Cluster Head Rotation: A Proposed Method for Energy Efficiency in D2D Communication

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Abstract—**In this paper, the authors propose a novel Cluster Head Rotation method to spare the cluster head burden in energy consumption. The clustering method, which is a state-of-the-art approach in D2D communication, is expected to reduce the devices' energy consumption. However, this method may induce significant energy burden for cluster head, which can bring significant disproportion in cluster head and cluster member energy consumption ratio. The authors performed several simulations to prove the eminence of Cluster Head Rotation. According to our simulation, Cluster Head Rotation achieve a better balance in energy consumption (1.25:1 for CH:CM) compared to standard clustering method (3:1 for CH:CM). Furthermore, the overall energy consumption of Cluster Head Rotation is also 75% lower than standard clustering method.**

Keywords—D2D, energy efficiency, peer-to-peer, mobile computing, mobile networks, and mobile agents

I. INTRODUCTION

As a state-of-the-art concept in wireless communication, the Device-to-Device (D2D) communication enables direct communication between devices without burden the base station (BS) [1]. The D2D communication is a promising solution to handle the local traffic of mobile network [2]. Moreover, the D2D communication is expected to decrease the energy consumption. The energy efficiency itself is one of the main issues of D2D communication. Due to the advancements in the technology of electronic devices, energy efficiency has drawn increasing concern recently. One substantial necessity for a D2D device is its low energy consumption. Typical scenarios include many small devices, such as sensors, operating on battery power in possibly remote locations [3].

Even though the modern cellular technologies are designed for efficient transmission of speech as well as data traffic, there is a need for further optimizing the networks and procedures to be able to support higher number of devices and devices with constrained capabilities [3]. Furthermore 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. The D2D communication gives us solutions for this problem [4].

As a state-of-the-art method in D2D, the clustering method is expected to reduce the devices' energy consumption. The benefits of this method had been proofed in several works [5], [6], [7]. However, due to its multiple tasks as data receiver and distributor, the Cluster Head (CH) may experience major burden in energy consumption. This could lead to much shorter battery life compared to Cluster Members' (CMs).

The novelty of this work is the authors propose a new method in D2D method for energy efficiency. The method is called Cluster Head Rotation method. The method is expected to not only reduce energy consumption but also to balance the energy consumption of Cluster Head (CH) and Cluster Member (CM). In this work, the CH and CM ratio of clustering method and Cluster Head Rotation method are compared via simulation. The comparison of energy consumption of clustering and Cluster Head Rotation method is also simulated and examined.

The channel model and energy calculation is cited and inspired from [5], [6]. The work of this paper is linked with work in [7], which is performed by the same author(s). So they share some contents, simulation models, and results. The comparison model for each method is inspired from [7]. However, work in [7] did not contains Cluster Head Rotation in its simulation.

The rest of this paper is organized as follows. First, in Section I, the introduction of energy efficiency and cluster formation in D2D is presented. In Section II, the system model is presented. In Section III, our approach in this work is presented. Although expected and proved to deliver better energy efficiency to the mobile communication system, there is a potential issue in D2D clustering method which can be solved with Cluster Head Rotation method. In Section IV, the simulation results and discussions are presented. These simulations consist of cluster head and cluster member energy ratio and devices energy consumption per cell. Finally, our work is concluded in Section V.

II. SYSTEM MODEL

In this work, user devices energy efficiency in a Long Term Evolution Advanced (LTE-A) cell is examined. One Base Station (BS) is located in the center of the cell. The random user device distribution is used. The cell diameter is 1 km. The carrier bandwidth is 10 MHz, divided into 50 resource blocks. The downlink content distribution is examined via Orthogonal Frequency-Division Multiple Access (OFDMA). The LTE-A parameter is derived from The 3rd Generation Partnership Project (3GPP) release [8]. The communication channel parameter is cited from [9]. The D2D model is inspired from 3GPP's Proximity Services (ProSe) [10].

