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Device Discovery Schemes for Energy-Efficient Cluster Head Rotation in D2D

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Abstract

In this paper, novel device discovery approaches for the cluster head rotation, which is a state-of-the-art method for the Device-to-Device communication, are proposed. The device discovery is the process to detect and to include new devices in the Device-to-Device communication. The proposed device discovery is aimed to attain energy efficiency for the communication devices. We propose two schemes for the device discovery: eNB-assisted and independent device discovery. Compared to previous work, the proposed device discovery is utilizing the cluster head rotation method, to achieve better energy efficiency. In this work, several simulations were performed and discussed for both schemes. In the first simulation, the device energy consumption is examined. After that, the number of devices that get rejected is studied. The device discovery processes in multi cluster head scenario, which is cluster head rotation, are examined in this paper. The result of the simulation shows that eNB-assisted device discovery can provide better energy efficiency. Also, the number of rejected devices of the eNB-assisted device discovery is slightly lower than independent device discovery.

Keywords*: device discovery, energy efficiency, D2D, wireless mobile communication, 5G*

1. Introduction

The Device-to-Device (D2D) communication is a future wireless technology that will enable direct communication between two or more devices via peer-to-peer (P2P) communication without burdening the network [1, 2]. Due to the fact that energy efficiency is recognized as a leveraging factor for the development of mobile communication technology [1], [3-5], the D2D communication is also expected to increase the energy efficiency of mobile devices. Furthermore, there are two key processes in the D2D communication: the data transfer and device discovery [6]. Thus, the device discovery, which is important to establish the proximity based communication ([7, 8]), is recognized as a significant part in D2D communication.

As one of the most important feature in D2D communication, the device discovery was studied in various researches [9-12]. In [12], the device discovery procedure is utilized for effective channel measurement. According to the simulations, the proposed method is capable of increasing the throughput by 50% [12]. Generally, there are two options of device discovery: independent or network-assisted. However, usually works about D2D device discovery only analyze one mode of device discovery. As an example, in [9-10], [12], only network-assisted device discovery was discussed. On the other hand, in [11], only independent device discovery was analyzed. Hence, to gain full understanding about device discovery, these two modes need to be compared side-by-side.

One popular method to reduce the energy consumption is by forming groups that consist of several devices. In each group (referred to the cluster), the cluster head (CH) obtains the data content from the network and distributes it to another device, which known as the cluster member (CM). This scheme will significantly diminish the energy consumption due to the significant reduction of the number of long-range (LR) communication links. Nevertheless, the CHs has potential to consume more energy compared to CMs due to its role [13]. Not only D2D,

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the clustering approach to improve for energy efficiency also effective to be applied in wireless sensor network (WSN) [14]. The cluster head rotation in WSN already proposed in several works ([15, 16]), while the approach in D2D is still under development [13].

However, due to its focus to providing a new concept in D2D content distribution, the work in [13] did not contain device discovery factor in the cluster head rotation. The device discovery can be described as a procedure for a device to transmit beacon and acknowledgment to other establish D2D communication with other devices. This is an important factor which can significantly improve the energy consumption. Therefore, novel device discovery procedures for cluster head rotation are proposed in this paper.

Moreover, the device that enters the cluster in the middle of serial data transmission may miss the previous data transmission from the previous CH. As an example, a UE that enter the cluster in the middle of third data transmissions may miss the data transmission from first and second CH. This issue may cause several CMs get incomplete data content. This will lead to data retransmission, which cause significant energy inefficiency for CHs.

Furthermore, as a developing wireless technology, D2D still leave uncertainty in its application. One of these aspects is whether the eNB is utilized for device discovery or not. If we consider the eNB assistance in D2D as a vantage factor over the other device communications (e.g. CRN and MANET) [1], we should leave device detection to eNB. On the other hand, D2D is also expected to avoid overloading the network, which leave device discovery as device's task. Unfortunately, for the best of our knowledge, there is no publication that specifically compares these two approaches for device discovery in D2D communication with multi-cluster heads scenarios. Hence, this work is focused on comparing these approaches in the perspective of device discovery in cluster head rotation method.

The development of device discovery has been studied in various works. The work in [10] featured a D2D device discovery scheme based on the random access procedure of LTE-A. In [11], the energy efficient, fast discovery for D2D, is proposed. By utilizing a particular beacon transmission pattern, the devices in the group will declare the existence of the other devices in the proximity. The work in [17] proposed the firefly algorithm to discover and synchronize the proximity devices. The two approaches in device discovery (whether network assistance is used or not) are emphasized in [6], although the experiment for comparison was not performed.

