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Energy Efficient Device-to-Device Weighted Clustering Method in Public Safety Networks

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Abstract
In this work, device-to-device weighted clustering communication is observed in the system of public safety network. Previous algorithm is aimed to avoid unnecessary cluster head re-selection for a steady cluster in the mobile ad-hoc network with a weighted clustering method. Public Safety Network for disaster area, however, differs from the traditional network due to several restrictions, such as shorter end-to-end delay requirement and unavailability of backbone resources. We propose the Improved Weighted Application Clustering Algorithm (IWACA) with additional weight factor for selection of cluster heads in the public safety network. The cluster heads selection algorithm, which is based on the energy-aware of User Equipment (UE) and Quality of Services (QoS), is also taken into consideration and evaluated in the simulation. The results show that energy saving as much as 5.96% can be attained with our proposed algorithm (IWACA) compared to Brust's. In addition, the delay is decreased 10.96% lower than previous method. With this improvement, the IWACA method becomes more feasible for public safety networks.

Keywords: Clustering communication; Device-to-device; Energy efficiency; Public safety network

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1. Introduction

Device-to-device (D2D) communications are expected to play an important role for public safety networks as the next step towards future 5G system [1], [2]. The key excellence in 5G is the provision of effective support system over public safety communication to ensure decision-making and action [3]. Especially in the area of public safety networks, to establish communication wherever the network exists, or even where the network does not exist, would be a great help. For example, if a tornado strike, the public network is not functional or only partially functional, the power supply or the radio tower is down, to provide a reliable communication to all users in the disaster area is the key to survivors and rescue teams [4]. In the critical circumstances, a central controller can send critical data and instructions through the public safety system, to the SAR team, emergency team, and police. In addition, in some severe situations, the UEs power consumption of the victims and SAR team is deemed as one of important factors due to lack of UEs power supply in the disaster area [4]–[7]. To magnify the performance, 3GPP proposes a novel architecture which forms several D2D clusters on the network and select some UEs elected as the cluster head (CH) as relays to communicate with Base transceiver stations (BTSs) and the other elected as a cluster member (CM).

Several researchers have involved D2D clustering strategies and its application in emergency situations. The decrease in the consumed power and the rise of total link capacity can be allowed by the application of clustering mechanism in the system [8]–[10]. A preliminary investigation of the D2D weighted clustering algorithm (WCA) was performed in [11], which proposed an algorithm that forming one CH with 1-hop clusters. The CH election is basically determined by the weight of each node. For WCA a weighting factor to calculate the weight is used. Also, a weight factor (that used distance among neighbors, mobility speed of neighboring UEs, vertex degree, and signal strength of the supporting network) is utilized. To acquire this information, every node in simulation is assumed to know the relative distances or geographical location of other nodes nearby. The WCA update rules are invoked by the remote nodes anytime. The CH continuously sends an information to the neighboring nodes. Next, the neighbors evaluate if the distance between the neighbors and CH get larger. Then, the device shall notify the current CH about the breaking of connection and select the subsequent reachable CH. In case there is no CH obtainable, the selection method is invoked to make another cluster. Matthias R. Brust et al., proposes weighted application aware clustering algorithm (WACA) focus on the problem of lessening CH reelections by considering criteria of stability node. These criteria are based on UE parameters as well as on topological characteristics [12].

With clustered nodes arrangement, two main scenarios are possible: 1) In the surrounding area, a number of User Equipments (UE) having similar interests can build a cluster consisting of CH and CM. 2) The controller or coordinator creates the clusters based on supporting information received from the UEs. Next, it merely contacts one UE in the cluster for trasmitting the data, which then forward it to the other UEs in the vicinity of the CH.

