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Analysis of Power Consumption Rates of Clustered Devices in Device to Device (D2D) Communications

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Abstract

Efficient utilization of resources in D2D communication demands that cluster of devices should be formed. When clusters are formed, a cluster head (CH) is selected to coordinate both intra-and inter-cluster communications. In this study, Self Organizing Map (SOM) was adopted to cluster D2D devices, using the distance between the devices and the base station (BS) as the cluster input data. The influence of attenuation on power consumption of the devices was considered in deriving the power consumption model. It was shown that more power is consumed by the CH when the distance between the CH and the BS increases, as well as when the number of cluster members (CMs) associated with the CH increases. In addition, it is more energy efficient for the CMs to communicate directly with the CH than for CMs to communicate with the BS through the CH.

Keywords: Device to Device Communication, Self Organizing Map, Clustering, Device to Device Power Consumption

1. Introduction

Device to device communication (D2D) was introduced in 3GPP LTE Release 12 specification. It was integrated as part of 4G (Long Term Evolution Advanced (LTE-A)) & 5G networks. D2D allows User Equipments (UEs) to communication directly without the coordination of the eNodeB (i.e. the base station) (Condoluci et al, 2015). There are various applications and enormous benefits of D2D technology. It reduces intensity of traffics, saves network resources, reduces network latency and helps to offload traffic from core network. In the absence or unavailability of the base station (during emergency or natural disaster), D2D enables UEs to share information and communicate directly. In addition, power consumption is enhanced because there are short distances between the UEs (Jameel et al, 2018; Paramonov et al, 2017).

For efficient utilization of services specified by 3GPP, clusters of the devices should be formed (Paramonov et al, 2017). Cluster formation enables the division of large network into groups of proximate devices. This allows network optimization, and enables the enhancement of social ties and interactions (Bentaleb, Boubetra & Harous, 2013; Wang et al, 2015). Studies on 5G showed that cluster formation aids in traffic signal reduction, offers better spectral and energy efficiencies (Ashraf et al, 2016; Paramonov et al, 2017; Wang et al, 2015).

Formation of clusters in D2D requires most often the selection of a device that would act as the cluster head (CH). The CH coordinates the activities of the cluster members (CMs) and other intra and inter-cluster communications (Ishtiaq et al, 2019; Khatoon & Amritanjali, 2017). Most often the CH acts as a relay, assists members with poor channel conditions, thereby helps to extend the coverage of the network. This reduces fading and prevents link failure (Ashraf et al, 2016; Jameel et al, 2018; Paramonov et al, 2017). The CH is best chosen to ensure cluster stability and reliability. This is needed to ensure continuous session or service delivery (Sharafeddine& Farhat, 2018). According to Paramonov et al (2017) , the choice of CH selection affects the Quality of Service (QoS) offered to other cluster members.

Clustering of devices have been employed extensively in wireless networks such as mobile ad hoc networks (MANETs), vehicular ad hoc networks (VANETs) and cellular networks (Ahmad et al, 2017; Han et al; 2019). Literatures have proposed various D2D clustering algorithms and approaches. Some literatures considered efficiency of spectrum utilization as key cluster formation criterion, but as suggested by Paramonov et al (2017), the channel bandwidth between the CH and the CMs should also be considered in cluster formation algorithms. Regardless of the cluster formation technique or approach adopted, clustering should address a set of objectives according to Khan et al (2020). The set of objectives include the stability of cluster, satisfaction of QoS, social awareness and network load balancing. Various clustering approaches adopted in literatures include the use of distance, throughput, social tie/relationship, device mobility, its geographic location, energy level, etc, as the cluster formation criteria. Some studies used only a single metric to form clusters while others adopted combination of these metrics as cluster formation criteria (Ezeh, Idigo & Okorogu, 2021; Khan et al, 2020) .

Throughput was adopted to form D2D clusters by Paramonov et al (2017). Normal and uniform distributions of the CMs were considered by the authors and it was shown that normal distribution average throughput between the CH and the CM is two times larger than the uniform distribution. Similarly, the rate of cluster association/or disassociation can be reduced by using mobility or energy level of the devices as cluster formation criteria. On the other hand, the use of social relation or tie as a cluster formation criterion can aid in identifying the demand for network resources as well as the nature of social tie existing among the users. Furthermore, the use of device geographic information as clustering criterion ensures cluster stability and social awareness. This is because social interest is likely to exist between proximate UEs, thus clusters of these users can be formed with minimal distances between the CMs and between the CMs and the CH. Such short distances reduce energy consumption of the CH as well as the CMs, hence ensuring cluster stability (Ezeh, Idigo & Okorogu, 2021; Khan et al, 2020).

