POWER AWARE CLUSTERING IN MOBILE AD HOC NETWORKS

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COMMITTEE DECISION

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DEDICATION

To Islam,

the greatest religion that gives us the motive to work and achieve

To my parents, my sister Nisreen and my brothers,

for their support, patience, and encouragement through my life

To 'Homat al-Nahda', the revival keepers,

who changed and enlightened my life and gave it a great meaning,

who gave me wonderful specimens for ambition and eagerness,

To all my friends and students,

I dedicate this work.

AKNOWLEDGEMENT

All the praise is due to Allah, the Lord of all creatures, for the warmhearted gracious support in every moment which gives me the perseverance and the ability to continue. And may the prayers of blessing of Allah be upon Prophet Muhammad and upon his family and all his companions.

My gratitude and respect to my supervisors Dr. Wesam Al- Mobaideen and Dr. Basel A. Mahafzah, who spent a lot of their time guiding me to improve and complete this work. I am thankful for their constructive criticism and invaluable advice. Special thanks for Dr. Wesam Al- Mobaideen for his invaluable guidance and his patience in helping me through these years.

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Ghada M. Jaber

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LIST OF ABBREVIATIONS

ABP	Adaptive Broadcast Period
ACK	Acknowledgement
ahm	Advertisement HELLO Message
ANDA	Ad-hoc Network Design Algorithm
AP	Access Point
BNs	Boundary Nodes
CAI	Collision Avoidance Information
CBR	Constant Bit Rate
CH	ClusterHead
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear To Send
COMPOW	Common Power
dBm	decibel-milliWatt
DCF	Distributed Coordination Function
Eidle	Energy consumed in idle mode
Ercv	Energy consumed in receiving mode
Psense	Energy consumed in sensing mode
Etrans	Energy consumed in transmitting mode
FCP	Fixed Centered Partitioning
FTP	File Transfer Protocol
GloMoSim	Global Mobile information system Simulation library
GW	Gateway
hm	HELLO Message
IR	Improvement Ratio
JAcc	Join Accept
jhm	Join HELLO Message
JRej	Join Reject
JRep	Join Reply
JReq	Join Request
m	meter
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network
mWhr	milliWatt /hour
NIC	Network Interface Card
PC	Personal Computer
PCM	Power Control MAC
PECD	Power Efficient Clustering Distribution
Pidle	Idle Power
Preceive	Receive Power
Psense	Sense Power
PSP	Power-Stepped Protocol
RTS	Ready To Send
RX	Receiving
SR	Size Restricted
TPC	Transmission Power Control
TX	Transmitting
txPower	transmission power level

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ABSTRACT

Power control is an important issue in Mobile Ad-hoc Networks (MANET). Since the nodes have limited power, many algorithms are developed to control the power consumption and prolong the network life time. Clustering is one of the effective approaches to deal with power control in MANET.

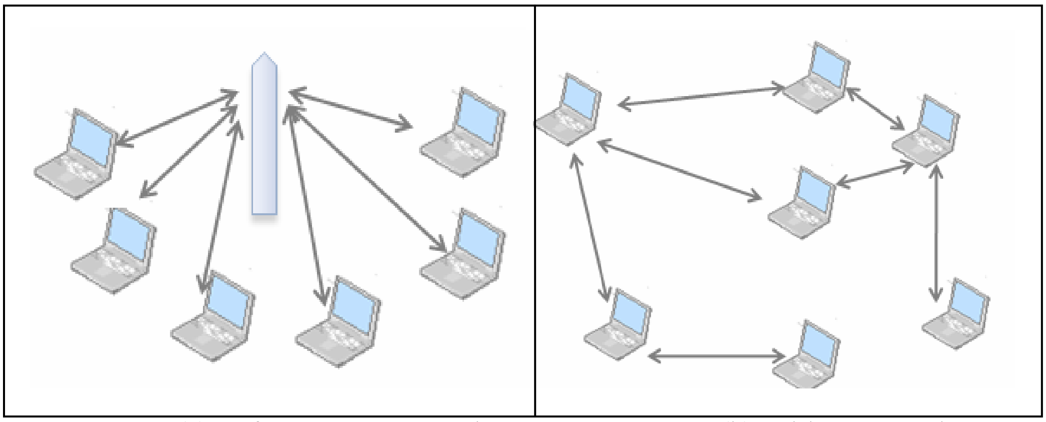
Clustered networks are divided into groups where each cluster contains a special node called Clusterhead (CH). Optimal cluster size is controlled by the balance between delay minimization using large clusters, and spatial reuse of the channel using small clusters. To manage the issue of efficient cluster size, many algorithms use a size threshold to achieve balanced load clusters and avoid forming big clusters. In case that some clusters reach the maximum threshold, other small clusters must join the rest of nodes even if they are distant and need large power levels. This thesis presents a new cluster formation algorithm called Power Efficient Clustering Distribution (PECD) which decreases the effect of distant boundary nodes on power consumption. The objective of PECD is to prolong the network lifetime regardless of the power consumption in each cluster or the number of its members.

PECD decreases the power needed for communication with boundary nodes by joining them to the closest cluster not to that with less members. Different scenarios were designed and implemented using GloMoSim simulator. Simulation results show that PECD algorithm increases the network lifetime and save the power consumption compared with Size Restricted (SR) algorithm by 13%.

1. Introduction

1.1 Mobile Ad Hoc and Clustered Networks

The wireless networks standard IEEE802.11 supports two operational modes. The first is called infrastructure wireless network which uses a radio base station (a part of the Access Point (AP)). The second is called ad-hoc wireless network which operates without using an AP (Halsall, 2005). The two alternative modes are shown in Figure 1.



(a) Infrastructure networks (b) Ad-hoc networks

Figure 1. IEEE802.11 operational modes Source: http://www.acorn.net.au/telecoms/adhocnetworks/

In the infrastructure mode, as shown in Figure 1 part (a), all the communications go through the AP. The wireless devices can not communicate directly. The AP also acts as a bridge to another wireless or wired network (Halsall, 2005).

Mobile Ad-Hoc Networks (MANETs) consist of mobile hosts with wireless communications without support of fixed infrastructure or central administration. As shown in Figure 1 part (b), mobile hosts (nodes) communicate directly or through intermediate nodes which act as routers (Chlamtac, *et al*, 2003) and (Sesay, *et al.*, 2004).

The system of MANET can operate alone or may have an interface with a fixed network. Nodes are free to move arbitrarily and can be located on cars, ships and airplanes. The ad-hoc topology may change with time as the nodes move or adjust their transmission and reception parameters. The connectivity of the nodes depends on their positions, transmitter and receiver coverage patterns and the transmission power levels (Meskauskas, 1998).

Clustering is one way to increase performance and scalability. It is an effective approach to deal with power control for ad hoc networks. Clustered networks are divided into groups of nodes. As shown in Figure 2, each cluster contains a special node called Clusterhead (CH). Clusterheads (the dark bold nodes) are used to manage nodes and route the packets in and out their clusters. This reduces the number of control packets and the amount of information needed to store the network state (Cheng, *et al.*, 2006) and (Johnen and Nguyen, 2006). Clusters can be either distinct or overlapping. In overlapping clusters, neighboring clusters can have a common node called Gateway (GW), whereas in distinct clusters each node belongs to exactly one cluster (Chiang, *et al.*, 1997).

Figure 2 shows an example of three clusters where the lines represent the communications between clusters. Clusterheads are responsible for sending messages to their members, where GWs (the light bold nodes) communicate with adjacent clusters and inform their clusters about the global updates. The other nodes are called mobile stations (or ordinary nodes). There are two kinds of routing here, routing within the cluster (intra-cluster) and routing between different clusters (inter-cluster) (Cheng, *et al.*, 2006) and (Johnen and Nguyen, 2006).

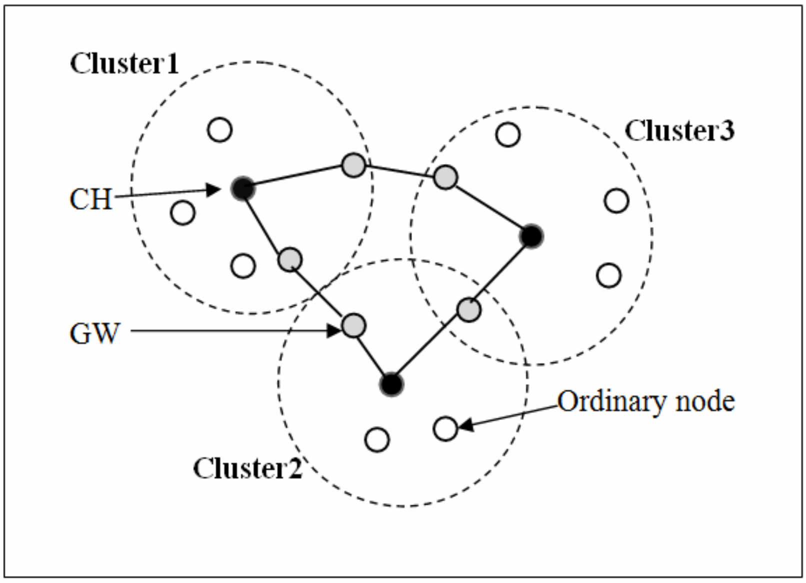


Figure 2. An example of three clusters

1.2 Motivations and Objectives

MANETs have been recently the topic of wide research (Krunz, *et al.*, 2004), (Chlamtac, *et al*, 2003), (Yu, *et al.*, 2004) and (Sesay, *et al.*, 2004). The reason of such interest is the ability of providing wireless solutions for situations where cellular infrastructures are expensive or hard to deploy. MANETs are distributed by its nature and so they are more robust against single-point failures (Krunz, *et al.*, 2004).

Mobile devices rely on finite battery power which is one of the important constraints in designing algorithms for these devices. For this importance, many researches are produced for saving power consumption in wireless networks in general and in MANET in particular (Sesay, *et al.*, 2004).

Power control problem means, in general, how to assign a transmission power level for every transmitted packet in a wireless ad hoc network (Kawadia and Kumar, 2003). Power control is one of the major issues in wireless ad hoc networks that affects the signal quality and has an impact on the Physical layer. It determines the number of neighbors and thus determines the number of hops. Furthermore, it increases the transport layer's protocols performance because of its impact on the ratio of collisions and congestions. For all of these reasons, the study of energy efficient mechanisms has a significant importance (Kawadia and Kumar, 2005) and (Yu, *et al.*, 2004). The importance of power control is not only for saving power, it is also a necessity to reduce the interference between nodes. When nodes use the strictly necessary power, the channel interference can be minimized (Kwon and Gerla, 1999).

Many algorithms try to moderate the cluster size and balance the distribution of nodes among clusters. Some approaches use a threshold to restrict the size of the cluster and avoid forming big clusters. In case that some clusters reach the maximum threshold, other small size clusters must join the rest of nodes even if they are distant and need large power levels. Distant nodes in clusters consume more energy to communicate with their CHs, which is not an energy efficient policy. This thesis presents a Power Efficient Clustering Distribution (PECD) algorithm which aims to decrease the effect of distant Boundary Nodes (BNs) on power consumption.

The purpose of PECD algorithm is to prolong the lifetime of the ad hoc network regardless of the power consumption in each cluster or the number of its member nodes. The objective of this work can be summarized as follows:

1. Studying the proposed PECD algorithm and evaluates its reduction of power consumption of the network compared with Size Restricted (SR) algorithm which restrict the size of the cluster.

2. Studying the effect of changing the number of BNs on power consumption for SR and PECD algorithms.

3. Evaluating the power results for SR and PECD algorithms when the placement of BNs is changing.

1.3 Contributions

The PECD algorithm uses non-overlapped clusters managed by CHs. Clusterheads communicate between each other using small multi hops through Gateways to save the power consumption. Each CH decides to add or leave the BNs with respect to the transmission level needed to join them. This algorithm decreases the power needed for communication with BNs by joining them to the closest cluster not to that with less members. Different scenarios were designed and implemented using GloMoSim simulator. This simulator does not give the accurate value of power consumption. Consequently, we add some changes to the simulator and build a new power model to compute the power consumption for each node in each mode.

The first experiment evaluates the power consumption to compare PECD with SR algorithm under different simulation time, traffic loads and packet sizes. PECD algorithm uses less power ranges when joining the BNs to the closest CHs, and that decreases the power consumption for this algorithm by 3-18% compared with SR algorithm. The second experiment compared SR and PECD algorithms for different numbers of BNs (one to five nodes). The PECD algorithm gives better results for power consumption by 15%. The last experiment shows how to choose the effective cluster formation depending on BNs locations. The network power consumption was evaluated for SR and PECD algorithms when the placement of BNs is changing. Our proposed PECD algorithm outperforms SR algorithm and makes the efficient cluster formation choice in term of power consumption.

1.4 Thesis Organization

This thesis contains six chapters outlined as follows:

Chapter one: gives a brief introduction about the wireless networks, clustered MANET, and the power control in MANET. It also highlights the main objectives of the study.

Chapter two: reviews some power consumption protocols for non-clustered and clustered Ad hoc networks.

Chapter three: describes the proposed Power Efficient Clustering Distribution algorithm.

Chapter four: gives an introduction about the GloMoSim network simulator, and a detailed description of the power model used in the experiments. This chapter also displays the considered simulation parameters and the scenarios that were used to obtain the results.

Chapter five: shows the simulation results for power consumption and their analysis.

Finally, the conclusions of our work and the future works are presented.

2. Background and Related Works

Transmission Power Control (TPC) is an active area of research that focuses on reducing the energy consumption and increasing the throughput and network capacity (krunz, *et al.*, 2004). There have been limited amounts of research on TPC in clustered MANET. However, the focus was on non-clustered wireless ad hoc networks (Agarwal, *et al*., 2001), (Wattenhofer, *et al*, 2001), (Narayanaswamy, *et al*., 2002) and (krunz, *et al.*, 2004).

Clustered networks have many advantages and goals. Johnen and Nguyen (2006) mentioned the following benefits for clustering:

- Clustering improves the system capacity by improving the reuse of resources.
- Cluster members can share resources as printers, software and memory space.
- Reducing the amount of routing information.
- Reducing the amount of information needed to store the state of the network. Each CH collects the information about its cluster members.

In Clustered networks, each cluster contains the nodes that can communicate through their CH by at most k hops. The 2-hop clustering is a special case of *k*-hop clustering with three properties. First, the CH can communicate with all nodes in the cluster with a single hop. Second, there are no two CHs directly linked. Finally, each two nodes in the same cluster are at most 2-hops away (Kwon and Gerla, 1999). In our proposed algorithm we use a 2-hop clustering approach where every node in the cluster can be reached by at most 2 hops from any node in that cluster.

Clustering formation consists of two phases: CH election and assignment of nodes to CHs (Chiasserini, *et al*, 2004). Many algorithms are proposed to choose the CH. Some of these approaches are:

1. The "lowest ID" clustering algorithm in which the node with the lowest ID is selected as the CH (Hollerung, 2003) and (Gerla and Tsai, 1995).
2. Highest-Degree (or connectivity-based) clustering, where the node which has the most neighbor nodes becomes the CH (Hollerung, 2003).
3. The *k*-LowestID and *k*-CONID algorithm (with k =1 and k=2). This algorithm combines the two approaches Highest-Degree and Lowest-ID. The primary criterion for selecting CHs is the connectivity, and “lowest ID” is considered as a secondary criterion. The k hops here is used in a different way, where the cluster nodes are at most k hops from the CH not from each other as in *k*-hop clustering (Chen, *et al.*, 2002).
4. Fixed Centered Partitioning (FCP) algorithm, where random centers nodes are chosen and the clusters are then formed around these fixed nodes (Erciyes and Marshall, 2004).
5. Weight based clustering algorithm where every node has a weight that indicates its probability to be a CH. The node with the biggest weight is more suitable for the role of CH (Johnen and Nguyen, 2006). The weight can be a combination of different parameters such as degree, mobility and power. This gives a flexibility of highlighting a parameter based on the used application (Chen, *et al.*, 2002) and (Venkataraman, *et al.*, 2007).