In this research, the command center support is observed. This type of communication is proven to be more efficient compared with the non-network assisted method, in regards to energy consumption, spectral resources, and the device discovery rate [13]–[16]. Recently, we develop the modification in the WACA algorithm for D2D communication. The modified algorithm is expected to be used with the specific constraint in the public safety network being considered. The addition of another factor about the characteristic of a UE into the evaluation formula is considered, such that the UEs chosen as cluster heads may have a better behavior to reduce battery consumption and thus ensures energy-efficient operation of the public safety teams for the longest possible time than those without additional factor. In this paper, the contribution of our work is developing a D2D clustering algorithm that selects cluster heads based on developing modification of WACA for MANET to LTE public safety network by adding one specific constraint. The D2D clustering algorithm is called Improved Weighted Application Aware Clustering Algorithm (IWACA).

The discussion is structured below. The system modeling and formulation is explained in Section 2, while the proposed method is described clearly in Section 3. The numerical results are shown and immediately analyzed in Section 4. At last, future works and conclusion are given in Section 5.

2. System Model and Formulation

In this research, we considered the utilization of the D2D weight cluster method for enhancing the service of public protection and disaster relief team, ensuring more efficient power consumption, as well as more prominent video transmission quality from/to the affected area. Previous work [3] analyzes the joint communication between uplink (UL) and downlink (DL) direction in a public protection network.

In case of UL communication, we assumed users from the various public safety teams send real-time information or instruction to the central command center. The information or instruction consists of video recorded from the area of interest, sensor measurements, location information, etc. In addition, safety team could also record real-time multimedia content of the disaster location. All of the data packets are traversed from the UE of each SAR member to a central coordinator device. The coordinator collects all the received data packets from public safety team. The analyzer team processes the data, and then send back the processed information of the DL communication to the various public safety teams.

Fig. 1 shows the schematic diagram of D2D IWACA's scenario. Each cell contains a BTS in the center and a lot of UEs is assumed to be spread randomly in the cell area with uniform distribution. UEs can form D2D pairs of D2D clusters to communicate over the Short (SR) links.

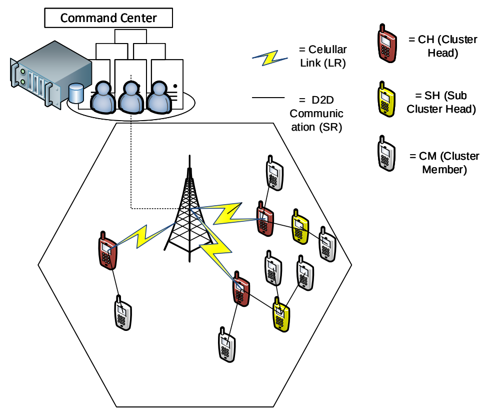

Fig. 1 Diagram of the D2D IWACA architecture.

For each clusters, a UE is selected as CH which acts as a relay between UEs and BTS. Sub cluster heads (SH) is responsible for relaying the information to all other CMs. SH is in charge of the similar tasks as cluster head regarding their CMs. The only distinction from CH is the SH must not keep a core network connection and must relay the request and data from its CMs to the corresponding CH. We employ the standard terminology "device" to represent several nodes, such as the UE and BTS. If there are J UEs in the network, they must be indexed as device n_1 to n_J, where the BTS being represented by J_0 and given the index 0. We denote by C_i the coalition of nodes forming a single cluster with n_i as CH communicating on the LR with the BTS on behalf of all the cluster members.

2.1 Rate calculation

We used the rate calculation in [9], [10], [3]. The rate of data transfer between node n_j and node n_k within sub carrier x is expressed as $R_{jk}^{(zx)}$. The bandwidth of the sub carrier is $W^{(X)}$, whereas the SNR gap is β, and $\gamma_{jk}^{(x)}$ is the link between node n_j and node n_k in sub carrier x. Replicating the approach in [3], data transfer rate between those nodes can be expressed as:

$$R_{jk}^{(zx)} = W^{(X)}.log2(1+ \beta\, \gamma_{jk}^{(x)}) \quad (1)$$

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

$$H_{jk}^{(x)}=(-125Db - 3.76log10\ d_{jk})-8dB+10\ log10F_{jk}^{(x)} \quad (2)$$

In the equation, the Rayleigh channel model is denoted by $F_{jk}^{(x)}$. The detailed formulation of the sending rate could be read in [3].

