Impact of Number of Devices and Data Rate Variation in Clustering Method on Device-to-Device Communication

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Abstract—**Clustering and cooperative clustering method in D2D communication, a promising technology for 4G and 5G communication, will decrease energy consumption in mobile communication. The novelty of this work is we analyzed the impact of variation in number of mobile terminals in one cell, data transfer rate, and number of cluster members in one cluster for energy consumption. Clustering and cooperative clustering method, which are two sophisticated methods for D2D communication, are expected to make D2D communication more efficient in energy consumption. Energy efficiency of devices was examined through several simulations. The first simulation, we studied the impact of different number of mobile terminals per cell for energy efficiency. The result shows that cells with a greater number of mobile terminals has higher mobile consumption. Furthermore, compared with other cells, a cell with cooperative clustering method has less energy consumption. Secondly, we also examined the impact of different data transfer rate for devices energy consumption. The result shows that energy consumption rate is decreasing exponentially along with the increment of data transfer rate. Finally, we investigated the impact of different number of cluster members per cluster. The result informs that in the scenario with clustering method, the variation in the number of MT per cluster relatively did not affect energy consumption. However, in the scenario with cooperative clustering method, each one increment of number of mobile terminals per cluster increase energy consumption approximately by 25%.**

Keywords—Device-to-Device communication, D2D clustering method, D2D cooperative clustering method, energy efficiency, LTE-A, 5G

I. Introduction

Energy efficiency is one of the most important issues in today's communication. Many smart devices in today communication are limited by battery life [1], and D2D can offer a solution for this problem by reducing long-range (LR) link so that device battery consumption can be reduced. As an alternative of using cellular resources via LR link, a direct short-range (SR) link is utilized via peer-to-peer communications [2]. Because energy efficiency is one of the most important issues in D2D development, developing D2D communication to become an alternative of green communication is an important matter.

Data transfer is more optimal and efficient via multicasting by clustering method [3], [1]. This method is even better to be applied in scenarios with dense environment and relatively uniform data contents, such as watching playback in stadium, getting speakers content in seminar room, and emergency broadcasting [4], [5]. The cooperative clustering method use game theory approach to form coalitions between D2D clusters. With cooperative clustering method, clusters can merge to form a new cluster with lower energy consumption [5].

D2D communication can maximize the potential of the device to meet the 5G requirements. According to [6], smarter device is one of emerging technologies in mobile communications, and has potential to become one of supporting technologies for 5G (together with device-centric architecture, millimeter-wave technology, and massive MIMO). Former cellular generation (2G, 3G, and 4G) has been built to have full control in infrastructure side. On the other hand, 5G system should not follow this concept and exploit the device's intelligence more [6]. One way to do this is by allowing the D2D communication.

In addition to the energy efficiency issue, D2D communication was expected to handle growing traffic of mobile communication. To give good service to their customer, cellular operators must face the need of traffic and bandwidth. Device-to-Device (D2D) communication gives us solutions for this problem [7]. There is a huge increase in the number of mobile communication traffic during several past years. According to Cisco, at the end of 2014, the traffic of wireless communication data peaked at 2.5 Exabyte monthly. In 2014, the international mobile data increase by 69 percent [8]. D2D communication is expected to enables a huge amount of data to be transferred via cellular spectrum, by allowing the data transferred to proximity devices [5]. The data is received through nearest BS and distributed via devices. Although there are some technical challenges in D2D development, D2D communication can play significant role to increase spectral efficiency, lessen energy consumption, decrease delay, offload traffic from BS, and even bring down congestion in core network [9].

Furthermore, D2D communication was expected to support cellular communication by enhance proximity-based service [10], [11]. As discussed in [4], the demands on cellular traffic are increased exponentially as the traffic of audio streaming; web browsing and video have the most share of cellular data traffic on the wireless web. There is a challenge to accommodate not only the desired demands of traffic but also the need of quality of service (QoS) and quality of experience (QoE), and collaboration among mobile terminals (MTs) via peer-to-peer (P2P) is expected to tackle this problem [4].

The research of this paper, especially about the D2D method, is based and inspired from the work and concept in [5]. The new method of this work is we used various parameters to study the impact of D2D for energy efficiency in different simulations. In this work, we analyzed the impact of variation of the number of mobile terminals per cell, data transfer rate, and the number of cluster member per cluster. To the best of our knowledge, our work was never conducted before. The first simulation, we studied the impact of different number of mobile terminals per cell for energy efficiency. The goal of this simulation is to get an optimum number of CM per cluster. Secondly, We also investigated the impact of the different rate in energy consumption, to get information how rate variations affected energy consumption. We expected to get information how the data transfer rate can affect energy consumption. Finally, we investigated the impact of different number of cluster members per cluster to analyze relations between the number of CMs per cluster and rate of energy consumption.