According to (Fodor et al, 2014), three characteristics of a good D2D cluster algorithm are: selection of CH, association of CMs to CH, and efficient intra- and inter-cluster communication. Thus, the choice of CH is factor to be considered when forming clusters of D2D UEs. This is because the choice of CH affects the network parameters such as energy efficiency and QoS experienced by the CMs in the cluster. In literatures such as Afshang et al (2015) and Hassan & Maher (2013), distance between the CMs was adopted as CH selection criterion. But Paramonov et al (2017) stated that the choice of CH should be considered based on the QoS. The reason is because of the variant channel features and resources that exist between the CMs and the CH. The study by Chaowen et al (2018) utilized SINR and distance to select CH and association of CMs to CHs.

But the study by Cao et al (2014) selected CH using three factors, i.e., the device energy level, the distance and the social ties that exist between proximate devices. The authors showed that involvement of social tie made the social trust of the proposed method to be more than the method that depended on only distance. Furthermore, Zhou (2013) used weights of some parameters to select appropriate CH. The parameters that were assigned weights are the of CMs to be supported, tendency of the CH to be mobile, the received signal strength, the device's capability and the period of time a device can act as a CH. After evaluation, the device with least weight is chosen as the CH. It was shown from the study that though high communication rate was achieved, a great deal of energy was expended during discovery phase. A comparison between the CH chosen based on Received Signal Strength and CH selected based on device distance was made by Udofia (2020). The author used Self Organizing Map as the clustering algorithm and showed that the values of threshold or the parameters utilized in the algorithm influenced the number of CH chosen.

In addition, in terms of energy dissipation and device mobility, the devices selected to act as the CHs must be reliable. This is required to avoid service or session discontinuity during D2D connections (Sharafeddine & Farhat, 2018). It was stated by Zhao et al (2019) that the clustering algorithm adopted and the criteria used in CH selection are critical and important factors that influence network energy efficiency. Due to the fact that CH coordinates both intra-/inter-cluster communications, much energy burden is placed on it. Excessive energy depletion of the CH would cause cluster instability due to network life time degradation (Bentaleb, Boubetra & Harous, 2013; Khatoon & Amritanjali, 2017). An approach to prevent cluster instability due to CH energy depletion is to avoid devices with low energy level form being chosen as the CH. Another technique as proposed by Narottama et al (2015) required that the selection of CH be rotated among the UEs at intervals. This technique showed that better energy consumption was achieved.

In this study, Self Organizing Map (SOM) was used to cluster D2D UEs using the distance of the UEs from the base station as the cluster formation criteria as well the criterion to select the CH. The choice of this approached was based on the fact the power consumption of a UE is a function of distance. If the distance of CH is closer to the base station, less power is consumed by the CH and vice versa.

2.0 Material and methods

The devices were assumed to be randomly and uniformly distributed around the base station which is located at the centre. Each device communicates with the base station through a CH. The system is diagrammatically represented in figure 1. One hundred of UEs were used in the cluster formation. In a cluster, a UE closest to the base station is chosen to serve as the CH, the rest of the devices become the CMs.

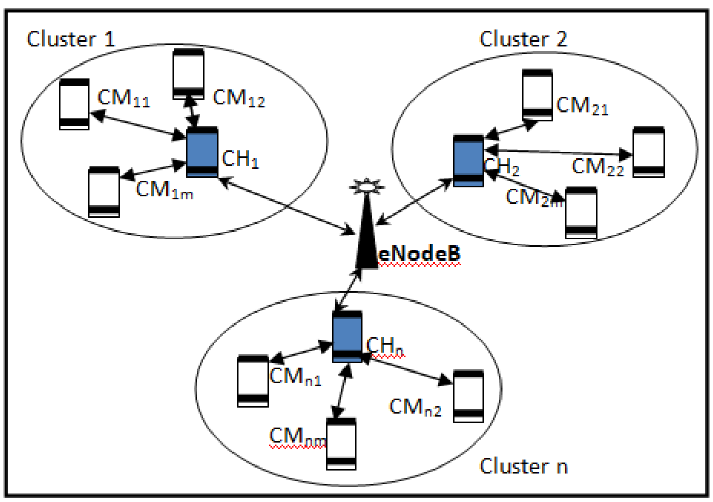

Figure 1: System Description

2.1 System Description

The base station chosen is located at the dense urban city of Lagos, Nigeria. Its geographic coordinates are: Latitude (λ_c) 6.51523044 and Longitude (φ_c) 3.37737146. The devices were assumed to be concentrated within 250m^2 (0.250km^2) area around the base station. Using GPS application, the Latitude (λ) and Longitude (φ) of each device can be determined. Let the geographic information of a UE be represented as $P(\lambda_i, \varphi_i)$. This geographic information can also be represented in Cartesian coordinates x_i and y_i as $P(x_i, y_i)$. This implies that the geographic coordinate of a UE at location P_i and a time t_i can be mapped to Cartesian coordinate equivalent:

$$P_i(t_i) = P_i(\lambda_i, \varphi_i) = P(X_i(t_i),\ Y_i(t_i)) \quad (1)$$

where $i = 1, 2, \ldots, n$.

