Performance Evaluation of a Weighted Clustering Algorithm in NSPS Scenarios

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II. Abstract

In national security and public safety (NSPS) scenarios, the concept of device-to-device (D2D) clustering allows user equipment (UEs) to dynamically form clusters and thereby allows for local communication with partial or no cellular network assistance. We propose and evaluate a clustering approach to solve this problem in this thesis report. One of the key components of clustering is the selection of so called cluster head (CH) nodes that are responsible for the formation of clusters and act as a synchronization and radio resource management information source. In this thesis work we propose a weighted CH selection algorithm that takes into account UE capability, mobility and other information and aims at balancing between energy efficiency, discovery rate and cluster formation time. Numerical results show that the clustering approach consumes more energy but it can achieve a much higher discovery rate and communication rate for the system. Simulation results indicate that the weighted clustering approach is a viable alternative in NSPS situations.

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1. Introduction

Device-to-device (D2D) communication in cellular system has been proposed and observed as a remarkable and significant alternative way to communicate between devices instead of occupying the resources of cellular network. D2D communication could be established between physical proximate user equipment (UEs) instead of communicating via base station (BS) or other central network element. With direct D2D communication only one channel is needed between the two devices instead of two (uplink and downlink channels) in regular cellular communication. In this case only half of radio resources are needed compared to cellular system. Moreover, direct link has smaller delay thus providing better user experience [1]. So D2D communication has great advantage to utilize in small but highly densely populated areas where exist many devices but limited network resources such as in a concert where there are lots of audiences trying to make calls or surf internet. To share information based on proximal location of the users is the solution and the goal of D2D communication. With the application of D2D communication we can gain spectrum efficiency and also the coverage of the cellular network. Moreover, devices only need to communicate with close devices and communication could be achieved with less energy. Thus, the power consumption is decreased.

Figure 1: Superiority of D2D communication

Before starting the D2D communication, devices need to discover the others, so device (peer) discovery phase is needed. During this phase devices can discover the others and create direct links between them. If the discovery phase and communication phase take place simultaneously, we call this discovery a-posteriori discovery, while when the discovery phase is before the communication phase, we call it a-priori discovery [2]. In this work, we focus on a-priori discovery.

1.1. Background

Two types of D2D communication are discussed most nowadays: non-network assisted and network assisted D2D communication. Non-network assisted systems are also called ad hoc systems such as Wi-Fi and Bluetooth. Network assisted systems such as Flashlinq and LTE-A systems, network can help with the synchronization, radio resource management (RRM) and provides the configuration of certain parameters. Compared with non-network assisted system network, assisted D2D communication is more efficient in terms of required time/frequency resources, energy consumption and discovery rate/time [3].

Nowadays, daily life relies on communication. Providing effective support communication can ensure decision making and action. Especially in the area of national security and public safety (NSPS), to establish communication wherever the network exists, or even where network does not exist, would be a great help. For example, if an earthquake happens, the power supply or the radio tower is down, the public network is not functional or only partially functional, to provide a reliable communication to all users in the disaster area is the key to survivors and rescue teams. In such disaster recovery case, since the network is not fully functional, D2D communication is a more direct and efficient choice.

Furthermore, NSPS scenarios have recently been recognized as important application areas for wireless communications. Both in the US and in Europe, spectrum and infrastructure resources are dedicated to ensure robust broadband services in disaster situations. At the same time, the 3GPP has started working on defining the requirements and standardizing the technology enablers for NSPS scenarios. LTE advanced is recognized as a solid technology basis to meet such requirements. The new requirements drive new solutions to support solutions both with and without infrastructure. In Rel-12, D2D communication is studied both for commercial use cases and for NSPS.

1.2. Aim

The goal of this thesis report is to design and analyze peer discovery approaches. Clustering approach is the main solution. At the same time, distributed neighbor discovery approach is studied and compared. For clustering approach, devices firstly form into small clusters and then discover each other within a cluster and between clusters. Distributed neighbor discovery approach is also called spatial coloring approach. The devices gather information and autonomously pick a radio resource to transmit. The devices try to pick the radio resource wisely according to the gathered information in order to discover more devices.

To measure the performance we look at several parameters:

- System load (input)
- Energy consumption (output)
- Discovery rate (output)

System load is the ratio between the number of users and the number of radio resources. If the radio spectrum resource is a constant, the more devices lead to the higher load. If the spectrum resources are infinite, the system load is always much smaller than 1, the system is a lightly loaded system. If the number of devices is much larger than the number of radio spectrum resources, the system is called a heavily loaded system. The performance of the discovery depends a lot on the system load. Energy consumption is also an important parameter. The battery of a UE, e.g. a mobile, has normally limited power. Once the battery is empty, the device will be unable to communicate. If the energy consumption is high in the discovery phase and the battery drains fast, it is bad for the whole D2D communication. So it is very important to discover other devices using small amount of energy. Discovery rate and time are the most important parameters in the D2D discovery phase. Discovery rate is the ratio between the number of devices which can be discovered and the total number of devices in the system. Discovery time is the time needed to complete the discovery. The main goal of the discovery phase is to let the devices in a certain area discover others. So the discovery rate and energy consumption are the direct references to the discovery performance. Once devices discover each other, devices communicate. We call this phase the communication phase. Beyond a reliable discovery, we would like to provide a good quality-of-service (QoS). The average communication rate is a way to quantify the QoS. We would like to provide a high communication rate.

In general the goal of this work is to design and analyze peer discovery algorithms with minimum network assistance that allow devices to discover other devices in an efficient way in terms of energy consumption, spectrum resources, discovery rate and time. Network can assist in many aspects. In this thesis work, minimum network assistance means that the network provides synchronizations for the devices and helps with the radio resource management (RRM). During the discovery, algorithms are applied to increase both discovery rate and communication rate.

2. Theory of D2D discovery

Network assisted system can receive assistance from the base station such as:

- Synchronizing and broadcasting the available resource to all devices.
- Broadcasting the total number of devices which want to discover the others and want to be discovered by the others in the system.

The more information provided by the network, the more efficient discovery can be established [2]. However, it relies on the network. If the devices are not completely within the network coverage, the network assisted D2D discovery cannot be established. In this thesis work, minimum network assisted system is studied. Network only provides the minimum necessary information such as synchronization and RRM. Some other approaches can also achieve synchronization in the system. So even if there is only partial network coverage or no network coverage, this D2D discovery algorithm is still functional and works as in Ad hoc system.

2.1. Concept of neighbor discovery

2.1.1. Master and slave

In this work, the devices are divided into two kinds: masters and slaves. They can be regarded as transmitters and receivers in telecommunication. The device which announces its presence and wants to be discovered by and communicate to the others is called a master while the device which searches for devices and wants to receive information is called a slave. In reality masters and slaves can be physically identical or different. Some devices want to search the others and be searched by the others, while some devices only want to search or only wait for being searched (e.g. printer).

The devices are 2-dimensional (2D) uniformly distributed. Single cell case is considered. This leads to dissimilar coverage at the edge of the cell. The devices at the edge have fewer neighbors than the ones in the middle. These devices will also suffer less interference because there is no signal from the outside of the cell. In reality it is possible when a device is at the edge of a cliff or beside sea and there are much fewer signals coming from there. But we would like to study the general case like in the urban area where the devices are uniformly distributed. Wrap around technique is used to avoid the dissimilar or non-uniform distribution situation. In general, the hexagon cell is copied and pasted along each border. Then the original cell becomes a central cell and there are 6 identical cells surrounding it. Without wrap around, if there are one device at the most south corner and one at the most north corner, the real distance between them is very long basically. It is about the diameter of the cell. However, with wrap around, the virtual distance with wrap around is very short; it looks like the two devices are close to each other. The concept "distance" we used in this work indicates the virtual distance.

2.1.2. Potential pair and discovered pair

We define one master and one slave as a pair. Any links between masters and slaves are potential pairs (e.g. ten masters and ten slaves form one hundred potential pairs). If the signal-to-interference-and-noise-ratio (SINR) from a master (transmitter) to a slave (receiver) is larger than a certain threshold, we say this pair is a discovered pair. The threshold is also called decoding threshold. A slave can discover a link if the received SINR is larger than the decoding threshold. The discovery rate is the ratio between the number of discovered pairs and number of potential pairs. Decoding threshold presents the decoding ability. If the received SINR is larger than the decoding threshold, slaves can decode and read the information contained in the received signal from a master. After a slave receives a decodable signal it will give a responding feedback.

2.1.3. Beacon signal and paging signal

At the beginning of the discovery phase, masters start to broadcast the beacon signals when they want to be found by the others. The beacon signal contains information such as master ID. If a slave captures the beacon signal and the SINR of the beacon is larger than the decoding threshold, the slave can obtain the ID information and thus know which master sending the beacon. Then the slave sends back a paging signal. The master can decode the paging signal and know which slave sending the feedback. Eventually, it can know how many slaves have discovered it. In some case, a master would like to be discovered by as many slaves as possible. Without the NW assistance, the master has no awareness about how many slaves exist nearby in total. With NW assistance, the master is conscious about the proportion of slaves who discovers it.