The second phase of cluster formation is assigning nodes to the cluster and determining the cluster size. Cluster size is the number of nodes inside the cluster or cluster members. Optimal cluster size is controlled by the balance between minimizing the delay of message delivery using large clusters, and enabling spatial reuse of the channel using small clusters. Using small cluster sizes means having multiple clusters and increasing the number of CHs. It also increases the routing information which is hard to manage. On the other hand, having large clusters leads to smaller number of CHs with more members. This in turn increases the power consumption of CHs and causes a rapid exhaustion of their power. From the discussion above, we can notice that there is a tradeoff between cluster size and the number of CHs and between cluster size and the power consumption (Gavalas, *et al.*, 2006) and (Wei and Chan, 2005).

To manage the issue of efficient cluster size, many algorithms are proposed to achieve balanced load clusters and control the number of nodes in each cluster (Kwon and Gerla, 1999), (Chiasserini, *et al*, 2004), (Gavalas, *et al.*, 2006) and (Venkataraman, *et al.*, 2007). In addition there are four approaches to optimize the cluster size and improve the power efficiency. The first approach is to minimize the sum of distances between ordinary nodes and their CHs by optimizing the organization of the cluster. The second is to use the lowest power level needed by ordinary nodes for intra-cluster communications. Clusterheads use the lowest power needed for inter-cluster communications (Wei and Chan, 2005).

The third approach deals with clusters with different power ranges. Each node in the network can belong to different clusters of different power levels. Different routes are formed by taking different combinations of the power ranges for each hop. Power consumption can be saved by optimizing these multihop routes. The last approach is to use K-tree where each node in a cluster is at most K hops from other nodes in that cluster. To save power cluster members can send data to their CHs using multihops with lower power ranges instead of using a large single hop (Wei and Chan, 2005).

2.1 Power Control Protocols in MANET

There are many algorithms investigated for saving power in the various protocol layers (Sesay, *et al.*, 2004). Table 1 lists some of the strategies used in different layers. Our proposed idea is concerned with power consumption and decreasing the transmission power level for nodes. The PECD algorithm uses power saving strategy on the physical layer.

Table 1. Some strategies for power saving in different layers (Sesay, *et al.*, 2004)

Layer	Power saving strategies
Physical layer	o controlling the transmission power o using a directional antenna
Data-link layer	o avoiding unnecessary retransmissions and collisions whenever it possible o turning off the power when there is no transmission o allocating contiguous slots for transmission and reception
Network layer	o using efficient route reconfiguration mechanisms o optimizing the size of control headers o considering battery life in selection the route o reducing the amount of control messages
Transport layer	o handling the packet loss locally o avoiding the repeated retransmissions o using power efficient schemes for error control

Some research developed algorithms that use power control to adjust the transmission levels for nodes as needed (Agarwal, *et al.*, 2001), (Narayanaswamy, *et al.*, 2002), (Kawadia and Kumar, 2003), (Yu, *et al.*, 2004) and (Krunz, *et al.*, 2004). Other research adjust the CH power level to control the cluster size and control the overhead on CHs (Kwon and Gerla, 1999) and (Chiasserini, *et al*, 2004). On the other hand, the longest lifetime of the network was an important matrix of studies (Wattenhofer, *et al*, 2001) and (Chiasserini, *et al*, 2004).

The IEEE 802.11 standard is the most influential Medium Access Control (MAC) protocol for MANETs. This protocol generally uses a Carrier Sense Multiple

Access with Collision Avoidance (CSMA/CA) mechanism, with extensions for exchange of control handshake packets between the sender and the receiver. These packets are the control packets RTS/CTS (request-to-send/clear-to-send) which are used to reserve a *transmission floor* for the data and acknowledgment (ACK) packets. The nodes use the maximum power level to transmit the control and data packets. When a node hears RTS or CTS message it delays its transmission and waits until the ongoing transmission finishes. This mechanism has two drawbacks. First, preventing the concurrent transmissions will negatively impact the channel utilization. Second, using the maximum power level for data and control packets wastes the node's energy and decreases its lifetime. Therefore, a solution is needed to save energy and allow concurrent transmissions in the same vicinity (Krunz, *et al.*, 2004).

Agarwal, *et al.* (2001) modify the original IEEE 802.11 MAC protocol and propose a *power control loop* protocol. It allows the node to choose different power levels for different neighbors taking into account the difference in distances. Using different power levels in transmitting to neighbors will reduce the interference between nodes. The main goal for the *power control loop* protocol is to find the minimum transmission power level required for each node to successfully transmit to each neighbor. First, the node starts with an initial value for the transmission power level. After exchanging and losing the messages, the MAC layer ratchet up or ratchet down the transmit power level until finding the minimum power level required for that node to transmit to its neighbor.

If the communicating nodes are close to each other, the *power control loop* reduces the total energy consumed successfully. Compared to the unmodified MAC, it saves about 10-20% of the consumed power, and improves the overall throughput by 15%. On the other hand, if the communication happens at the maximum distance between nodes, the *power control loop* will consume more energy and reduce throughput (Agarwal, *et al.*, 2001).

A power control algorithm for a multihop wireless network is proposed in (Wattenhofer, *et al.*, 2001). This approach aims to increase the network lifetime while preserving global connectivity and good throughput. The idea is to find the minimal operational power needed for each node with ensuring the same maximum connected node set as in using the full transmitting power for all nodes. This algorithm does not need to share and know the global position information of other nodes. It is a distributed algorithm which only relies on local information by using the directional information from neighboring signals.

The Distributed Topology Control algorithm consists of two phases. First, each node u broadcasts a neighbor discovery message with a small radius. Each receiving node replies with acknowledgment to node u. Node u collects all information from the acknowledgments and records the directions which they came from. Then it checks if there is at least one neighbor node in every cone of α degree and centered on u, where if $\alpha \leq 2\pi/3$, then the algorithm will guarantee the maximum connected node set. Node u continues this neighbor discovering process and increasing its transmission power radius until having a node in each direction or reaching the maximum transmission power (Wattenhofer, *et al.*, 2001).

In the second phase, the algorithm removes the redundant edges without impacting the connectivity. The routes with more power are removed and the multi short hops route is kept. That will increase the performance by reducing interference, power consumption and enhancing throughput. This algorithm shows that the multihop routes are efficient in power consumption. The algorithm is only simulated for a static network. If the mobility is low, a proactive approach may be used to reconfigure the network topology. When the mobility is high, an on-demand approach may be the only way to keep the reconfiguration control traffic low (Wattenhofer, *et al*., 2001).

A Common Power (COMPOW) protocol was provided in (Narayanaswamy, *et al*., 2002). The COMPOW protocol runs the routing algorithms one at each admissible power level then figures out the lowest power for connectivity. Then Nodes will use this power level throughout the network.

COMPOW works fine if the nodes are distributed homogeneously, but a single outlying node may cause every node to use high power. Therefore, it is not optimal to use a common power level when the distribution is inhomogeneous. Figure 3 shows an example of this situation. All nodes except F are reachable by 1mW while node F needs 100 mW to be reachable. If the COMPOW algorithm is used then the 100 mW will be used as the lowest power level needed to connect the network. On the other hand, only 1 mW is enough for most communications (Kawadia and Kumar, 2003) and (Kawadia and Kumar, 2005).

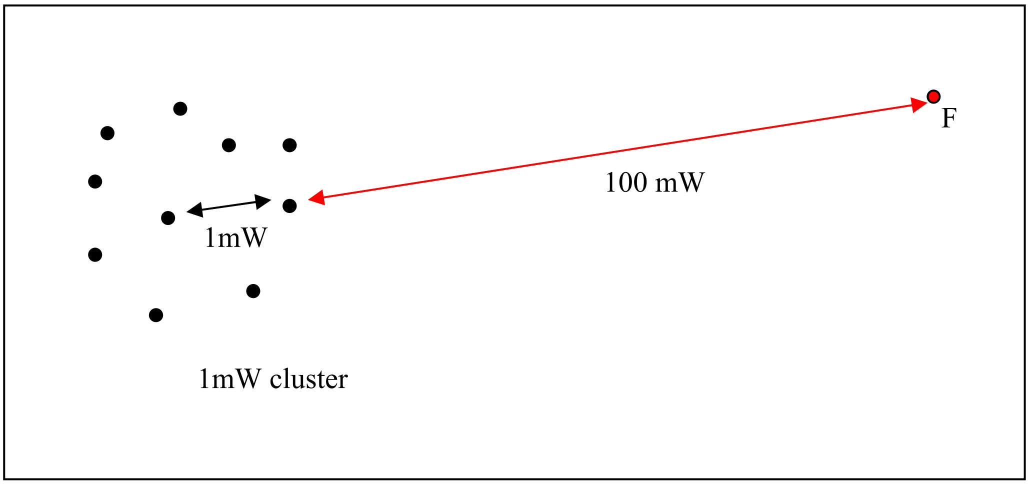


Figure 3. A common power level is not appropriate for non-homogeneous networks (Kawadia and Kumar, 2003)

One of the TPC approaches that decreases the energy consumption is the *SIMPLE* protocol. This protocol uses the maximum power level for the control packets

RTS/CTS and lower power levels for data packets. Using low power level for transmitting data packets saves a substantial amount of energy. The *SIMPLE* protocol on the other hand needs a power-aware protocol to find energy-efficient route to the destination and provide a good energy saving (Krunz, *et al.*, 2004).

As the *SIMPLE* protocol, the power control MAC (PCM) protocol uses a maximum power level for RTS/CTS packets, while data packets are sent using the minimum necessary power level. This protocol tries to reduce the collisions that occur in other protocols, and hence increase the throughput. Many MAC protocols use different power levels for transmitting control and data packets, and use low power levels in sending data packets in order to save energy. However, these protocols degrade the network throughput and consume more power consumption than using IEEE 802.11 without power control. During the data transmission, some nodes can not sense this transmission and consider the channel to be idle. If these nodes start their transmitting with the maximum power level, that will cause collisions with the ACK packet (Jung and Vaidya, 2002).

To solve this problem, Jung and Vaidya (2002) develop the PCM protocol which increases the transmission power level periodically during data transmission. This mechanism enables the nodes in the carrier sensing mode to sense signals. The PCM protocol achieves power savings without causing throughput degradation. On the other hand, increasing and decreasing the transmit power make the implementation of this protocol difficult. The PCM also does not improve the spatial reuse compared with IEEE 802.11 (Jung and Vaidya, 2002).

Another protocol that improves the throughput and decreases energy consumption simultaneously is called *interference–aware MAC* Protocol. It is based on using Collision Avoidance Information (CAI). Senders broadcast this information to all possible interference neighbors before starting their transmissions. In this way the transmission power of future packets will be bounded. As shown in Figure 4, node B broadcasts a CAI to all possible interfering neighbors (C, D and E) before starting the transmission. The CAI bounds the transmission power levels of future generated packets by these nodes. Nodes D and E transmissions can take place if their power signals are not high and collide with B (Krunz, *et al.*, 2004).

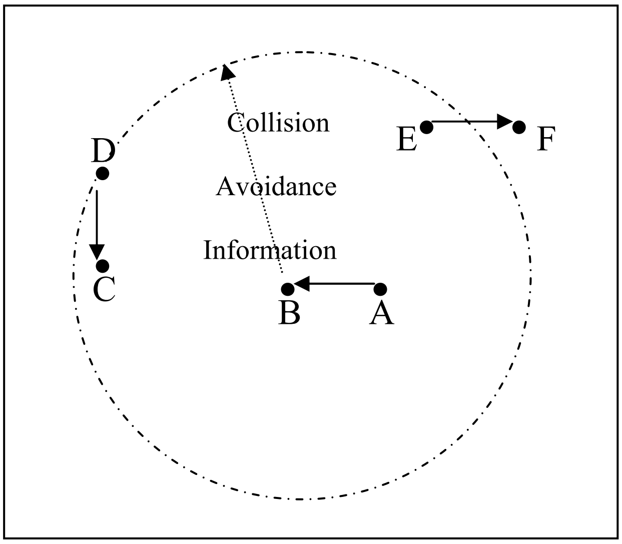


Figure 4. Broadcasting collision avoidance information in interference-aware MAC protocols (Krunz, et al., 2004)

Although the *interference–aware MAC* Protocol solves the drawbacks of the unmodified MAC protocol, this protocol is designed based on assumptions which are only valid for some ranges of speeds and packet sizes. It also requires additional hardware support (Krunz, *et al.*, 2004).

2.2 Power Control Protocols in Clustered Networks

Most of the previous studies assume that nodes have random layout, while nodes tend to be cluttered rather than to be distributed randomly. Nodes may be concentrated in some positions as in disasters or accidents. This type of placement represents a clustered layout. The clustered layout needs a special care due to the severe interference in dense subareas, and low connectivity and channel underutilization in sparse subareas (Yu, *et al.*, 2004). Several algorithms have been proposed for cluster formation while little work has been done for energy efficient clustered networks (Chiasserini, *et al*, 2004).

Authors in (Kwon and Gerla, 1999) try to get better channel utilization by using power control. When a uniform cell or cluster size is used, the available recourses will easily be exhausted if the area is densely populated. Kwon and Gerla (1999) try to control the number of nodes in the cluster to get better service. Clusterheads can increase/decrease their pilot transmission power and thus the physical cluster size.

A CH uses power control and adjusts its pilot to maintain proper cluster size. If the cluster has too many members (ordinary nodes and gateways), then the CH reduces its pilot signal to shrink the area of its cluster. On the other hand, if a cluster is isolated or has little connectivity, its CH increases the pilot to join more nodes (Kwon and Gerla, 1999).

This algorithm gives better services and avoids forming dense clusters with large members (Kwon and Gerla, 1999). In case that the cluster has little connectivity and the nodes to be added are distant from the CH, then the CH needs large power level to join these nodes and maintain a proper cluster size. Distant nodes also must use the same large power to communicate with their CHs. Using large power levels consumes more power and decreases the network lifetime.

Kawadia and Kumar (2003) propose multiple solutions for the power control and the clustering problems in non-homogeneous networks. They developed the COMPOW protocol to be applied on clustered Ad hoc networks. The goal is to use lower power levels for intra-cluster communications and higher levels only for communication with other clusters. One of the proposed solutions is a protocol implemented in the network layer called CLUSTERPOW. In CLUSTERPOW protocol, clusters do not have special nodes as CHs or GWs. The nodes communicate through any intermediate nodes. The route in CLUSTERPOW consists of multiple hops of different transmission power levels. The CLUSTERPOW algorithm uses the lowest transmission power level *p*, where *p* is chosen such that the destination is reachable by using multihops with power levels less or equal to *p*. The algorithm is executed for every packet at the source and every intermediate node until the destination (Kawadia and Kumar, 2003) and (Kawadia and Kumar, 2005).

Figure 5 shows an example for a route from Source (S) to Destination (D). The network has three levels of clustering with three power levels (1 mW, 10 mW and 100 mW). To send a packet from S to D, a power level of 100 mW is used until the packet reaches to N2. N2 and D belong to the same 10 mW cluster. A power level of 10 mW is used for the next hop until reaching the 1 mW cluster where the destination belongs. Finally, a 1 mW hop is used to get the packet to destination D (Kawadia and Kumar, 2003).

