

ON THE ENERGY EFFICIENCY OF CLUSTERING ALGORITHMS FOR RELAY ASSISTED DEVICE-TO-DEVICE COMMUNICATION

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Abstract

The energy efficiency of data transmission in Device-to-Device (D2D) communication extends battery lives necessary for service continuity. One communication method in D2D is clustering where one User Equipment (UE) relays data between cluster members and the base station (NodeB). This paper evaluates the energy efficiency of three D2D clustering algorithms: Round Robin, where the cluster head selection is rotational among cluster members, Minimum Distance, where the UE closest to the NodeB is selected cluster head, and Minimum Remaining Power where the UE with the highest battery level is the cluster head. A simulation is developed considering various scenarios where UEs are at different distances from the NodeB, and either stationary or moving at certain speeds. Results reveal that the Minimum Distance is the most energy efficient algorithm when UEs are nearby the NodeB and moving. It also outperforms other algorithms as long as UEs are on the move; so that selection of cluster head is rotated among cluster members. Results also show that maximum energy savings due to clustering are up to 47.4% compared to traditional LTE.

Keywords: Cluster-based D2D, Device-to-Device, Energy Efficiency, Maximum Remaining Power, Minimum Distance

Introduction

Device-to-Device (D2D) communication is an emerging technology that enables User Equipment (UE) to communicate without requiring network infrastructure such as base stations (Gandotra and Jha, 2016; Moghaddas-Goloian *et al.*, 2019). D2D is suitable to contribute to realizing 5G user expectations in terms of capacity, reliability and service quality. D2D improves network capacity by providing connectivity for out-of-reach devices

while offloading cellular traffic and reducing transmission power and interference. It offers low latency communication for services including file sharing, multimedia downloads, online games, and others. Since D2D requires close proximity among connected UEs, it is most suitable for local services such as social applications and emergency applications (Mumtaz and Rodriguez, 2014; Kar and Sanyal, 2017).

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Clustering in D2D is introduced to allow nearby devices to form a group where a Cluster Head (CH) is selected based on some criteria. The CH is directly connected to the base station, whereas other cluster members communicate through the CH with no direct link with the base station. Cluster members benefit from low energy consumption, reduced transmission power and lower latency. Other non-cluster devices experience reduced interference and enhanced service availability. The advantage of cluster-based D2D to the cellular network is cellular offload, as the base station communicates with a single device using a single cellular channel instead of all the devices in the cluster.

A number of previous studies discussed clustering in D2D (Kollias *et al.*, 2015; Narottama *et al.*, 2015; Shen *et al.*, 2016; Ali, 2018; Aslam *et al.*, 2020; Girici and Kazez, 2021; Ahmed, 2023). A cluster head rotation method is proposed in (Narottama *et al.*, 2015) to balance the energy consumption of the CH compared to other cluster members (CMs). The method calculates the average battery level of all devices and exempts devices with battery levels lower than the average from acting as CHs. Candidate devices with higher battery levels become CH in rotation. The proposed method was able to achieve an energy consumption ratio of (1.25:1 for CH:CM) compared to (3:1) for standard clustering method. Paper (Shen *et al.*, 2016) adopts the employment of caching in clustered D2D to facilitate synchronous file sharing. CMs retrieve video files from the cache and are treated equally, since no device is appointed as CH. Results revealed energy savings in the cache assisted approach, with more savings achieved for videos of higher quality. Clustering is proposed in (Kollias *et al.*, 2015) to improve the capacity of a LTE-A network by minimizing utilized resources. Intra-cluster communication is carried out using uplink resources, since they are less utilized compared with downlink resources. Spectral efficiency is increased by solving an integer linear optimization problem. Results show that the proposed algorithm increases network capacity.

The article in (Aslam *et al.*, 2020) proposed a content distribution algorithm for D2D. The algorithm forms UEs with similar interests into clusters based on distance and channel conditions. It evaluates the impact of user interests on throughput and energy consumption. Results revealed that the proposed algorithm outperformed benchmarked clustering algorithms in terms of throughput and reduced energy consumption of user devices by 6%. The proposed algorithm considers only users with similar file sharing interests at close proximity. Therefore it is not suitable in scenarios where users

with different interests are scattered in a wide geographical area, since this leads to overlapped clusters with large distances between cluster members.

The work in (Girici and Kazez, 2021) investigated cache management and content discovery for clustering-based D2D networks. The work proposed caching content at helper nodes and provide it to other cluster nodes. Results showed that the procedure reduced latency and network overhead even under high user density. However, the work did not consider users' movement which influences network overhead due to inter-cluster handovers. Moreover, additional energy consumption experienced by helper nodes due to content delivery is not evaluated.