2.1.4. Peer discovery resource (PDR)

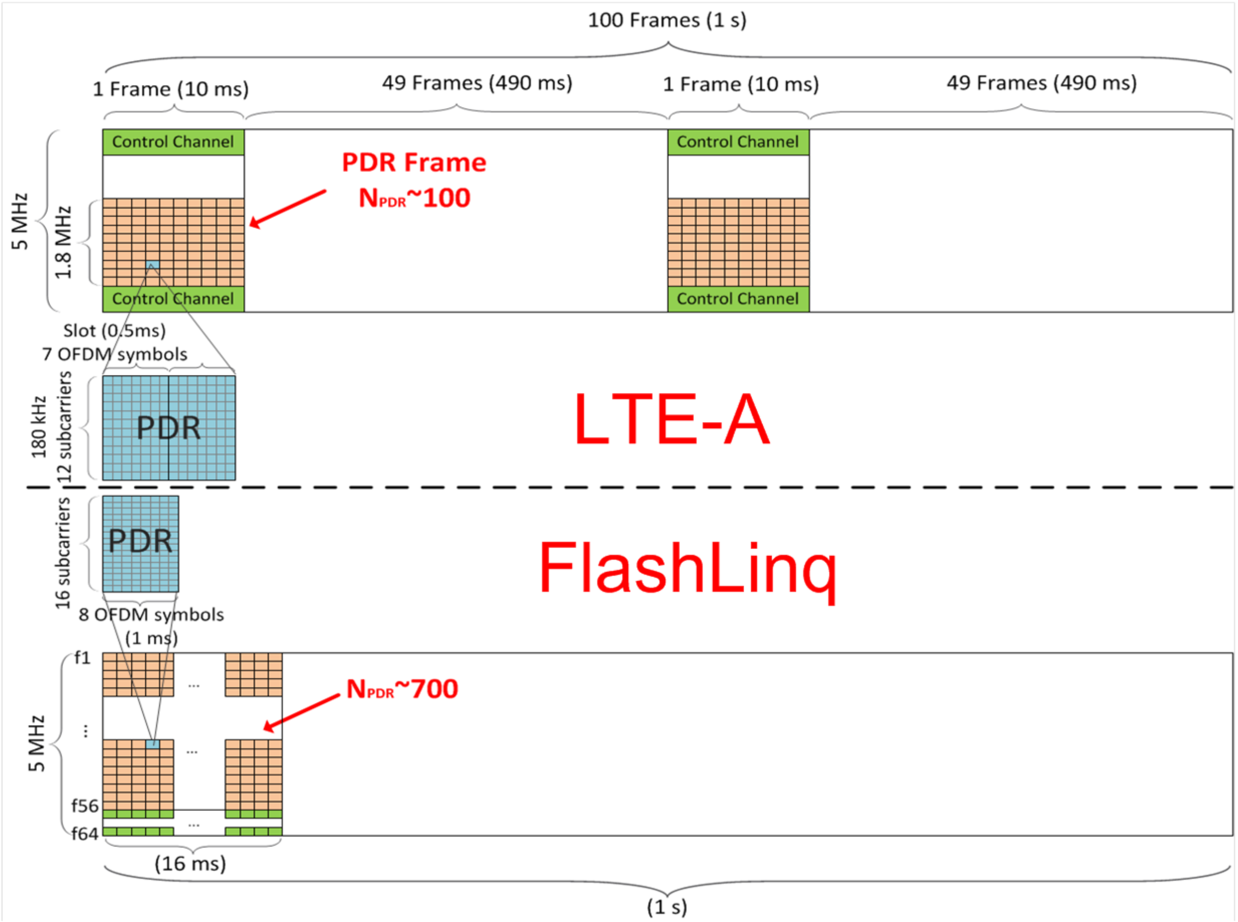

Figure 2: PDR frame structure

The radio spectrum resource involved in the discovery is called the peer discovery resource (PDR). A PDR slot is a specific time and frequency unit which can be used by masters to transmit the beacon signal. In the Flashlinq frame, one PDR lasting for 1ms is formed by 8 orthogonal frequency-division multiplexing (OFDM) symbols. OFDMs are orthogonal to each other, so there are no interference between each of them and each PDR. The PDR broadcasting lasts for 16ms in 1s. The rest time is for the communication and is not the focus point in this paper. While for LTE-A system, based on the model used in [2], one PDR lasts for 1ms is formed by two PDR slots. Each PDR slot lasting for 0.5ms is formed by 7 OFDM symbols. There are two beaconing periods in 1s and each beacon period lasts for 10ms. We call one beaconing period plus the following communication period to be one time frame (0.5ms). For both systems, 5MHz is available and certain amount of frequency is left for channel control and some other functions. In total, there are maximal 700 PDRs in one beaconing period of Flashlinq system and 100 PDRs in one beaconing period of LTE-A system.

With this carrier form, a large amount of information can be stored in one PDR such as device ID, value of received signal strength, number of detected devices and so on. With this information, the devices who received the beacon signal are awarded of certain parameters related to the master. This information can help the device to pick the PDR. Both beacon and paging signals can contain information. After the master received the paging signal, it can also obtain the information contained in the signal. This information can also help to pick the PDR. The paging signal and paging period are not simulated in the simulation. We assume devices can transmit and receive PDR at the same time. The transmitted signal does not interfere the received signal.

We define one time unit to be one discovery phase plus one communication phase which lasts for half a second. The discovery phase is also known as the beacon broadcasting phase. At the beginning of the beacon broadcasting phase, one device will autonomously pick one PDR to broadcast the beacon signal. How to pick the PDR is the key in our study. When the system is heavily loaded, i.e. the devices are more than the PDRs, there will be collisions. Collision means that more than one device pick the same PDR to broadcast the beacon signal. At the slave side, received interference is caused by collision. The slave can only decode the link whose SINR is larger than the decoding threshold and read the information contained in that link. Collision has great impact on the performance. Wisely picking the PDR for a master is the key to avoid collision and decrease the interference.

In this paper, we try to use only small amount of PDRs out of all available PDRs. We try to use only a few PDRs to achieve the discovery. In this case, when the number of PDRs is a constant, the system load depends on the number of devices in this area. Therefore, in the simulation, by varying the number of devices we can vary the system load.

One subtask in this paper is to design and analysis a few algorithms which help the masters to pick the PDR and wisely broadcast the beacon signal in order to improve the performance.

2.2. Concept of clustering approach

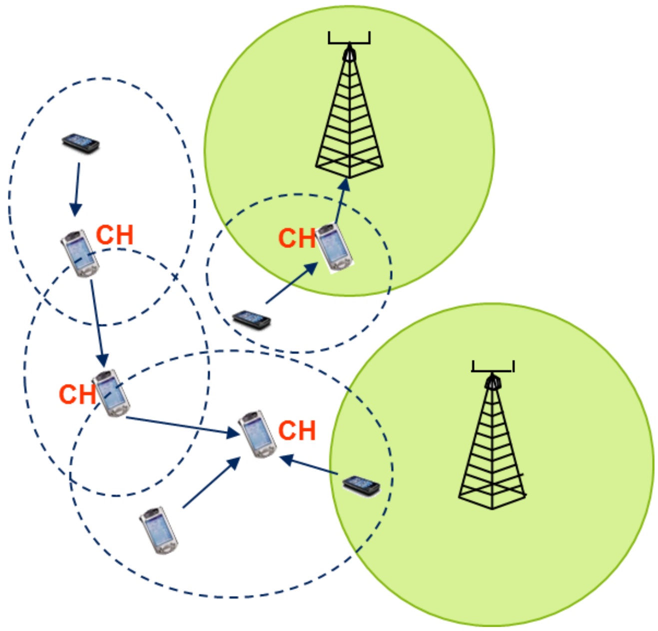

Figure 3: Concept of clustering approach

Dividing the geographical region to be covered into small zones is called clustering. Different from the distributed neighbor discovery approach that all the slaves need to discover as many devices as possible, in this approach each slave does not need to discover all the other masters but only one certain node, known as cluster head (CH). CHs are responsible for forming clusters which consisting of a number of nodes and providing the topology of the network in D2D communication. Any nodes with certain functionality can become a CH, and then other non-CH nodes register to the most suitable CH and become members of that cluster. Eventually all nodes are either CHs or cluster members. All CHs form a dominant set, which is framework of the temporary network. Devices can communicate with the help of CHs. In this approach, the CHs are masters and other non-CH members are slaves. The CHs must have some functions e.g. they must be able to work in dual mode. Dual mode means that they can work in both low power mode and high power mode at the same time. Also they must be able to transmit and receive in extra frequency band. Each CH uses low power, low frequency mode for intra-cluster discovery and high power, extra frequency mode for inter-cluster discovery. We call the low power for intra cluster communication the intra transmission power and the high power for inter cluster communication the inter transmission power. This approach is also functional when the whole network is down. And all the devices in this area will form a new network so that every device can communicate to any other devices in this area. Due to the dominant set can use extra frequency resource, there are more PDRs. Thus we assume that there are no collisions between CHs. At the very beginning of the discovery phase, each device picks one PDR to broadcast the beacon. We assume during the communication phase, CHs use the same PDR as they use in the discovery phase. Some algorithms are applied to help organizing the cluster. Once the cluster is organized, the discovery rate is limited by the received SINRs of the slaves for the intra links, since there is no interference in the inter communication, and received SNRs of the masters for the inter links. The average communication rate is limited by average SINR over all the slaves for intra communication and average SNR over all the masters for inter communication. The whole system transmission rate is limited by the lower value of these two.

The key of this approach is to decide which devices should act as CHs. Following points must be considered in reality to select the CHs:

- Capacity

  Does this device have the function to be a CH? CH must have certain functions, e.g. dual mode function.

- Network coverage

  Is this device in the network coverage? If a device is in the network coverage, other devices are equivalent to connect to the network through it. Besides, network can assist D2D communication and make the system more efficient. So if the system is partial covered by the network, it is good to pick a device within the network coverage to be CH.

- Number of neighbor nodes

  How many nodes are near it? Each CH may have an optimal number of cluster members to support. More cluster members cost more computation and it is not efficient. Less cluster members are a waste of resources. So it is good to let the CHs support a certain amount of cluster members. Hence, a device which has the number of neighbors approximately equal to the optimal number of devices to support is a good CH candidate.

- Distance to neighbor nodes

  Are neighbor nodes close to it? The distance mentioned here is the virtual distance calculated by the received signal strength. This can also be the sum of the received signal strength from the neighbor nodes. If the neighbors are close to the CH, the received SINRs are large, the communication rates are high. If its neighbors are centralized, the device is a better CH candidate compared to others.

- Mobility

  Does this device move fast? If it moves fast, it can easily move out of the current cluster and the stable cluster situation is changed and a CH re-selection is needed which costs computation and time. Thus, slowly moving devices are more suitable to be a CH.

- Cumulative time

  How long has this device been a CH? As a CH works in dual power mode and runs advanced function, it consumes more power than a non-CH device. It is bad to always keep a same node to be CH continuously, it drains the battery fast. Once a device has been a CH for a long time, it is good to select another CH.

In this paper, we assume that every device is capable to be CHs. Network coverage is not discussed. All the other factors mentioned above are considered.

The performance we are interested in:

- Connectivity
- Number of CHs
- Number of dominant set updates
- Discovery rate
- Transmission rate

Connectivity is the ratio between the number of CHs which can communicate to any other CHs and the total number of CHs. Full connectivity is the basic requirement of the D2D communication to ensure that every device can communicate to any other devices. This is also the discovery rate between CHs which presents how many CHs can discover any other CHs. As mentioned above, the number of CHs has great influence to the performance so the number of CHs is important to look at. The number of dominant set updates is the number of selections over a period of time. The selection should be invoked as rarely as possible to reduce the computation cost. The reselection is event triggered. It only invokes when one device moves out of the coverage of all the CHs. Discovery rate directly links to the D2D discovery performance. Finally, after a basic functional D2D communication system is established, we would like to improve the average transmission rate of the system.

We can divide our algorithm into 6 states: initial configuration, neighbor identified, CHs identified, clusters identified, connectivity achieved and final connectivity achieved [4]. We can also divide our procedure into 4 steps: neighbor detection, CH selection, member allocation and connection establishment.

3. Clustering approach steps

There are four steps in the clustering D2D discovery approach: neighbor detection, CH selection, member allocation and connection establishment.

3.1. Neighbor detection

Neighbor detection involves two states: initial configuration and neighbor identified.

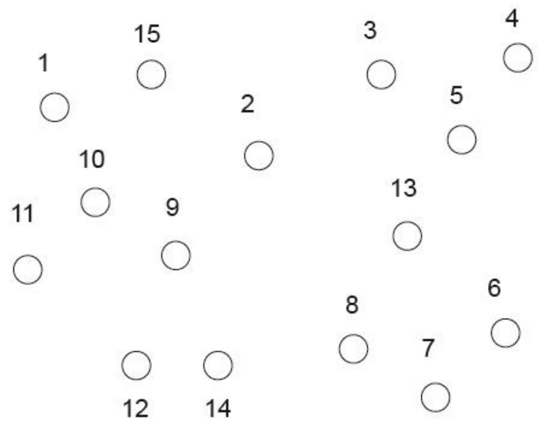

Figure 4: Initial configuration

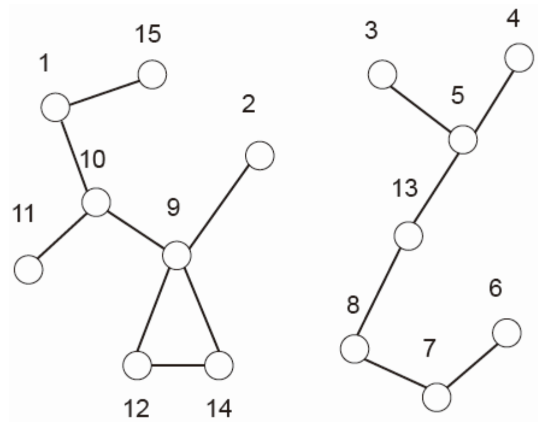

Figure 5: Neighbor identified

The first state (Figure 4) is the initial geographic illustration of devices. With some mechanism, every device is able to identify its neighbors. If the received signal from a master to a slave has good quality, we say the slave is a neighbor to the master. The received signals at the neighbors are larger than the decoding threshold. The link is directional, e.g. when node A is a neighbor of node B, it does not imply that B is a neighbor of A. In this state, every device knows which other devices are its neighbors and how many neighbors it has.

