 Comparison on average CH energy (see online version for colours)

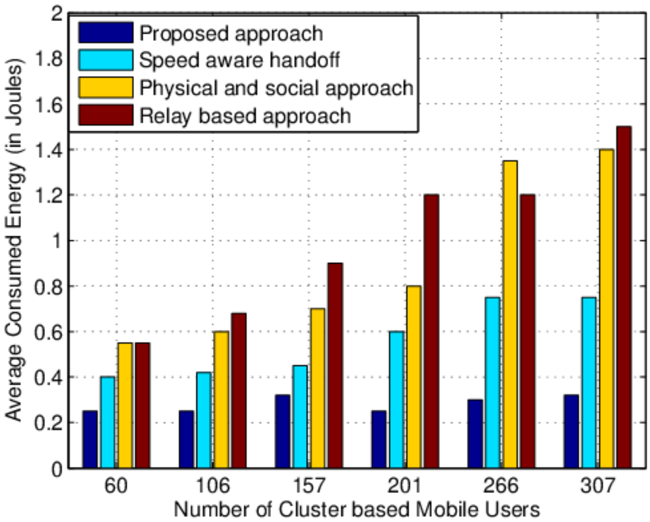
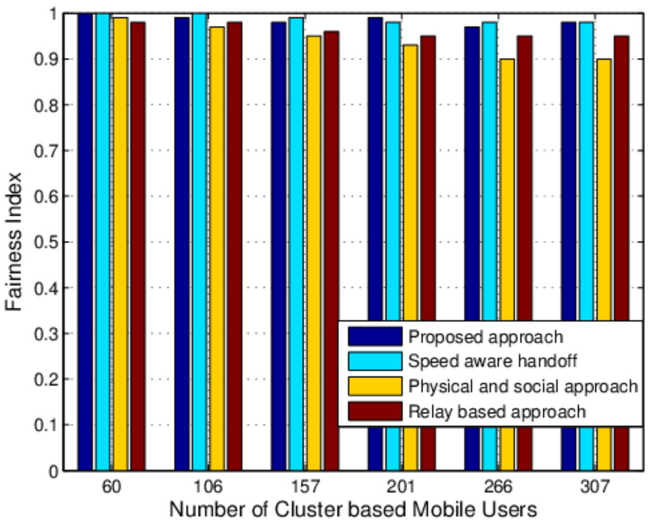


Figure 17 Comparison on JFI (see online version for colours)



We made a comparative study on the obtained multicasting rate for different approaches as shown in Figure 15. This is because the multicasting rate is one of the influencing parameters of the consumed energy. As observed in Figure 15, the proposed energy aware handoff results in much higher multicasting rate in comparison to the other approaches. The proposed approach formulates the target clusters for the mobile users under handoff with minimum consumed energy which in turn takes care of maintaining the average multicasting rate higher. Here too, we observe that in all cases the average multicasting rate has no uniform trend with variation in number of cluster-based mobile users. This all together depends on the variations in cluster-based mobile users and their signal conditions. Furthermore, the multicasting rate becomes saturated when the user density is too much higher. We argue that the formulated clusters accommodate maximum members at higher user density and does not increase with the increase in more cluster-based users and hence a saturated multicasting rate.

The major objective of the proposed approach is to formulate the clusters while satisfying the mobile users under handoff with the minimum consumed energy. For this, we have measured and plotted a comparative study on the average consumed energy of the CHs shown in Figure 16. We observe that the proposed handoff strategy not only leads to minimum average energy dissipation on the CHs for the formulated clusters but also results in a more uniform distribution of energy dissipation of the CHs in comparison to the other approaches. This surely justifies a novel approach to cluster formation by our energy aware handoff strategy.

We provide a comparative result by considering Jain's fairness index (JFI) in the context of number of satisfied users for different user densities. Such fairness is considered for different variations of velocity. The fairness ratio (F_k) for k^{th} variation of velocity can be defined as:

$$F_k = \frac{n_k^s}{n_k^r}. \tag{13}$$

In equation (13), n_k^s and n_k^r indicate the number of served users and the number of requesting users respectively for k^{th} variation of velocity. Hence, if p number of variations are considered then Jain's fairness index can be defined as:

$$JFI = \frac{\left(\sum_{k=1}^{p} F_k\right)^2}{p \times \sum_{k=1}^{p} (F_k)^2} \tag{14}$$

In our context, JFI will indicate the fairness among the served users. The value of JFI varies between 0 and 1 (Tewari and Ghosh, 2019).

Considering Jain's fairness index as the performance metric, we have presented a comparative study on the values of JFI against different user densities. As evident in Figure 17, even though the proposed approach considers the dissipated energy of the CHs along with a reasonable link quality before admitting a user in a cluster, the obtained fairness is highly compared with all other existing approaches. In all cases, the fairness is more than 90%.

We have considered three different performance metrics such as the percentage of successful handoff, average multicasting rate, and the average consumed energy of the CH to present a quantitative performance analysis represented in Table 4. We observe that the proposed approach results in more than 90% successful handoff of the requesting users which is significantly better than the other contemporary approaches. Additionally, it is important to note that the proposed approach leads to a considerable energy saving alongside the average multicasting is also higher.

Table 4 Quantitative performance measurement

Parameter metrics	*Proposed approach*	*Speed aware approach*	*Physical and social approach*	*Relay-based approach*
Successful handoff percentage	90.46%	87.5%	78%	83.5%
Average multicasting rate	7.48 Mbps	6.21 Mbps	4.71 Mbps	5.29 Mbps
Average CH energy	0.28 Joules	0.56 Joules	0.90 Joules	1.05 Joules

8 Conclusions and future scope

This paper presents an effective handoff strategy for multicasting users in 5G cellular networks. We specifically address the issue of high energy dissipation in battery-operated devices acting as CHs, primarily caused by the low multicasting rate of mobile users. To maintain service continuity, we propose an energy-aware handoff strategy aimed at maximising service coverage while ensuring seamless communication. The proposed approach achieves more than 90% successful handoffs and a high fairness index. Additionally, it results in minimal energy dissipation of 0.3 Joules, which is nearly double the energy savings compared to well-known approaches. A detailed comparative analysis, combined with both quantitative and qualitative performance evaluations, underscores the novelty of the proposed approach.

Addressing the reduction of handoff frequency and latency remains a critical research area. Future directions for this work involve predicting and evaluating the mobility patterns of multicasting users to anticipate their next target during handoff. Additionally, the focus will be on developing strategies to decrease frequent handoffs and creating an inter-cluster, mobility-aware handoff model that effectively minimises latency during transitions.

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