The work in (Ahmed, 2023) evaluates the implementation of an energy-efficient relay-based multihop D2D network for disaster management. The clustering algorithm selects relay nodes and cluster heads such that network coverage is extended. It considers different distances between the base station, relay nodes and cluster heads. A second paper (Ali, 2018) proposed using energy harvesting in D2D networks for disaster management. The proposed idea utilizes energy harvested from the base station for D2D communication to extend the network lifetime. Clustering is employed to improve network performance in terms of coverage and energy efficiency, which was proved by demonstrated results. The work however assumes that nodes are interested in the same content. When considering scenarios with little or no similarity in requested content, energy consumption of cluster heads significantly increases, as each cluster member requires the cluster head to download its unique request from the base station.

Devices-to-Device (Ds2D) communication scheme is proposed in (Shakir *et al.*, 2017) where a sink device aggregates radio resources of multiple devices ensuring optimal packet split. The goal is to minimize delay and energy consumption and extend battery life. The scheme considers multiple data rates and proved to outperform the traditional random packet D2D. However, Ds2D communication requires coordination between multiple devices over multiple radio interfaces which increases complexity. The work in (Mohammed *et al.*, 2021) evaluates the energy consumption of relay-assisted D2D in a single-cell environment compared to data delivery under traditional LTE using simulation. The simulation evaluated the influence of different parameters including simulation time, packet transmissions interval and distance on energy efficiency. Attained results demonstrated that relay assisted D2D

reduced total energy consumption of devices by up to 40% compared to LTE.

One important factor that determines the success of D2D employment is energy efficiency. In general, energy efficiency in cellular mobile communication is the ratio between the number of packets received by the base station and the total energy consumed in the transmission process (Boyle *et al.*, 2017). The significance of energy efficiency in wireless communication including cellular networks is due to the fact that terminal devices in such networks (mobiles and sensors) are power constrained. Fast energy drainage implies less communication time. In the situation where users rely on other mobile devices for communication (such as D2D and sensor networks), high energy consumption in communication consequently reduces the network lifetime.

Another factor that increases the feasibility of clustering in D2D is the online alteration of the CH such that it changes as communication progresses. This ensures that the optimum UE is selected as CH only until a better relay is found. Having alternative CHs imposes minimum side effects on the relay node such as fast battery drain.

To the best of our knowledge, no prior work has evaluated the energy efficiency of online alteration of the CH comparing differing clustering approaches. In this paper, the energy efficiency of cluster-based D2D is evaluated employing three approaches that differ in CH selection criteria. These approaches are: Round Robin (RR) which equally distributes CH responsibilities among cluster UEs, the Minimum Distance (MD) algorithm which selects the UE with the minimum physical distance from the NodeB, and the Maximum Remaining Power (MRP) algorithm which prefers the UE with the fullest battery to relay data. A simulation is developed to evaluate the energy efficiency of the three algorithms in a single cell with four UEs. The main contributions of this research are summarized as follows:

1. The energy consumption of cluster-based D2D is found under MD, MRP and RR. Maximum energy savings for each algorithm compared to traditional LTE are attained.
2. The energy consumption of data transmission is calculated for CH and non-CH UEs to demonstrate the trend of loss in battery power under each algorithm.
3. The performance of the three approaches is compared in terms of energy efficiency and UE battery lifetime considering various mobility and proximity scenarios.

It is worth mentioning that the work considered in this paper does not include cluster

formation. It compares the performance of operating the selected clustering algorithms in a previously formed cluster. The process of arranging UEs in clusters is out of the scope of this paper. Additionally, other evaluation parameters can be used to compare the performance of clustering algorithms including throughput, delay and reliability. Nevertheless, D2D communication relies on the continuous operation of participant devices. Prolonging the battery life of devices is the utmost priority to extend network lifetime.