In this step (Figure 5), each device is able to identify its neighbors. The step happens at the beginning of the discovery phase. Every device is broadcasting using one PDR. We define a device is a neighbor of the master if its received SINR value is larger than a certain threshold. Multiuser detection is assumed i.e. a device can detect multiple users if the received SINR is larger than the decoding threshold. We call it the neighbor detecting threshold (neighbor TH) which in some sense describes the coverage of a device. The value is always larger than the decoding threshold which defines the decoding ability. The information such as user ID is encoded in the beacon during this step. From the previous study [2] we know that the key to improve performance is to avoid collision. Wisely picking PDR to avoid collision is critical to improve performance. Distributed neighbor discovery approach focused on avoiding collision is discussed.

3.1.1. Distributed neighbor discovery approach

This approach is also called greedy coloring approach. Each PDR can be regarded as a "color". There are no interferences between different colors but devices with the same color interferes each other. Before discovery starts, a listening phase is needed. Listening phase in this approach is also called coloring phase. This step is done before it actually starts to broadcast the beacon signal. In this phase, the new master gathers information before it decides to broadcast using which color. After each master picks a color in the coloring phase, it broadcasts beacon on the picked colors. How they pick the colors in order to improve the performance is the key of our study. The purpose of the discovery phase is that all the slaves can discovery as many masters as possible. When the system load is high, the masters must pick colors wisely to complete the discovery efficiently. Few algorithms are proposed.

Algorithms "random" [2]

In the coloring phase, each master picks a color out of the available colors with equal probability. This is a very simple algorithm. The disadvantage is that masters may pick the same color even if they could avoid collisions. If the number of colors is much larger than the number of masters (e.g. ten colors and three master), the possibility to collide is very small. However, if the number of colors is almost same as the number of masters (e.g. ten colors and ten masters), the probability not to collide is very small. It only happens when a given color is chosen by at most one master. We define load density to be the ratio between number of masters and number of colors. In this way, when the density is much less than 1, the collision probability is very low; when the density is approximately equal to 1, the collision probability is low but not collision-free guarantied. When the density is high, each color is picked almost by same amount of masters.

Algorithm 1: max min "distance" [5]

The idea of this algorithm is to separate the masters with the same color as far as possible. This algorithm is also called greedy (coloring) approach in some other studies [5] [6] [7]. The purpose of this algorithm is to maximize the minimum "distance" of the closest master using the same color. The "distance" here actually refers to pathloss which is calculated by the received signal strength. It is not the spatial distance but the “distance” which puts the channel fading into account. We assume the transmission power is same for all devices. Each master joining listens to the broadcasting of the existing masters and decodes the received signals. The listening period is the listening phase which is a short time period before the discovery phase. During this phase, a master listens to the channel and gathers information which can help it to pick the color. In simulation, we assume masters join one by one. Each device listens and picks a color. The listening phase takes a short time so that the total system discovery time increases. If every device transmits every time frame, then the listening phase only needs 1 time unit and each master is able to gather the channel information. Because the beacon signal contains the ID information, the master can know the pathloss between it and the other masters. It can then find out the closest master of each color. Each master when joining picks a color which maximizes the minimum “distance” between the other masters with the same color. This algorithm focuses on measuring the received signal strength. It requires per-color and per-node measurements by the new master which means the new master measures the received signal strength on each color from each master (e.g. ten colors and ten masters mean to measure one hundred received signal strength).

Algorithm 2: Min interference [6]

This algorithm is an enhanced version of algorithm 1. The first algorithm focuses on maximizing the distance to the closest master using the same color. It does not consider the total distance between the new master and other masters using the same color. It might be that the sum of the received signal from the further masters is larger than the closest one and the ones using that color. Therefore the idea of this algorithm is to look at the “sum distance” instead of the “minimal distance”. The purpose of this algorithm is to minimize the sum of the received signal at the new master over all colors. Each master when joining picks a color which minimizes the sum of the interference that the new master will suffer from the other masters using the same color. This algorithm also focuses on the received signal strength as the previous algorithm but it only needs per-color measurement (e.g. ten colors and ten masters mean to measure ten sum of the interference). It does not need to obtain the ID information in the received signal because it does not need to identify the transmitter. It only needs to measure the sum of the received signal strength over all colors. This algorithm also needs the listening phase. Compared to algorithm one, this algorithm seems better because the measurement is easier and the interest parameter is the sum of the interference which is more directly associated to performance of interest.

Algorithm 3: Max average SINR

The previous two algorithms consider only masters. Slaves are not involved in the coloring phase in the previous algorithms. Algorithm 3 and later algorithm 4 take slaves into account. These two algorithms are SINR-based algorithms. The idea of this algorithm is to pick the color which maximizes the average SINR over all the slaves. The purpose is to maximizing the average SINR over all the slaves. Each master when joining picks a color which maximizes the average SINR over all the slaves. In order to let masters have the information of the SINR at the slaves, this algorithm actually requires slaves to keep broadcasting. The broadcasting signal has to contain ID information and the value of the sum of the interference of each color. In the listening phase, the new master gathers information of the received signal strength of the broadcasting signal and obtains the ID information and the sum of each color's interference. With these values, the new master can calculate the received signal strength at each slave which is the numerator of the SINR. The denominator can be calculated by using the sum of the interference minus the received signal strength of each color and plus the noise, it will pick the color which maximizes the average SINR over all the slaves. This algorithm focuses on measuring the received signal strength and obtains the information carried on the signal. It requires per-node and per-color measurement by the new master (e.g. ten colors and ten masters mean to measure ten received signal strength and obtain ten pieces of information from each signal, which in total are one hundred measurements). After the master decides to use a particular color, it will start to broadcast the beacon signal.

Algorithm 4: max discovered pair

This algorithm is similar to algorithm 3 but the parameter of interest is different. In this algorithm the idea is to maximize the discovered pair instead of the average SINR over all the slaves. It is a decoding threshold based algorithm. The purpose is to maximize the discovering pair (SINR > decoding threshold). Each master when joining picks a color which maximizes the number of discovering nodes. The new master does the same things as algorithm 3 but calculate the number of links which SINR is larger than the decoding threshold. Compare to algorithm 3, this algorithm seems better because the number of discovered pairs is more associated to the discovery rate compared to the value of average SINR over all the slaves.

Comparison

Compared to the last two algorithms with algorithms 1 and 2, the SINR based algorithms (algorithms 3 and 4) are more directly linked to the performance in terms of detection, communication rate and capacity. But they require carrying much more information by the beacon signal which is hard to achieve in reality. The advantage of algorithms 1 and 2 is that they are very simple. Compared to algorithm random, it needs a listening phase before picking the color which takes some time. However, it tries to separate the devices using the same color in order to decrease the interference which may also decrease the total discovery time for both the whole system and one individual device.

Table 1: Comparison between distributed neighbor discovery algorithms

	ALG 1	ALG 2	ALG 3	ALG 4	ALG random
Focus	Max min distance	Min interference	Max average SINR	Max discovered pair	Equal probability
Listening phase	Yes	Yes	Yes	Yes	No
Slave broadcast	No	No	Yes	Yes	No
Per color measure	Yes	Yes	Yes	Yes	No
Per node measure	Yes	No	Yes	Yes	No
Reference	Pr	Sum(Pr)	SINR	SINR	--

Coloring more round

We assume that all devices pick color one by one before beaconing and start to transmit beacon signal at one time. However the devices that pick color earlier have no idea about the situation later after more devices have picked. So the situation may be totally different between the beginning and the ending. The color picking based on these four algorithms is local optimal. The device picks the color which is optimal to itself, but it may not be the optimal to the whole system i.e. it is not global optimal. In order to solve this, the coloring process can be restarted once more when all the devices have already picked a color. Then the coloring will be different. We can do this over and over again until a stable situation is achieved which means that the color for each device stays unchanged no matter how many more times to re-color. We assume this is the global optimization for the whole network.

The master will pick one PDR according to one of the algorithms above and broadcast the beacon using it. The slaves that can receive a signal which SINR is larger than the neighbor detecting threshold will be the master's neighbors. During this step, multiuser detection is required meaning that all the links which SINRs are larger than neighbor TH can be detected. Thus a master can detect more than one neighbor.

3.2. CH selection

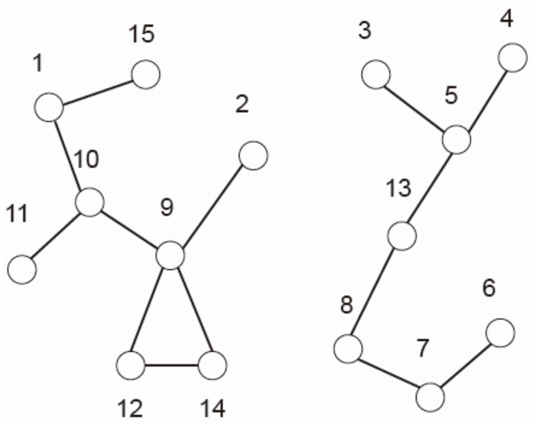

Figure 6: Neighbor identified

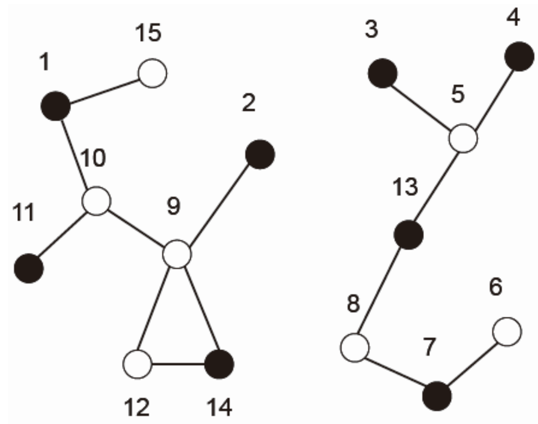

Figure 7: CHs identified

Some devices are selected to be CHs during this state. How to select the CHs is critical. There are a lot to consider in this state.

After the neighbor detection, every device is aware of who its neighbors are and how many neighbors it has (Figure 6). Some of the devices are selected to be the CHs (Figure 7) and responsible for forming the clusters and provide topology of the NW. It is not recommended to have too many or too few CHs. CH requires the device to be a more advanced device which is more expensive. Moreover, it provides the topology of NW, so it consumes more power. So it is not good to have too many CHs due to the design cost and power consumption. Meanwhile, a CH can only cover certain area, so it is not good to have too few CHs otherwise it cannot provide full coverage to this area.

The most important question is who should be the CH. There are some ways to decide this. The way used in this paper is called a weighted clustering algorithm [4].

3.2.1. Weighted clustering algorithm

Each node is assigned weight based on its suitability of being a CH and based on the weight the most suitable one can be selected as CH. Some factors can be taken into consideration:

- Optimal number of nodes to support (δ)

- Sum of received signal strength
- Mobility
- Cumulative time
- Capability
- Etc.

Each device can ideally support a certain number of devices which is a pre-defined value δ. To serve more or fewer devices is not good for the MAC layer computation. Sum of received signal strength shows how close the neighbors are from the device. Mobility presents the maximum displacement for a device in one direction in one time frame. The displacement of each device, in simulation, can be calculated as:

$$Disp = x \cdot mobility + j \cdot y \cdot mobility$$

where x, y are randomly variables and $x, y \in unif(-1,1)$

Mobility is important because it is not proper to select a device moving fast to be CH. Otherwise it is easy to move away from its original location and cannot provide efficient coverage. Cumulative time is the time for how long the current device has acted as CH. A CH consumes more power than a non-CH member. If a device has been CH for a long time, the battery drains fast, it is better to select another device to be the CH for some time. If a device does not have the function of being a CH, i.e. it is not capable, and then it is the least suitable one. Anyway, in reality, some of these factors may not be important or very important we can vary the coefficient of each factor to change the importance of them.