In each cluster, user devices are divided into Cluster Head (CH) and Cluster Member (CM). The CH is utilized to receive the data content via Long Range (LR) communication links from BS and distribute it via Short Range (SR) communication links to CMs in the cluster through multicasting. The CMs receive the data content via SR communication links from CH.

A. Channel Model and Rate Calculation

The data transfer rate derivation is cited from [5]. The notation $W^{(x)}$ denotes the passband bandwidth of the subcarrier. The notation β denotes the SNR gap. The communication link of node n_a and n_b via subcarrier x is denoted by symbol $\gamma_{ab}^{(x)}$. The equation to calculate the rate of data transfer between two nodes is presented as [5]:

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

Moreover, the channel gain $H_{ab}^{(x)}$, in dB, is presented as:

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

From the equation, the notation K symbolizes the path loss constant. The path loss exponent is denoted by v. The distance between two nodes is denoted by the d_{ab}. The notation ε_{ab} denotes the log-normal shadowing. Finally, the Rayleigh fading is expressed as $F_{ab}^{(x)}$. The complete derivation to calculate the channel gain and data transfer rate can be found in [5], [6], [7].

B. Energy Calculation

The energy calculation in [5] is used in this work. The data content which distributed to CMs is notated by S_T. The receiving power between nodes is notated by P_{Rx}. Furthermore, the transmit power between nodes is notated by P_{Tx}. The rate of data transfer is notated by R. The energy which consumed by user devices in cluster C_k is formulated by:

$$E_{C_k} = \frac{S_T. P_{Rx,lk}}{R_{lk}} + \frac{S_T. P_{Tx,k}}{\min_{i \neq k; n_i \in C_k} R_{ki}} + \sum_{j \neq k; n_j \in C_k} \frac{S_T. P_{Rx,kj}}{\min_{i \neq k; n_i \in C_k} R_{ki}} \quad (1)$$

III. PROPOSED METHOD

A. Issue in Clustering Method

Although expected and proved to deliver better energy efficiency to the mobile communication system, there is a potential issue in D2D clustering method. In this method, a CH in a cluster has more energy-consuming tasks compared to CMs. The main role of CH in this method is to get the data content from eNB via LR communication link and deliver the data to its respective CMs. From energy consumption perspectives, this means the CH must spend energy to transmits the data from BS and delivers it to CMs. On the other hand, the CMs only needs to spend energy for receiving the content from CH.

B. Cluster Head Rotation Method

In this work, the Cluster Head Rotation method is proposed. The main idea of this method is to offload the burden of a single CH. This method is proposed to offers better solution in CH-CM equality in energy consumption. The principle of the method is several CHs are used to distribute the data contents to CMs. The example of data transfer process in this method is presented in Figure 1.

In this method, the full data content (notated by S_T) is divided into n data fragments. Each data fragments is assigned to distribute by different CH. This data fragmentation can be described as data content division into information chunks in peer-to-peer communication. Each data content is notated by

$S_{fragment,i}$. The i stands for transmission iteration number.

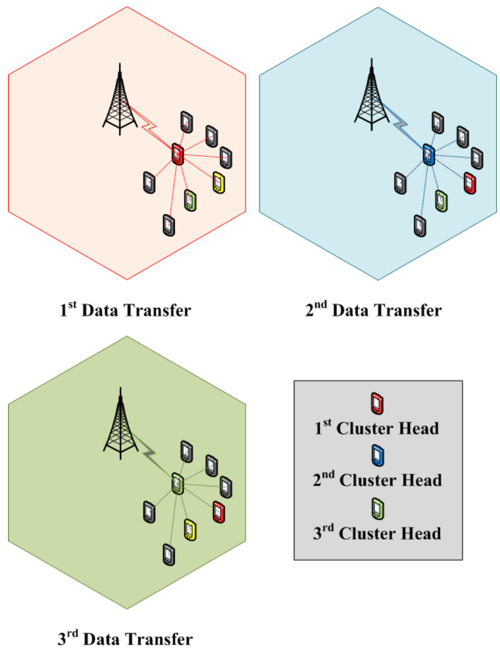

Figure 1. Data transfer process in Cluster Head Rotation method.