Materials and Methods

This work evaluates the Round Robin, Minimum Distance and Maximum Power clustering algorithms. This section explains these algorithms and provides thorough details about the implemented simulation. D2D Clustering Approaches

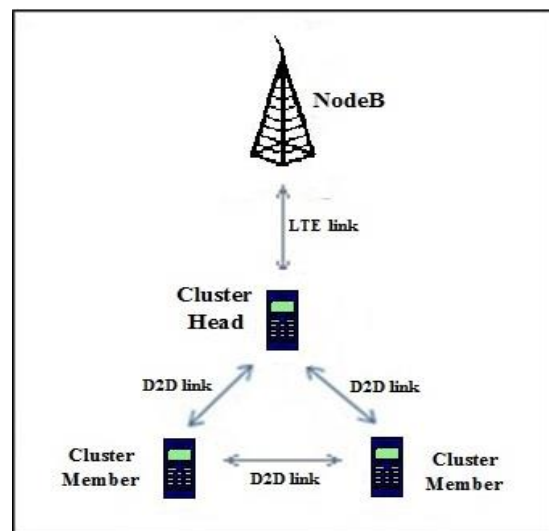


Figure 1. Cluster-based D2D

In cluster-based D2D shown in Figure 1, a UE communicates with the cell NodeB through another UE in its proximity. This intermediate UE, which is the CH, acts as a relay node that forwards traffic between the UE and the NodeB (Mohammed *et al.*, 2021). The selection of the CH depends on the parameter that the clustering algorithm employs for the selection process. The value of the parameter is measured for each UE in the cluster, and based on these measurements the CH is selected. Following are the clustering algorithms implemented in this work.

Round Robin (RR)

There are situations where a CH continues to act as a relay node for the whole communication period, either by remaining the closest in distance to the NodeB or for having the maximum battery power compared to other UEs. In these situations a single UE suffers from high battery power loss. The RR algorithm forces the distribution of traffic relaying to all participating UEs by changing the CH after each time period. The algorithm selects the first UE in the list of cluster members as the CH for a given time period. When this time expires, the second UE in the list becomes the CH. This process is repeated until all UEs in the list participate acting as CH. Afterwards the selection process continues from the top of the list. UEs with initial battery power lower than a certain level should be exempted from acting as CHs to avoid a complete battery drain.

Algorithm 1 Round Robin**Begin:**

1. Initialization: set counter to 0
2. for simulation time, do
3. set CH to UE [counter]
4. calculate energy consumption of CH according to LTE
5. calculate energy consumption of other UEs according to D2D
6. set counter = (counter + 1) % number of UEs
7. end for
8. return energy consumption of all UEs

Minimum Distance (MD)

The MD algorithm selects the UE with the minimum physical distance to the cell NodeB as a relay node to other UEs in its vicinity and appoints it as CH. The power consumption of transmitting data from the NodeB to the UE is a function of the distance between the two entities (Al-Hourani *et al.*, 2016). Selecting the closest UE to the NodeB ensures minimum power consumed using LTE mode due to the reduction of the signal path. Cluster members are continuously monitored to insure that the CH is the closest UE to the NodeB. In the case where another UE becomes closer to the NodeB by a certain threshold, the closer UE becomes the new CH.

Algorithm 2 Round Robin**Begin:**

1. for simulation time, do
2. Find UE at minimum distance
3. set CH to UE [counter]
4. calculate energy consumption of CH according to LTE

5. calculate energy consumption of other UEs according to D2D

6. set counter = (counter + 1) % number of UEs

7. end for

8. return energy consumption of all UEs

Maximum Remaining Power (MRP)**Algorithm 3 Maximum Remaining Power****Begin:**

1. for simulation time, do
2. Find UE with maximum remaining battery power UEmax
3. set CH to UEmax
4. calculate energy consumption of CH according to LTE
5. calculate energy consumption of other UEs according to D2D
6. end for
7. return energy consumption of all UEs

One challenge facing clustering in D2D is the battery consumption of the CH. The CH is in charge of the transmission and reception of traffic that belongs to other UEs. The battery of the CH must have sufficient initial power such that the user is not influenced by the side effects of relaying data. The CH loses battery power at a higher pace compared to other UEs in the cluster and therefore a UE with a low battery should not be selected as a CH. On top of that, the battery of the CH should not be allowed to drop below a certain level (or percentage) to protect the user's device from running out of power. The MB algorithm selects the UE with the maximum initial battery power as CH. This UE consumes more power in forwarding traffic between the NodeB and cluster members and its battery continues to lose power. The CH continues its role until its battery's remaining power falls lower than the battery power of another UE in the cluster by a certain threshold. When this occurs, the other UE with the maximum remaining power is selected as the new CH and communication resumes. This strategy ensures fairness over participating UEs as well as lengthening of network lifetime.

Simulation Environment

The architecture environment used in this work considers an LTE cell controlled by a NodeB. The cell has four active UEs which are connected to the NodeB and make download requests. To evaluate the influence of device mobility and distance on energy efficiency, four mobility scenarios are considered:

Near NodeB, fixed locations (near-fixed)

In this scenario, UEs are located in close proximity to the NodeB (tens of meters) and do not move. Therefore the distances of UEs from NodeB and from each other are set at the start of the simulation and remain constant throughout the simulation time.