2.2 Energy calculation

We used the energy computation expression published in article [5]. The consumed energy in the uplink direction for UE members of certain cluster C_j is symbolized as EC_{UL}. The multimedia content transmission duration is expressed as *ST*, while *R* is the data sending rate, P_{RX} is receiving power level, and P_{TX} is sending power level. Thus, total consumed energy for UL EC_{UL} can be written as:

$$EC_{UL} = \alpha\sum\frac{ST.PT,SR}{Rik} + \beta\sum\frac{ST.PR,SR}{Rik} + \sum\frac{ST.PT,LR}{Rik} \quad (3)$$

Shown with EC_{DL} thus, energy consumed for uplink EC_{UL} is formulated by:

$$EC_{DL} = \alpha\sum\frac{ST.PR,SR}{Rik} + \beta\sum\frac{ST.PT,SR}{Rik} + \sum\frac{ST.PR,LR}{Rik} \quad (4)$$

The detailed approach to the computation of UE consumed energy and remaining battery is found in [5].

2.3 Node lifetime

Scenarios for network lifetime testing are similar to energy consumption test scenarios. But when the simulation time has run out and not all nodes run out of energy, it will be done round addition to find round where there are all half of the number of dead nodes.

2.3 Delay

Delay is the finite amount of time it takes a packet to reach the receiving of the node at the endpoint after being transmitted from the node of sending endpoint. Source nodes are all nodes present in the experimental simulation whereas the receiving node is the BTS node as the command center. According to [5], [17] the delay constraint propagation delay and transmit delay. The transmit delay refers to the ratio of data volume and transmit rate. For example, the transmission delay from the n_j node to n_k is $\frac{ST}{Rkj}$, R_{kj} is the rate of the transmit link and ST is the ratio of data volumes transmitted, that is 1 Mbits. The propagation delay refers to the delay caused by propagation on the wireless link. Thus, the propagation delay of the n_j node to n_k is $\frac{d(nj,nk)}{c}$, where c represents the speed of light, that is $3x10^8$ m/s. Therefore, Delay for sending data 1Mbits (ST) from n_j node to n_k node can be written as:

$$Delay = \frac{ST}{Rkj} + \frac{d(nj,nk)}{c} \quad (5)$$

3. Proposed Method

We herein discuss Improved Weighted Application-aware Clustering Algorithm (IWACA) method, as well as the weight factor used to initiate cluster classification.

3.1 System parameters

The criteria of how to choose the CH are probably the key point when dealing with clustering. The number of CHs heavily affects the total latency, overhead, inter- and intracluster communication method, and update rules (i.e. cluster reorganizing) as well. In this paper, we assumed that each device is capable to be a CH. To determine the suitability of a node for being CH, we consider the device power level, signal strength, dissemination degree, local clustering, and data rate. The features below are taken into account in the proposed method:

1) *Device power*

Battery power required for the UEs to communicate with other UEs can be used efficiently within certain transmission range. As a CH works in the dual power mode and runs the advanced function, it consumed more power than a CM. The remaining battery power must be taken into account when selecting CH.

2) *Signal strength*

In the cellular communication case, devices nearer to a base station obtain higher data utilization and bitrate than those farther. A longer distance typically results in on-off connection and lower throughput. Selecting devices in the closer proximity to the BS or node-B provides higher throughput for data [12].

3) *Dissemination degree*

A CH is a main node for data delivery. In order to transmit the content efficiently, CH node must be characterized by higher vertex degree than those of the neighboring nodes (more number of links to others in the coverage area). In practice, the optimal number of CM in a cluster relies greatly on the method used, as presented in [12], [18]. For example, a Bluetooth master-and-slave scenario can handle up to seven slaves. Greater than seven members causes delays in data delivery. Paper [18] introduced a parameter δ that expresses the optimal degree for a CH node to gain higher data utilization.