The rest of paper is organized as follows. In Section I, we present the introduction of D2D communication and the application of D2D in energy efficiency. In Section II, we present our approach. Our works and simulations are presented and discussed in Section III. Finally, we conclude our work in Section IV.

II. SYSTEM MODEL

In this work, we focused on the environment in one cell. We assumed a communication cell that consists of one BS that located in the center of the cell and MT devices that spread uniformly. A number of devices are formed a cluster that have a device which acted as a cluster head (CH). The rest of device in the cluster is called cluster member (CM). Similar data content is sent from BS via LR to a number of CHs, and then each CH is sent the content to its respective CMs via SR.

Model design for this simulation is based from work in [5]. We assumed an LTE cell in a dense urban area with uniform random user distribution. We use one BS in that cell, without relay and carrier aggregation. The cell radius is 1 km. We use 10 MHz LTE bandwidth that divided to 50 resource block (RB). Power for CH receiving data from BS, denoted by $P_{R,LR}$, is 1.8 Joule/s. Power for each CH transmitting data to its corresponding CM, denoted by $P_{T,SR}$ 1.425 Joule/s, is. Power for CM receiving data from CH, denoted by $P_{\mathrm{R,SR}}$, is 0.925 Joule/s. BS capacity is assumed by 2000 Kbps. We use OFDMA for DL and SC-FDMA for UL, with 64QAM modulation. We assume data content that has distributed is 1 Mb. Same as [5], we used LTE parameter from 3GPP release in [12], and channel model from [13].

A. Rate calculation

We use the rate calculation in [4] and [5]. The rate of data content transfer between node $n_a$and $n_b$through subcarrier x is denoted by $R_{ab}^{(x)}$. The pass band bandwidth of the subcarrier is denoted by $W^{(x)}$. The SNR gap is defined by β, and $\gamma_{ab}^{(x)}$ is the link fo node $n_a$and $n_b$via subcarrier x. Using approach in [5], rate of data transfer between node is calculated as:

$$R_{ab}^{(x)} = W^{(x)}.log2\left(1 + \beta\gamma_{ab}^{(x)}\right) \quad (1)$$

Furthermore, channel gain $H_{ab}^{(x)}$ is expressed as (in dB):

$$H_{ab}^{(x)} = (-K - vlog_{10}d_{ab}) - \varepsilon_{ab} + 10log_{10}F_{ab}^{(x)} \quad (2)$$

In the equation, K represent as pathloss rate of data content transfer can be found in [5] constant, v as pathloss exponent, and d_{ab} as distance between nodes. The log-normal shadowing is denoted by ε_{ab} . The Rayleigh fading is represented by $F_{ab}^{(x)}$. The complete approach to calculating rate of data transfer can be found in [5].

B. Energy Calculation

In this paper, we use an energy calculation formula based on [5]. The energy that used by MT which member of cluster C_k is denoted by E_{C_k}. The distributed content is denoted by S_T. The data transfer rate is denoted by R. The receive power is denoted by P_{Rx}. Moreover, the transmit power is denoted by P_{Tx}. Thus, energy consumed by cluster C_k is formulated by:

$$E_{C_k} = \frac{S_T.P_{Rx,lk}}{R_{lk}} + \frac{S_T.P_{Tx,k}}{\underset{i\neq k;n_i\epsilon C_k}{min} R_{ki}} + \sum_{j\neq k;n_j\in C_k} \frac{S_T.P_{Rx,kj}}{\underset{i\neq k;n_i\epsilon C_k}{min} R_{ki}} \quad (3)$$

The complete approach to calculating MT energy consumption is in [5].

III. SIMULATION DESIGN

In this work, we conducted four simulations. We used MATLAB as simulation software. The goal of these simulations is to analyze the impact of variation of the number of mobile terminals per cell, data transfer rate, and number of cluster member per cluster. Each simulation consisted of four scenarios. These scenarios are used to compare the energy consumption of a cell with traditional communication, a cell with D2D communication but without clustering and cells with clustering and cooperative clustering method. These scenarios are described as follows:

A. Scenario I: System Model Without D2D Communication

In this scenario, we assume that every MT has a direct link to BS via LR communication. Every MT will get identical data content, and we will get results corresponding to the number of users in the cell. Therefore, given N_{MT} for the number of MTs in one cell, in this scenario we have N_{MT} of LR link between LR and MTs.