Far from NodeB, fixed locations (far-fixed)

Similar to the first scenario, locations of UEs are fixed, only here they are located relatively further away from the NodeB (hundreds of meters).

Near NodeB, with mobility (near-mobile)

This scenario considers users' movement during data transfer. The distances of UEs from NodeB and from each other change over simulation time. At the start of the simulation, each UE is randomly assigned an initial distance from NodeB, a speed as well as a direction (towards or away from the NodeB). During the simulation, each UE travels at a fixed speed, which varies from the speed of other UEs. Distances from each UE and other UEs and NodeB are calculated every simulation time.

Far from NodeB, with mobility (far-mobile)

The mobility pattern of this scenario is similar to the previous scenario, except, in this scenario UEs are initially located far away from the NodeB.

Note that the work in this paper assumes linear movement for UEs where each UE moves either towards or away from the NodeB. A more realistic approach can implement UE movement such that it follows a specific pattern to exemplify streets for example. This approach requires further investigation.

Results and Discussion

The simulation was implemented on a laptop running Windows 10 with an Intel core i3 processor, 4GB RAM and 500GB hard disk. Table 1. shows input parameter values used in the simulation where power consumption parameters are derived from (Alsharif *et al.*, 2013; Pasca *et al.*, 2016; Höyhty *et al.*, 2018; Mohammed *et al.*, 2021). For the near scenarios, UEs are assumed to be at 40, 45, 50, 55 meters from the NodeB. In the case UEs are moving, their speeds are randomly generated with an average of 18 kilometers/hour heading either towards or away from the NodeB. Under the far scenarios, UEs are considered to be at 400, 450, 500, 550 meters from the NodeB. When mobility is considered, UEs' speeds are randomly generated with an average of 60 kilometers/hour heading. Each of the four

mobility scenarios was tested under all clustering algorithms.

Table 1. Simulation parameter values

Parameters	Values
Simulation time	100 seconds
Distance of UE from NodeB in the near scenario	40-55 meter
Average speed in the near scenario	18km/hour
Distance of UE from NodeB in the far scenario	400-550meter
Average speed in the far scenario	60km/hour
Data rate	80 Mbps
Battery Voltage	5 volts
Battery Capacity	2100 mAh
Power consumed in transmission mode	0.55 Watts
Power consumed in receiving mode	0.42 Watts
Power consumed in idle mode	0.5 Watts

In (Mohammed *et al.*, 2021), the simulation used input values for power consumption of data transmission variant with respect to distance derived from 0(Alsharif *et al.*, 2013; Höyhty *et al.*, 2018). These values were used to calculate the resultant energy consumption for data transmission during a time period under LTE and D2D. In this work, we utilize energy consumption output values attained in (Mohammed *et al.*, 2021) for each distance and use them as inputs to evaluate the energy efficiency of clustering algorithms. These energy consumption values are shown in Table 2. The simulation is executed considering traditional LTE as well as the four clustering algorithm. Energy consumption results are evaluated and compared to determine the most energy efficient algorithm under each scenario.

Table 2. Distance (Meters) and total transmission energy (watts)

Distance	Total transmission energy using LTE	Total transmission energy using D2D
10	56	6.2
20	69	7.7
40	96	10.7
50	137	15
100	271	30
200	540	60
1000	675	75

Round Robin

Applying the Round Robin algorithm results in UEs becoming CHs for equal time periods. Consequently, all UEs are susceptible to approximately the same additional energy

consumption due to relaying other UEs' data. The difference in energy consumed by one UE and another solely depends on the difference between their distances from the NodeB. Figure 2. reflects this difference. Figure 3. shows the energy consumption of Round Robin algorithm under the near-mobile scenario. The energy consumed by a UE is relative to its distance from the NodeB. Therefore as can be seen in Figure 3., the energy consumption of each UEs is exemplified by a wave where the wave rises as the UE moves away from the NodeB and falls as it approaches it.