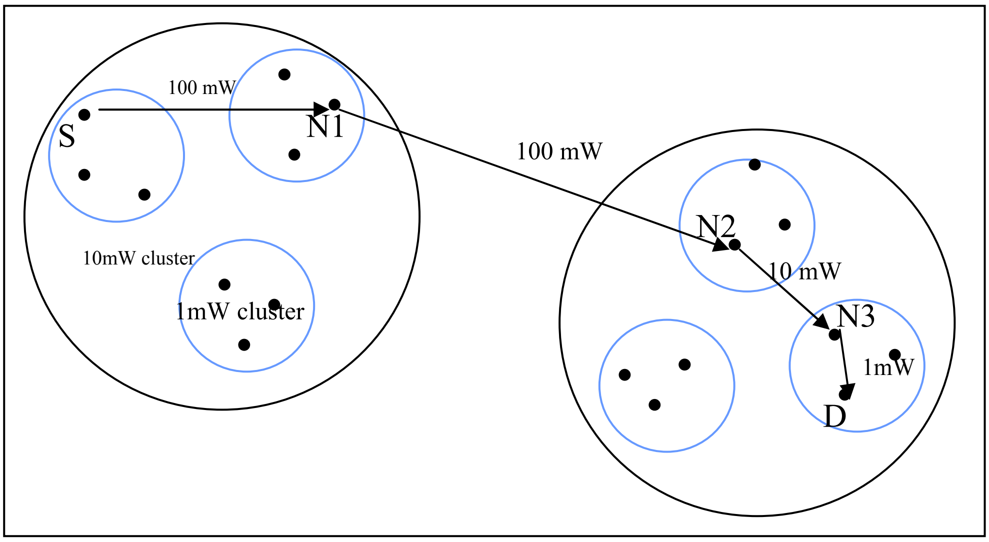


Figure 5. Routing by CLUSTERPOW in a typical non-homogeneous network (Kawadia and Kumar, 2003) and (Kawadia and Kumar, 2005)

This approach is a good solution to solve the problems of power control and clustering in non-homogeneous networks. On the other hand, the four-phase handshake of the IEEE 802.11 MAC protocol works fine only when using a common power. So, any power control approach which uses multiple power levels, at the same time, will have less throughput because of the MAC interference (Kawadia and Kumar, 2003).

Another solution for clustered layout is to use TPC and allow nodes to adjust their transmission power according to traffic intensity and node connectivity. This simple TPC mechanism creates *asymmetric links,* where one node A can reach node B, but B can not reach A. Due to this problem and to maintain symmetric links, most TPC protocols use variable radio power for data packets and transmit the control packets with the maximum power (Yu, *et al.*, 2004).

Authors in (Yu, *et al.*, 2004) proposed a *power-stepped protocol* (PSP) used to maximize the utilization of channels in clustered MANET by decreasing interference range of nodes. To avoid the harmful effect of the asymmetric links in clustered layout networks, the PSP protocol allows each node to choose the transmit power level in coordination with its neighbors. It also uses the same transmission radio power for control/data packets and does not need a frequent power adjustment. The PSP algorithm gives better performance in terms of average packet delay and packet delivery ratio compared with the Distributed coordination function (DCF), the basic medium access method in IEEE 802.11 (Yu, *et al.*, 2004).

Chiasserini, *et al* (2004) propose an Ad-hoc Network Design Algorithm (ANDA). ANDA is an energy efficient approach to prolong the lifetime of the clustered network by maximizing the lifetime of the CHs. It is based on adjusting the cluster size through using power control by CHs, and thus controlling the number of nodes in each cluster. Clusterheads exhaust their energy more quickly than other nodes. They are critical elements, and the network lifetime is related to CH failure. To prolong the CHs lifetime it is important to efficiently assign nodes to CHs. The cluster size is controlled by changing the CH transmission power level.

The ANDA algorithm improves the network lifetime and can be improved more by joining it with CHs' rotation. It is optimum if the scenarios are static and can be used for dynamic scenarios by using a rule to determine when a network reconfiguration is needed (Chiasserini, *et al*, 2004).

For better utilization of the resources, especially in the resource-limited networks, it is suitable to limit the number of nodes in the cluster (Venkataraman, *et al.*, 2007). Many researches limit the size of clusters with an upper threshold to avoid large energy consumption by CHs and get better management of resources inside the cluster. The next two sections describe two examples of these algorithms.

2.3 The Adaptive Broadcast Period algorithm

Gavalas, *et al.* (2006) propose an Adaptive Broadcast Period (ABP) algorithm which is an efficient cluster size management approach. The ABP algorithm limits the size of clusters with an upper threshold and forms moderate clusters which minimize message delays and minimize the overhead on CHs. To achieve efficient cluster size, each CH sends the number of its members with a 'Hello' message. If this number reaches the threshold, no more nodes can ask for the membership. Managing the cluster size guarantees balanced load among clusters and fair distribution of the resource consumption and data traffic.

2.4 Size-Restricted (SR) Cluster Formation and Cluster Maintenance Technique

It is a size-restricted strategy for the cluster formation and cluster maintenance for mobile ad hoc networks. It is based on *S–K tree-partitioning* algorithm that works in a distributed manner to avoid the single-point failure. Every node here is responsible for the clustering decisions (Venkataraman, *et al.*, 2007).

This algorithm uses two constraints. The first is the number of nodes per cluster which is the cluster size (*S*). The second constraint is the maximum hop in the cluster (*K*). K represents the maximum distance between any two nodes in the cluster (Venkataraman, *et al.*, 2007). We suppose K to be 2 in our experiments.

Figure 6 shows an example of this algorithm where node A tries to join a cluster and node B is a member of that cluster. To join a cluster, node A broadcasts a join request message (JReq) which contains its ID (represented in the figure by Message 1). Node A may get a join reply or a join reject (JRep/JRej) from the nodes within its transmission range (Message 2). If the nearby node is not able to accommodate due to the cluster size, then a reject message will be sent to node A. Otherwise, when node A receives join replies, it will join the cluster which has the lowest members in case of receiving more than one reply. Node A then sends a join accept message (JAcc) that contains its ID (Message 3) (Venkataraman, *et al.*, 2007).

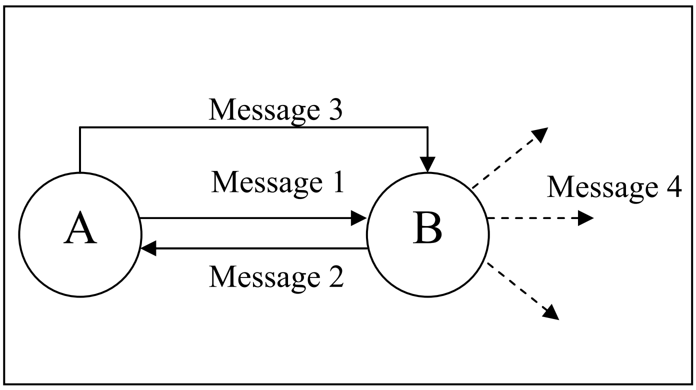


Figure 6. Node joining a cluster in SR algorithm (Venkataraman, *et al.*, 2007)

After node A joins the cluster, node B broadcasts a new node message (Message 4) to inform the members about the arrival of node A. All members then update the current size of the cluster (*n*c). When there are two concurrent nodes trying to join the cluster, and the size is only one less than *S*, then the node with lower ID is accepted and wins the contention. In case that A receives a reject message from all its nearby nodes, then A forms a new cluster of its own (Venkataraman, *et al.*, 2007).

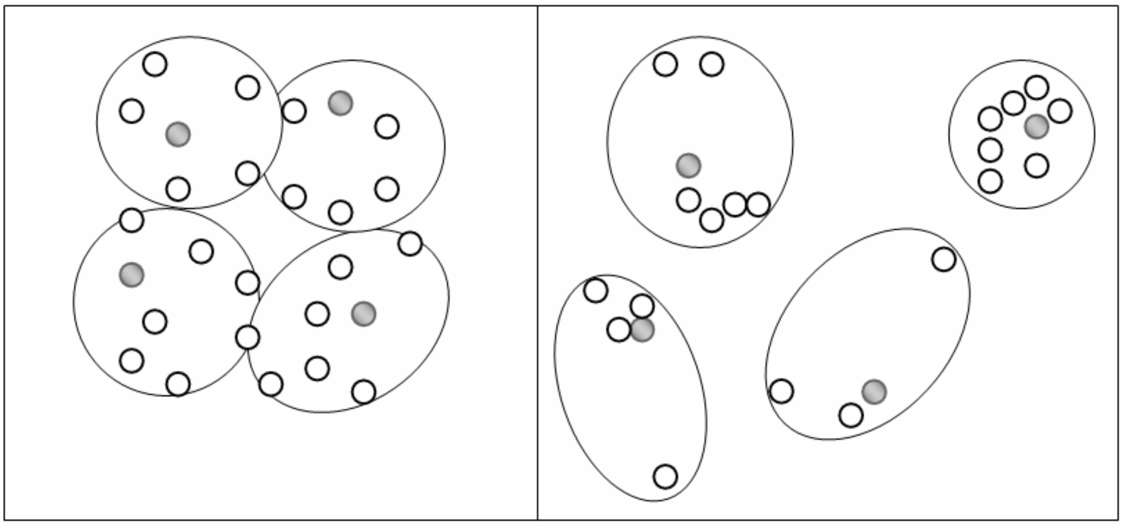
Because of using the size restriction, this algorithm gives better management of the cluster resources. The resources in each cluster will be shared by at maximum S nodes even if the number of nodes in the network increases. It also uses a cluster merging strategy to get less number of clusters (Venkataraman, *et al*., 2007).

In general, the algorithms which restrict the cluster size aim to better utilization of the resources. In case that the cluster has few members and the nodes to be added are distant from CH, then the CH needs large power level to join these nodes. Distant nodes also must use the same large power to communicate with their CH. Using large power levels consumes more power and decreases the network lifetime.

3. Power Efficient Clustering Distribution Algorithm

3.1 The Proposed Idea

The objective of Power Efficient Clustering Distribution (PECD) approach is to decrease the effect of Boundary Nodes (BNs) on power consumption. It considers the problem of power control when nodes are non-homogeneously spread in space. When nodes are homogeneously dispersed as in Figure 7 part (a) it is easy to choose common transmission power level or even cluster's size. But, when nodes are non-homogeneously distributed in space as shown in Figure 7 part (b), then the power level for CH (bold nodes) is hostage to the border nodes which are far from others.



(a) Homogeneous dispersion of nodes. (b) Non-homogeneous dispersion of nodes.

Figure 7: Homogeneous vs. Non-homogeneous clustered networks

Many algorithms, as SR algorithm, limit the size of clusters and avoid formation of big clusters, because big clusters increase the power consumption of CH, and cause a rapid exhaustion of its power. However, a cluster must join a distant node if other clusters reach the maximum allowed size. Distant nodes in clusters consume more energy to communicate with their CHs, which is not an energy efficient policy. In contrast, PECD decreases the power needed for this communication by joining these nodes to the closest cluster not to that with less members. Therefore, PECD decreases the power levels used by CHs and BNs, and thus increase the network lifetime and save the power consumption for all clusters.

3.2 Assumptions

The proposed approach has the following assumptions:

1. The network is divided to non-overlapped two-hop clusters to enable it to save power.
2. The number of nodes covered by the ad-hoc network is known.
3. CH can adjust its transmission power to determine its cluster size.
4. CHs communicate between each other using multi hops through Gateways. Using multi hops saves the power consumption compared with using single hop with large transmission power.
5. CHs exchange information with each other, such as the number of nodes in each cluster, and the power needed to communicate with border nodes.
6. Gateways choose their power to connect their clusters with others. They can use more power level than their cluster members unless it does not exceed the maximum power allowed for each node.
7. All ordinary nodes use the same power level, only BNs, Gateways and CHs can use more transmission power as needed. Clusterheads may need more transmission power than ordinary nodes to join the distant BNs. Also the BNs use the same power as their CHs.
8. Each node uses one transmission range for all transmissions.
9. The transmission power is chosen depending on the distance.

3.3 Algorithm Details

First each CH broadcasts an advertisement HELLO message with its maximum power and other nodes try to detect these messages. When nodes detect such signals they send back a HELLO message to those CHs in their power range. Each CH collects its information about these nodes in its range. It measures the reception power level for each message, and computes the number of nodes around it.

After exchanging the needed information between clusters, CHs decide to join or leave the BNs. Then each CH specifies its size by adjusting (increasing/decreasing) its transmission range to use only the strict necessary power. If the distant node is closer to one of the CHs and needs less power range for communication, then that CH increases the transmission power to reach and join this node, even if it will have more members than other CHs. On the other hand, other clusters shrink and reduce their signals to make the area of the clusters smaller and save their power.

Finally, each CH sends a join HELLO message to its members in its range to begin their transmission. To reduce energy consumption, each ordinary node uses power control to set the transmission power level based on the strength of the join message. Gateways also choose the power level needed to connect their cluster with adjacent clusters.

Figure 8 presents the proposed PECD algorithm for CH node u. In Step (1), a CH node u broadcasts an Advertisement HELLO Message (ahm) to all nodes in its transmission range. It uses the maximum power level to cover the farthest area as possible. Step (2) then examines whether there is a HELLO Message (hm) received from the ordinary node v. If it receives such a message, it measures the power level for that message to determine the distance of node v. Then it counts the number of nodes around it. After that in Step (3), each CH exchanges its collected information with others. In Step (4), CHs decide to join or leave the BNs based on the power levels needed to reach these nodes. The BN is joined to the closest CH which needs less power level to join that node. Each CH specifies its size by adjusting its transmission range to reach the selected nodes. If there are two CHs that need the same power level to reach one of the BNs, then the CH with fewer members will join it. Finally in Step (5), each CH sends a Join HELLO Message (jhm) to its members in its new power range to inform them that they now belong to that cluster.

```
Algorithm of Cluster Formation in PECD for CH u

/* hm: HELLO Message */
/* ahm: Advertisement HELLO Message */
/* jhm: Join HELLO Message */
(1) send ahm with u max power transmission range
(2)  if receive hm from other node v
       (2.1) measure the reception power
       (2.2) increment the cluster_size by one to calculate the number of nodes in u
             range
(3)  exchange information with other CHs
(4) adjust the transmission power to determine the size of the cluster
(5) send jhm to its members which are covered by the new power level

endif
End
```

Figure 8. PECD Algorithm used in each CH node for cluster formation

Figure 9 presents the proposed PECD algorithm used in each ordinary node for cluster formation. In Step (1), each ordinary node v examines whether there is an ahm received from any CH node u. If there is one, node v sends back hm for that CH as an acknowledgement. If the received message is jhm, as shown in Step (2), then the node now belongs to CH u. Node v will adjust its transmission range to that level needed to reach its CH u. Finally, the algorithm stops. Otherwise, the algorithm moves to Step (3) where node v will elect itself as CH and transmit the advertisement of being a CH to other nodes.