Equation (1) also implies that we can approximately transform earth spherical or ellipsoidal surface into two Cartesian dimensions. Let (φ_c) represent the Longitude of the base station located at the centre. Let λ_i and φ_i represent respectively the Latitude and Longitude of a UE. The equivalent Cartesian coordinates of the UE is determined as follows:

$$y_i = (\varphi_i - \varphi_o) * R \quad (2)$$
$$x_i = (\lambda_i - \lambda_o) * R * cos((\varphi_c * \pi)/180) \quad (3)$$

where R = 6371 (km) is the radius of the earth, λ_o and φ_o are respectively the Latitude and Longitude at the origin of the Cartesian plane. Thus the Cartesian position $P(x_i, y_i)$ of a UE can be used to determine its distance with respect to the base station located at $P(x_c, y_c)$ as follows:

$$d_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} \quad (4)$$

where *i = 1, 2, …, n*.
The value of d_i in equation (4) is the distance between the UE and the base station and this value forms the input to the cluster algorithm.

2.1.1 Self Organizing Map Clustering Algorithm

The values of the distances of the UEs are utilized as input to Self Organizing Map (SOM) clustering algorithm. SOM is one of the unsupervised Machine Learning Algorithms. It is able to competitively determine the cluster of a data set. A simplified SOM cluster algorithm is shown as follows:

Determination of number of clusters, this is same as number of output neurons.
The weight vector of the output neuron is initialized
Set the value of the Learning Rate $(\alpha(t))$
Set the value of the Neighborhood Function $(h_{cj}(t))$
While condition for stopping is not yet met
For each in input d_i
Update the weight vector $w_j(t+1)$ *of the nearest output neuron and the neighboring neurons as:*

$$w_{ji}(t+1) = w_{ji}(t) + \alpha(t)h_{uj}(t)[d_i(t) - w_{ji}(t)] \quad (5)$$

End for
Reduce Learning rate
Reduce Neighborhood function
End while

The key feature that makes SOM to have advantage over vector quantization algorithm is its ability to update the winner as well as the neighboring neurons.

2.1.2 The Link and Channel Models

The system describes a scenario where the CMs connect to the base station through the CH. Thus, in this study, two links were considered: the link between the CM and the CH (CM-CH) and the link between the CH and the base station (CH-BS). The CM-CH link utilizes the D2D link, while CH-BS link uses the conventional cellular channel. The choice of different links is because of dual mobility in CM-CH link. In CM-CH link, both UEs have mobility tendency, whereas in CH-BS link, only CH has mobility tendency. In CM-CH link, the dual mobility influences the increase in Doppler Spread as a result of the effect on fast fading and shadowing temporal correlation. In outdoor shadowing, Log normal path loss is specified according Babun (2015) and this is adopted in CM-CH D2D link. Hata path loss model was considered in CH-BS link. Log normal path loss model, $\mathrm{PLoss_{LN}}$(dB) is given as:

$$PLoss_{LN}(dB) = PLoss_{FS} + 10nlog\left(\frac{d}{d_0}\right) + X_\sigma \quad (6)$$

where d is the distance between the transmitter and receiver, d_0 is the reference distance, n is the path loss exponent, $PLoss_{FS}$ is the free space path loss and X_σ is the zero mean Gaussian random variable (standard deviation), which signifies the path loss variations along the path.
Similarly, Gadze et al (2019) described Hata path loss model for urban area as:

$$PLoos_{urban}(dB) = 69.55 + 26.16\,log(f) - 13.82\,log(h_{tx}) - \propto h_{rx} + [44.9 - 6.55\,log(h_{tx})]log\,(d) \quad (7a)$$

where, d is the distance in km, the UE antenna height is given as h_{rx} in meters, and BS antenna height in meters is represented as h_{tx} and f is the frequency in MHz. For large city, the variable $\propto h_{rx}$ is given as:

$$\propto h_{rx} = 3.2[log\,(11.75h_{rx})]^2 - 4.97;\ f > 300\text{MHz}$$
$$\propto h_{rx} = 8.29[log\,(1.54h_{rx})]^2 - 1.1;\ f \leq 300\text{MHz} \quad (7b)$$

2.1.3 Channel Rate/ or Capacity

The channel capacity according to Shannon equation is given as:

$$R_c = BW.log_2(1 + SINR) \quad (8)$$

here, BW is the channel bandwidth, SINR is the Signal to Interference and Noise Ratio, which is expressed by Anamuro et al (2018) as:

$$SINR = {}^{P_{rx}}/_{N_o BW} \quad (9)$$

here, P_{rx} is the received power, *BW* is the channel Bandwidth and N_o is the noise spectral density. In this study, Additive White Gaussian Noise (AWGN) is assumed. Substituting equation (9) into (8) gives the rate as:

$$R_c = BW.log_2(1 + {}^{P_{rx}}/_{N_o BW}) \quad (10)$$

2.1.4 Derivation of Power Consumption Model

According to Anamuro et al (2018), the received power of Okumura-Hata path loss model can be expressed in linear form as:

$$P_{rx} = P_{tx} . {}^{K}/_{d^{\gamma}} \quad (11)$$

The decibel equivalent is:

$$P_{rx}(dB) = P_{tx}(dB) + 10log_{10}K - 10\gamma log_2(d) \quad (12)$$

where γ is the path loss exponent, d is the transmission distance and *K* is the constant path loss factor. The effective isotropic radiated power (*EIRP*) is given as:

$$EIRP = P_{Loss}(dB) + RSSI(dBm) \quad (13)$$

Therefore, the required transmission power (P_t) is expressed as:

$$P_t \geq P_{Loss}(dB) + RSSI(dBm) \quad (14)$$

where:

$$RSSI = RSRP + 10log_{10}(12 * N) \quad (15)$$

here *RSRP* is the Reference Signal Received Power, and *N* is the number of Resource Blocks (RBs). According to 3GPP, for bandwidth of 10 MHz, the RB is 50. Also, the minimum value of *RSRP* i.e. $RSRP_{min}$ is -112 dBm (3GPP, 2014).

Therefore:

$$RSSI_{min} = RSRP_{min} + 10log_{10}(12 * N) \quad (16)$$

This implies that for 10 MHz bandwidth, *RSSI* minimum is -84.22 dBm. Equation (14) becomes:

$$P_t \geq P_{Loss}(dB) - 84.22\ (dBm) \quad (17)$$

Thus, the respective minimum required transmission power for CM-CH and CH-BS links are:

$$P_{tx,CM-CH} \geq PLoss_{LN}(dB) - 84.22 \text{ (dBm)} \quad (18)$$

$$P_{tx,CH-BS} \geq PLoos_{urban}(dB) - 84.22 \text{ (dBm)} \quad (19)$$

Using equation (12), for CM-CH and CH-BS links, the received power (in dB) is given as:

$$P_{rx,CM-CH}(dB) = P_{tx,CM-CH} + 10log_{10}K - 10\gamma log_2(d_{CM-CH}) \quad (20)$$

$$P_{rx,CH-BS}(dB) = P_{tx,CH-BS} + 10log_{10}K - 10\gamma log_2(d_{CH-BS}) \quad (21)$$

here, d_{CM-CH} and d_{CH-BS} are the separating distances over CM-CH and CH-BS links respectively. Thus, by equation (10), the rate or capacity of each channel is expressed as:

$$R_{CM-CH} = BW.log_2\left(1 + {}^{\mathrm{P}_{\mathrm{rx},CM-CH}}/_{N_o.BW}\right) \quad (22)$$

$$R_{CH-BS} = BW.log_2\left(1 + {}^{\mathrm{P}_{rx,CH-BS}}/_{N_o.BW}\right) \quad (23)$$

But the power consumption of a UE during transmission is the combination of transmission power P_{tx} and the power consumption of the digital and analogue circuitry, P_{tc}. Thus, power consumption of a UE during transmission is given as:

$$P_{t,con} = P_{tx} + P_{tc} \quad (24)$$

Since P_{tc} is the summation of power consumed by the UE's analog circuits and digital circuitry, it is given as:

$$P_{tc} = P_{on} + P_{ta} \quad (25)$$

here P_{on} is the power consumed by the UE's subsystems such as CPU, screen display, etc; P_{ta} is the power consumed when the transmitter is transmitting data. Hence equation (24) becomes:

$$P_{t,con} = P_{tx} + P_{on} + P_{ta} \quad (26)$$

Similarly, the equivalent power consumed during signal reception ($P_{r,con}$) is expressed as:

$$P_{r,con} = P_{rx} + P_{on} + P_{ra} \quad (27)$$

where, P_{rx} is the received power, P_{ra} is the power consumed when the receiver is receiving data. The studies made by Lauridsen et al (2014) and Höyhtyä, Apilo & Lasanen (2018) indicated that for a 4G UE, the value of P_{on} is

853mW, while P_{ta} is 29.9mW, and $P_{ra} is$ 25.1mW. The total power a UE consumed while transmitting and receiving data is expressed:

$$P_{Tot,con} = P_{t,con} + P_{r,con} \tag{28}$$

$$\text{i.e. } P_{Tot,con} = P_{on} + (P_{tx} + P_{ta}) + (P_{rx} + P_{ra}) \tag{29}$$

Note that P_{on} is the power consumption by the UE's subsystems (CPU, screen display) during transmission and reception of data.