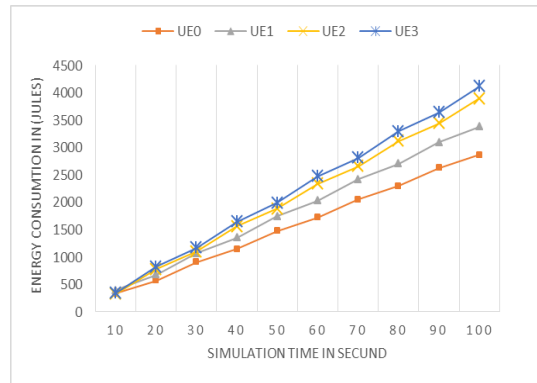


Figure 2. Round Robin Energy consumption under the near-fixed scenario

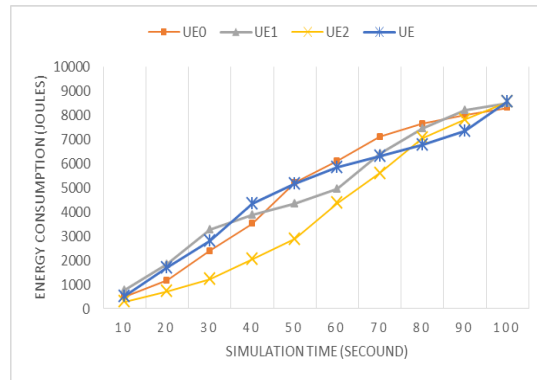


Figure 3. Round Robin energy consumption under the near-mobile scenario

Figure 4. and Figure 5. show the energy consumption of Round Robin algorithm under far-fixed and far-mobile scenarios, respectively. When UEs are far from the NodeB, (400 to 550 meters), their energy consumption is relatively similar, even when UEs are moving. The UE serving as CH suffers increased energy compared to other UEs during that time period. Consequently, the most energy is consumed by the CH each simulation time

regardless of its location. These effects result in the braid-like curves shown in Figure 4. and Figure 5.

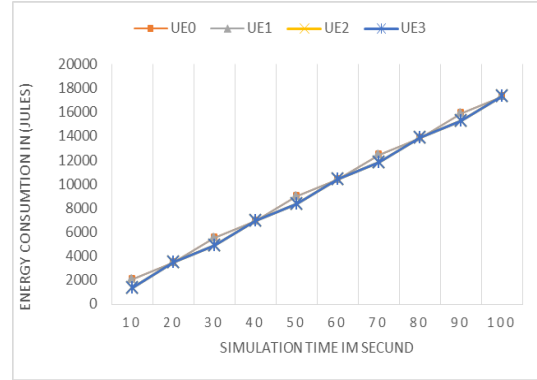


Figure 4. Round Robin Energy consumption under the far-fixed scenario

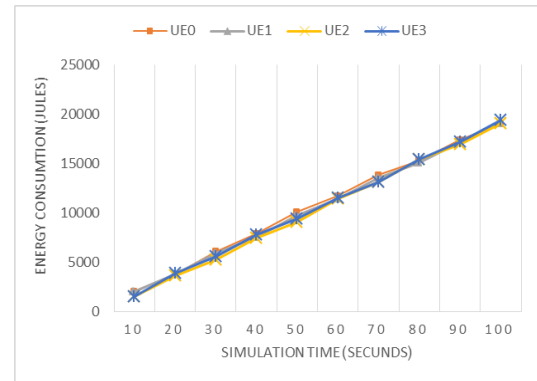


Figure 5. Round Robin energy consumption under the far-mobile scenario

Minimum Distance

The minimum distance algorithm selects the closest UE to the NodeB to act as CH. Figure 6. shows the energy consumption of the algorithm under the near-fixed scenario. Observing Figure 6., UE0 experiences much higher energy consumption compared to other UEs. This is due to the fact that UE0 is the closest UE to the NodeB, and since UEs are stationary, UE0 is the CH for the whole simulation duration. In contrast, all other UEs experience low energy consumption, as all data transfer is carried out over energy-efficient D2D links. Under the far-fixed scenario, shown in Figure 7., the energy consumption of data transmission is high when the distance from the NodeB is large. The CH's battery drains fast as the simulation progresses. The battery of the CH is completely drained after 50 seconds, and UE0 powers down. In this case communication may

continue using traditional LTE. An improved algorithm may consider a scenario where devices' batteries are not allowed to fall below a certain level, similar to the approach in (Narottama *et al.*, 2015). However, here we opt to evaluate a number of algorithms in their simplest form.