The Cluster Head Rotation method consists of 3 separate procedure:

1. CH Candidate Selection
   a. The data transfer rate and battery level of devices in the cluster are sorted.
   b. The mean value of battery level and data transfer rate are calculated. These level are used as the threshold values.
   c. The devices that have data transfer and battery level below the threshold value are eliminated.
2. CH Rotation Selection
   a. The weight factor is used to determine which factor get prioritized: data transfer rate or battery level.
   b. Calculate the points of CH candidates.
   c. From the points of CH candidates, the CHs for rotation is selected. In this point, the number of rotating CHs (notated by N_{CH}) is also obtained.
3. Data Transfer
   a. Data content S_T divided into fragments. Each fragment is notated by $S_{fragment,i}$. The notation i shows the turn of data transfer related to a CH (notated by $CH_{rotation,i}$).
   b. The data fragment content is $S_{fragment,i}$ transfered to CMs via $CH_{rotation,i}$.
   c. The data transfer process is repeated until all data fragment is sent to CMs, i.e. $i = N_{CH}$.

IV. SIMULATION DESIGN

In this research, the simulations were conducted via MATLAB software. The goal of this work is to compare the overall energy consumption and CH/CM energy consumption ratio between clustering and Cluster Head Rotation method.

These simulations are organized as follows. First, the energy consumption ratio of CH and CM for both methods were examined. Secondly, the device energy consumption per cell with the variation of data transfer rate was studied. Finally, the devices energy consumption per cell with the variation of the number of devices per cell was examined.

V. RESULTS AND DISCUSSIONS

In this work, the simulations were to compare Cluster Head Rotation method with normal clustering method. These simulations consist of cluster head and cluster member energy ratio and devices energy consumption per cell. These simulations are intended to analyze how Cluster Head Rotation method can affect energy efficiency. The energy consumption simulation method is taken from [7].

A. Cluster Head and Cluster Member Energy Ratio with Variable Number of Devices per Cluster

This result highlighted the problem of clustering method. The method to give positive impact to devices energy efficiency, but there is a gap of energy efficiency between CH and CM. The cluster head will consume 3.5 times more energy compared to the cluster member. According to our analysis, this is caused due to the content-distributing role of CH. The CH receive its data content from BS via energy-consuming LR link.

Figure 2 informs us about the ratio of energy consumption difference between CH and CM. In clustering method, the energy ratio of CH versus CM is 3.5:1. According to analysis, this result is caused by the role of CHs to transmit the data content via multicast to their CMs in clusters through SR communication links. This role leads to CH's higher energy consumption compared to CM's energy consumption. This is because a CH consumes energy for both receiving data (from BS via LR communication link) and transmitting data (to CM via SR communication links). The CM only spends energy for receiving data from CH through SR communication link.

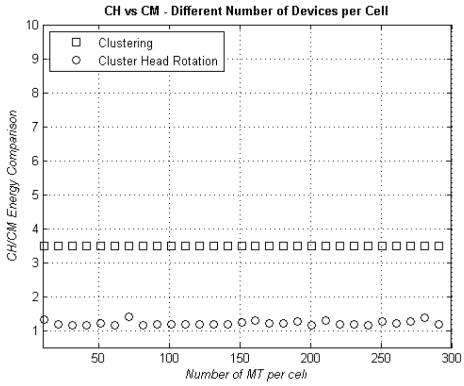

Figure 2. Energy consumption ratio of CH and CM.

In Figure 2 the energy consumption ratio of CH and CM in a cell that utilize Cluster Head Rotation can be examined. The graph tells us that the energy ratio of CH versus CM is 1.25:1, relatively similar for each number of MTs. According to our analysis, by using the Cluster Head Rotation, the data transfer time of each CH can be decreased due to the significant augmentation of CHs. The data content transfer time in each cluster divided by the number of rotating CHs. This leads to fairer devices energy consumption for CHs.