The purpose of this work is to provide a comparison of different approaches of energy-efficient device discovery for cluster head rotation in D2D communication. Thus, the novelty of this work is threefold. First, we propose and compare the efficient device discovery method for cluster head rotation in D2D communication in two schemes: (i) eNB-assisted and (ii) independent device discovery. In the eNB-assisted scheme, the new device recognition and declaration are aided by the eNB. On the other hand, in independent device discovery, the new devices themselves send the beacon to be recognized by the CHs. Furthermore, the CHs also utilized to announce and carry the information of the new devices. Finally, we also provide side-by-side comparison between two schemes of device discovery modes.

The rest of this paper is organized as follows. In the Section 2, the system model is explained. In the Section 3, the approach of our work is introduced. In the Section 4, the result of this work is explained. Finally, the conclusion of this work is presented in the Section 5.

2. Proposed Schemes

In this work, we propose two scenarios of device discovery, which are the eNB-assisted and the independent device discovery. The main issues for designing device discovery are not only to improve devices' energy efficiency, but also to satisfy the users' experience. The problem is, there is an unavoided trade-off between these two factors. On the one hand, device energy constraint permits us to perform device discovery as infrequent as possible, since device discovery signal consumes device battery. On the other hand, to satisfy the user experience, the device discovery must be performed as fast as possible. Unfortunately, this rapid discovery will call for frequent device discovery, which will induce battery drain. Hence, the balance of these two factors must be considered in the designing process of D2D device discovery. Furthermore, the balance of energy consumption between devices in the cluster also must be considered.

In both scenarios, the main goal is to perform energy efficient device discovery for cluster head rotation. Thus, the device discovery is aimed to assembly the clusters in the cell area. These approaches are expected to reduce the energy consumption of the devices. Ultimately, the differentiation is summarized in Tabel 1. In the table, several key distinctions of roles of network elements for each device discovery scheme is addressed.

Table 1. Differentiation between eNB-assisted and Independent Device Discovery

Description	eNB-assisted	Independent
Initial cluster formation authorization	eNB	eNB
CH selection	eNB	eNB
Table holding	eNB	UE
New device recognition	eNB	UE (CH)
New device authorization	eNB	UE (CH)

2.1. The eNB-assisted Device Discovery

In this scenario, the eNB is responsible for D2D device discovery in its cell area. We assume that eNB can recognize the UEs in its area. As presented in Algorithm 1, the process can be described as follows. First, the eNB sends a discovery signal (DS) to UEs in its area to detect which UEs that capable for D2D communication. After that, the UEs that capable to perform D2D communication responds by sending a confirmation to eNB. Secondly, the eNB will select several CHs by considering device’s throughput and battery level. The detailed process for CHs selection in CH selection can be seen in [13]. The eNB broadcast the DS in an interval. However, to keep device energy consumption at the minimum level, the UE confirmation signal is often lesser compared to the DS of the eNBs. Finally, we propose an approach to handle the device(s) that enters and leaves the cell in the middle of data transfer process. As explained before, the cluster head rotation method utilizes several CHs to handle the data content distribution, which ensure better energy consumption fairness. However, if one device (or more) entering the cluster in the middle of CH_{1+n} Broadcast, it may skip previous data content broadcast from previous CH(s). To tackle this issue, the additional broadcast slot in the cluster head rotation is proposed. The main idea of this concept is to allow CH(s) perform additional broadcast to satisfy new device(s).

The Figure 1 informs us about the application of this concept. Firstly, the first CH, which denoted as CH_1, broadcast the data content to the CMs. The original broadcast period is depicted as the initial broadcast, which denoted as A_1. Next, a certain period of time is allocated for an update period (U_1). During this period, the eNB act as an informer for the CH which informs CM alteration in the cluster. If there is a new device in the cluster, the eNB will command the CH_1 to re-broadcast its data fragment for the new device(s). It should be noted that the window for eNB recognizing the arrival of the new UE(s) is the detection period, which is D_n, occurs between the start of initial broadcast and the end of update period. Therefore, the duration of D_1 is equal to the aggregation of A_1 and U_1. Additionally, the time period, which eNB needs to inform the CH_n about the change in the cluster, is denoted as E_n. Since we prioritize the UEs’ energy efficiency over eNBs’, we prefer to keep the D_1 open to ensure fast device discovery. This may slightly decrease the energy efficiency of the eNB, but this scheme will ensure fast device discovery and guarantee device energy consumption (which is the main goal of this approach). Hereafter, as presented in Figure 1, the above process is repeated for each CH.