B. Scenario II: System Model With D2D Communication, Without Clustering Method

In this scenario, we propose a system model with D2D communication, but without D2D clustering method. In this scenario, all MTs in the cell will be divided into two: MTs which transmit content and MTs which receive the content. The number of MTs which transmit content, MT_{Tx}, is $\frac{N_{MT}}{2}$. Similarly, The number of MTs which receive content, MT_{Rx}, is $\frac{N_{MT}}{2}$. Because this scenario is not use clustering, MTs are treated equally so there is no CH that sends the data packet to CM. In this scenario, each MT_{Tx} sends the data packet to its corresponding pair, MT_{Rx}. Peer to peer communication is utilized in this scenario for each respective MT_{Tx} and MT_{Rx}. The D2D pair in this secenario is formed by assign two proximity device to have pair-to-pair communication.

C. Scenario III: System Model With D2D Communication, Using Clustering Method

In this scenario, we use D2D communication with clustering method. Clustering method in this scenario is inspired from work in [6]. We assume that every device in the cell will form clusters with certain number of device per cluster. In each cluster, CH gets data content from BS using LR communication, and then CH spread the content to CM in its corresponding cluster using SR communication. In our simulation, each device forms cluster with its proximity device(s), with one device act as CH.

D. Scenario IV: System Model With D2D Communication, Using Cooperative Clustering Method.

In this scenario, we use D2D communication with cooperative clustering method, inspired from work in [6]. At the beginning of the procedure, all MTs in the cell are connected to BS through LR links. Similar to the scenario without D2D communication, each cluster formed by one MTs. In this scenario, each device forms cluster with its proximity device, with one device act as CH. Based on work from [6], the brief procedure for this scenario is given as follows:

- The clusters are sorted based on its energy consumption. The energy of each cluster is denoted by E_{C_n}, for n is the name of the cluster.
- Iterate the clusters, starting from clusters with highest consumption of energy. If the two clusters, C_j and C_k, satisfy the requirement of forming a cooperative cluster, $E_{C_j \cup C_k} \leq E_{C_j} + E_{C_k}; j = \arg\min_{i \neq k} E_{C_i \cup C_k}, E_{C_j} < E_{C_k}$, a new cooperative cluster is formed.
- Repeat the procedure until finally no further change cannot be made.

IV. Results and Discussions

A. Simulation I: Simulation of MT Energy Consumption with Variable Number of Devices per Cell

In this simulation, we studied the rate of energy consumption by varying the number of devices per cell. The range of number of devices, notated by N_{CM}, is between 1 and 300. Each scenario was tested with different number of devices per cell. Because the number of CH per cluster, notated by N_{CH}, is static (N_{CH} = 1), we only focus on varying N_{CM}. In the Fig. 2, we presented the result of energy consumption of scenario I, II, III, and IV. In our simulation, scenario II consumed more energy than scenario I. Scenario I consumed approximately 14% less energy than scenario II.

This result shows that D2D communication without clustering spends energy more than conventional cellular communication. It indicates that D2D communication is better applied with clustering method. In our analysis, using scenario II (D2D communication without clustering) has decreased the LR links, but it also increase device transmission link. D2D communication in scenario IV is the most energy efficient since it spent least energy than the other scenarios. It spent roughly 23% less energy than scenario III.

In our analysis, scenarios which utilize D2D clustering method (scenario III and IV) had lower energy consumption than scenarios without clustering method (scenario I and II) because clustering method can diminish the utilization of LR links from BS. The LR links from BS consume more energy than SR link from MT. Furthermore, cooperative clustering method that was performed in scenario IV can reduce more energy consumption since it can merge clusters to a new cluster with less energy consumption than the sum of the independent clusters.

According to the simulation results, we can conclude that the key to reducing energy consumption is by reducing LR links and diminishing the number of MTs communication links. These factors can be achieved by utilizing clustering and cooperative cluster method. These methods will play a significant role in device-centric architecture like 5G architecture.