The weighted clustering algorithm should be invoked as rarely as possible to reduce the computation cost. The reselection should be invoked whenever there is a major change in the weights for any reason. So the current CH selection is not long enough to provide coverage to this area or not efficient. In this paper, the selection is event triggered. It only triggers once a device moves out of the coverage of all the current CHs. It means that the current dominant set is unable to provide coverage to all the nodes. In this case, a reselection is needed. It may also be triggered by other events but they are not considered in this paper.

3.2.2. CH selection procedure

During CH selection procedure, each device calculates its own weight, broadcasts captured weights of other devices and compares them to its own. The one which is most suitable will be one CH. The steps are as the follows:

Step 1: Find the neighbors of each node v, which defines its degree d_v

$$d_v = \sum\{v' \neq v \big| dist(v, v') < tx_{range,v}\},$$

where $dist(v, v')$ is the distance between node v and v'. $tx_{range,v}$ is the transmission range of node v.

Step 2: Compute the degree difference, $\Delta_v = |d_v - \delta|$, for every node v, where δ is the optimal number of nodes to support.

Step 3: Compute the sum of the received signal strength from its neighbors of each node. Normalize the value to 0/1 (Good/Bad candidates)

$$|1/SumPr_v| = \left|1/\sum_{v' \in V\ v' \neq v} Pr_v(v, v')\right|,$$

where $Pr_v(v, v')$ is the received signal strength its neighbor v' to each node v.

Step 4: Compute the mobility of every node

$$M_v = \sqrt{(X_{v,t} - X_{v,t-1})^2 + (Y_{v,t} - Y_{v,t-1})^2},$$

where $X_{v,t}$ and $Y_{v,t}$ are the horizontal and vertical displacement of node v at time t.

Step 5: Compute the cumulative time T_v, for how long node v has acted as a CH, where T_v is the time that node v has been a CH.

Step 6: Calculate the combined weight W_v

$$W_v = w_1\Delta_v + w_2|1/SumPr_v| + w_3M_v + w_4T_v,$$

where Δ_v is the degree difference, $|1/SumPr_v|$ is the sum of the received signal strength, M_v is the mobility, T_v is the cumulative time and W_v is a calculated weight of node v which quantify its suitability to be a CH.

Step 7: Choose the node with the smallest w_v as CH. All the neighbors of the chosen CH are no longer the candidates to be a CH

Step 8: Repeat steps 1-7 for the remaining nodes

The first component in the weight formula in step 6 is called degree difference which is the difference between real number of neighbors and optimal number of nodes to support (δ). The second component represents how close the neighbors are from their CH. The value is normalized to 0 or 1. In reality, certain nodes whose sum of the received signal strength is larger than a threshold, i.e. their neighbors are close to them, are good to be CHs. In simulation, we say that the nodes whose sum of the received signal strength is above the average are good to be a CH. The third component is the mobility of a device. A slowly moving device is more suitable to be a CH. The last component is the time the device has been a CH. If it has been CH for too long time, it is not suitable to be CH any longer. In general, the node with the smallest weight is the most suitable candidate to be the CH.

Every device can calculate its own weight autonomously. This weight information is contained in the broadcasting signal along with its ID. A neighbor receives the weight and stores the information. It can compare its own weight with the received weights thus knows if it is a good candidate. This stored information is exchanged with its neighbors and proceed until all nodes are aware of the minimum weight. And the node with the minimum weight will be selected to be CH. If the devices are divided into few groups but there are no links between these groups, e.g. in Figure 6, each group has one minimum weight and there will be more than one CH to be selected at one time. In this way, the global minimum weight can be found.

3.3. Member allocation

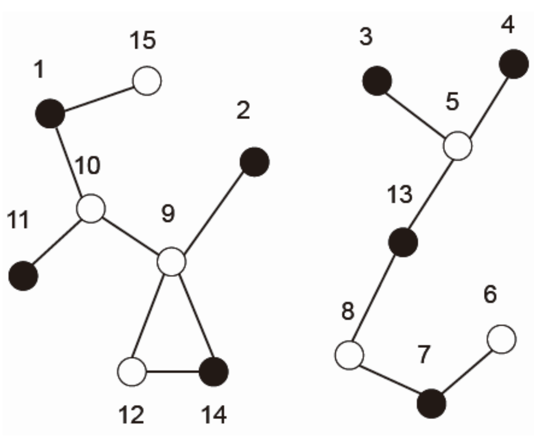

Figure 8: CHs identified

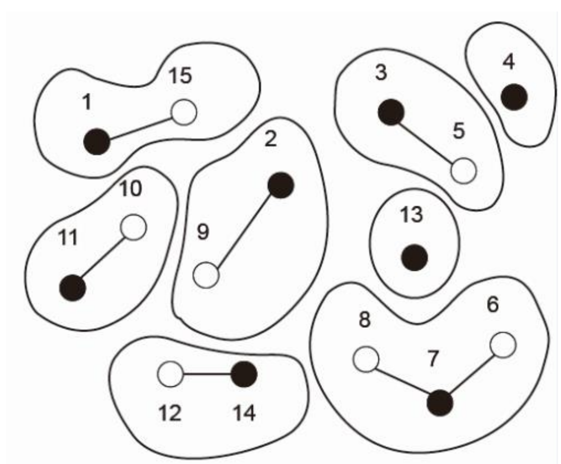

Figure 9: Clusters identified

After the previous state, devices are recognized as CH or non-CH devices (Figure 8). Each CH is responsible to form one cluster. The non-CH device will pick one CH to attach to and become a member of that cluster (Figure 9).

From this step devices are selected to be CHs or non-CHs. After this step devices are divided into different clusters. CHs use the same PDR as used in the neighbor detection to broadcast the beacon. The non-CH devices will attach to the CH which sends the link that has the best SINR and become the member of that cluster. Since only few nodes are broadcasting now, for a single node, the interference is smaller than when all nodes are broadcasting. Because all non-CH devices can detect a CH, when interference decreases, it can guarantee that each non-CH device can discover at least one CH. So the discovery rate is 100% meaning that all non-CH nodes can attach to one CH.

3.4. Connection establishment

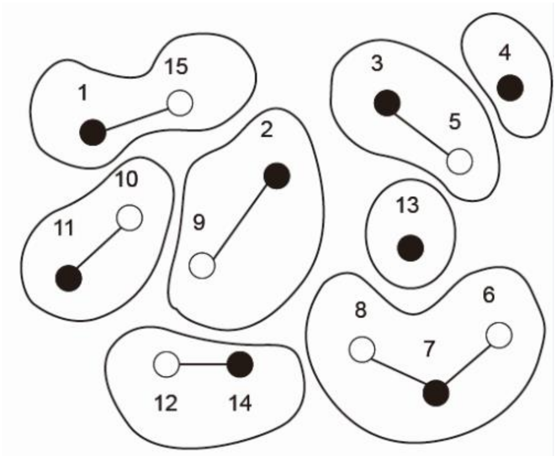

Figure 10: Clusters identified

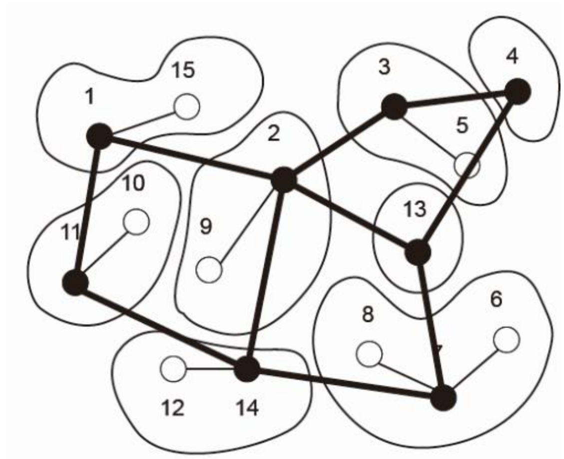

Figure 11: Connectivity achieved

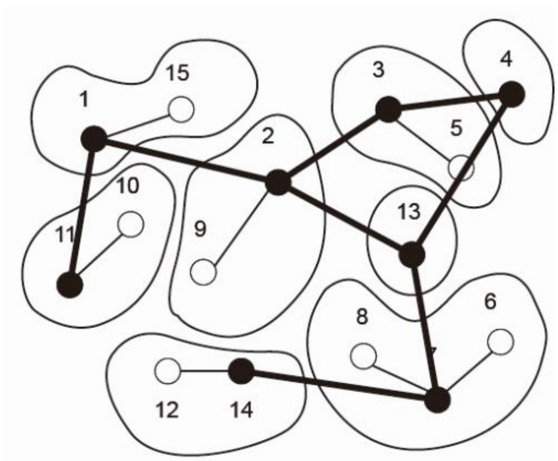

Figure 12: Final connectivity achieved

In order to communicate with the devices in other clusters, the links between clusters need to be established. Clusters are linked through CHs. In this states, CHs discover each other and links between them are created (Figure 11). The final state is what the system will be when discovery finished (Figure 12). Different from the previous state, unnecessary links are removed. In this way, the routine table is easier and devices can concentrate the power to support only the necessary links.

During this step, CHs need to discover each other. It is almost the same procedure as in neighbor detection but with fewer nodes. Only CHs are broadcasting in this step and trying to discover each other. Moreover, we assume that CH is a more advanced device which can operate in dual mode. For intra cluster communication, CHs use low power, low frequency to communicate to cluster members. The low power which CHs use is the same when devices are broadcasting beacon in previous steps. Low frequency means that only limited PDRs is available for the intra communication. The number of PDRs is finite. When the number of CHs is almost equal or larger than the number of PDRs, there is a high probability to collide. While for inter cluster communication, we assume CHs use high power, extra frequency to communicate. Because CHs can use extra frequency, the number of PDRs is large. We say that for inter cluster communication, there will be no collision. Thus, for intra communication, the communication rate is limited by the intra cluster SINR at cluster members while the inter cluster communication rate is limited by the inter SNR at CHs. The ratio between the number of CHs which can discover any other connected CHs and the total number of CHs is called connectivity. To establish connection means to achieve full discovery rate and full connectivity. After connection has established, the system can be further optimized by improving the average inter communication rate. Because the average inter communication rate is limited by the worst hop between CHs, by removing the worst hop but still providing a full connectivity can improve the average communication rate. The weaker connections are removed gradually till the full connectivity is still guaranteed. Only the strongest connections are remained. After this step, all CHs aware the routing information so once a package is arrived from its cluster member it knows to which CH it needs to deliver. The benefit from this step is that the CHs can concentrate the energy to support only the necessary links.

4. Simulation results and discussion

4.1. Simulation Environment Parameters

The decoding threshold (DT) defines the decoding ability. The DT is set to 1 dB, i.e. if a received signal has SINR larger than 1dB it is able to be decoded.

Table 2: Simulation environment parameters

Cell radius	500 m
Noise	-107 dBm
Transmission power	24 dBm
Decoding threshold	1 dB
Lognormal shadow fading	6 dB (NLOS) 3 dB (LOS)
Pathloss factor	4 (NLOS) 1.69 (LOS)

Refer to [8] and [9], the propagation formula we use in the simulation is:

$$G_{PL} = \alpha \cdot G_{PL}^{LOS} + (1-\alpha) \cdot G_{PL}^{NLOS}$$

where α is a parameter changing over distance as follows:

$$\alpha = \begin{cases} 1, & d < 4 \\ e^{-\frac{d-4}{3}}, & 4 < d < 60 \\ 0, & d \geq 60 \end{cases}$$

where d is the distance in meter between two devices.