However, it is possible that not every CH need to perform additional broadcast. For example, if the advent of the new devices is only happening in the first detection period, i.e. D_1, the CHs except CH_1 do not need to execute the additional broadcast. Therefore, in this scenario is the first additional broadcast, which is B_1, that is performed by CH_1. Obviously, this scenario decreases the energy burden of other CHs. On the other hand, this might harm the balance of energy consumption between UEs, particularly when there is a large amount of incoming UEs in D_1. This may betray the energy consumption fairness, which seems to be the core idea of the cluster head rotation.

Algorithm 1: enB assisted device discovery
initial UE discovery
Cluster Head selection process, A = 0, B = 0, C = Initial Cluster Member amount
initial Broadcast, A = A + 1, **repeat** B = B + 1 **until** B = Cluster Member amount
if B = C **do**
if A = threshold **do**
if B = max number of CM per cluster **do**
(**1**)
else do (**2**)
else do (**3**)
else do additional broadcast, A = A + 1, **then** do (**5**)

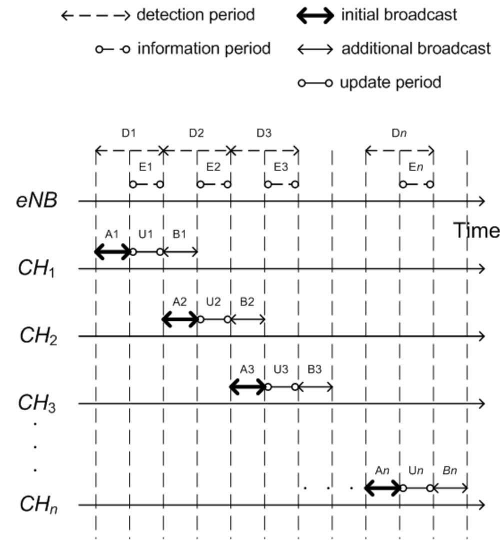

Figure 1. eNB-Assisted Device Discovery in Cluster Head Rotation

2.2. The Independent Device Discovery

In this scenario, the UEs independently perform device discovery without encumbering the eNB. Similar as [17], the UEs will broadcast DS to its proximity devices. As presented in Figure 2, compared with the eNB-assisted approach in the previous scenario, the DS is transmitted in a longer interval for reserving the UEs battery in this scenario. Due to the lack of network supervision, compared to the eNB-assisted device discovery, the procedure for independent device discovery is significantly more complicated. In this scheme, there are three separate processes: initial device discovery, CHs selection, and additional device discovery.

As presented in Algorithm 2, the independent (without the supervision of the network) UEs discovery for the enhancement of cluster head rotation is proposed. This procedure is aimed to anticipate the advent of new UEs during data distribution. From CHs perspective, there are the windows for initial broadcast, additional broadcast, and information update. Moreover, for arriving UE, the device discovery window and the window for receiving info are utilized. The process can be described as follows. First, the CH broadcasts its data fragment to the CMs. The following detection period will allow the CH to recognize the new device(s). Afterwards, if the new device(s) is detected by the CH, the CH will undertake additional broadcast to serve the new device(s). Finally, this process is repeated for the following CH(s).

Moreover, in this scheme, the new device(s) will broadcast beacon regularly to find a D2D cluster activities. If the new device(s) beacon is detected in the update window of a particular CH, the new device will be recognized. Hereafter, the new device(s) will receive the data fragments. As an example, In Figure 2 the beacon of a new device, UE_x, is recognized by first CH (CH_1), after CH_1 executing its initial broadcast. Next, the CH_1 will perform additional broadcast to transfers its data fragment to the UE_x. However, the next device (UE_y), miss the update period of CH_1 and gets its beacon recognized in the update period of CH_2. As the result, the CH_2 is not included in this session of cluster head rotation.

The scheme also utilized the table that contains the CHs in the cluster. In a session of cluster head rotation, the table data from the previous CH will be passed to the next CH. The table will be updated for each successful recognition of a new device. As presented in the pseudocode, the initial table is sorted after the formation of the cluster. Thus, if a new device joins the cluster during the process of data distribution, the table will be updated.