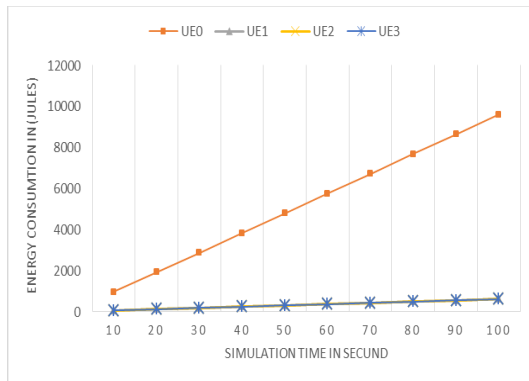


Figure 6. Minimum Distance Energy consumption under the near-fixed scenario

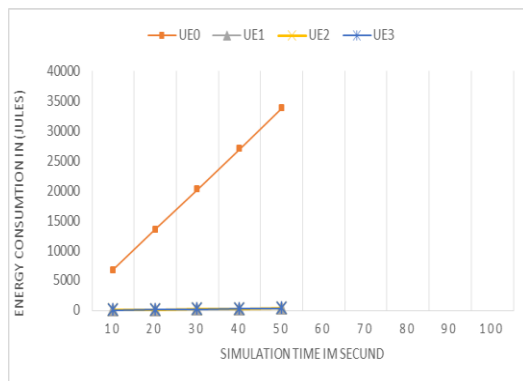


Figure 7. Minimum Distance Energy consumption under the far-fixed scenario

Figure 8. and Figure 9. demonstrate the energy consumption dynamics when UEs are moving, under the near-mobile and far-mobile scenarios, respectively. The energy consumption trend of UEs is similar under both scenarios. The energy consumption of each UE is influenced by the variation in distance from the NodeB and whether the UE is a CH. When a non CH device moves closer to the NodeB, it becomes a candidate to become a CH afterwards. On the other hand, when the CH moves far from the NodeB, it is expected that it will be replaced by an alternative CH. The process of CH replacement creates the wide wave effect observed in Figure 8. and Figure 9.

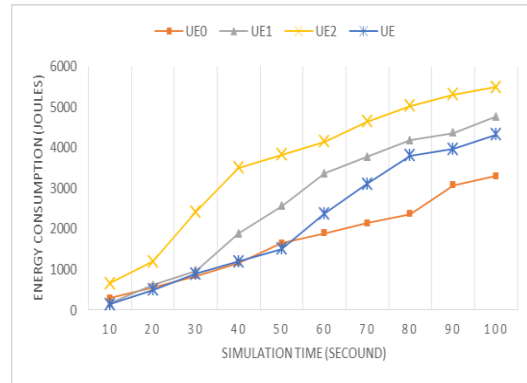


Figure 8. Minimum Distance Energy consumption under the near-mobile scenario

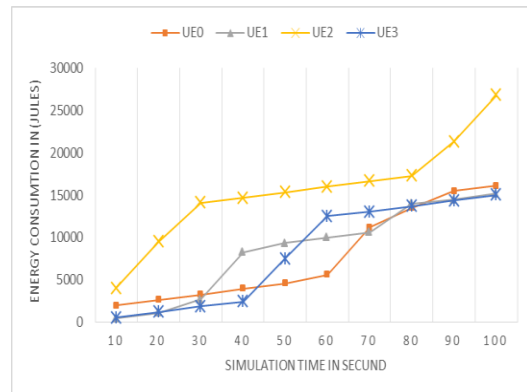


Figure 9. Minimum Distance Energy consumption under the far-mobile scenario

Maximum Remaining Power

Under this scenario, the selection of the CH is solely based on battery power level. This implies that the UE with the highest power level is the CH until its battery level falls below the battery level of another UE. The time duration for this condition to take place depends on the distance of the UE from the NodeB and initial battery readings. As time elapses (time 30 and 40), the power level of all UEs becomes similar. This is clearly observed in Figure 10. and Figure 11., which show UEs' remaining battery power under the near-fixed and near-mobile scenarios, respectively. Afterwards, the algorithm will alternate the CH selection between UEs, concentrating on UEs closest to the NodeB, since these UE preserve their batteries for longer. In the case where all UEs are at the same proximity from the NodeB, the algorithm behaves similar to Round Robin.

The same effect occurs under the far-fixed and far-mobile scenarios depicted in Figure 12. and

Figure 13., respectively. However it is less perceived, due to the high energy consumed as soon as the simulation starts, resulting in all UEs having similar remaining power at an early stage.