To clarify our approach, let us consider the following example in Figure 10. As shown in Figure 10 Cluster 1 minimizes its transmission range to hold 8 nodes, while

Cluster 2 increases its power to join the BNs (7 and 8). The goal is to decrease the total power consumption regardless of the number of nodes in each cluster. The algorithm does not take into consideration the power consumption of individual clusters, but the consumption of the whole network. Although Cluster 2 will consume more power than cluster 1, and the overhead on its CH will be more, but the total consumption will be better.

```
Algorithm of Cluster Formation in PECD for ordinary node v

/* hm: HELLO Message */
/* ahm: Advertisement HELLO Message */
/* jhm: Join HELLO Message */

(1)  if receive ahm from other CH node u
      (1.2) send hm to node u

(2) else if receive jhm from other node u
     (2.1) set u as CH
     (2.2) adjust transmission power by using the needed level to communicate with u
     (2.3)  exit
  (3) else v transmit its ahm

endif
End
```

Figure 9. PECD Algorithm used in each ordinary node for cluster formation

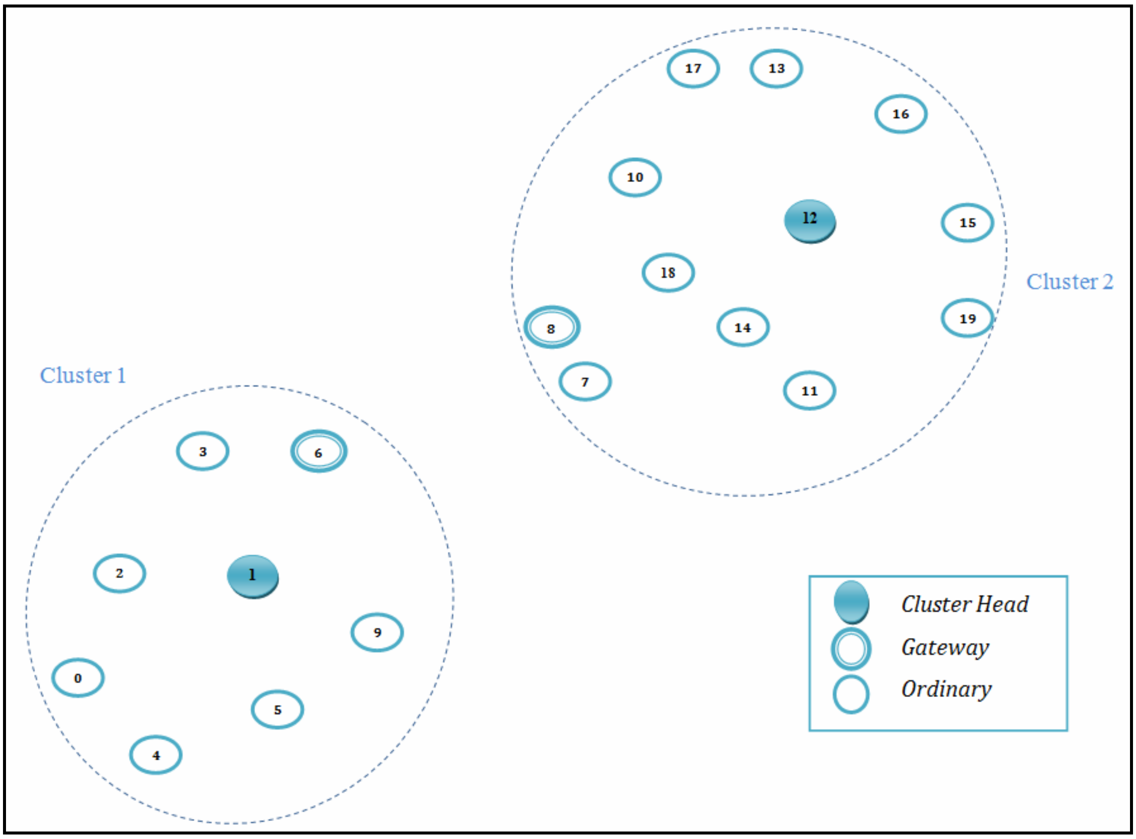


Figure 10. An example illustrates the proposed PECD approach

4. Experimental Environment

4.1 Overview

This chapter introduces the system and simulation environments. It includes the specification of the PC used in the experiments. It also describes the simulator which is used to simulate the different scenarios and get results. Energy model is also presented in this part. We begin with an introduction to the simulator, its power model, the changes that we add, the simulation parameters and finally the scenarios that have been implemented to compare the schemes in term of power consumption.

4.2 System Specifications

The experiments were evaluated using a notebook PC. The following table presents the system specifications.

Table 2. System specifications

Item	Value
Processor	Intel Core Duo CPU 1.83GHz
System Model	HP 530 Notebook PC
Memory (RAM)	1015MB
OS Name	Microsoft Windows Vista Business

4.3 Simulator's Overview

The performance of PECD algorithm is evaluated through simulation using Global Mobile Information System Simulation Library (GloMoSim) simulator. GloMoSim is a library for simulating wired and wireless networks; it is designed to support specific wireless communication protocols (Zeng, *et al.*, 1998). And it is a scalable simulation environment that uses parallel execution to reduce the simulation time (Bajaj, *et al.*, 1999). More information about GloMoSim is provided in the appendix.

4.4 Simulation's Parameters

The simulation Parameters are summarized in Table 3. The table presents the general parameters used in all experiments. The additional parameters that used in each scenario will be described later. The first scenario uses the two application layer protocols: FTP/GENERIC and CBR as traffic generators. The other two scenarios use only the first protocol. The selection of these two protocols is suitable because they allow us to specify the packet size.

Table 3. Simulation Parameters

Parameter	Value
Area	1200 x 1000 m
Node placement	Clustered way
Node mobility	None
Traffic Generator	FTP/GENERIC and CBR
SEEDs	1-5
Routing protocol	Static

All the nodes contend to send their packets to random destinations. There is no certain source or destination, they are chosen randomly. To get more accurate results each experiment was repeated five times with five different SEEDs (1 to 5). The SEED represents a random number used to initialize various random numbers in the simulation such as the delay time before broadcasting packets (Nuevo, 2004). The confidence level is 90% in all experiments.

4.5 Power Consumption Model:

Nodes in the wireless ad hoc networks can be in one of the following four states:

- Transmit: the mode in which the node is transmitting a packet with transmission power *Ptransmit*.

- Receive: when node is receiving a packet with reception power *Preceive*, even if the packet is not intended to this node.
- Idle (listening): node keeps listening to the channel to detect signals with power *Pidle*, even when there is no message being transmitted.
- Sleep: when the node can not detect radio signals or when the radio is turned off (Mahfoudh and Minet, 2008).

Network simulators implement these modes in different ways. In the GloMoSim simulator, the energy consumption model is implemented in the physical layer. It defines four radio modes which are: transmitting (TX), receiving (RX), sensing and idle modes. In sensing mode, the node detects some signals, but it is not able to receive them. Figure 11 shows the main radio states and how the state transition occurs (Margi and Obraczka, 2004).

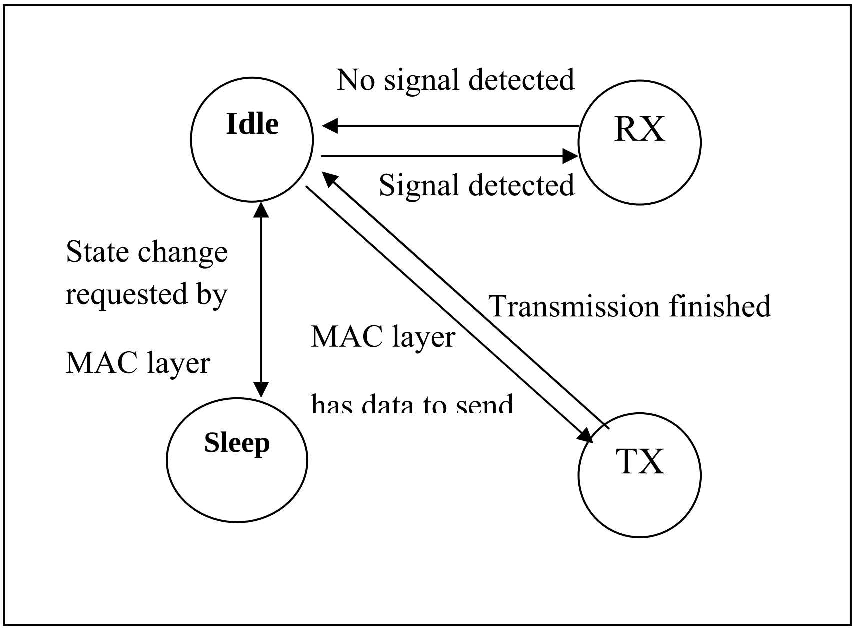


Figure 11. State diagram for radio modes (Margi and Obraczka, 2004)

The power consumption model in GloMoSim can be summarized by the following equation:

$$\text{Power\_Consumption} = Etrans + (simulatinTime \times Preceive), \qquad (1)$$

where *Etrans* is the consumed power dissipated in transmitting packets, and *Preceive* is the *receiving power* used by nodes in the receiving mode.

The consumed power is evaluated by two steps. First, the simulator computes the consumed power for transmitting the packets (*Etrans*). Then it multiplies the simulation time by the receiving power (*Preceive*) and adds the result to the *Etrans.* It assumes that the nodes are sensing all the time, even if there is no transmission, and that the sensing state consumes the same value as receiving. This is the reason for multiplying the simulation time by the cost of being in RX mode, so the node is either transmitting or receiving. This means that the model does not distinguish between RX, sensing and idle states (Margi and Obraczka, 2004).

This model does not give the accurate value of power consumption. First, it does not evaluate the power consumed by each node. Second, it does not give us how much the node spends in each mode and thus the power consumed in each mode. Finally, it does not consider the different powers used by nodes in each mode (Margi and Obraczka, 2004). Consequently, we add some changes to the simulator to compute the power consumption for each node in each mode. The idea is to determine the duration a node spends in each mode and multiply it by the power needed by that mode.

Different equations are used to compute the power consumption in each mode. For the transmitting mode, we use the same equation used in GloMoSim because it implements a useful equation that depends on the transmission power level (txPower). Using this equation enables us to change the power level and choose different levels for nodes. That is an important issue in our research since gateways and CHs may need different power levels from ordinary nodes.

The consumed power dissipated in transmitting mode is evaluated as follows:

$$Etrans = txDuration \times \begin{pmatrix} (BATTERY\_TX\_POWER\_COEFFICIENT \times txPower) + \\ BATTERY\_TX\_POWER\_OFFSET \end{pmatrix}, (2)$$

where:

- *BATTERY_TX_POWER_COEFFICIENT* = 16.0 / SECOND.
- *BATTERY_RX_POWER* = *BATTERY_TX_POWER_OFFSET*= 900mW.
- *txPower*: is proportional to the distance that the signal supposed to travel (Margi and Obraczka, 2004). In our experiments, nodes may use different power levels as they need in cluster formation. The power needed for each node will be described in each scenario.
- *txDuration*: denotes the transmission duration of a packet (Margi and Obraczka, 2004).

BATTERY_TX_POWER_OFFSET and *BATTERY_TX_POWER_COEFFICIENT* values are defined statically based on the WaveLAN specifications (Margi and Obraczka, 2004).

Other modes are evaluated by the equations used by (Mahfoudh and Minet, 2008). The consumed power dissipated in the receiving mode is evaluated as follows:

$$Ercv = Preceive \times Duration, \qquad (3)$$

where *Preceive* represents the receiving power, and *Duration* is the transmission duration of a packet (Mahfoudh and Minet, 2008). The following two equations evaluate the consumed power dissipated in sensing and idle modes:

$$Esen = Psense \times Duration, \qquad (4)$$

$$Eidle = Pidle \times Duration, \qquad (5)$$

where *Psense and Pidle* represent the sensing and idle powers (Mahfoudh and Minet, 2008).

Table 4 reports the values of *Preceive*, *Psense* and *Pidle* taken from a Lucent Wavelan Gold PC card.

Table 4. Power value in each radio state

Power state	Value (mW)
Receive	180
Sense	140
Idle	18

The power consumed by each node v_i for each transmitted packet is evaluated by equation (6):

$$Power\_Consumption\ (v_i) = Etrans + Ercv + Esen + Eidle, \qquad (6)$$

where $1 \leq i \leq n$, and n is the number of nodes in the network.

Finally, the total power is evaluated by taking the sum of all power consumed by all nodes for all transmissions. The total power consumed by the network is computed as following:

$$Total\_Power = \sum_{i=1}^{n} Power\_Consumption(vi), \qquad (7)$$

4.6 Simulation Scenarios:

This section describes the three scenarios used to compare the proposed PECD algorithm with SR algorithm. The first scenario compares the two algorithms in general. The second scenario shows different states of the network with different numbers of BNs. The last one presents different placements of BNs.

4.6.1 First Scenario

This scenario consists of 40 nodes placed in area between (0, 0) and (1200, 1000) meters. As shown in Figure 12 we consider the distant nodes (dashed nodes) as BNs.

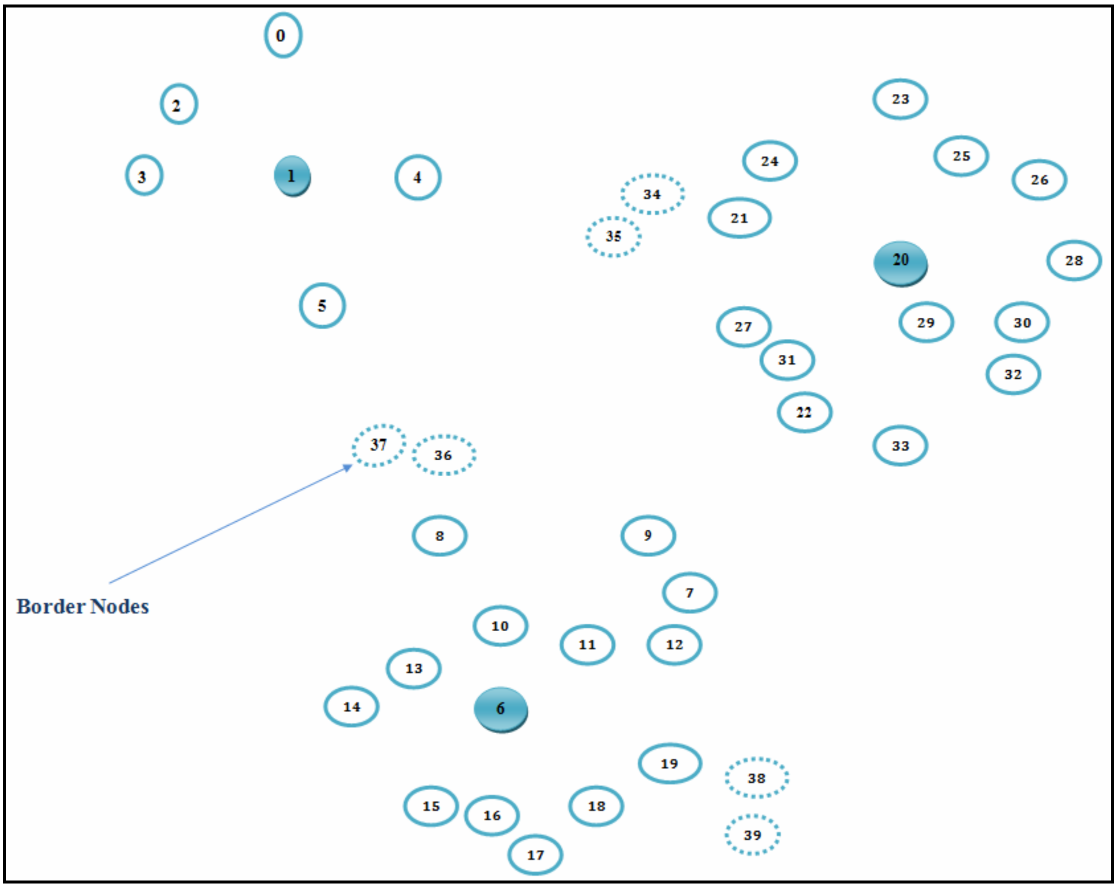


Figure 12. The network state for scenario1 before clustering

Suppose that we have three CHs (bold nodes), there are two ways to distribute the BNs between them. The first is when these nodes are joined to the smallest cluster size, and the second when nodes are joined to the closest cluster.