Algorithm 2: INDEPENDENT device discovery	
1	initial UE discovery and formation
2	initial table of Cluster Member
3	Cluster Head selection process, A = 0, B = 0, C = Initial Cluster Member amount
4	initial Broadcast, A = A + 1, **repeat** B = B + 1 **until** B = Cluster Member amount
5	**if** B = C **do**
6	**if** A = threshold **do**
7	**if** B = max device per cluster **do**
8	(**3**)
9	**else do** (**4**)
10	**else do** table update **then**
11	additional broadcast, A = A + 1, **then** do (**6**)

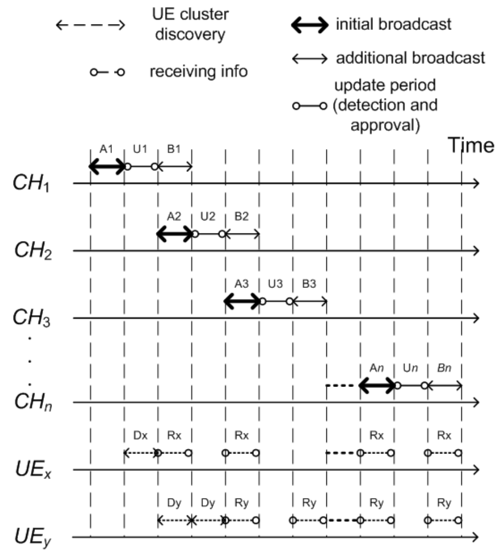

Figure 2. Idependent Device Discovery in Cluster Head Rotation

3. Simulation Model and Assumption

The approaches of this work were inspected via numerical simulation, which was focused on examining the UEs energy consumption. The energy calculation for this work is based on the mathematical model from [18]. Additionally, this work is focused on simulating the energy consumption of downlink communication.

The schemes are examined in LTE-A multicell condition (50 cells) with a dense urban environment. The UEs is distributed uniformly in the area, with the eNBs are located in each cell. As mentioned earlier, the UEs are acting as CH and CM. The CHs are responsible for receiving the data content from eNB via long range communication links and broadcasting it to its CMs through the short range communication link. The LTE-A and radio channel parameters in the simulation are adapted from [19-21]. The D2D concept in this work is also based on ProSe from 3GPP [22]. Furthermore, the parameters of the simulation are addressed in Table 2.

To maintain the focus of this work, we assumed that each device is capable of performing the D2D communication. However, the advisability of the devices to become CH is varied. The size of the content is uniformly altered, although the differentiation is limited (normally distributed between 0.5 and 2 MB). Eventually, the energy consumption is calculated based on CH packet distribution. The duration of the packet transmission, which directly affect the energy consumption, will be varied due to UEs throughput. The calculation of the energy consumption of the down-link communication is based on [23]. Furthermore, the device average energy consumption is calculated as total device energy consumption per number of distributed data content.

Additionally, in this work the energy calculation for signals between D2D devices is based on the formula in [24]. For this work, the formula is adopted for the data distribution process from CH to its related CMs [24]. The brief formula is presented below [24]:

$$E_{signal} = \sum_{X\in\{I,H,h,S,L\}} n_X \tau_X \Pi_X + \sum_{X,Y\in\{I,H,h,S,L\}} n_X p_{X,Y} T_{X.Y} \Pi_{X,Y} \quad (1)$$

Where the number of visits to the state X is denoted as n_X, the time spent during state X is denoted as τ_X and the power consumption of the device radio subsystem during state X is represented as Π_X [24]. Similar as [24], several radio resource control states are used. The I state denotes the idle state when the device is inactive [24]. While connected with the CH, a device has certain states: H state when it communicates, h while it stop the communication, S state for sleep mode (wake in some interval) and L state which apply longer sleep mode [24]. The second part of the equation, which express energy to switch between states, contains several additional elements: $p_{X,Y}$ that denotes the average relative number of times that state Y is visited from state X and state $T_{X.Y}$ which express the average time spent to transform between states, $T_{X.Y}$ that represents the average time spent to transform between states, and $\Pi_{X,Y}$ which expresses the power consumption to shift between states [24].