4) *Local clustering*

IWACA can develop a multi-hop cluster of arbitrary size by means of sub-head creation. Applying IWACA in a big network partition could produce more hop counts to CH. It is because of the distant chain of SHs associated to the CH. To combat this issue, articles [12] and [19] advise the use of a locally generated coefficient to support well-structured clusters.

5) *Data rate (device characterisric)*

In the past, Brust et al. proposed an efficient approach, which is called WACA, to determine the CH dynamically in MANET networks [18]. However, public safety networks may differ from traditional networks due to several constraints. In public safety networks, prolonging the network lifetime is usually an important issue [9]. In a high data rate environment, e.g. 4G and 5G communication, power consumption is deteriorated exponentially. It makes the calculation of energy consumption variation for each UE device become irrelevant. Therefore, we add the data rate constraint, hence the chosen cluster heads should obtain a better performance over public safety communication.

3.2 The proposed algorithm

The WACA algorithm is designed to select CH on the hybrid wireless network. Generally, public safety network has more problem than the network in the normal condition. Therefore, it is not suitable to apply WACA method straightly on public safety network because it doesn't take into account the data rate which is one of the important factors in communication systems.

In this research, we modified the WACA's clustering algorithm so it can be used on public safety network with considering specific obstacles on the network. We added one of characteristic factors inspired by [11] to the weight factor for choosing the cluster's head. So the chosen node as cluster's head on public safety network will behave better than without the weight factor. This algorithm is called Improve Weight Application Aware Clustering Algorithm (IWACA). Weight factor on IWACA consists of Device Power, Signal Strength for Backbone Connectivity, Dissemination Degree, Local Clustering, and Data Rate. The flow diagram of the proposed method is ilustrated in Fig. 2. Details of the IWACA algorithm for public safety networks is as follows:

Step 1. Initially, the algorithm identified the neighbors of device v, that is represented by angle of degree dv,

$$dv = \sum \{v' \neq v \mid dist(v,v')\mid < tx\ range, v\} \quad (6)$$

In the equation, *dist(v,v')* represents the distance between one device and another device (node *v* and node *v'*) and tx range as transmission distance from node v.

Then each device calculates the difference of degree for each node v,

$$\Delta v = |dv - \delta|. \quad (7)$$

In the equation, Δv represents the difference of degree, dv as a neighbor of each node, and δ as The optimal capacity of a CH to support a number of devices.

Step 2. Calculate the dissemination degree (Δdd) difference between the ideal δ for each node and the neighboring node (*dv*),

$$\Delta dd = 1 - \frac{|dv-\delta|}{\delta}. \quad (8)$$

Step 3. Calculate the amount of signal power (S_P) received from BTS for each node. It is initiated in the algorithm if it has an acceptable signal rated 1 if the signal is good and the value 0 if the signal is not good.

Step 4. Calculate the local CL clustering coefficients on each node, which defined as follows,

$$CL = \frac{|dv|}{n(n-1)/2} \quad (9)$$

Whereas |dv| is the direct link counts to the neighboring nodes of node d, while *n(n-1)/2* is all links in a network, and n represents the total number of devices.