In this propagation model we assume that if two devices are relatively close to each other the pathloss is a LOS situation. While the devices are far from each other, larger than 60m in this case, we say that NLOS propagation is between them. While the devices separate in a certain range, the probability that the propagation is LOS or NLOS is distance depended. The further they are, it is the more likely to be a NLOS propagation. The pathloss models are as:

$$G_{PL}^{LOS} = 16.9 \log_{10}(d) + 40.9 + 26 \log_{10}(\frac{f_C}{5})$$

$$G_{PL}^{NLOS} = 40\, log_{10}\, d + 30\, log_{10}(f_C) + 19$$

where d is the distance between devices in meter and f_C is the working frequency in MHz. In LTE-A system, the working frequency is designed to be 2 GHz.

The distribution of the SNR over all potential pairs is as the follows:

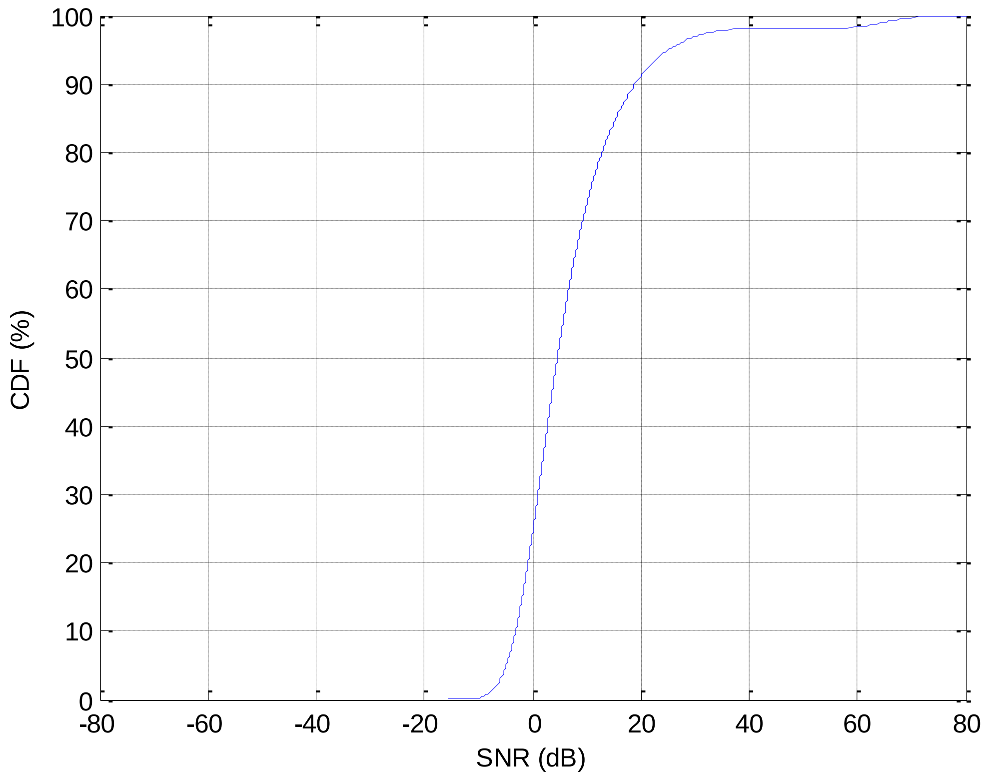

Figure 13: The CDF of the SNR of all the potential pairs

From the figure, we can see that there are 30% of the potential pairs which SNR is smaller than 1dB decoding threshold which indicates that 30% of the potential links cannot be detected due to noise limitation, i.e. the upper limit for discovery rate is 70% for distributed neighbor discovery approach. Devices want to discover as many potential pairs as possible. In this approach the system reaches the upper limit when there is no collision.

4.2. Distributed neighbor discovery approach results

In this approach, every device wants to discover as many devices as possible. Every device transmits with maximum transmission power (24 dB). The discovery rate is defined as the number of discovered pairs over the number of potential pairs. The figure below (Figure 14) shows the CDF of SINRs over all slaves of each algorithm with different load density from 1 to 10. When density is low, the probability to collide is low. The SINR tends to be SNR and is the upper limit. For higher density, the probability to collide is higher and the interference for each color is stronger so the SINR values are smaller. Thus, the CDF is pushed towards left. For density equaling to 1, when the number of devices is the same as the number of PDRs, the CDF of the received signal SINR over all slaves is shown by the most right line of each figure. As we can see, the CDF of SINR is the same as the CDF of the SNR as in Figure 13. This is because those algorithms 1 to 4 are focused on avoiding collision. When the number of PDRs is the same as the number of devices, these 4 algorithms can all ensure a collision free color allocation. Thus, there is no interference and SINR is equal to SNR. The SINR distribution is the same as the SNR distribution shown in Figure 13. As can be seen from Figure 13, when the neighbor detecting threshold is set to 1 dB, 70% of the links are larger than the threshold i.e. the discovery rate is equal to 70%. If we increase the density, there will be interference. The CDF of SINR moves leftwards. The discovery rate decreases when the density increases. When the density is equal to 10, the number of devices is much larger than the number of PDRs, the probability to collide is high. The CDF of the SINR is the leftmost line in each figure. The discovery rate is decreased to about 7%.

We can also see from these figures that the discovery rates for these four algorithms are similar for all load density.

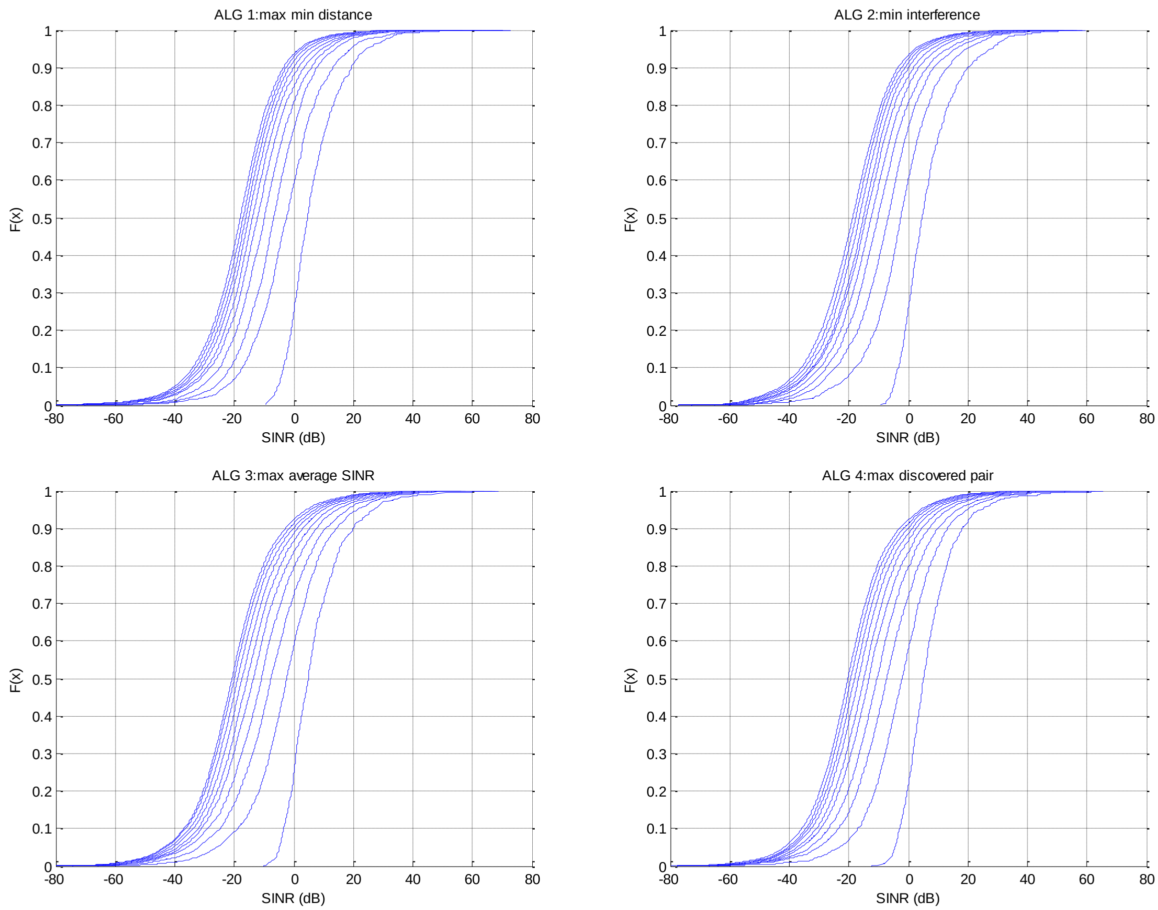

Figure 14: The CDF of the SINR with different load density for each algorithm

We compare the discovery rates at different densities between these algorithms and algorithm random. As shown in Figure 15, when density is equal to 1, these algorithms perform better than algorithm random because algorithm random does not try to avoid collision, i.e. algorithm random has a high probability to collide even if the number of PDRs is the same as the number of devices. Its discovery rate depends a lot on the number of collisions. When the density increases to 10, the result is shown in Figure 16, there are almost no differences in discovery rate between these algorithms. When the density is 2, as shown in Figure 17, we can see some differences in discovery rate. If we increase the density to 3, as shown in Figure 18, the differences between these algorithms are not obvious.

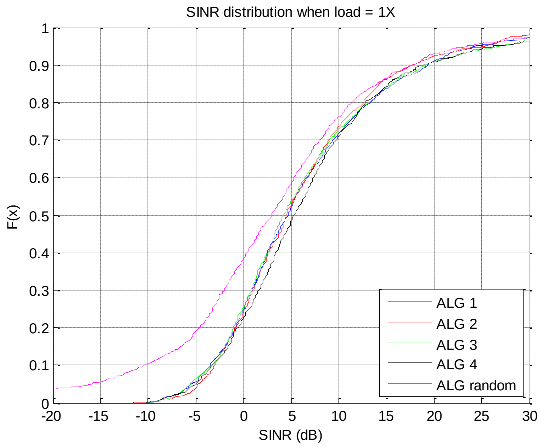

Figure 15: SINR distribution when load density = 1

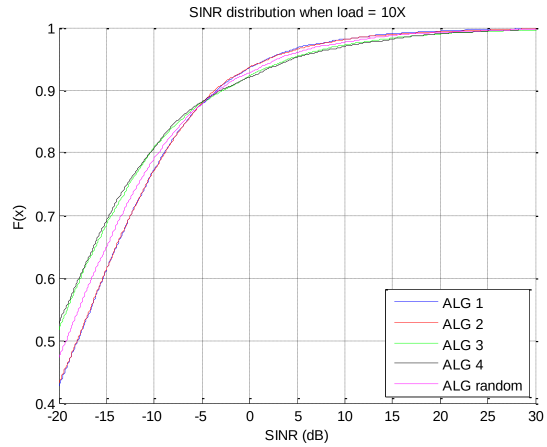

Figure 16: SINR distribution when load density = 10

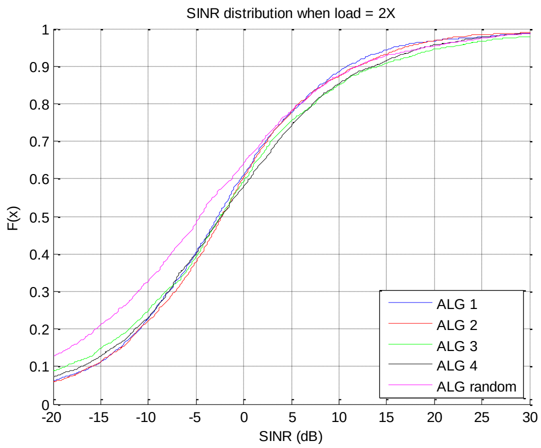

Figure 17: SINR distribution when load density = 2

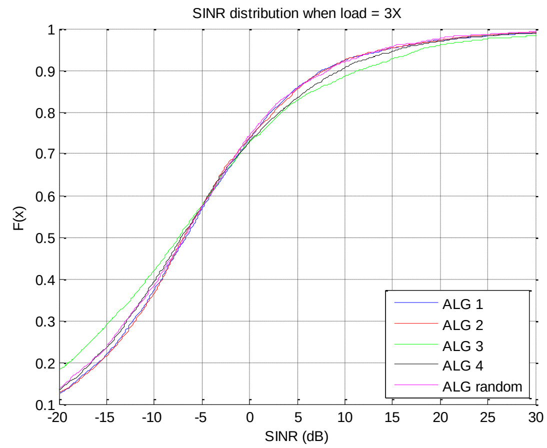

Figure 18:SINR distribution when load density = 3

In summary, these four algorithms perform better when the density is equal to or less than 2. In reality, in order to benefit from these four algorithms, two methods can be applied. The first is to increase the number of PDRs. The other one is to dynamically decrease the transmission probability to decrease the number of devices transmitting in the same time frame. Both ways are designed to decrease the load density. However, compare to algorithm random, these four algorithms all need a listening phase to gather information and pick color before broadcasting beacon. This step takes time and requires transmitting large amount of information in the beacon. It is not efficient in terms of time and design perspective. So in this paper, once a master needs to broadcast beacon, it applies algorithm random, i.e. the master randomly picks one available PDR to broadcast.