The system describes a situation where a CM transmits and receives from BS through a CH. The CH transmits and receives from both the CM and BS. Thus, the total power consumed by a CM $P_{CM,tot}$is given as:

$$P_{CM,tot} = P_{on} + P_{CM,tx} + P_{CM,rx} \tag{30}$$

Thus, in (30), $P_{CM,tx} = P_{CM-CH,tx} + P_{CM-CH,ta}$; also $P_{CM,rx} = P_{CM-CH,rx} + P_{CM-CH,ra}$
Therefore:

$$P_{CM,tot} = P_{on} + \left(P_{CM-CH,tx} + P_{CM,ta}\right) + (P_{CM-CH,rx} + P_{CM,ra}) \tag{31}$$

Similarly, the total power consumed by a CH $P_{CH,tot}$ is given as:

$$P_{CH,tot} = P_{on} + P_{CH,tx} + P_{CH,rx} \tag{32}$$

In equation (32), CH transmits and receives to and from both the BS and CMs, this implies that;

$$P_{CH,tx} = P_{CH-BS,tx} + P_{CH-CM,tx} + P_{CH,ta}; \text{ also } P_{CH,rx} = P_{CH-BS,rx} + P_{CH-CM,rx} + P_{CH,ra}$$

Thus:

$$P_{CH,tot} = P_{on} + \left(P_{CH-BS,tx} + P_{CH-CM,tx} + P_{CH,ta}\right) + (P_{CH-BS,rx} + P_{CH-CM,rx} + P_{CH,ra}) \tag{33}$$

The total power consumed by the cluster is given as:

$$P_{Tot,con} = P_{CM,tot} + P_{CH,tot} \tag{34}$$

Furthermore, the energy consumed by a system is the product of power (*P*) and the time (*T*) taken. That is, energy consumed by a UE is:

$$E_{UE} = P \times T \tag{35}$$

But time is given as $T = D_c/R$; here is D_c is the data size; *R* is the data transmission rate. Hence, equation (35) becomes:

$$E_{UE} = P_{Tot,con} \times {}^{D_c}/_{R} \tag{36}$$

Therefore, the energy consumed by a CM is expressed as"

$$E_{CM} = P_{CM,tot} \times ({}^{D_c}/_{R_{CM-CH}}) \tag{37}$$

Similarly, the energy consumed by CH comprises the energy consumed over CM-CH link and CH-BS link and it is expressed as:

$$E_{CH-CM} = P_{CH,CM} \times ({}^{D_c}/_{R_{CH-CM}}) \tag{38}$$

$$E_{CH-BS} = P_{CH,BS} \times ({}^{D_c}/_{R_{CH-BS}}) \tag{39}$$

Thus,

$$E_{CH} = E_{CH-CM} + E_{CH-BS} \tag{40}$$

If we assume that the CM and CH have equal power/energy consumption over CM-CH link, equations (33) and (40) shows that extra energy burden is incurred by CH over CH-BS link. Therefore, the energy/power consumed by a CH is dependent on the distance between the CH and BS (CH_{dn}), the number of CMs served by CH (CM_n) as well as the distance between the CH and CM (d_{CMn}). These dependent factors are depicted in figure 2.

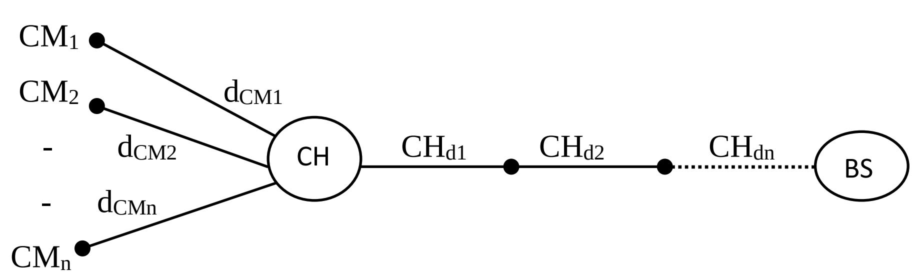

Figure 2: Factors Influencing Energy Consumption of Cluster Head (CH)

In this study the influence of distance on the power consumptions of the UEs is investigated. And this requires that the influence of attenuation (or path loss) on the power consumption when the UEs transmit and receive data is considered in the study.

2.1.5 Cluster Formation Procedure:

The cluster formation starts by determining the geographic locations of the UEs, which is equivalent to the Cartesian UEs positions. The distance between each UE and the base station is evaluated and the values of these distances are used as the data input to the cluster algorithm. A CH is selected for each cluster based on the UE that has least distance between it and the base station. The rest of the UEs in the cluster become the CMs. The cluster formation procedure is shown in the flow chart of figure 3.