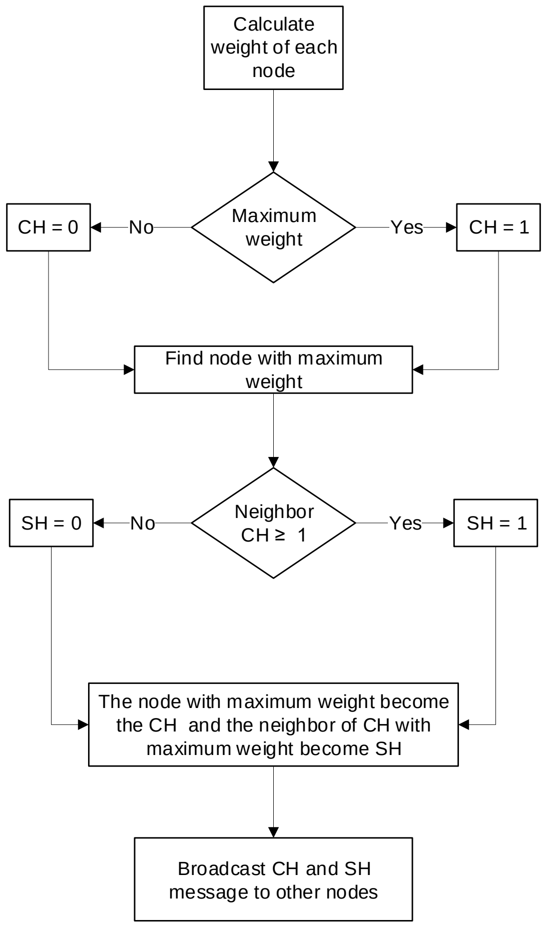

Fig 2. IWACA flowchart.

Step 5. Calculate the energy on the device. Given device *v* has energy *P(v)*, then calculate the energy of *Pd* (device power) eligibility on each node as follows,

$$Pd = \frac{3}{2} + \frac{1}{2} log \left(P(v) - \frac{3}{5} \right) \quad (10)$$

Step 6. Calculate the C_v (characteristic device) for each node,

$$Cv = \frac{c * rv}{Ev} \quad (11)$$

where *rv* is the sending datarate, *Ev* is the initial power level, and *c* is a gain or amplifying factor.

Step 7. Calculate the weight factor combination

$$W_V = w_1 \Delta dd + w_2 S_P + w_3 C_L + w_4 P_d + w_5 C_v \quad (12)$$

In the IWACA algorithm, the five coefficient values are set as w_1=0.05, w_2=0.5, w_3=0.1, w_4=0.3 and finally w_5=0.05, according to the previous IWCA [20] experiments with a little adjustment for the device characteristics.

Step 8. Select a device with maximum W_V as the CH.

Step 9. Select the node except the CH that has the maximum W_V as Sub Cluster Head. The neighboring nodes from CH and SH can't be selected anymore and are already 1 cluster.

Step 10. Repeat steps 1 to 9 above for all other devices until all nodes have their own clusters.

Step 11. In the event that the cluster head selection fails, then algorithm must be iterated.

4. Results and Analysis

We discuss overall performance metric of the IWACA algorithm, by means of MATLAB numerical simulation. Its performance was then compared with WCA and WACA. The model considered in this paper comprises an arbitrary amount of mobile UEs with identical initial power and any mobility pattern. Each node can forward the message to all nodes in the transmission coverage. The speed is presumed by defining any value maximum 1 km/h to each device. We studied the average and total energy consumption, as well as QoS parameters such as delay, throughput and node lifetime by fluctuating the node counts per cluster. In [21], it was found that mobile phone towers with higher variability of calls made during the disaster were located in the most affected area. This proves that people communicate more than normal traffic in the event of a natural disaster [22]. The number of devices variation is between 1 and 250 devices. These simulations are intended to analyze how IWACA can affect energy efficiency, reduce delay, and increase node lifetime for public safety networks.

As shown in Table 1, a simulation parameter is used. In the simulation, we consider an area of LTE with the number of active users in that cell to be varied and incremented, for each test scenario to be tested at 50, 100, 150, 200, 250 users. The cluster radius is approximately 1 km. We utilize bandwidth of 10 MHz, then divided it into 50 resource-blocks or RB. Receive power level at the CH node, denoted by $P_{R,LR}$, is 1.8 Joule/s, whereas transmit signal level from each CH node to its respective CM, $P_{T,SR}$ is 1.425 Joule/s. Receive power level at CM side, expressed as $P_{R,SR}$ is 0.925 Joule/s. We use 64QAM modulation and distributed data size of 1 Mbit. Furthermore, we used LTE parameters from 3GPP standard in [12].