First algorithm: Size Restricted (SR) Algorithm

This algorithm use a size restricted strategy that limits the number of nodes inside a cluster. If we suppose that the maximum cluster size is 14 nodes, then the formation of the three clusters will be as shown in Figure 13. The figure shows that CH2 (node 6) can not join any BN to its cluster because it has the maximum number of nodes (14 nodes). Clusterhead3 (node 20) also adjusts its transmission range to join the closest 14 nodes. In contrast, CH1 (node 1) increases its range to have a proper number of members including nodes 34, 35, 36 and 37. Because none of the clusters can join nodes 38 and 39, they form a new cluster and choose one of them as a CH. In this case CH1, CH2, CH3 and CH4 have respectively 10, 14, 14 and 2 members.

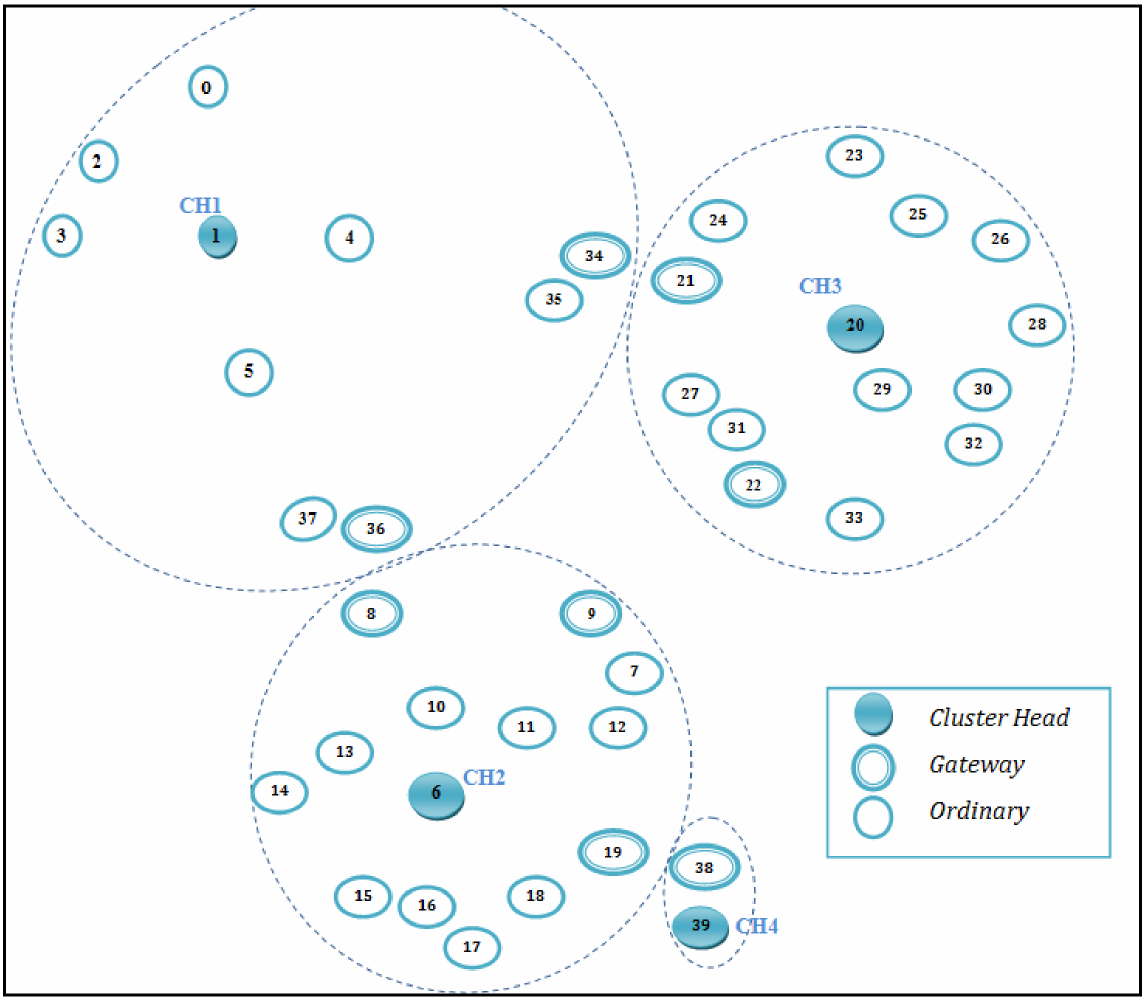


Figure 13. Scenario1 using SR algorithm

As discussed before CHs may need different power levels to form their clusters. Clusterhead1 and part of the BNs (34, 35, 36, and 37), need to use more radio power level than other nodes (CH2, CH3, CH4 and Ordinary nodes). This means that these nodes will consume more power in their communication, especially CH1 because of its responsibility towards its members.

Second algorithm: Efficient Clustering Distribution (PECD) Algorithm

In the proposed algorithm, the BNs are joined to the closest CH which needs less power range to cover them. First, nodes 36, 37, 38 and 39 are added to CH2 (node 6), so node 6 increases its range to join these four nodes even if it will exceed the maximum number of nodes. Clusterhead3 (node 20) also do the same and expands its transmission range to join nodes 34 and 35. In contrast node 1 shrinks its transmission range to have only 6 nodes. This situation is presented in Figure 14.

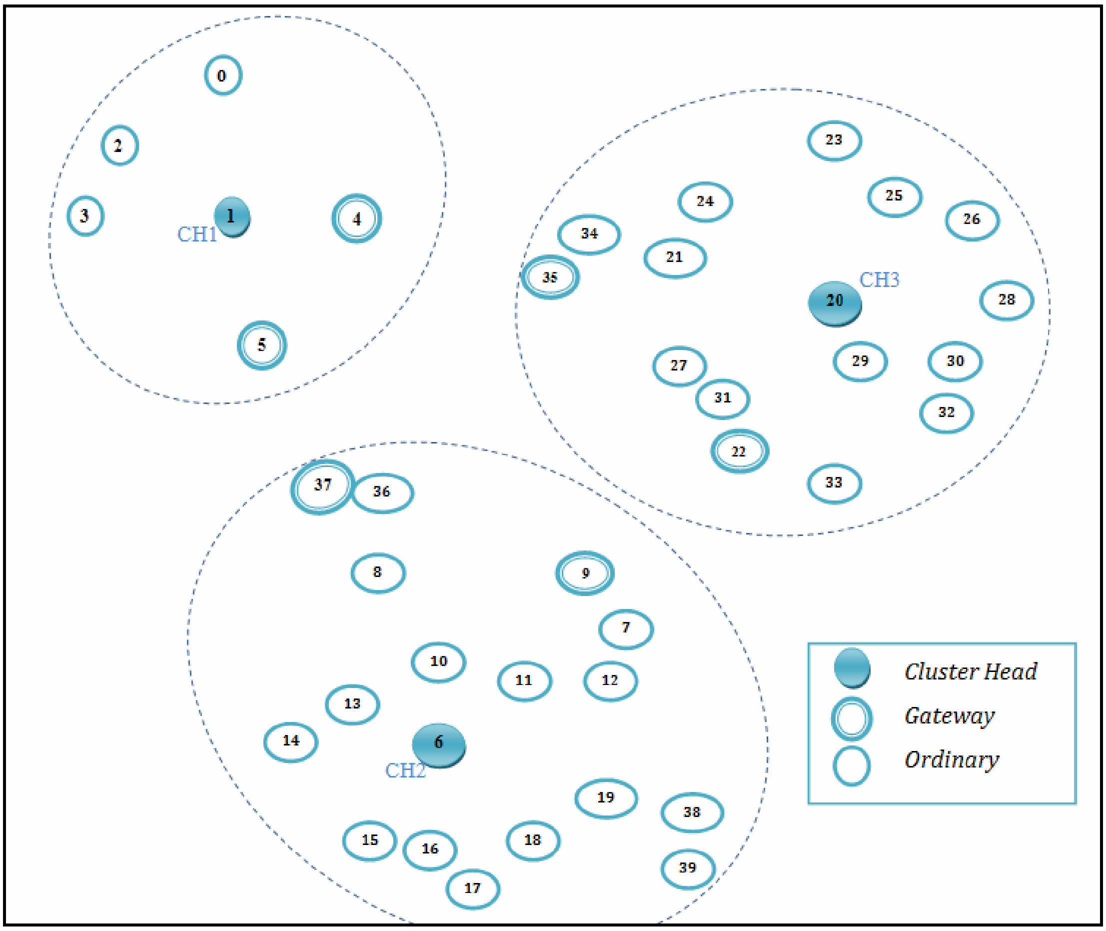


Figure 14. Scenario1 using the proposed PECD algorithm

It is clear from Figure 14 that the power levels used in this case are different from the previous algorithm. Because CH2 and CH3 ranges have been expanded to join the BNs, they need more transmission power range than CH1 and Ordinary Nodes. The BNs also must use the same power to reach their CHs.

Scenario Parameters:

The scenario is evaluated for different simulation time and different numbers of packets (10, 500, 1000 and 5000) to change the traffic rate. Different sizes of packets are also used to note its effect on the results. Additional parameters for this scenario are listed in Table 5.

Table 5. Scenario1 Parameters

Parameter	Value
Number of nodes	40 nodes
Simulation Time	5,10,15,20 and 25 minutes
Traffic Generator	FTP/GENERIC and CBR
Number of Data Packets	10,500,1000 and 5000
Packet size	500, 1000, 1500 and 2000 bytes
Maximum cluster size	14

4.6.2 Second Scenario: Different Numbers of BNs

This scenario shows different states of the network with different numbers of BNs. The scenario consists of 20 nodes placed in area between (0, 0) and (1200, 1000) meters. As shown in Figure 15, the first state of the network has one distant node (the dashed node). Suppose that we have two CHs (the bold nodes), there are two ways to distribute the nodes between them.

First algorithm: Size Restricted (SR) Algorithm

If we restrict the maximum number inside the cluster to be 10 nodes, then the formation of the two clusters will be as shown in Figure 16. Clusterhead2 (node 12) can not join the boundary node 8 with its cluster, so it adjusts its transmission range to join the closest 10 members. In contrast, CH1 (node 1) increases its transmission range to join node 8 and have 10 members. Each cluster now has the same size (10 nodes) which is the maximum number of nodes allowed in each cluster. It is clear from the figure that node 1 needs more power level than node 12 to join the distant node 8.

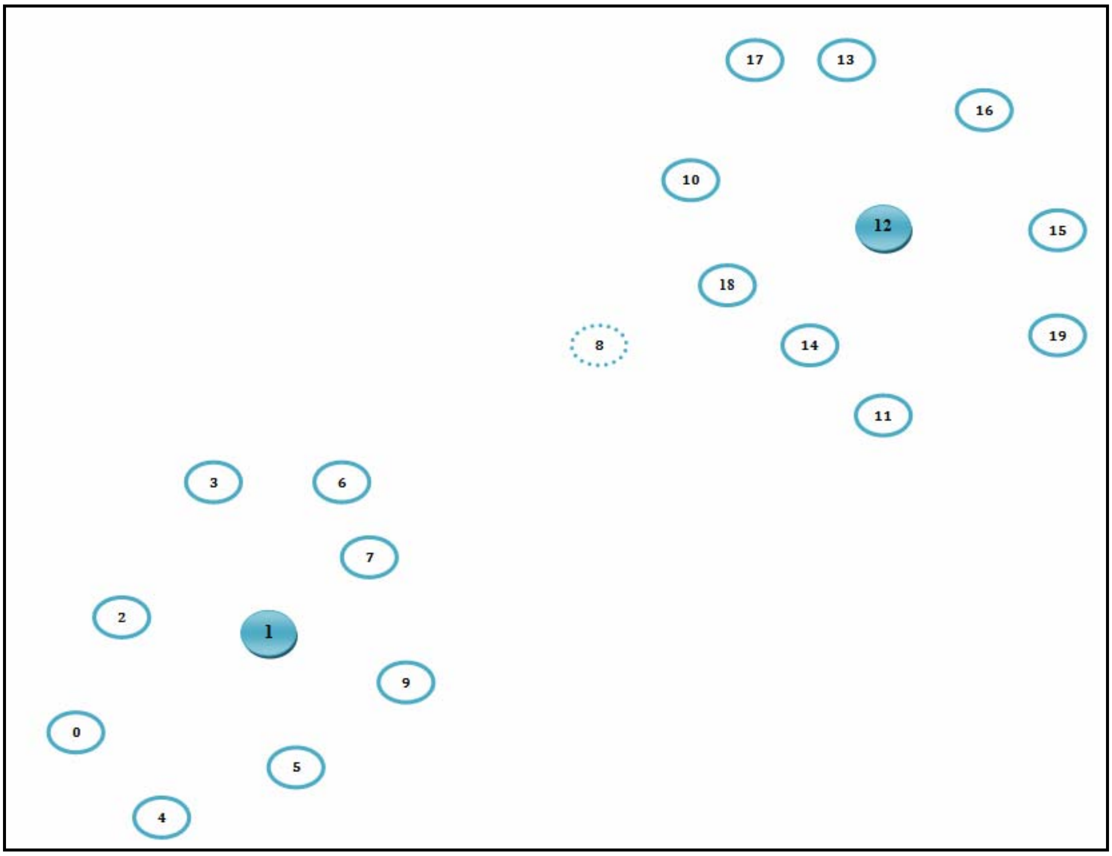


Figure 15. The network before clustering with one boundary node

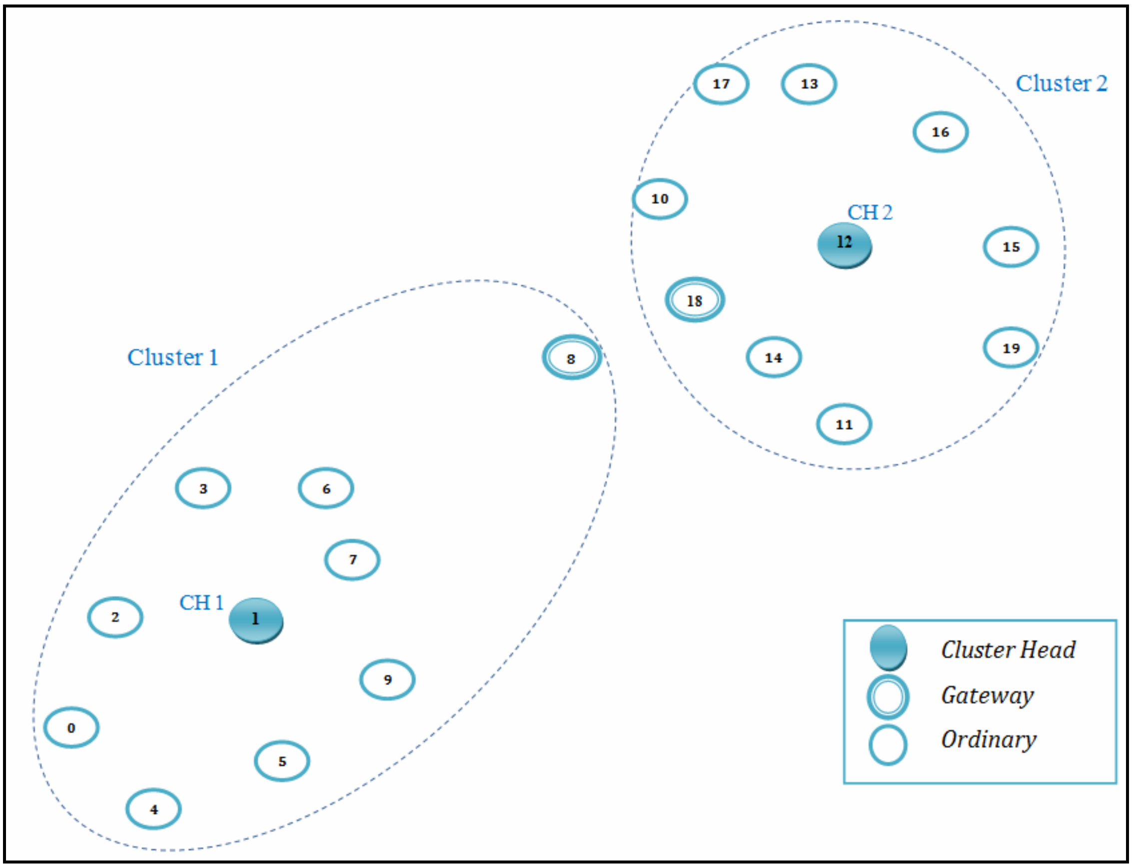


Figure 16. Scenario2 using SR algorithm

Second algorithm: Efficient Clustering Distribution (PECD) Algorithm

In the proposed algorithm node 8 is joined to the closest CH which needs less power range to cover it, so CH2 joins node 8 and exceeds the maximum number of nodes to have 11 nodes. In contrast CH1 (node 1) shrinks its transmission range to have 9 nodes. This situation is presented in Figure 17. The power levels used in this case are different from the previous algorithm. Clusterhead2 and node 8 use more transmission power range than the rest of nodes: CH1 and Ordinary Nodes.