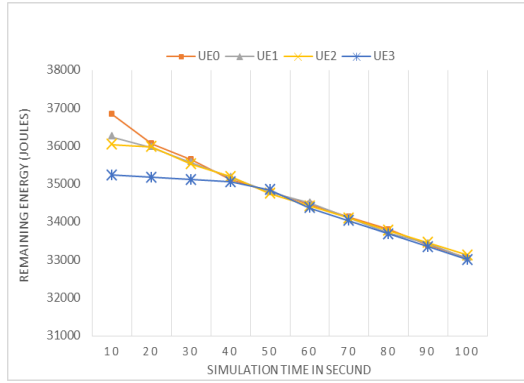


Figure 10. UE Remaining Battery Power under the near-fixed scenario

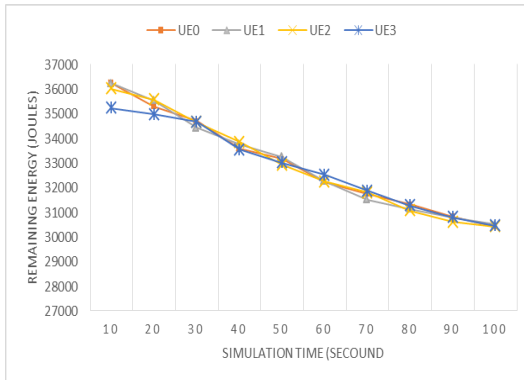


Figure 11. UE Remaining Battery Power under the near-mobile scenario

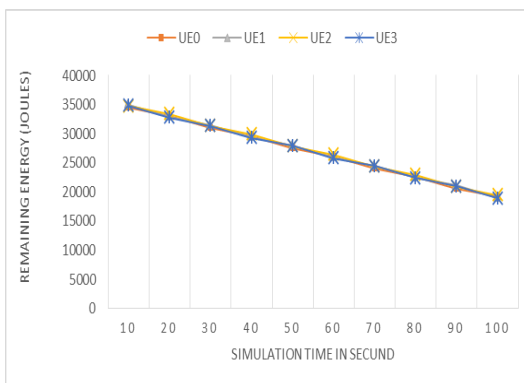


Figure 12. UE Remaining Battery Power under the far-fixed scenario

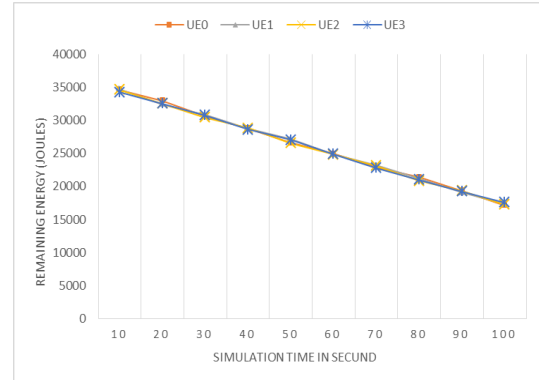


Figure 13. UE Remaining Battery Power under the far-mobile scenario

Comparison between clustering algorithms

Figure 14. throughout Figure 15. compare the total energy consumption of UEs under traditional LTE, Round Robin, Minimum Distance and Maximum Remaining Power under the near-fixed, near-mobile, far-fixed and far-mobile scenarios, respectively.

Considerable energy savings (the difference between the total energy consumption of the two methods) are achieved by utilizing cluster-based D2D, with maximum savings of 83.6% of total energy consumption. When UEs are close to the NodeB, the Minimum Distance algorithm achieves the most energy efficiency compared to other clustering algorithms (47.4% and 24.8% improvement over Round Robin and Maximum Remaining Power, respectively).

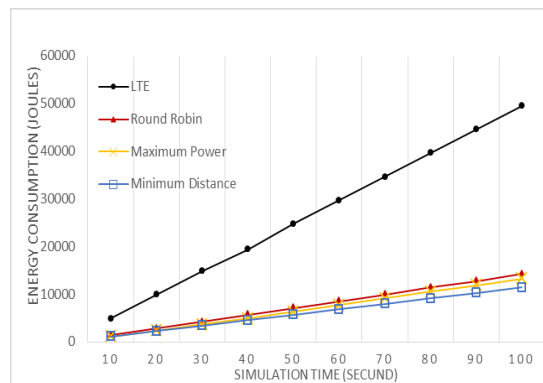


Figure 14. Energy consumption of clustering algorithms under the near-fixed scenario

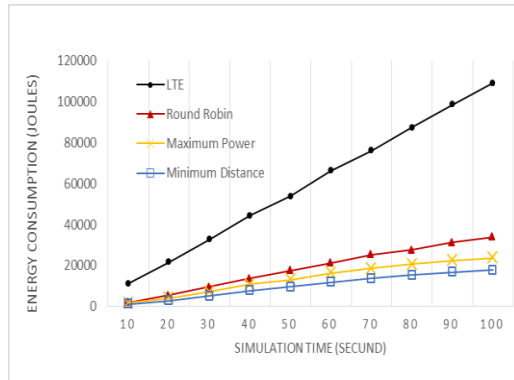


Figure 15. Energy consumption of clustering algorithms under the near-mobile scenario