Table 2. Parameters of the Simulation

Parameter	Value
Cell diameter	500 m
Number of cells	50
Average CH/ CM ratio	1/5
Maximum CH per cluster	5
Number of devices per cell	300
Data content size	0.5 – 2 MB
Maximum BS Tx power [21]	10 W
Maximum devices Tx power [21]	0.125 W

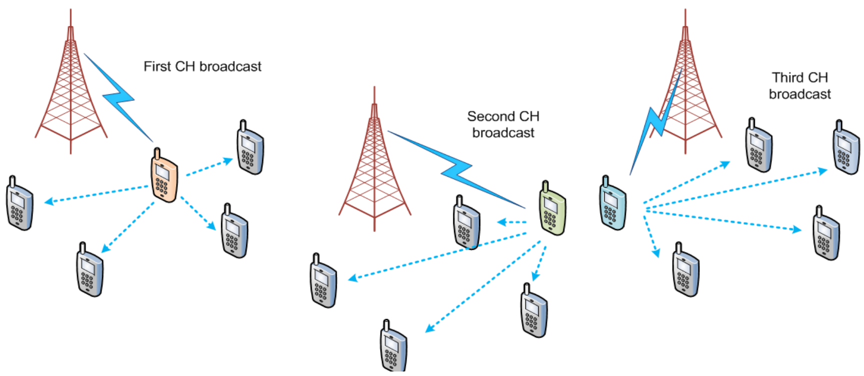

Figure 3. Cluster Head Rotation in D2D [13]

4. Results and Analysis

In this work, we perform the simulation to examine and compare the devices' energy consumption of eNB assisted and independent device discovery for Cluster Head Rotation. Thus, the energy efficiency between the two proposed schemes can be compared. Secondly, we examine the number of the rejected devices in both scenarios. Finally, the equality of energy consumption between CHs and CMs in the both scenarios is studied via the simulation.

4.1. First Scheme: eNB-Assisted Device Discovery

4.1.1. UEs Energy Consumption of eNB-Assisted Device Discovery

Figure 4 informs us about the overall energy consumption for the each cell. In this simulation, the aggregate number of energy consumption per cell is inspected. The purpose of this simulation is to obtain average energy consumption by simulating D2D communication in 50 cells, which utilized eNB-assisted device discovery. To mimic the real condition, the devices are free to activate or de-activate the D2D communication anytime, even in the middle of the data transfer series of cluster head rotation. According to our simulation, the highest energy consumption is 277 Joules and the lowest is 248 Joules. From the result, we can conclude that the energy distribution is arguably flat for all cells. The average energy consumption for each cell is 265 Joules. According to the analysis, this caused mainly because of the eNB consistent eNB aid to all cells for new device detection.

4.1.2. Rejected Devices in eNB-assisted Device Discovery

In Figure 5, the number of total rejected devices for each cell is given. In the simulation, the new devices can be rejected because of the two factors: reaching the maximum number of devices or joining outside the joining period. The purpose of this simulation is to analyze the possibility for the new devices to be rejected in the eNB-assisted D2D device discovery. The rejection of the new devices occurs if the number of the devices exceeds a certain number (40 devices in this case). The highest number of rejected devices in a cell is 35 devices per cell. Additionally, the average number of rejected devices is 6 devices per cell. Moreover, although there is some cell with a high number of rejected devices, there is also a significant amount of cells (64%) with zero rejected devices. Thus, from the simulation, we can conclude that the rejection rate of eNb-assisted device discovery for the new devices is 0.157%.