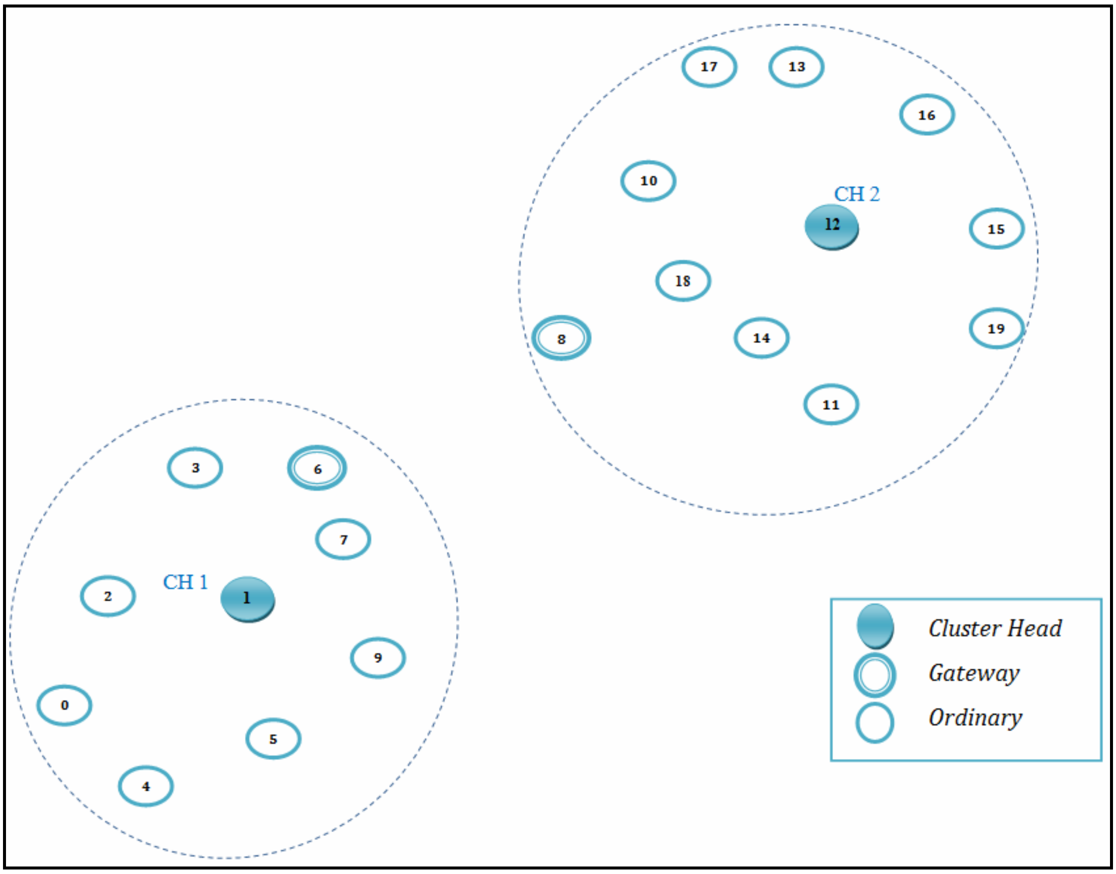
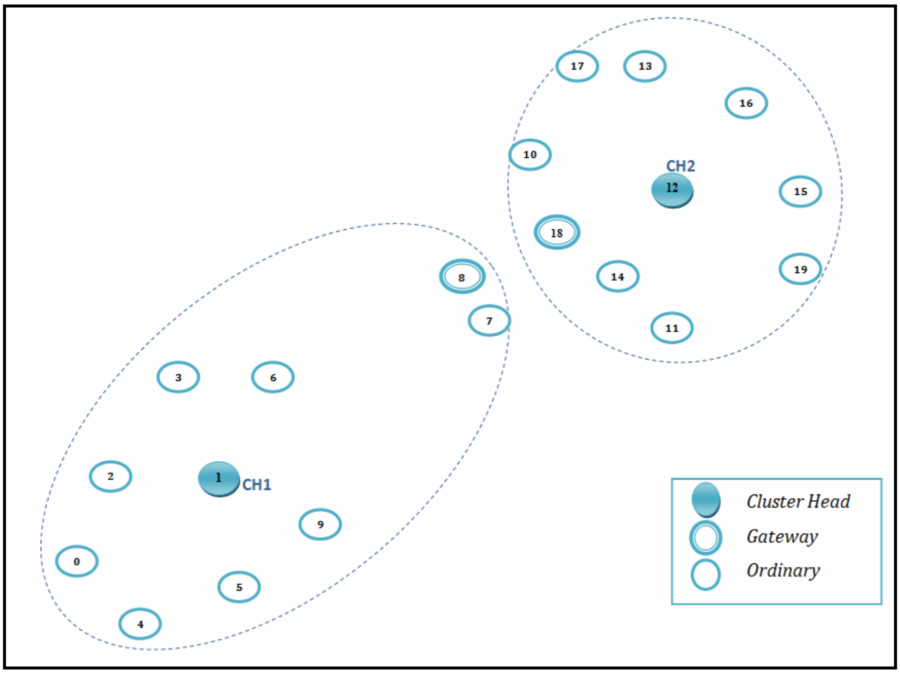
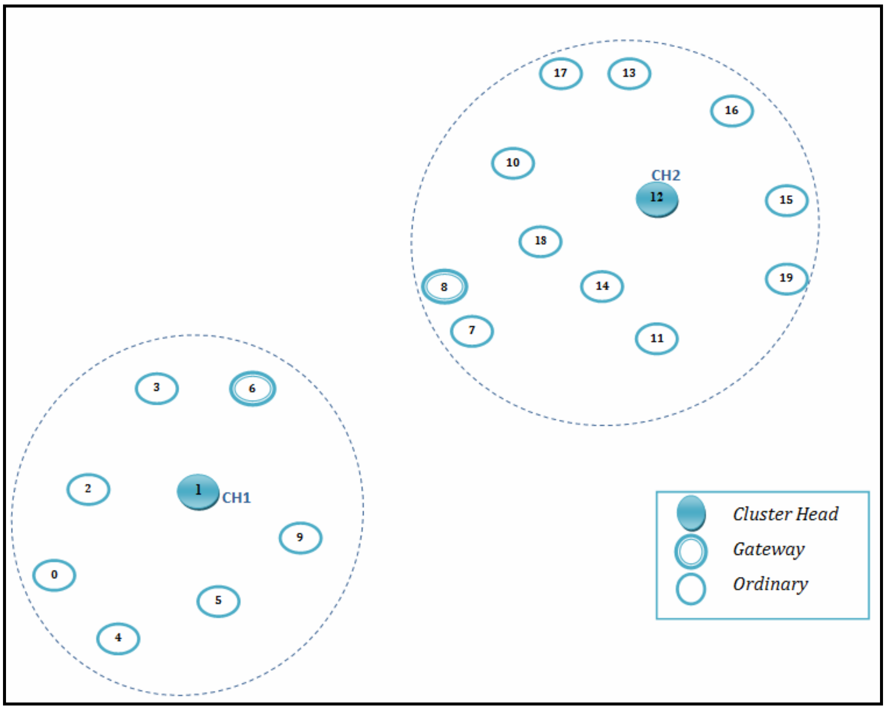


Figure 17. Scenario2 using the proposed PECD algorithm

The following four figures (Figure 18, Figure 19, Figure 20 and Figure 21) show the network states when the number of BNs is increasing. The network in Figure 16 and Figure 17 has one boundary node while Figure 18 shows the network with two BNs. The two cases of clustering are shown in the figure. The power levels needed in this case for the two algorithms are the same as in one boundary node. The only difference is that node 7 here is also a boundary node and uses the same power as node 8. In part (a) the result of cluster formation leads to even number of members for the two clusters which are 10 nodes. In part (b), when the proposed PECD algorithm is used, the two clusters have different sizes: 8 and 12 nodes.



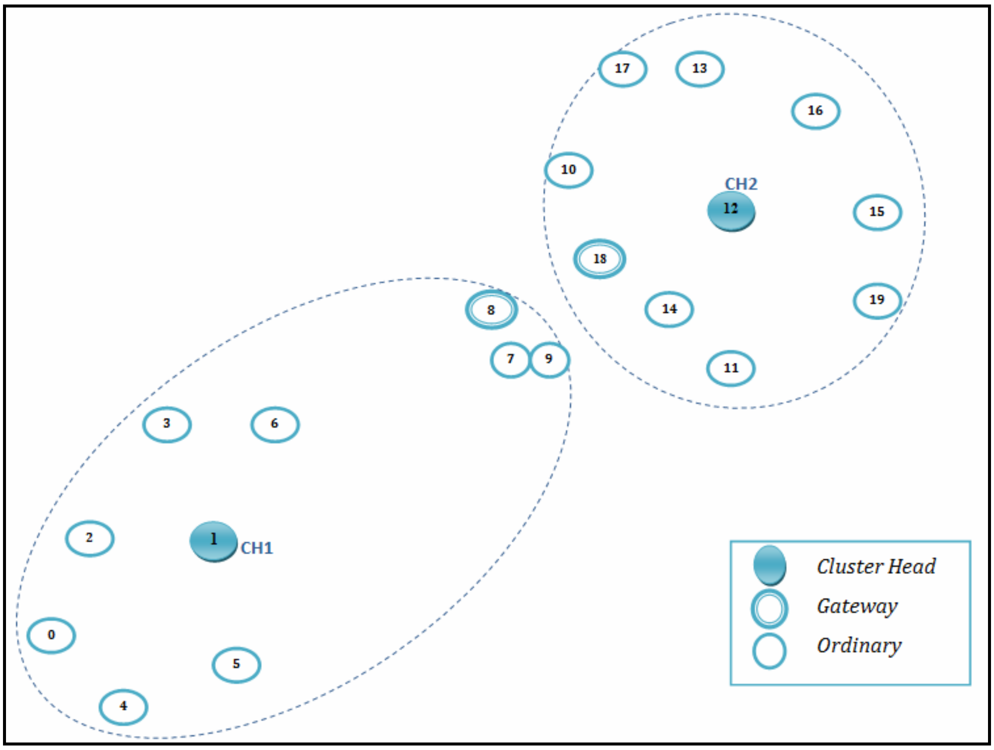
(a) SR algorithm



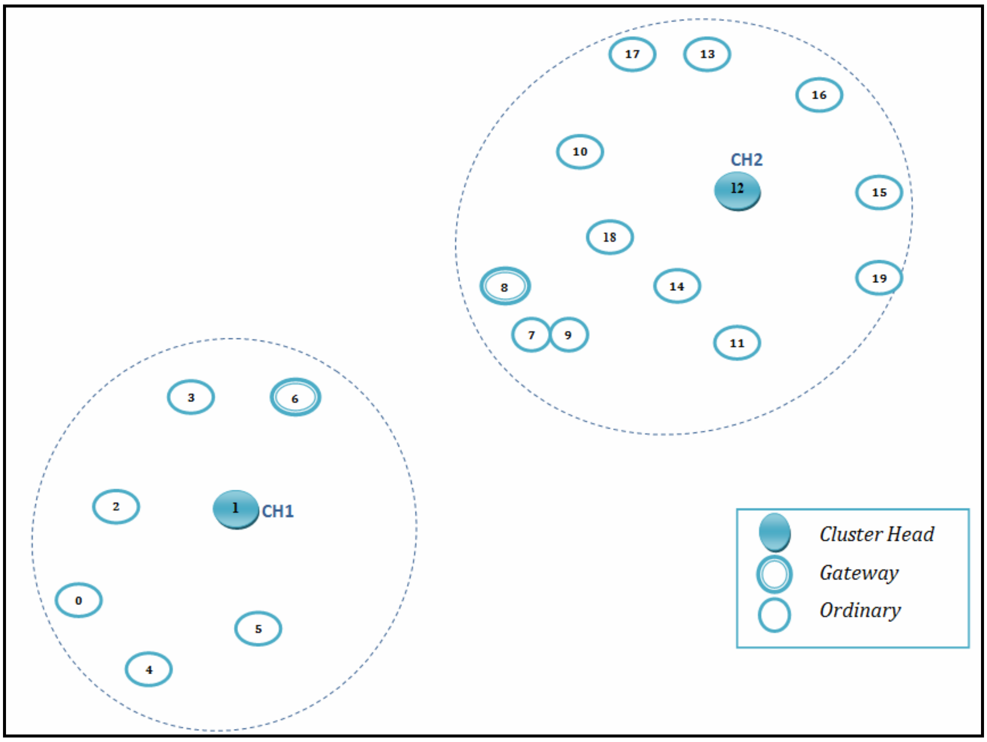
(b) The proposed PECD algorithm

Figure 18. Two Boundary Nodes

Figure19 Shows the third case for this scenario when it has three BNs. In part (a) also the clusters have even sizes, but in part (b) cluster 1 has 7 members while cluster 2 has 13 nodes.