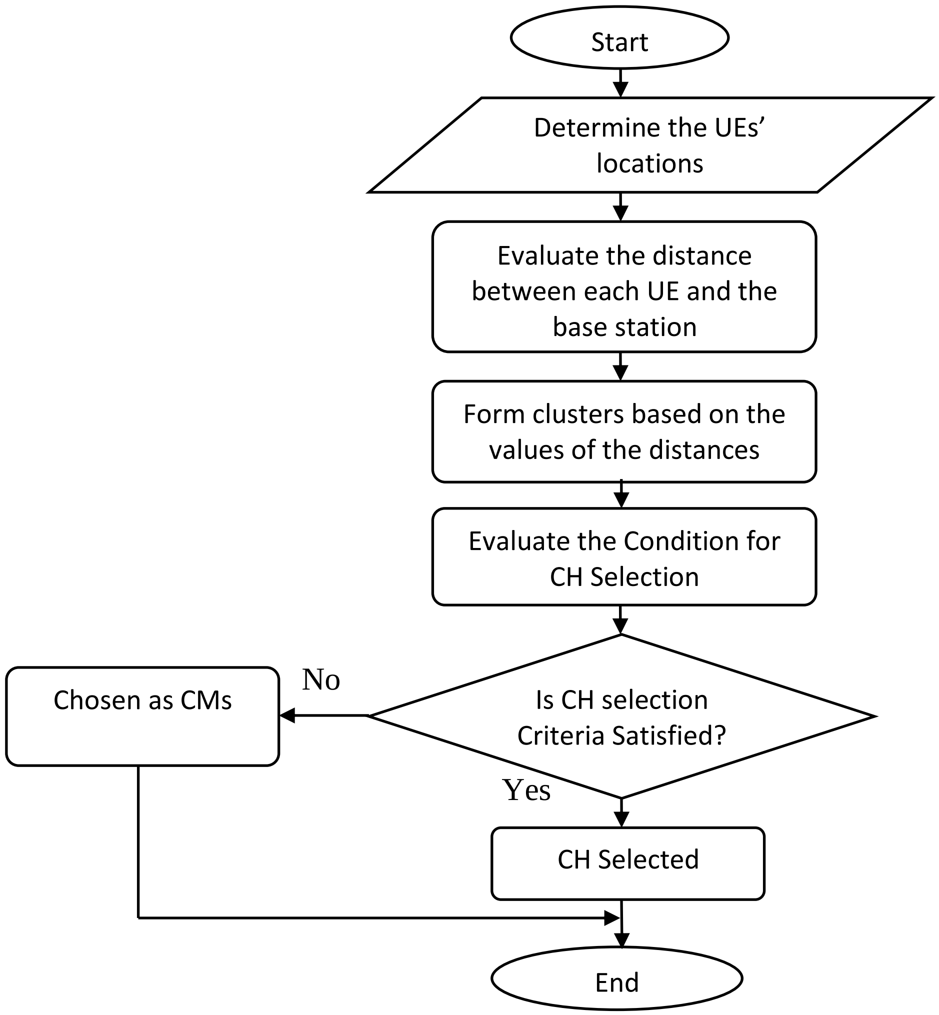

Figure 3: Flow Chart Showing the Cluster Formation Procedure

3.0 Results and Discussions

SOM topology adopted in the study is 3x3 hexagonal topology. This implies nine clusters were formed. The details of the clusters are shown in table 1, while the topological display is shown in figure 4.

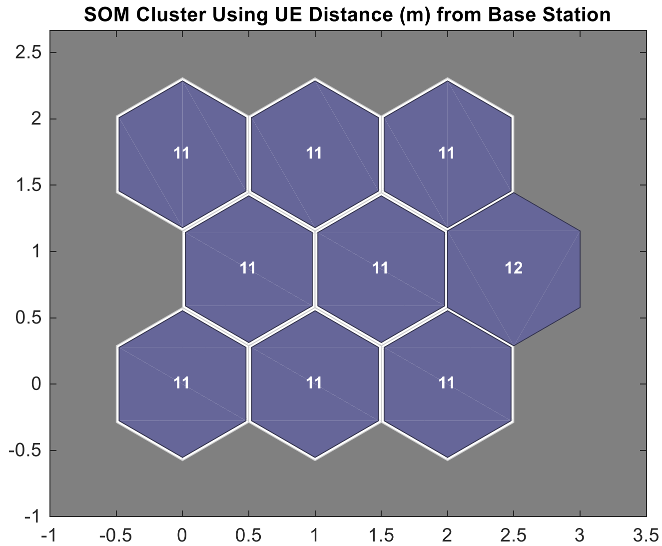

Figure 4: SOM Cluster Display

Table 1: Cluster Formation Details

Cluster No	CH ID	Distance (m)	No. of CMs
1	97	41.01	10
2	87	10.63	10
3	28	56.17	10
4	73	12.03	10
5	42	28.21	10
6	6	51.24	11
7	59	18.14	10
8	50	10.52	10
9	19	30.71	10

Figure 4 shows the number of UEs in each cluster. This comprises both the CH and the CMs. The details of the formed clusters are depicted in table 1. The clusters are numbered 1-9 under the column “Cluster No.”. UE ID (or CH ID) is dummy number used to identify the UEs as well as the CH. The distance of the CH from the base station and the number of CMs in each cluster are shown in table 1. The number of CMs is one less than the total number of the UEs (CMs & CH) in a cluster.