4.2.1. Decoding threshold effect

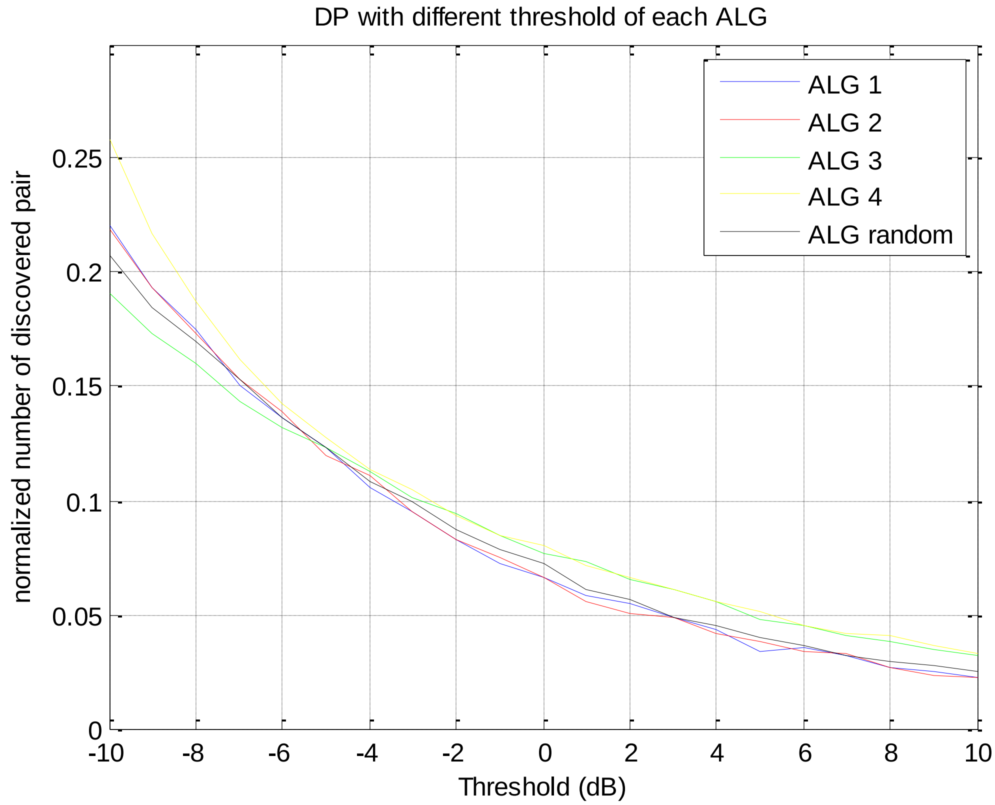

Figure 19: Discovery rate over different decoding threshold

One way to increase the discovery rate in distributed neighbor discovery approach is to decrease the decoding threshold. This can be achieved by installing advanced decoder in the UE so it can decode the signal with lower SINR value. The results are shown in Figure 19. As we can see, when the decoding threshold decreases, the discovery rate increases. But the discovery rate increases similarly for all algorithms. There is no obvious strength for algorithm 1 to 4. Algorithm random is still the optimal algorithm to apply. Later in this paper, the decoding threshold is set to 1 dB.

4.3. Clustering approach results

Table 3: Simulation parameters for clustering approach

Parameters	Studied Value

Number of devices	40
Number of PDRs	10
Optimal support (δ)	10
Intra P_{tr}	250, 50, 25, 10, 2.5, 0.5 (mW)
Inter P_{tr}	1, 10 (W)
Neighbor detecting threshold	1, 4, 7, 10 (dB)
Mobility	10, 20, 30 (m)

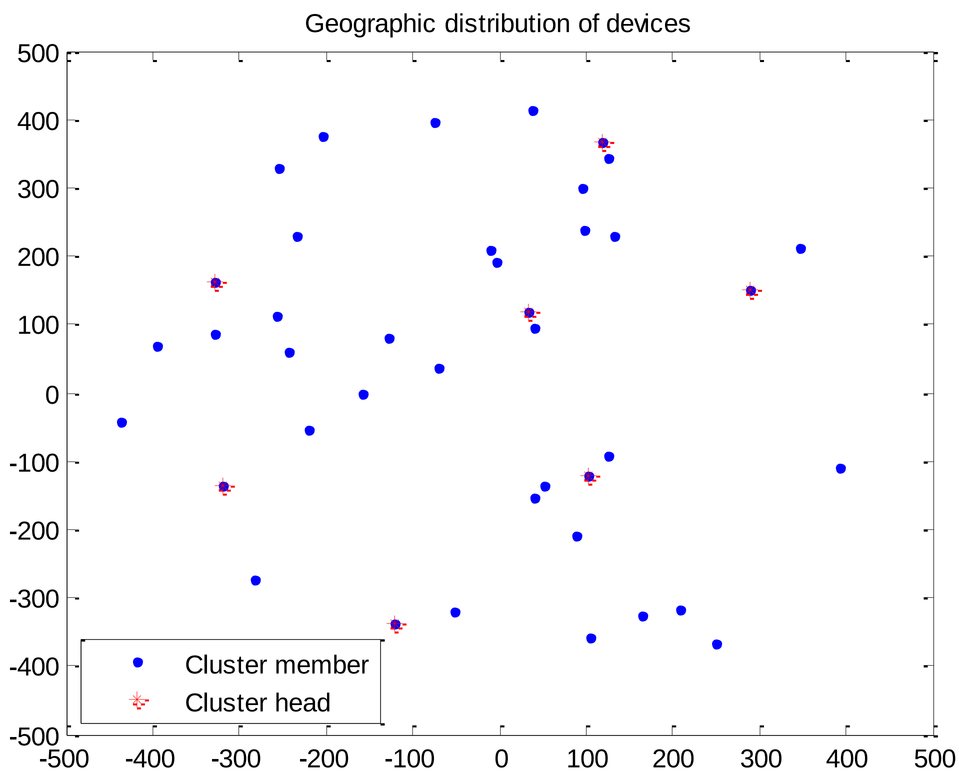

Figure 20: Geographic illustration of the distribution of devices

Figure 20 illustrates the distribution of devices after the CH selection step. As we can see, the CHs are basically uniformly distributed to provide coverage to the whole area. The distances between them are approximately equal. The selection as mentioned in Chapter 3.2 considers a several factors. We would like to see how these facts affect the CH selection step especially the mobility. Furthermore, as mentioned in Chapter 3.4, the system performance depends a lot on the number of CHs. The more CHs, the smaller clusters and the closer the CHs are. The CH is autonomously selected so the number of CHs is unable to be directly controlled. But a few parameters have potential effect on it such as: transmission power and neighbor detecting threshold. As mentioned in Chapter 3.2, we would like the re-selection process to be invoked rarely to reduce the computation cost. The selection is triggered by mobility in this project. So the relation between the number of re-selection and mobility should be studied.

4.3.1. CH selection performance

Transmission power is the parameter we can adjust in reality. It directly affects the coverage of the device. If the transmission power is large, once it is selected as the CH, it can support large area. So the number of CHs is small. Mobility has effect on the CH selection. If devices move fast, they are easier to move out of the current dominant set coverage. Once a device moves out of the current dominant set coverage, the re-selection is triggered. Thus, the re-selection is more frequently invoked.

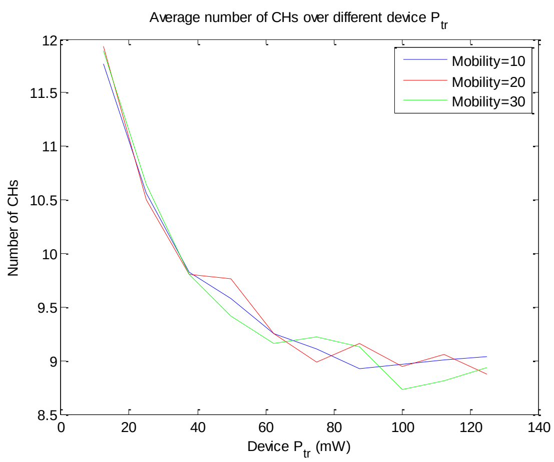

Figure 21: Number of CHs over transmission power with different mobility

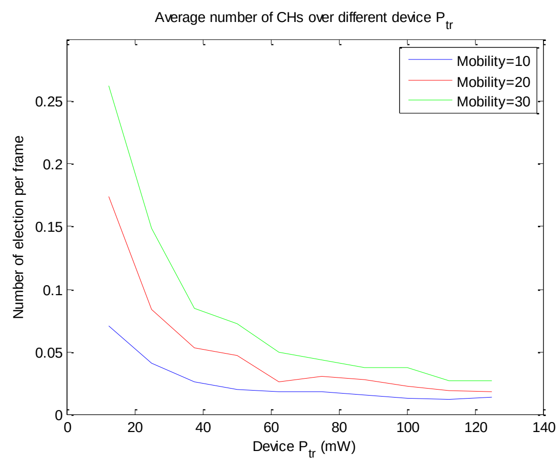

Figure 22: number of re-selection over transmission power with different mobility

As we can see from Figure 21, when transmission power is large, the number of CHs is small. We can also see that mobility will not affect the number of CHs. This is because that no matter how devices move, they are still uniformly distributed in this area. From Figure 22, we know that if devices move fast, re-selection is invoked more often. When transmission power increases, a device can provide coverage to larger area. For a device with certain mobility, it is harder to move out of the coverage. Therefore the re-selection invokes rarely when device transmission power is large.

4.3.2. Intra cluster performance

The system performance has two parts: within the cluster and beyond the cluster. For system performance, we would like to see the discovery rate and communication rate.