Table 1. Simulation Parameters and Assumptions

Parameter	Value
Cell diameter	1 km
D2D range	500 m
Frequency	2.4 GHz
Number of devices per cell	50 -250
Data content size	1 Mbits
Mobility of the devices	1 km/h
devices Rx power	0.925 J/s
devices Tx power	1.425 J/s
Battery capacity	6000 Joules

4.1 Number of cluster heads formed

Fig. 3 illustrates the average clusters built to the total nodes in D2D clustering based public safety networks. As the device density goes up, the proposed algorithm produces consistently less number of clusters compared with WCA and WACA. Our algorithm shows better results with regards to the cluster counts in the case where density factor and user movement speed in the PSN are adequately large. Decreasing the number of cluster heads greatly affects the packet overhead, delay, inter-cluster communication mechanism, and also the cluster reorganizing. We could relate this enhancement to the practice where subcluster heads was employed to form a multi-hop yet well-shaped cluster.

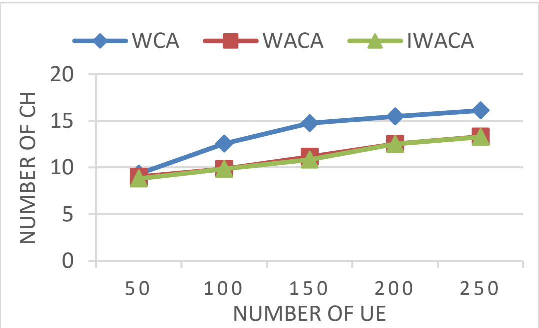

Fig. 3 Number of CH vs number of UEs.

4.2 Energy consumption

In this simulation, we investigated the effect of a node variability to the energy efficiency. Fig. 4 and 5 shows the simulation results of MT energy consumption in both direction.

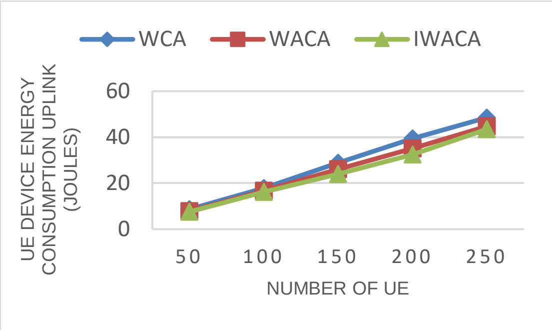

Fig. 4 The energy consumption of uplink

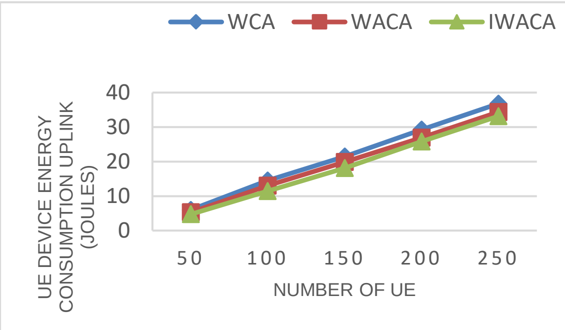

Fig. 5 The energy consumption of downlink

Fig. 4 presents the power consumption in the uplink direction. Obviously, the proposed algorithm IWACA for D2D communication performs significant improvement compared with WCA and WACA. According to the results of this simulation, IWACA clustering algorithm that can minimize the number of LR links and EU communication links also take into account the factor rate which is an important factor in energy consumption is the best clustering algorithm with having better energy efficiency better than WCA and WACA. The value of the uplink scenario is smaller when compared to the downlink because the uplink calculation of energy consumption including the calculation of energy consumption due to clustering algorithm process whereas in the downlink does not occur repetition algorithm process.