We used the UEs in cluster 1 to analyze the power consumptions of clustered devices when the CMs transmit and receive data from the BS through the CH. Cluster 1 has 10 CMs and the CH distance from the base station is 41.01m. The details of the CMs in cluster 1 are shown in table 2. The UE ID is a dummy number identifying the CMs in cluster 1. The Cartesian positions of the CMs are represented in y(m) and y(m) columns and the distance of each CM from the CH is shown. The power consumptions of the devices in cluster 1 are shown in figure 5.

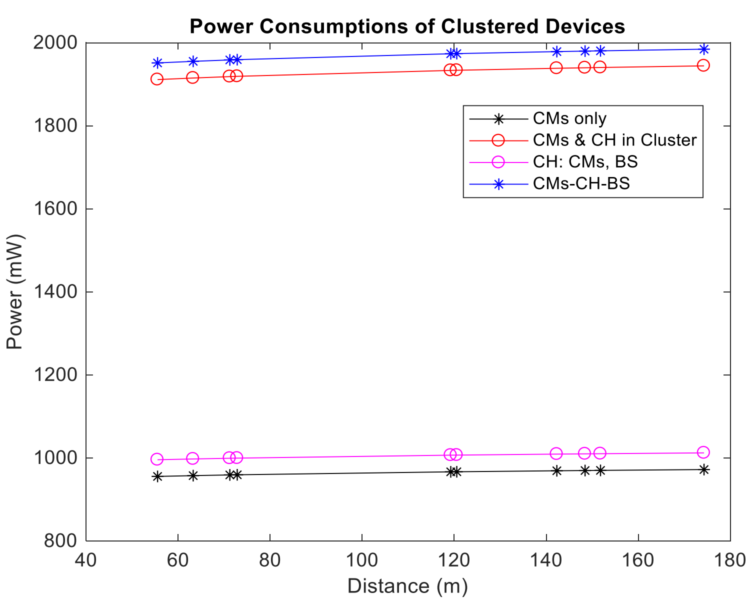

Figure 5: Power Consumption of the UEs

Table 2: The CMs in Cluster 1

UE ID	X (m)	Y (m)	Distance of CM from CH (m)
99	100.30	162.82	63.26
93	175.25	73.58	72.83
94	93.70	44.98	120.55
98	214.65	159.29	55.52
100	157.71	216.16	71.23
91	39.69	219.39	142.30
92	59.12	3.59	174.29
90	246.44	23.62	148.44
95	243.00	231.57	119.25
96	242.65	17.05	151.79

Figure 5 shows the power consumptions of the devices over various links. The power consumed by CMs over CM-CH link to transmit and receive data to and from the CH is represented by *CMs only*. This is the power consumed by the CMs only, the CH transmit/receipt from the CMs is not inclusive. The combined power consumed by CMs to transmit/receive to and from the CH and the power consumed by the CH to transmit/receive to and from the CMs is represented by the graph *CMs & CH in cluster*. The combined power consumed by the CH to transmit/receive from the base station and the power consumed by the CH to transmit/receive from the CMs is represented by the graph *CHs: CMs, BS*. This power represents the total power consumed by the CH in the cluster. The total power consumed by the UEs (CMs and CH) to transmit/receive data from the base station is represented by the graph *CMs-CH-BS*. This represents the power consumed when CMs transmit/receive data from the base station through the CH. It is shown that less power is consumed by the CMs to transmit/receive data from the CH than to transmit/receive from the BS through the CH. In addition, a good percentage of the power consumed in a cluster comes from the power consumed by the CH.

It was mentioned previously that power consumed by the CH is dependent on factors such as the distance between the CH and the BS and the number of CMs served by the CH. When the number of CMs is kept constant, figure 6 shows the power consumed by the CH when the distance between it and the BS is varied. As indicated in figure 6, As the CH-BS distance increases, the power consumed by the CH increases. Thus, the distance between the CH and the BS should be minimized to achieve low power consumption.

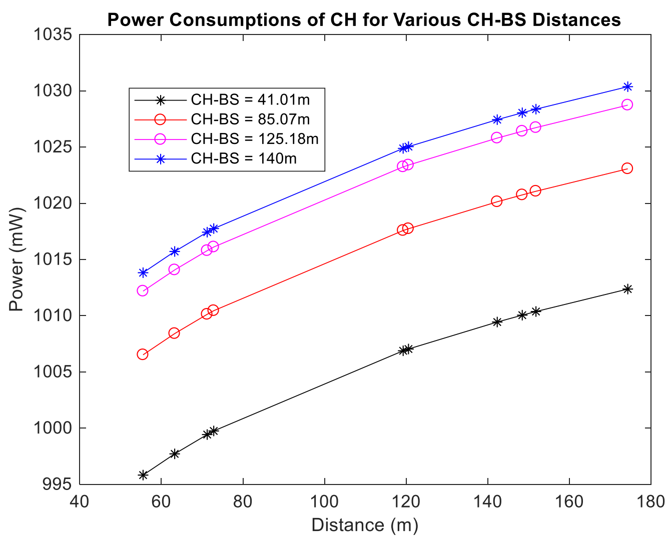

Figure 6: Variation of Distance between the CH and the Base Station

Furthermore, when the distance between the CH and the BS is kept constant at 41.01m, and the number of active CMs in the cluster is varied, the power consumed by the CH for various numbers of CMs is depicted in figure 7. It is shown in figure 7 that as the number of active CMs increases in a cluster, the CM-CH distances increases as well, and thus imposing more energy burden on the CH.