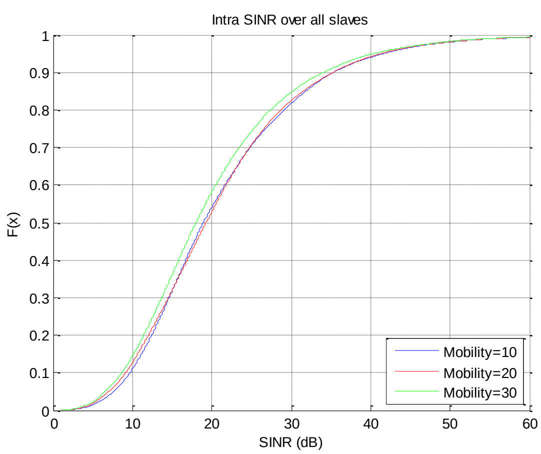

Figure 23: Intra SINR distribution with different mobility

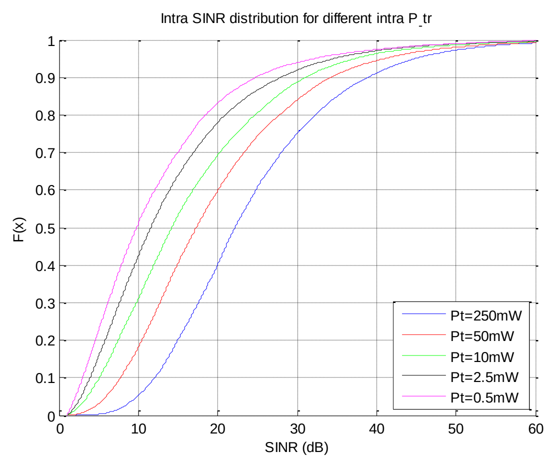

Figure 24: Intra SINR distribution with different intra transmission power

As mentioned above, no matter how devices move, they are still uniformly distributed in the area so mobility has no effect on performance. One point we need to notice is that the discovery rate, i.e. the proportion which is larger than 1 dB, is 100%. This is because when CHs broadcast beacon in member allocation step, they use the same PDRs as they use in the neighbor detection. In neighbor detection, as more devices are broadcasting, the interference is larger than in the member allocation. While in member allocation step, the interference is smaller. All non-CH devices can still but not only detect one neighbor CH. And a non-CH device will attach to the CH which has the strongest link. This makes sure that each non-CH device can discover at least one CH. So the discovery rate is 100% guaranteed. On the other hand, intra transmission power has effect on distances between CH members and their CH, the received signal strengths, number of CHs and the received interference from other CHs at one non-CH device. All these factors have effect on the intra SINRs over all CH members which are proportional to intra communication rate. To vary the transmission power may has positive or negative effects on the communication rate. As can be seen in Figure 24, when intra transmission power increases the average intra SINRs increase, so the intra communication rate increases. Therefore, increasing intra transmission power is positive with respecting to intra communication rate.

4.3.3. Inter cluster performance

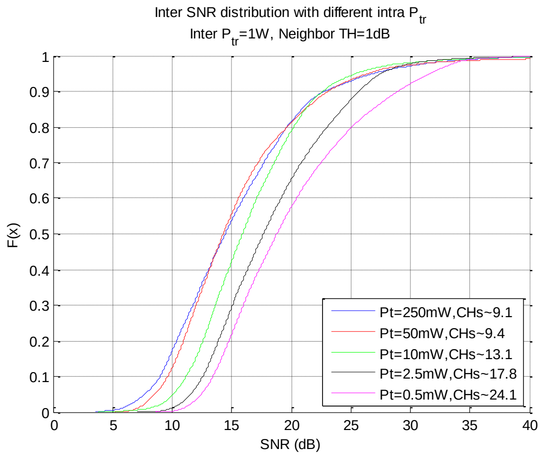

Figure 25: Inter SNR distribution with different intra transmission power

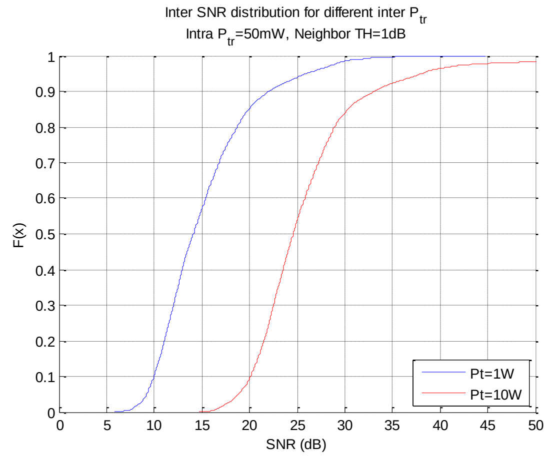

Figure 26: Inter SNR distribution with different inter transmission power

We also evaluate inter cluster communication from discovery rate and communication rate. For inter cluster communication, discovery rate is defined as connectivity. Full connectivity must be achieved to allow every device to be able to communicate to any other devices. This is achieved by ensuring that every CH can discover any other CHs. From Figure 25 we see that no matter what intra transmission power we use, full connectivity (all SNR larger than 1 dB) can always be provided. It indicates that even devices use maximum intra transmission power, i.e. CHs are far away from each other, the selected CHs are sufficient to discover other CHs. If the number of CHs is too small, the CHs are too far away from each other and unable to discover the others. Anyway, in our simulation model and environment, the clustering approach for D2D discovery can ensure a 100% connectivity. Since CHs are almost uniformly distributed, the inter cluster SNR depends on the distances between CHs. Obviously, the more CHs the faster inter communication rate can reach. Simulation result is shown in Figure 25. However, selecting more CHs leads to smaller intra communication rate because of smaller intra transmission power. So there is a trade-off between inter and intra communication rate. Moreover, if CHs use larger inter transmission power, the inter communication rate will increase. Result is shown in Figure 26.

4.3.4. Neighbor detection threshold effect

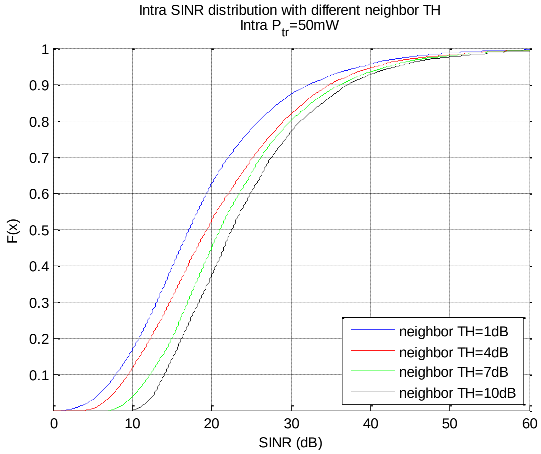

Figure 27: Intra SINR distribution with different neighbor detection threshold

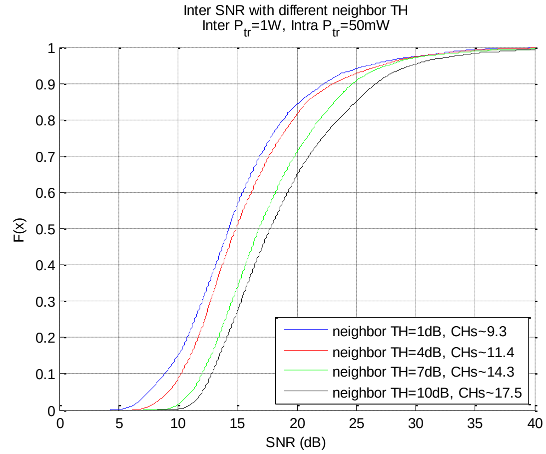

Figure 28: Inter SNR distribution with different neighbor detection threshold

Neighbor detection threshold defines how strong the received signal is while slave is defined as neighbor to the master when it receives a beacon. The value is always larger than the decoding threshold. If neighbor detecting threshold increases, the coverage of a device decreases. The received signals at the slaves will be stronger from their CH. Even though the interference is also larger, we can see that the intra communication rate is still increased from Figure 27. It is because the number of CHs increases and the distances from other CHs decrease. More CHs also leads to higher inter communication rate which is presented in Figure 28. Therefore, increasing neighbor detecting threshold improves the system communication rate.

4.3.5. Energy perspective

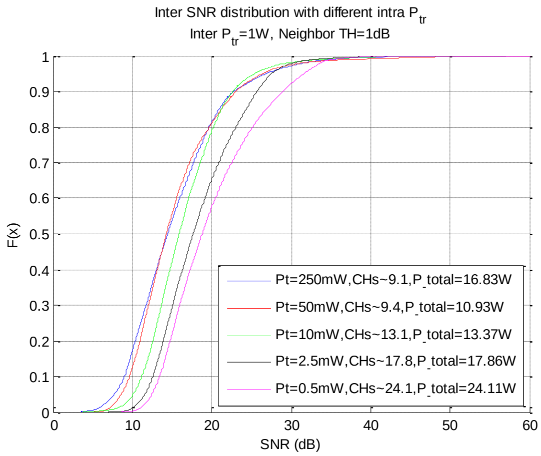

Figure 29: Inter SNR distribution with different calculated total power consumption by varying intra transmission power

From energy perspective, we want to see how the system performance improvement would cause the change of energy consumption. From Figure 29, when intra transmission power is large, the number of CHs changes not obviously. Inter communication rate does not improve a lot but power consumption increases a lot. Compared to the case when devices use 20% of the maximum power (50mW), the inter communication rate is approximately the same but the total power consumption is larger than when devices use maximum transmission power. Therefore, when intra transmission power is large, the system energy is not efficient.

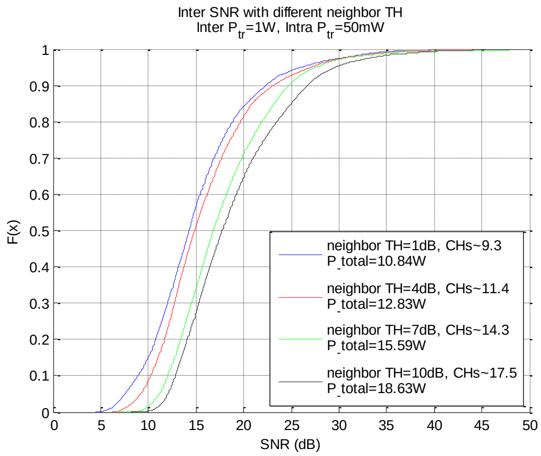

Figure 30: Inter SNR distribution with different calculated total power consumption by varying neighbor detecting threshold

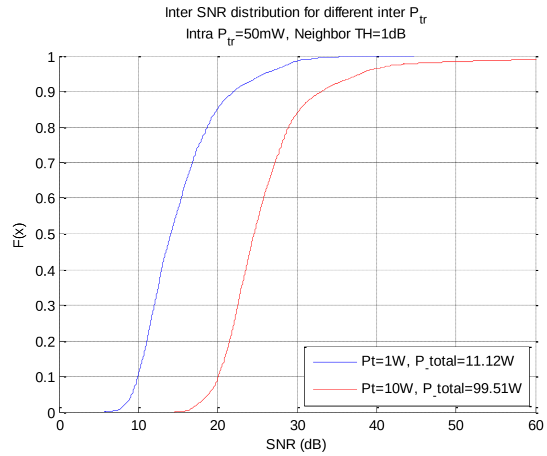

Figure 31: Inter SNR distribution with different calculated total power consumption by varying inter transmission power

If intra transmission power decreases, the total power consumption and the inter communication rate increase. From Figure 30 and Figure 31 we know that, no matter the inter communication rate increment is caused by neighbor detecting threshold increment or inter transmission power increment, the total system power consumption always increases. Then we focus on intra communication rate, from Figure 26, the intra communication rate increases when intra communication rate decreases. The intra communication rate has no linear relationship with total system energy consumption. And from Figure 27 we know that increasing neighbor detecting threshold, which leads total system energy consumption increases, will increase intra communication rate as well.

4.3.6. Energy efficiency and comparison

From the previous chapter, we know that the system performance depends on the intra transmission power, inter transmission power and neighbor detecting threshold. Among them, intra transmission power has the most significant effect on the performance. We set the neighbor detecting threshold to a constant 1 dB, the inter transmission power to a constant 1 W and vary the intra transmission power to quantify the system energy efficiency. System efficiency is defined as the ratio between average system communication rate and total system power consumption. It presents how many data the system can carry using 1 energy unit. The results are also compared to the distributed neighbor discovery approach.