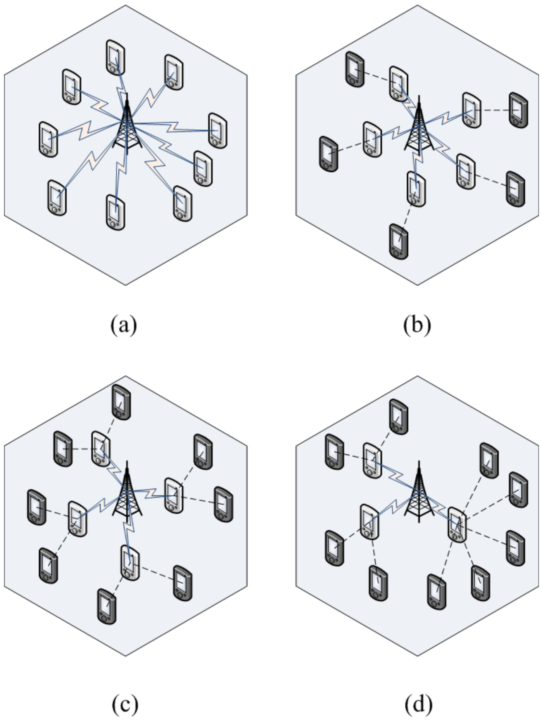

Figure 1. D2D scenarios: (a) without D2D communication (b) with D2D communication, without clustering method (c) with D2D communication, using clustering method (d) with D2D communication, using cooperative clustering method.

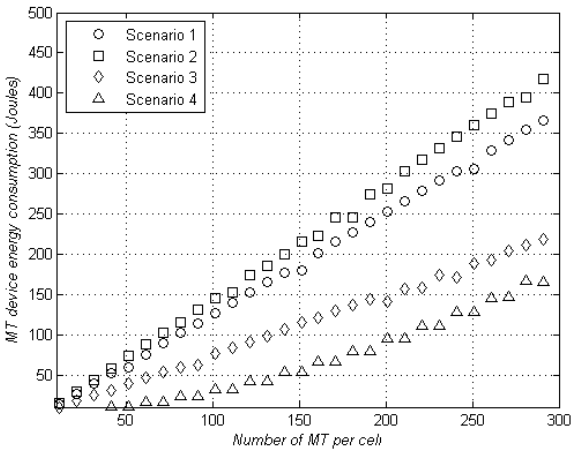

Figure 2. Total mobile terminals energy consumption per cell.

B. Simulation II: Simulation of MT Energy Consumption with Variable Rate

In this simulation, we investigated the impact of data rate variation for energy efficiency. Fig. 3 and 4 inform us about the simulation result of MT energy consumption with a variable rate for each scenario. In this simulation, each scenario was tested with different data transfer rate. As shown in Fig. 3 and 4, we also used different number of user device (100, 200 and 300 user device) per scenario. In each scenario, we can conclude that the peak of energy consumption is in low rate data transfer. Energy consumption is decreasing exponentially in accordance of rate addition.

In simulation II, scenario II is the least energy efficient among all scenarios. In contrast, scenario IV successfully spent least energy due to its cooperative clustering method, which can integrate clusters to a new cluster with more efficient energy consumption than the sum of the independent clusters.

In all scenarios, it is obvious that a big number of users spent more energy that small number of users. As example, in scenario III, at 50 Mbps data rate, 200 user devices spent roughly 35% less energy than 300 user devices, while 100 user devices consumed approximately 44% less energy than 200 user devices.

As the data rate grows faster, overall energy consumption decreased exponentially and made the difference of energy consumption (per number of user device) relatively irrelevant. In the 5G communication, which the expected rate of data transfer is in the order of Gbps, the difference of user device per cell will not significantly affect energy consumption.

The analysis of this result (energy consumption decreasing exponentially along with rate increment) is low rate data transfer took more energy because transmitting and receiving data take more time compared to the high rate condition. This result is concordant with (1). Since energy consumption counted as power usage per time unit, longer data transfer in LR and SR links will consume more power and then leads to more energy consumption.

C. Simulation III: Simulation of MT Energy Consumption with Variable Number of Devices per Cluster

In this simulation, we investigated the impact of different number of cluster members per cluster. This simulation shows us how the variation in number of device per cluster will affect MT energy consumption. In this simulation, scenario III and IV was tested with different number of devices per cluster. This simulation is only for D2D scenarios with clustering and cooperative clustering method. Since the number of CH is still one per cluster, the distinction in number of device per cluster is particularly in the number of CM.

Fig. 4 informs us about the simulation result of MT energy consumption with variable number of devices per cluster. According to our simulation result, for scenario III, the difference in the number of MTs per cluster relatively didn't affect the energy consumption. On the other hand, for scenario IV, the increment of energy consumption is linear with the addition of the number of MTs per cluster. In scenario IV, each one increment of the number of MTs per cluster added energy consumption approximately by 25%.

According to the result of the simulation, since the number of MTs per cluster didn't affect energy efficiency, we can conclude that cell with scenario III can have big or small number of clusters per cell. A small number of MTs per cluster leads to big number of clusters per cell and vice versa. However, cells with scenario IV are suggested to have big number of clusters to improve energy efficiency.