The energy consumption of the cluster as a function of capacity (or rate) is shown in figure 8. As indicated in figure 8, it is more energy efficient for the CMs to transmit/receive data to or from the CH than from the BS through CH. The extra energy incurred by the cluster during data transmission and reception comes from the CH. The parameters used in the study and analyses are shown in table 3.

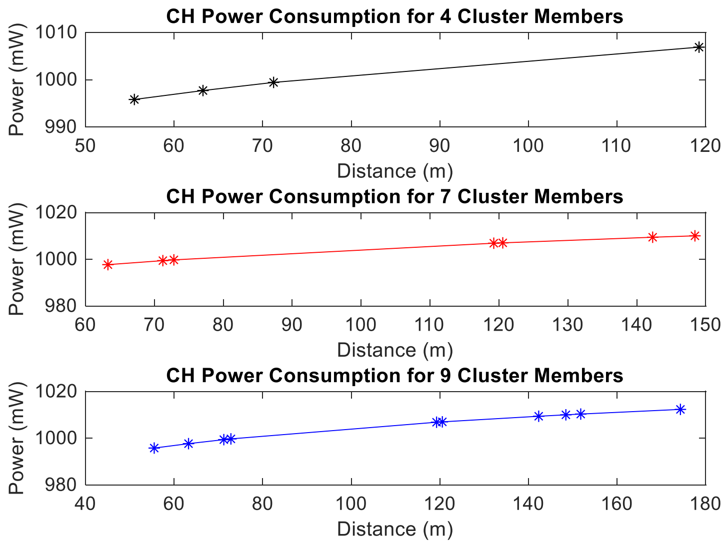

Figure 7: Power for Various numbers of CMs

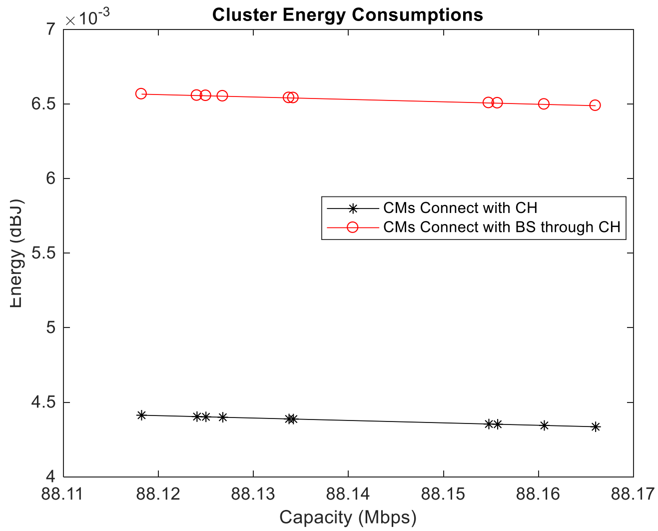

Figure 8: Energy Consumptions

Table 3: Parameters used in the Study

Parameter	Assumption
Cellular Diameter	1 km
Number of UE	100
Bandwidth	10 MHz
Required transmission power, P_t	$\geq P_{Loss}(dB) + RSSI_{min}(dBm)$
Power consumed by the UE's cellular subsystem, P_{on}	853 mW
Power consumed when the transmitter is active, P_{ta}	29.9 mW
Power consumed when the receiver is active, P_{ra}	25.1 mW
Frequency	2600 MHz
Cellular link path loss model	Hata model
D2D link path loss model	Log Normal model
Path loss exponent for cellular link	3.67
Path loss exponent for D2D link	3.5
Standard deviation, σ	9
Constant path loss factor (K)	0.0070
Noise Power Spectrum Density (N_0)	-174 dBm/Hz
Packet Size	200 bytes

4.0. Conclusion

In this work the power and energy consumed during transmit and receive data by the UEs in a D2D cluster was investigated. SOM cluster algorithm was utilized to cluster the UEs using the distance between the UEs and the base station as data input. It was shown that it is more energy efficient for the CMs to transmit and receive data from the CH than to transmit and receive data from the BS through the CH. In addition, increasing both the number of CMs and the distance between the CH and the base station increases power consumptions of the CH.

5.0 Recommendation

It is recommended that for efficient energy/power consumption in D2D clusters, the distance between the CH and the base station and the number of CMs associated with the CH should be minimized.

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