Fig. 5 presents the influence of the number of UE to the energy consumption over the uplink direction. Here, IWACA slightly outperforms the other two methods. Since we take the device datarate into account when choosing either the CH or SCH node, then the total consumed power could be decreased by a few Joules.

Figure 6 shows the simulation results of UE lifetime with a varying number of UEs per cluster. According to the results, IWACA algorithm requires less energy consumption than WCA and WACA algorithm so that network life is higher compared with them.

4.3 Uplink delay

The simulation results in Figure 7 show that the algorithms utilizing the D2D clustering method, using the WCA, WACA, and IWACA algorithms, result in a low average delay for one-time transmission and 1 Mbit video reception to the command center (uplink) Of 0.05 sec for each device. According to the analysis, this is because according to [12] which is a key factor in delay is distance and rate. Using IWACA, WACA, and WCA clustering methods with D2D communication it can reduce the use of LR links from UE and BTS communications and maximize close-up communications so that the rates obtained can be maximized and distance can be minimized [12]. The IWACA algorithm in this simulation has more advantage over WCA algorithm in terms of delay because this algorithm has sub cluster heads which can reduce the amount of CH that is reducing the number of LR link so it can hit the low rate in a communication device with the command center. According to IWACA algorithm analysis which is the development of WACA algorithm to be a better algorithm in terms of delay because the IWACA algorithm added weight factor which is one important factor that can affect the delay of the factor rate, by tightening CH selection with the rate factor, it will be obtained CH with the highest communication rate that causes the data transfer process takes place more quickly, can minimize delay results.

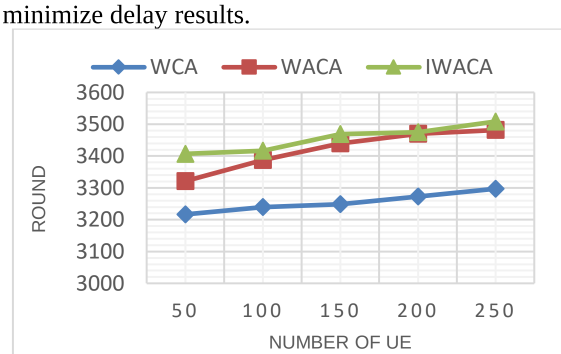

Fig. 6 node lifetime half death

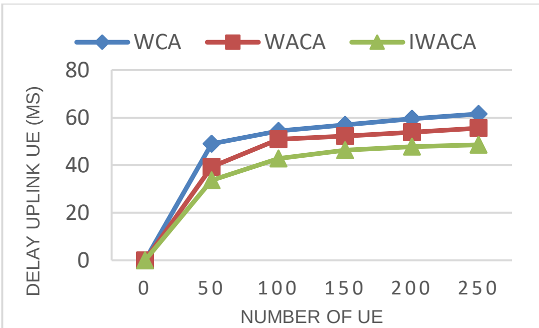

Fig. 7 Delay of uplink

5. Conclusion

The performance of public safety networks with D2D weighted clustering communications were discussed. IWACA was proposed in order to improve the energy efficiency metric. Using WACA, WCA, and IWACA, those problem in public safety network area can be solved. With IWACA algorithm, it was shown that the method could outperform the other methods in terms of energy efficiency, in both uplink and downlink sections. Moreover, it also had a shorter delay. Although this simulation is a public safety networks scenario in network assisted discovery, IWACA and WACA algorithms can support partial-coverage areas due to the clustering method using CH and SH to allow relays.

Future work will be to investigate a scenario with multiple cells and determine the optimum number of clusters. Another interesting research topic is to examine the influence of the device discovery process, as well as the distribution of numerous types of content traffic. We could extend the model of network assisted communications to ill-conditioned circumstances, where the mobile system coverage might be completely lost.

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