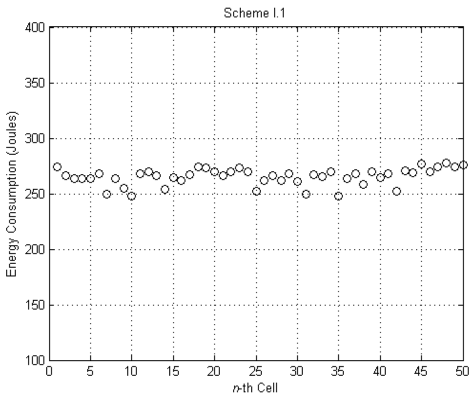

Figure 4. Devices Energy Consumption per cell in the First Scheme

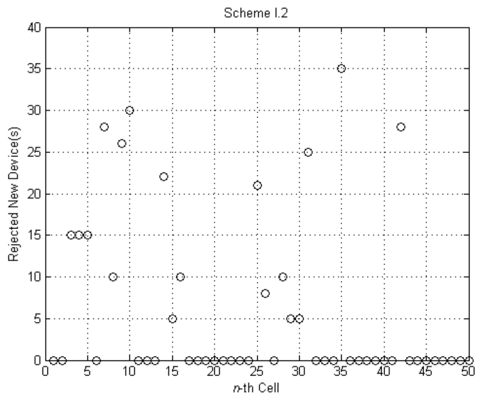

Figure 5. Rejected Devices in the First Scheme

4.2. Second Scheme: Independent Device Discovery

4.2.1. UEs Energy Consumption of Independent Device Discovery

In Figure 6, the presented energy consumption for each cell in independent device discovery is presented. In this simulation, the total of energy consumption accumulated from D2D communication using cluster head rotation and independent device discovery is studied. The purpose of this simulation is to analyze the average energy consumption of D2D communication which is simulated in 50 cells. To adjust with the real-life scenario, devices are allowed to activate or de-activate the D2D communication links even in the middle of the data transmission. According to the result of the simulation, the peak energy consumption is at 296 Joules and the lowest is 245 Joules. Moreover, the average energy consumption is 276 Joules per cell. Compared to the previous scenario, the result also shows more distributed energy level. According to the analysis, this is caused by the significant energy consumption of CMs to detect and recognize new devices.

4.2.2. Rejected Devices in Independent Device Discovery

The number of rejected devices for each cell in independent device discovery is presented in Figure 7. Same as previous scheme, the new devices can be rejected because of the two factors: reaching the maximum number of devices or joining outside the join window. As applied in the simulation with eNB-assisted device discovery, the rejection of the new devices happens if the number of the devices exceeds a certain number (40 devices in this case). From the simulation, the maximum number of rejected devices is 42 per cell. Furthermore, the average number of rejected devices is 8 devices per cell. Moreover, despite the high number of rejected devices in several cells the number of cells that has zero-rejected devices is high (62%) Finally, according to the result of the simulation, we can deduce that the rejection rate of independent device discovery for the new devices is 0.1675%.

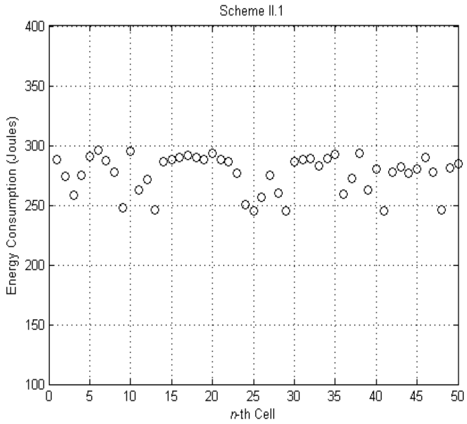

Figure 6. Devices Energy Consumption per cell in the Second Scheme

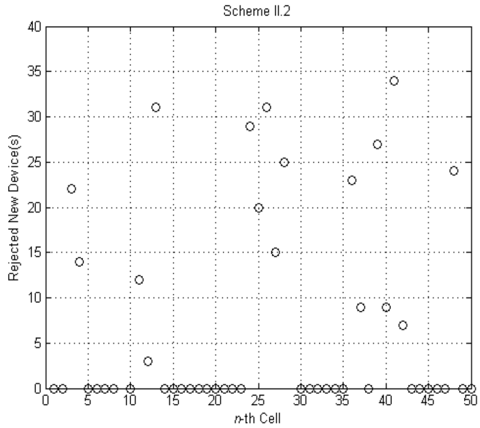

Figure 7. Rejected Devices in the Second Scheme

5. Conclusion

In this paper, the proposed energy efficient device discovery schemes: (i) eNB-assisted and (ii) independent device discovery for cluster head rotation is presented and compared. First, the simulation results show that the application of the eNB-assisted scheme can achieve better energy efficiency (3.63% lower than another scheme). However, with an arguably insignificant difference, the independent method in this work is proved as a reliable method in terms of energy efficiency. Secondly, the enB-assisted device discovery proves itself as the best contender to provide QoE by achieving the lower number of rejected devices (25% lower than another scheme). Finally, we can conclude that the eNB-assisted is better than the independent device discovery, although the difference in the performance is acceptable.

For the future works, we suggest to investigate the balance of the user experience and the energy efficiency, which lead to the development of an, even more, sophisticated method of additional broadcast.

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