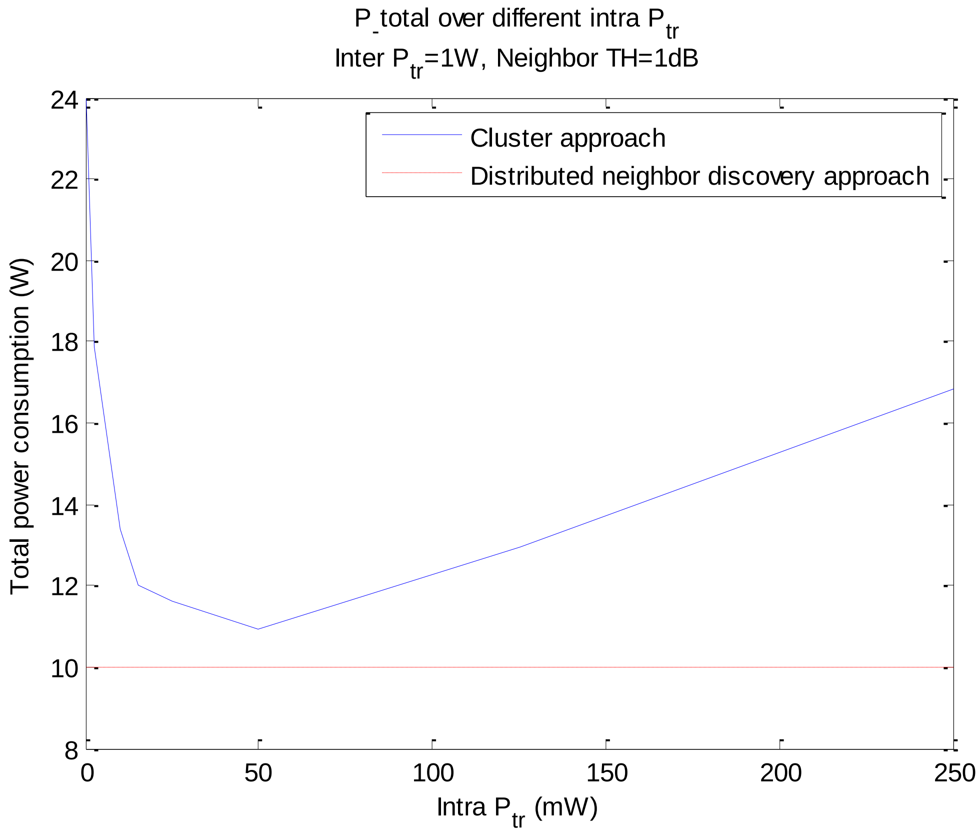

Figure 32: Total power consumption over intra transmission power

If we set the inter transmission power and neighbor detecting threshold to constant, the total power consumption over different intra transmission power is shown in Figure 32. There exists a minimal of system power consumption. Compared to distributed neighbor discovery approach, the clustering approach always consumes more power.

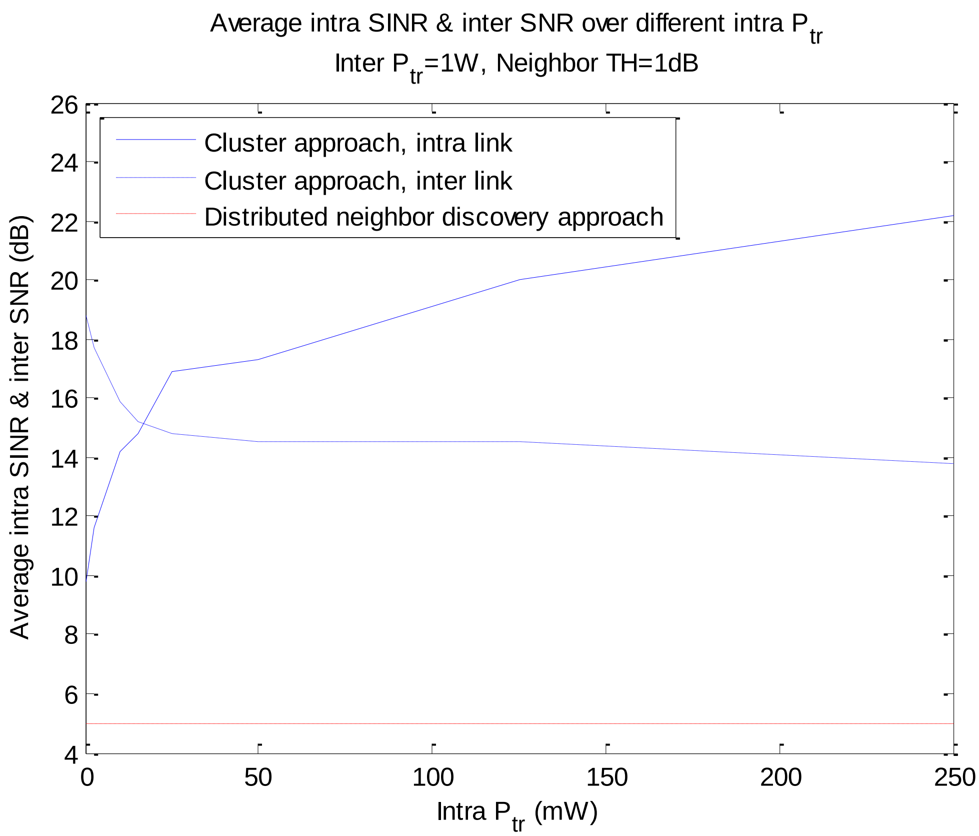

Figure 33: Average intra SINR and inter SNR over intra transmission power

The system communication rate is limited by the lower one of the intra communication rate and the inter communication rate. From Figure 33 we see that when intra transmission power is small, the system communication rate is limited by intra communication, because the received signals at the slaves are too weak. When intra transmission power is large, the system communication rate is limited by inter links, because the number of CHs is small. The whole system performance is the lower part of the two lines. We assume that in distributed neighbor discovery approach, after devices discover each other, they can also use the extra frequency and manage the radio resource (PDR) with some mechanism, so that there is no collision in the communication phase. Thus, compared to the best situation in distributed neighbor discovery approach, while there is no collision, the average communication rate is still much higher for clustering approach.

In order to evaluate the system efficiency, we calculate the energy efficiency as dividing the system communication rate by the total consumed energy. When the intra transmission power is very low, the system communication rate is very low. But the energy consumption is high, so the efficiency is very low. When the intra transmission power increases a little, the communication rate increases, but the energy consumption decreases therefore the efficiency increases. When the intra transmission power is very large, the system communication rate is almost stabilized but the energy consumption increases so the efficiency decreases. So we can expect a maximum system efficiency over all intra transmission power.

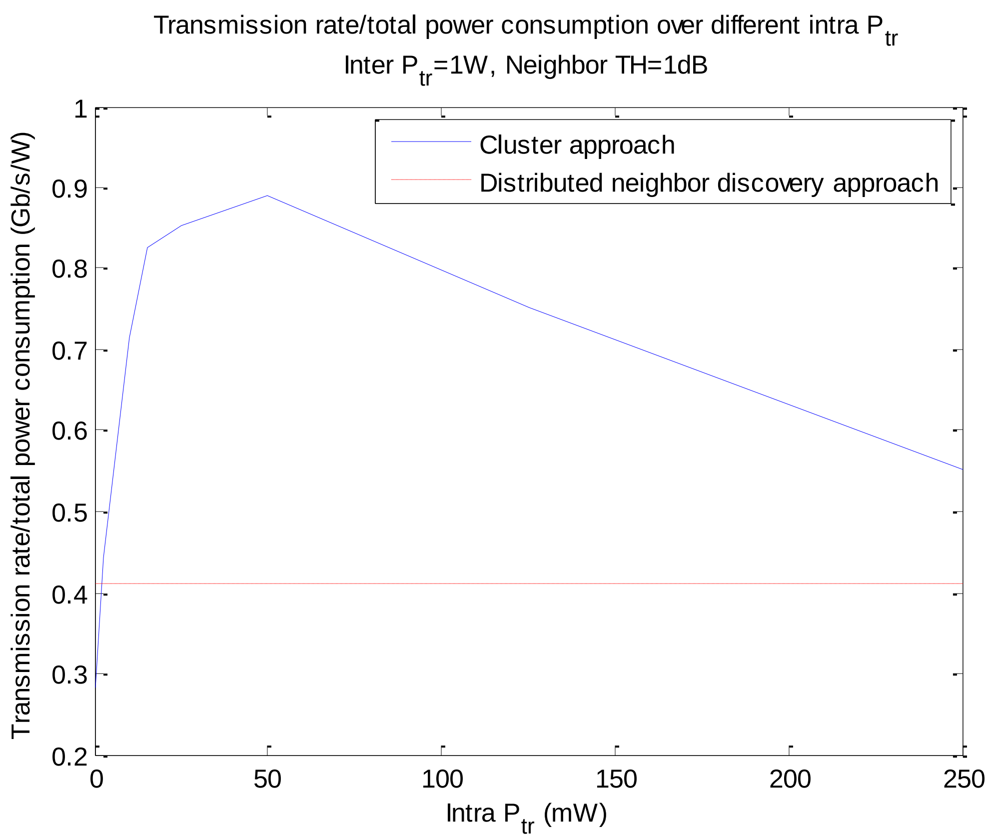

Figure 34: Energy efficiency over intra transmission power

Finally, we compare the energy efficiency in two approaches. From Figure 34 we know that, there exists a proper intra transmission power such that the energy efficiency is maximized. The system is not efficient to have either large or small intra transmission power. When intra transmission power is small, the system performance is limited by intra transmission. The intra communication rate is low because the signal power is low. Meanwhile the coverage of a CH is small so the number of CHs is large, and the total power consumption is large. So the energy efficiency is low. When intra transmission power is large, the system performance is limited by inter transmission. From Figure 33, the inter communication rate is almost the same when the intra transmission power is large but the system consumes much more power. So the system is not efficient. If the intra transmission power can be chosen properly, the average communication rate is twice large for clustering approach to the best condition of distributed neighbor discovery approach. The optimal intra transmission power depends on the number of devices, the load density as well as the CH selection.

5. Conclusion

This thesis report analyzes the performance of the discovery phase of D2D communication. Two approaches are studied: distributed neighbor discovery approach and clustering approach. Performances in terms of discovery rate, communication rate and energy efficiency are discussed and compared. Numerical results indicate that algorithms perform similarly in distributed neighbor discovery approach when load density is high. The discovery rate is rather low when load density is high. The clustering approach can solve this problem. By selecting some devices to be so called cluster heads, we can achieve full connectivity, i.e. that the discovery rate is equal to 1. However, the clustering approach consumes more energy in the discovery process. After the discovery is established, we evaluate the average communication rate. Compared to distributed neighbor discovery approach, clustering approach has a much higher communication rate. Finally, we compare the energy efficiency of these two approaches. We find out that if the intra transmission rate could be chosen properly, the energy in clustering approach can be twice efficient.

In this paper, the weight of each factor is a pre-defined constant in the CH selection. The values take number of neighbors, neighbor closeness, mobility and cumulative time into consideration. The values are not optimal but all of them are considered. For further study, modifying these parameters and trying to find the optimal would be a great help to system efficiency.

Since the intra transmission power has great impact on the system energy efficient, properly choosing the value is very important to optimize the system. The optimal intra transmission power depends on system load and CH selection result. For further study, developing a clustering approach with adaptive transmission power depending on the system load and number of CHs would be valuable.

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