B. *Devices Energy Consumption with Variable Data Transfer Rate*

In this simulation, the impact of variable data transfer rate for energy consumption is studied. According to the simulation result (presented in Figure 3), for both methods, the energy consumption is reducing exponentially with the increment of data transfer rate. As an example, for Cluster Head Rotation, with 200 user devices, 50 Mbps data transfer spent 150% more energy compared to 300 Mbps data transfer. Moreover, for clustering method, with 200 user devices, 200 Mbps data transfer spent 160% more energy than 300 Mbps data transfer. The result of this simulation is presented in Figure 3. The result of conventional cellular and standard clustering method is shared with [7].

For each method, the simulation is performed for 100, 200, and 300 user devices per cell. For both methods, the number of devices greatly affect the energy consumption. For example, in clustering method, at 150 Mbps, 300 user devices spent 100% more energy than 200 user devices and 400% more energy than 100 user devices. Moreover, in Cluster Head Rotation, at 150 Mbps data transfer, 300 user devices spent 80% more energy than 200 user devices and 200% more energy than 100 user devices.

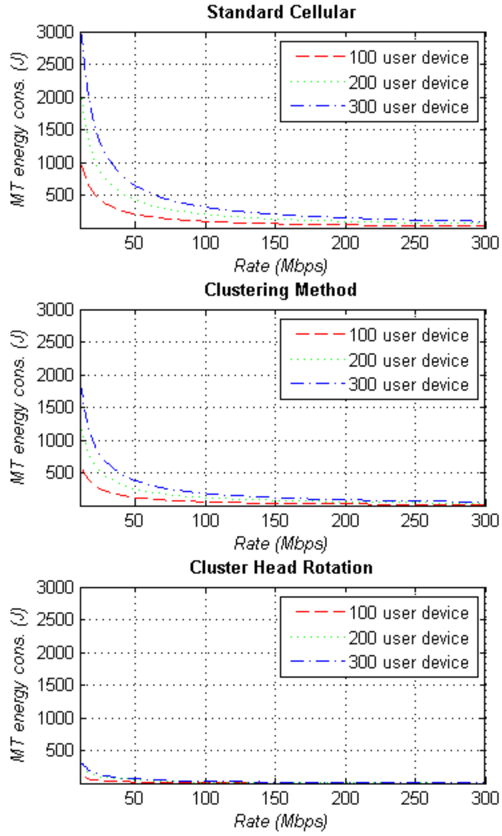

Figure 3. Devices energy consumption with variable data transfer rate.

C. *Devices Energy Consumption with Variable Number of Devices*

In this simulation, the devices energy consumption by differing the number of devices per cell was examined. The number of devices (notated by N_{CM}) is between 1 and 300 per cell. The number of CH per cluster (notated by N_{CH}) is stable ($N_{CH} = 1$). The variance of the number of devices per cell only focused on the number of cluster member (notated by N_{CM}) . To eliminate the result's instability, each simulation is iterated by 100 times. The instability is caused by data fluctuation which triggered by the random position of devices and fading element.

Figure 4 informs us about the MT energy consumption in clustering and Cluster Head Rotation method. The simulation results of conventional cellular and standard clustering method are shared with [7]. For each iteration, a different number of user devices was used. The range of the number of devices is between 0 and 300. In this simulation, the energy consumption of clustering and Cluster Head Rotation method was compared. The simulation result shows that among these methods, the Cluster Head Rotation achieve best energy efficiency.

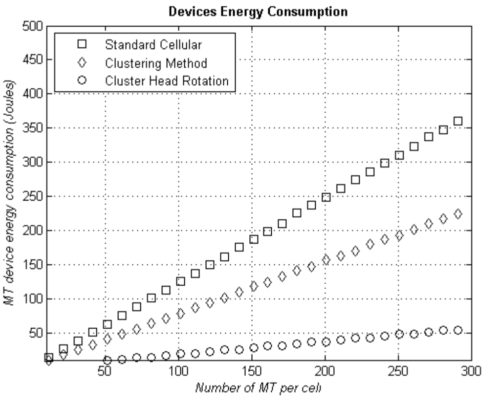

Figure 4. Devices energy consumption with the variable number of devices per cell.