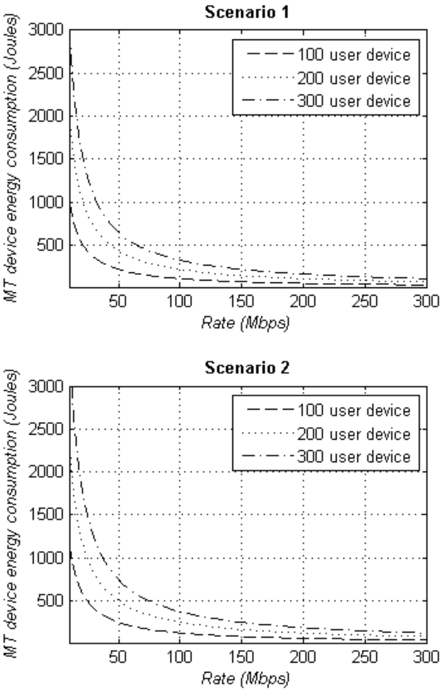

Figure 3. Mobile terminals energy consumption with variable rate, scenario I and II

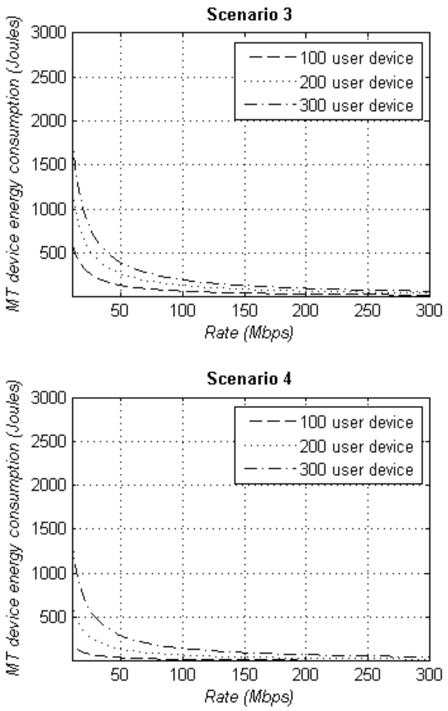

Figure 4. Mobile terminals energy consumption with variable rate, scenario III and IV

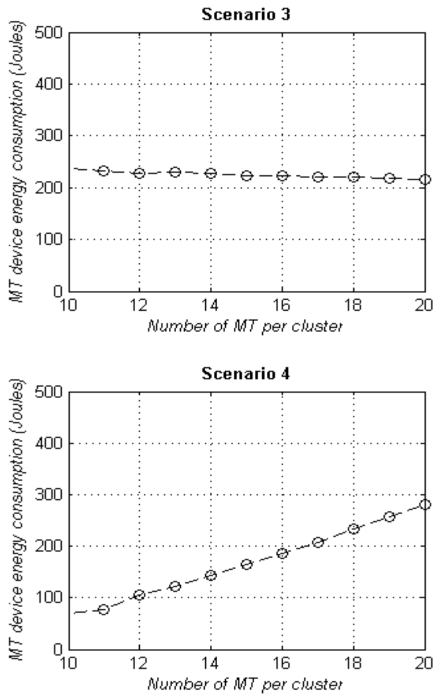

Figure 5. Total mobile terminals energy consumption per cluster

V. Conclusion

D2D communication with different scenarios in LTE is examined. We varied the parameters to examine how those parameters affect the energy efficiency of D2D communication. We conclude that clustering and cooperative cluster method can reduce energy consumption is by minimizing LR links and lowering the number of MTs communication links. As example, in scenario III, at 50 Mbps data rate, 100 user devices spent approximately 44% less energy than 200 user devices, whereas 200 user devices spent approximately 35% less energy than 300 user devices. We also deduce that, in higher data rate condition e.g. 5G communications, overall energy consumption decreased exponentially and made the difference of energy consumption per number of user device relatively irrelevant.

According to simulation result, a different data transfer rate will greatly affect the energy consumption. On the other hand, our simulation showed that different number of device per cluster in scenario III relatively did not affect the energy consumption. However, in cell with scenario IV, the increment of energy consumption is in accordance with the addition of number of MTs per cluster, each one rise for number of MTs per cluster increased energy consumption approximately by 25%, thus it suggested to have big number of cluster to improve energy efficiency. The future work of this paper could examined the effect of device recognition process, the distribution of various multimedia contents, and simultaneous usage of cellular and D2D communication for energy consumption.

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