(a) SR algorithm



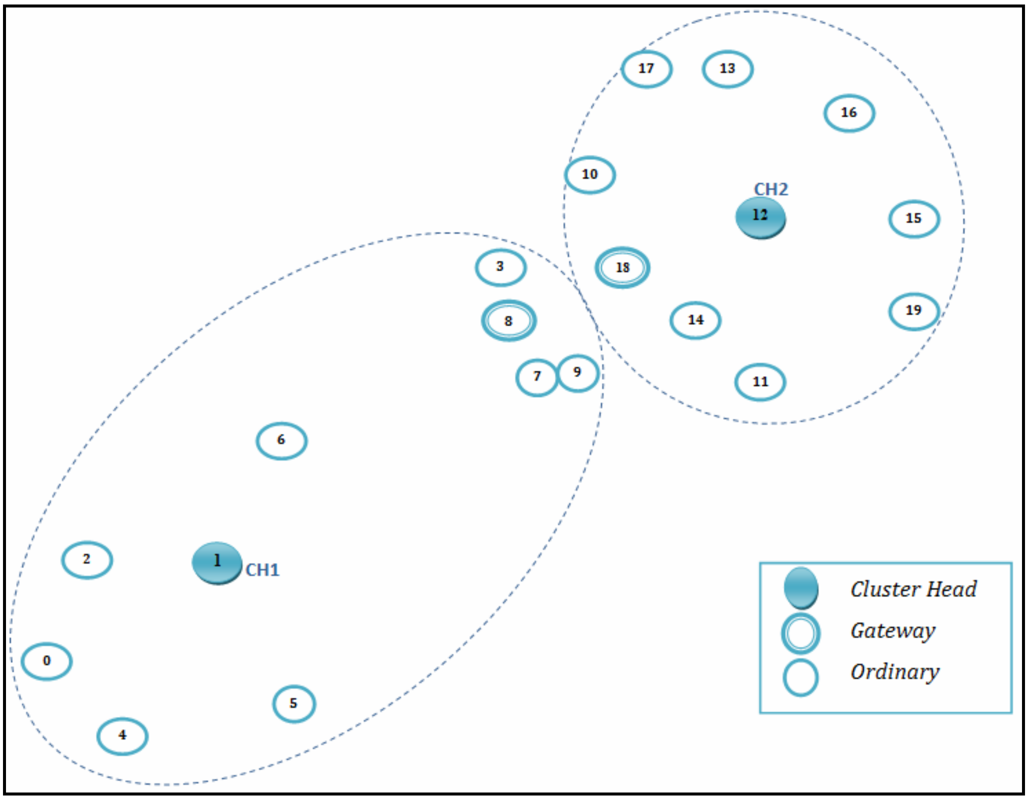
(b) The proposed PECD algorithm

Figure 19. Three Boundary Nodes

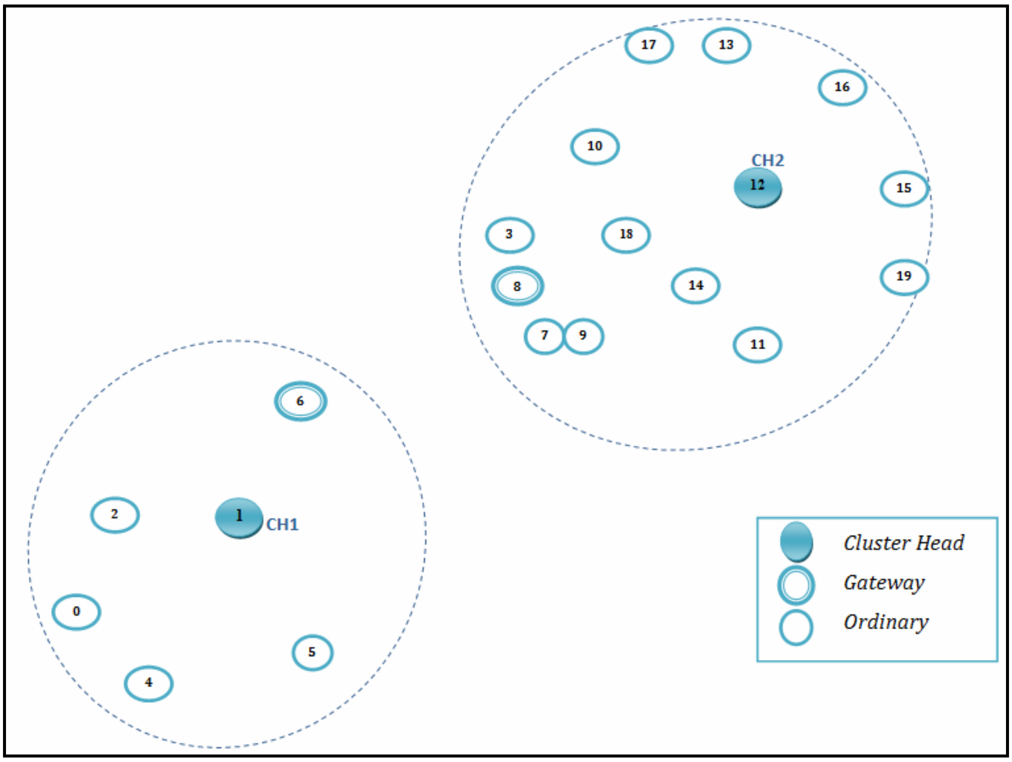
In case of having 3 BNs, the power needed for cluster formation is different from the previous two cases (Figure 17 and Figure 18). As it is shown in Figure 19 part (a), the third BN 9, is farther from CH1 than nodes 7 and 8. In SR algorithm, node 1 needs more power level to join node 9. In part (b), CH2 must use more power level than CH1.

The next case is when BNs increase to be four nodes. This situation is illustrated in Figure 20. The network now has four BNs (3, 7, 8 and 9). In part (a) the clusters have even number of members. In part (b) when the proposed PECD algorithm is used the two clusters have different sizes, 6 in the first cluster and 14 in the second. The power needed for cluster formation is the same as in the previous case; taking into account that node 3 here is a boundary node and it uses the same power levels as boundaries in case three (Figure 19).

The last case is when the network has five BNs (3, 5, 7, 8 and 9). The two possible approaches for cluster formation are shown in Figure 21. Part (a) shows an even distribution of clusters with 10 members for each cluster. Part (b) has two clusters with different sizes 5 and 15. The power levels used in this case are the same as the previous two cases (Figure 19 Figure 20).

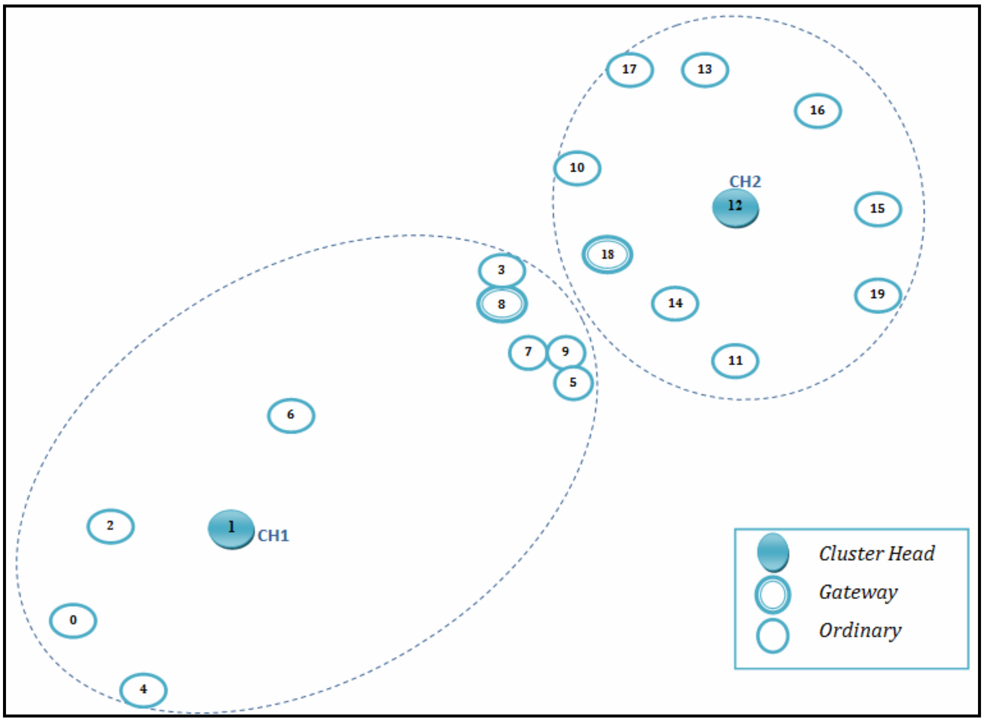


(a) SR algorithm

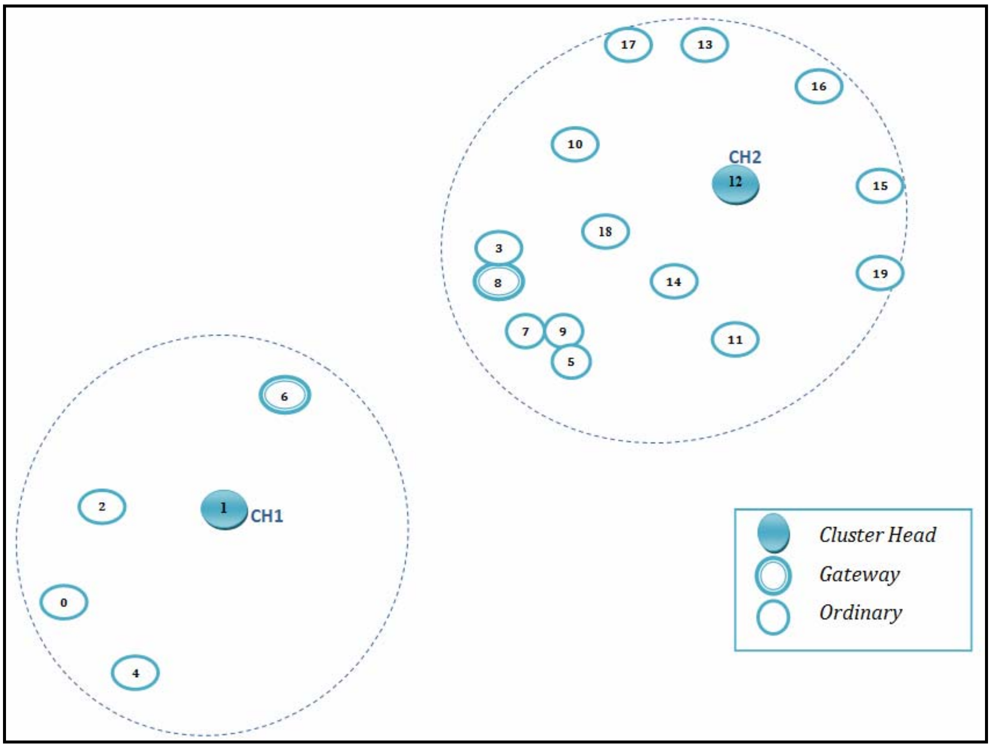


(b) The proposed PECD algorithm

Figure 20. Four Boundary Nodes



(a) SR algorithm



(b) The proposed PECD algorithm

Figure 21. Five Boundary Nodes

Scenario Parameters:

The main parameter in this experiment is the number of BNs. The scenario is evaluated for different numbers of BNs: one, two, three, four and five nodes. Additional parameters for this scenario are listed in Table 6.

Table 6. Scenario2 Parameters

Parameter	Value
Number of nodes	20 nodes
Simulation Time	15 minutes
Traffic Generator	FTP/GENERIC
Packet size	1460 bytes
Maximum cluster size	10

4.6.3 Third Scenario: Different placements for BNs

This scenario shows different states of the network with different placements of the BNs. The scenario consists of 20 nodes placed in area between (0, 0) and (1200, 1000) meters. Figure 22 shows the first placement of the five BNs (dashed nodes).

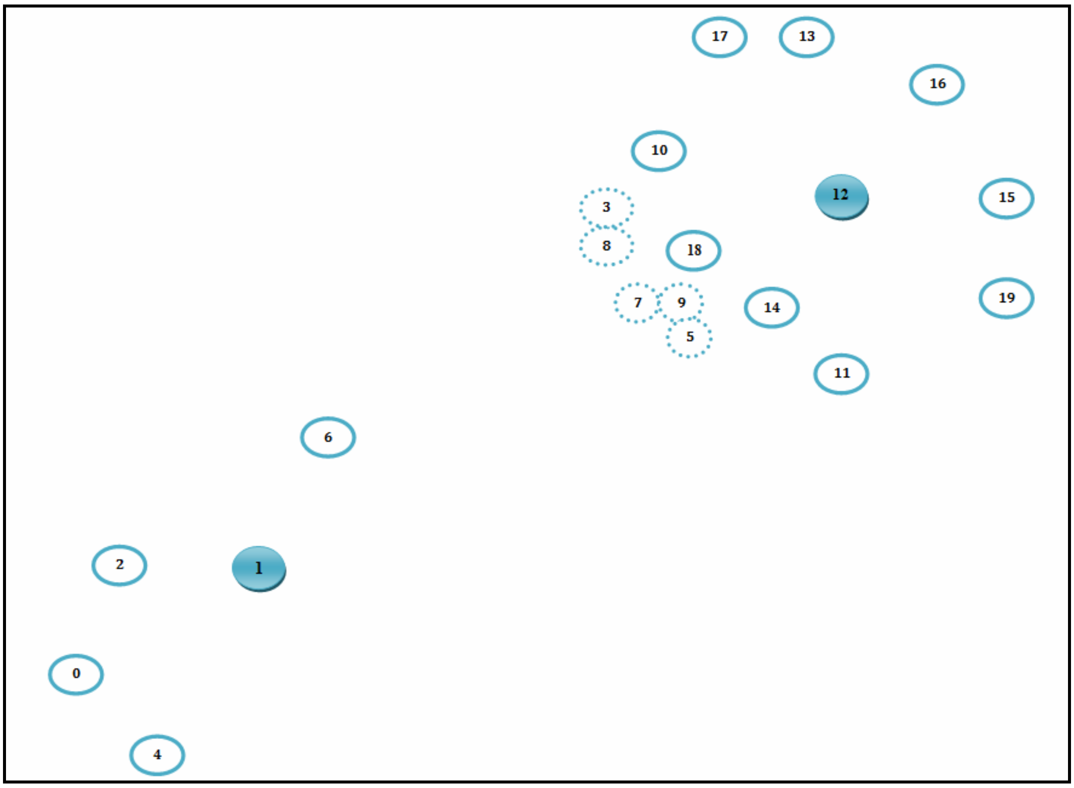


Figure 22. The network before clustering with five boundary nodes

Suppose that we have two CHs (bold nodes), there are two ways to distribute the BNs between them. The first is when these nodes are joined to the smallest cluster size, and the second when nodes are joined to the closest cluster.

First algorithm: Size Restricted (SR) Algorithm

If we restrict the maximum number inside the cluster to be 10 nodes, then the formation of the two clusters will be as shown in Figure 23. Clusterhead2 (node 12) can not join any of the BNs, it adjusts its transmission range to join the closest 10 members. In contrast, CH1 (node 1) increases its range to join all the BNs and have 10 members. Each cluster now has the same size (10 nodes) which is the maximum allowed number of nodes.

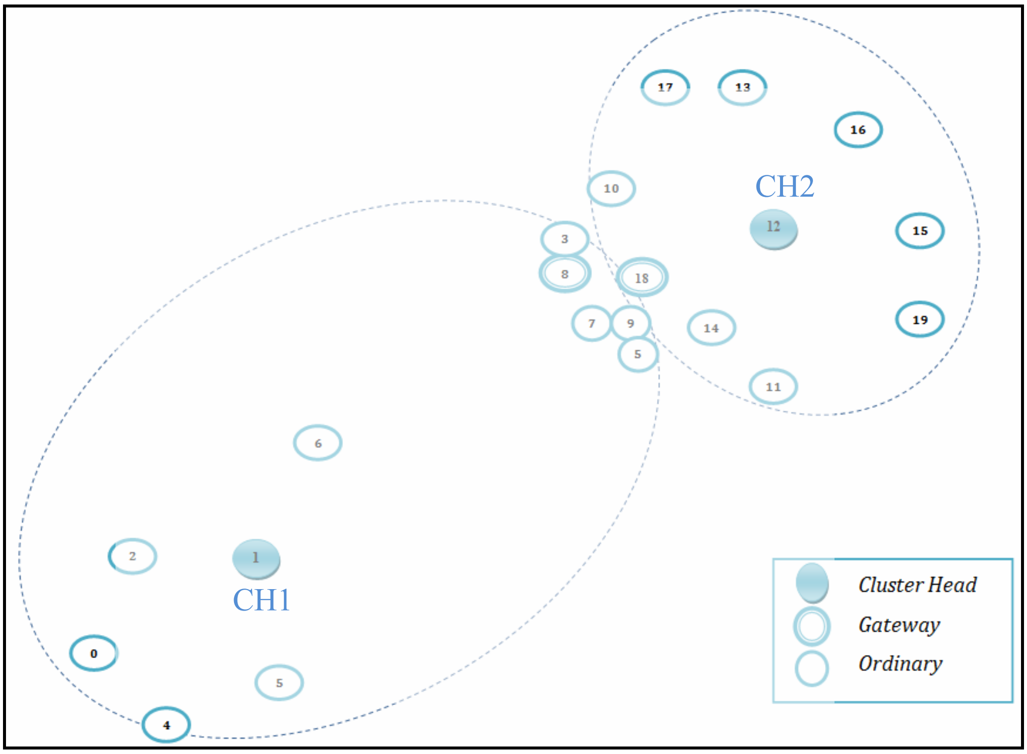


Figure 23. Scenario3 using SR algorithm

It is clear from the figure that node 1 needs more power level to join the BNs than node 12. The transmission power level used by CH1 and all BNs is more than the power level used by other nodes (CH2 and ordinary nodes).