The highest energy consumption for conventional data transfer is 372 Joule. In clustering method, the energy consumption increased linearly by 4.4% for each device increment. In this simulation, the peak of energy consumption for clustering method is 231 Joule, reached at 300 user devices. On the other hand, the Cluster Head Rotation method achieve a better result by consumed 53.6 Joule at 300 user devices. In this method, the energy consumption increased linearly only by 1.5% for each device increment.

VI. CONCLUSION

A novel method in D2D, the Cluster Head Rotation is proposed in this paper. The simulation of energy consumption ratio of CH and CM is studied. From the simulation, we learn that Cluster Head Rotation achieved more balanced (1.25:1 for CH:CM) energy consumption compared to standard clustering method (3:1 for CH:CM). From the result of our simulation, we also conclude that energy consumption is reducing exponentially with the increment of data transfer rate. As example, for clustering method, for 300 user devices the energy consumption reach 1700 Joule at 10 Mbps and 410 Joule at 50 Mbps

Finally, the energy consumptions of different methods were compared. According to our simulations, the Cluster Head Rotation, which only spent 51 Joule for 300 MT per cell, achieve highest energy efficiency compared to standard clustering methods. On the other hand, in our simulation, the clustering method spent 220 Joule for 300 MT per cell.

For future research, Cluster Head Rotation application in multi-cell condition will be examined. The development of simulation method will also be investigated.

REFERENCES

[1] A. Asadi, Q. Wang and V. Mancuso, "A Survey on Device-to-Device Communication in Cellular Networks," *IEEE Communication Surveys & Tutorials,* vol. 16, no. 4, pp. 1801-1819, 2014.

[2] N. Lee, X. Lin, J. G. Andrews and R. W. Heath Jr., "Power Control for D2D Underlaid Cellular Networks: Modeling, Algorithms, and Analysis," *IEEE Journal on Selected Areas in Communications,* vol. 33, no. 1, pp. 1-13, January 2015.

[3] T. Tirronen, A. Larmo, J. Sachs, B. Lindoff and N. Wiberg, "Reducing Energy Consumption of LTE Devices for Machine-to-Machine Communication," in *GC'12 Workshop: Second International Workshop on Machine-to-Machine Communications 'Key' to the Future Internet of Things*, 2012.

[4] L. AlWreikat, R. Chai and O. M. Abu-Sharkh, "Energy-Efficiency Based Resource Allocation for D2D Communication and Cellular Networks," in *2014 IEEE Fourth International Conference on Big Data and Cloud Computing*, 2014.

[5] E. Yaacoub, H. Ghazzai, M.-S. Alouini and A. Abu-Dayya, "Achieving Energy Efficiency in LTE with Joint D2D Communications and Green Networking Techniques," 2013.

[6] E. Yaacoub and O. Kubbar, "Energy-Efficient Device-to-Device Communications in LTE Public Safety Networks," in *Globecom Workshops 2012 (International Workshop on Green Internet of Things)*, Anaheim, CA, USA, 2012.

[7] B. Narottama, A. Fahmi and B. Syihabuddin, "Impact of Number of Devices and Data Rate Variation in Clustering Method on Device-to-Device Communication," in *IEEE Asia Pacific Conference on Wireless and Mobile*, Bandung, 2015.

[8] (3GPP), 3rd Generation Partnership Project, "3GPP TS 36.211 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, version 8.3.0, Release 8," 2008.

[9] (3GPP), 3rd Generation Partnership Project, "3GPP TR 25.814 3GPP TSG RAN Physical Layer Aspects For Evolved UTRA, v7.1.0," 2006.

[10] 3GPP, "Feasibility Study for Proximity Services (ProSe) (Release 12)," 3GPP TR 22.803 v. 12.2.0, Sophia-Antipolis, France, Jun. 2012.