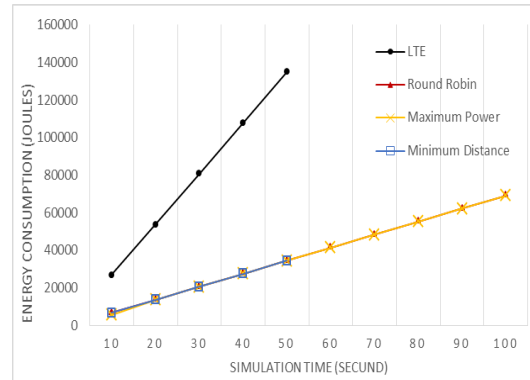


Figure 16. Energy consumption of clustering algorithms under the far-fixed scenario

The Minimum Distance algorithm is suitable for cellular environments where UEs are on the move. This allows more UEs to become CHs. In contrast, when UEs are stationary, a single UE is the CH, which results in the UE being burdened with additional energy consumption, especially at large distances from the NodeB. This can sometimes lead to the CH running out of power entirely. In Figure 16., the Minimum Distance algorithm CH ran out of power after 50 seconds under the far-fixed scenario, since the long distances result in high energy consumption and the immobility of UEs implies that a single UE is appointed as CH. Under traditional LTE, all devices lost battery power, as energy consumption values are extremely high using the LTE interface for such long distances (400 to 550 meters).

Round Robin and Maximum Remaining Power algorithms were able to moderate energy consumption over time. The energy consumption under the two algorithms is comparable. Under the far-mobile scenario, shown in Figure 17., the Minimum Distance algorithm slightly outperforms Round Robin and Maximum Remaining Power algorithms (maximum improvement of 4.3%). At the same time, all UEs ran out of power under traditional LTE after 60 seconds.

The results presented in this paper provide an upper limit for the energy consumption of D2D clustering. The work considers no similarity in user interests where each request for content is unique. This maximizes CH downlink traffic. In the case where user interest is considered, multicasting can be utilized to make a single download from NodeB to CH and distribute content to requesting UEs through D2D channels. Further reductions in energy consumption are anticipated.

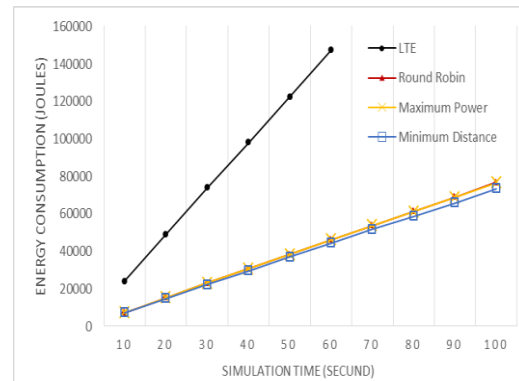


Figure 17. Energy consumption of clustering algorithms under the far-mobile scenario

Note that traffic aggregation is employed where UE requests are aggregated at the CH into one LTE transmission. A single transmission carries data for multiple users until the maximum data rate is reached. Any further increase in data traffic (caused by increasing cluster UEs) leads to increasing the energy consumption of the CH.

It is worth mentioning that clustering is assumed where no cluster collaboration is assumed and all communication between NodeB, CH and cluster UEs is independent of other clusters in the area. An extended scenario can be implemented where communication between CHs takes place and content is shared among multiple clusters. This has a dual effect on CH energy consumption. Inter-cell communication results in consuming additional energy on both signaling and data transfer between CHs. In contrast, sharing content between clusters implies importing content to the CH using the more energy-efficient D2D links instead of the energy-

consuming LTE links, reducing CH energy consumption.

Conclusions

This paper has evaluated the energy efficiency of clustering algorithms in D2D communication. Simulations were used to implement the Round Robin, Minimum Distance and Maximum Remaining Power clustering algorithms and evaluate energy consumption considering various scenarios. Results revealed that the algorithms have the most impact on energy consumption when devices are moving and at a close proximity to the base station, with the Minimum Distance algorithm achieving the most energy savings. Nevertheless, this algorithm is ineffective when devices are not moving, as the cluster head loses its battery power. The other algorithms produce comparable results. Overall, the employment of clustering algorithms reduced energy consumption of data transmission compared to traditional LTE, with maximum saving of 47.4%. In our future work we plan to extend the current work to evaluate a multi-cell environment in addition to evaluating the impact of channel interference on D2D communication performance.

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