Second algorithm: Efficient Clustering Distribution (PECD) Algorithm

In the proposed algorithm all the BNs are joined to the closest CH which needs less power range to cover them. Clusterhead2 joins the BNs and exceeds the maximum number of nodes to have 15 nodes. In contrast CH1 (node 1) shrinks its transmission range to have only 5 nodes. This situation is presented in Figure 24.

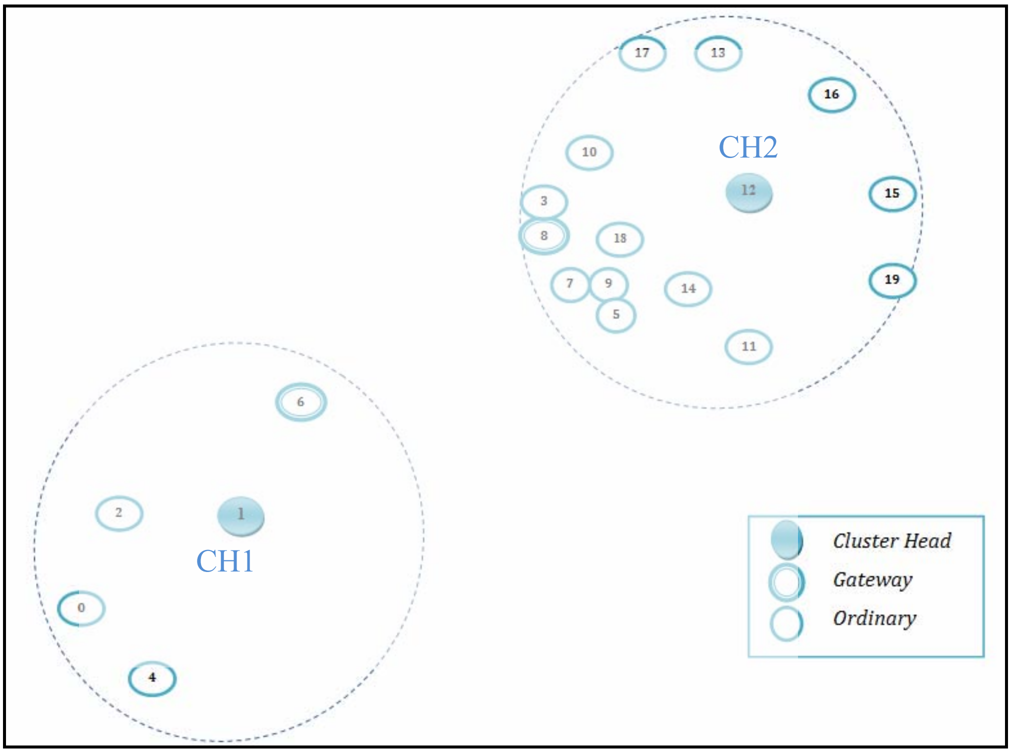


Figure 24. Scenario3 using the proposed PECD algorithm

The power levels used in this case is different from the previous algorithm. Clusterhead2 and BNs (3, 5, 7 and 9) use more transmission power range than CH1 and Ordinary Nodes. In this case, the gateways (nodes 6 and 8) need more power level than other nodes to connect the two clusters. The GWs can use more power level than their CHs if the used power does not exceed the maximum power range allowed for each node (determined before). Otherwise, the two clusters will remain unconnected.

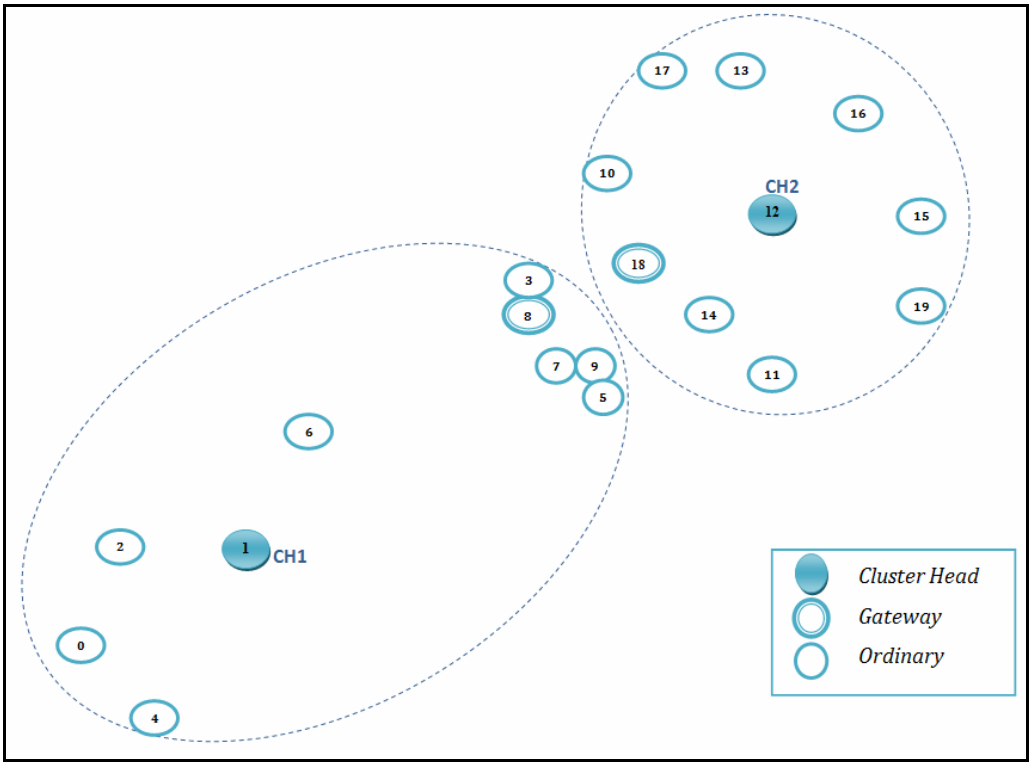
Table 7 summarizes the five cases with different five distances. Each value in the table represents the average of five different distances, one for each boundary node. In each case the BNs are moved by 67m on average. Each node is moved towards CH1 by 50m in x-axis and by 50m in y-axis. In table 7, the second column lists the average distances between the BNs and CH1 (node 1). The last column lists the average distances between BNs and CH2 (node 12). In the first two distances (1 and 2), the BNs are closer to CH2 than to CH1. In the other three cases they are closer to CH1.

Table 7. Average distances between BNs and CHs

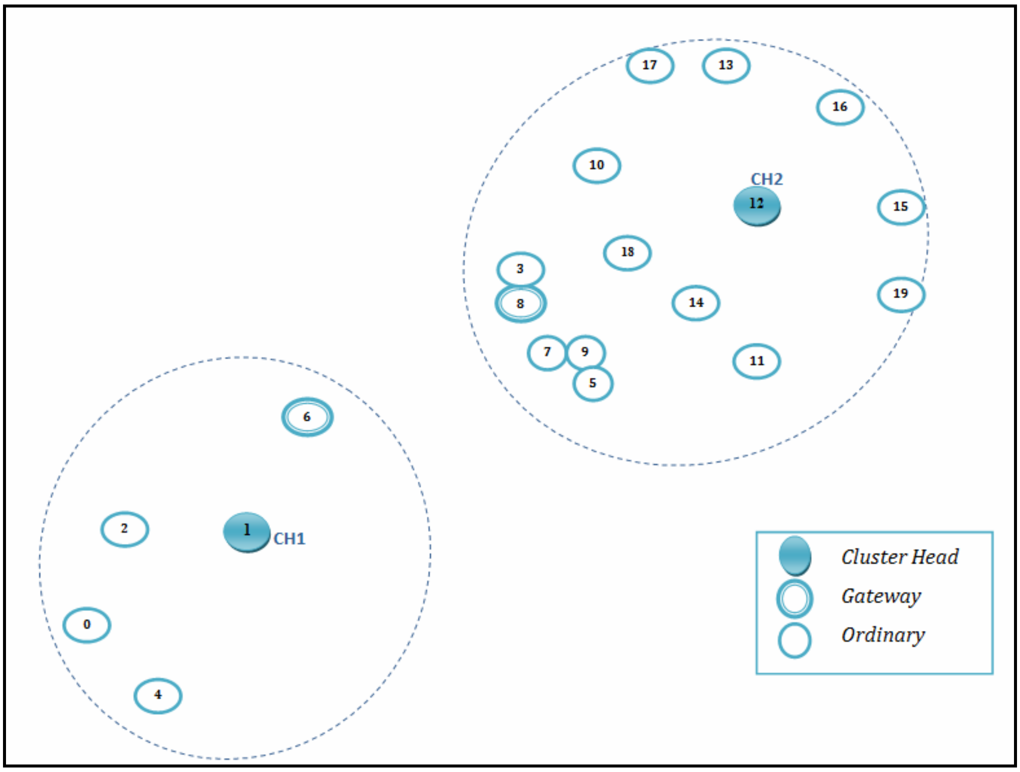
Distance	Avg. distance from (CH1)	Avg. distance from (CH12)
1	449.20	220.82
2	379.81	285.53
3	310.99	352.37
4	243.20	420.40
5	177.50	489.17

The following four figures (Figure 25, Figure 26, Figure 27 and Figure 28) show the network states when the distance between BNs and CHs is changing. The network in Figure 23 and Figure 24, show the first situation when the five boundaries are closer to CH2 than to CH1. The average distance between the BNs and CH2 is 220.82 meters. On the other hand the BNs here, in Figure 23 and Figure 24, are in the farthest distance from CH1.They are, on average, 449 meters far from CH1.

Figure 25 shows the network state in the next situation. The distance of BNs is increased to be 285m from CH2 and 69m closer to CH1. The two algorithms for clustering (SR and PECD) are shown in the figure. In each case of the five placements, the power levels are different because the positions of the boundaries are changed. In part (a) when boundaries are joined to cluster 1, CH1 and BNs use more power level than other nodes. In part (b), when the BNs are joined to cluster 2, the BNs and CH2 use more power level than CH1 and ordinary nodes.



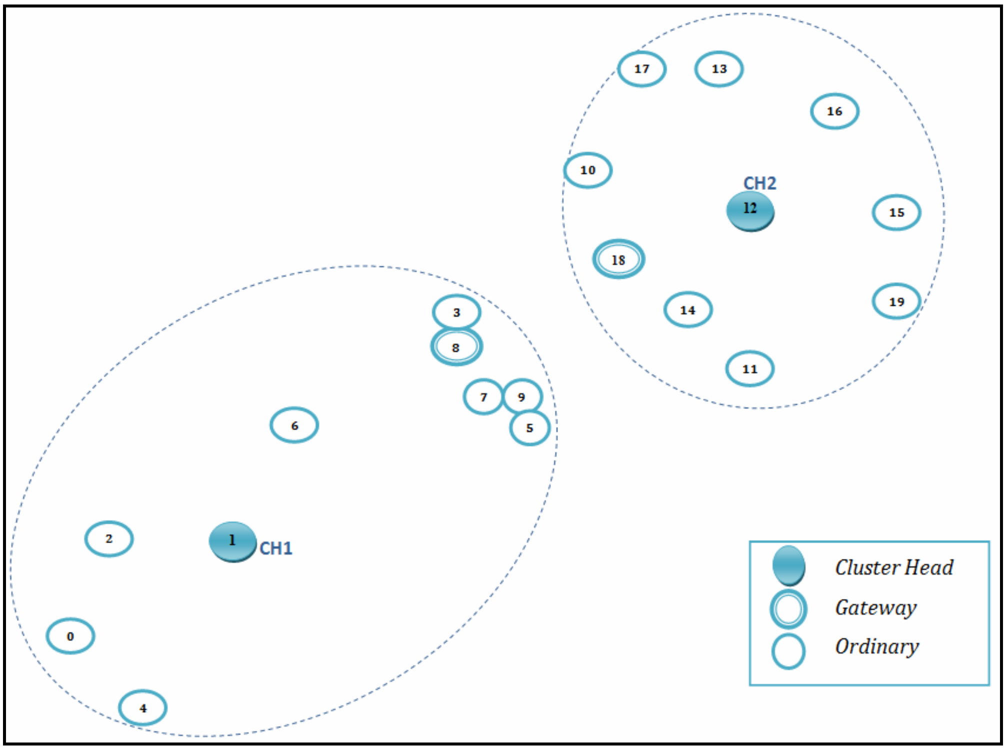
(a) SR algorithm



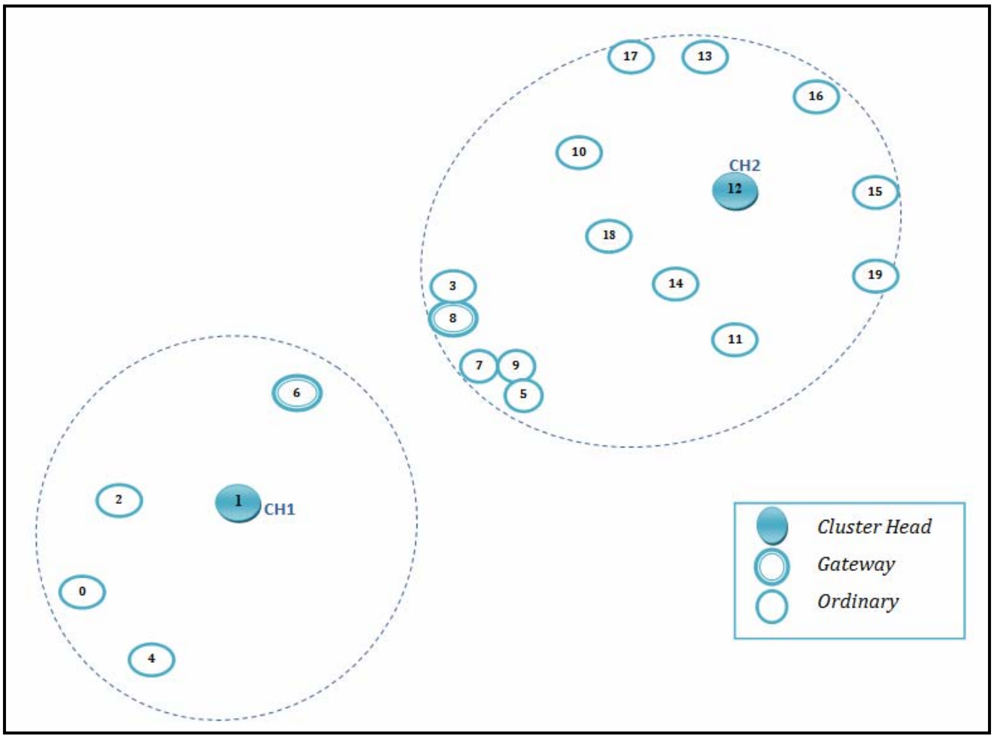
(b) The proposed PECD algorithm

Figure 25. Second case for BNs placement: 285.5m distance from CH2

Figure 26 shows the third case for this scenario when the BNs are 352m from CH2. Part (a) in this case is different from other cases, it does not only represent the SR algorithm; it also represents our PECD algorithm. Boundary nodes here are closer to CH1 than to CH2, so in PECD algorithm they will be joined to cluster 1 not to cluster 2. Part (b) describes the network if we add the BNs to the second cluster.



(a) SR and PECD algorithms

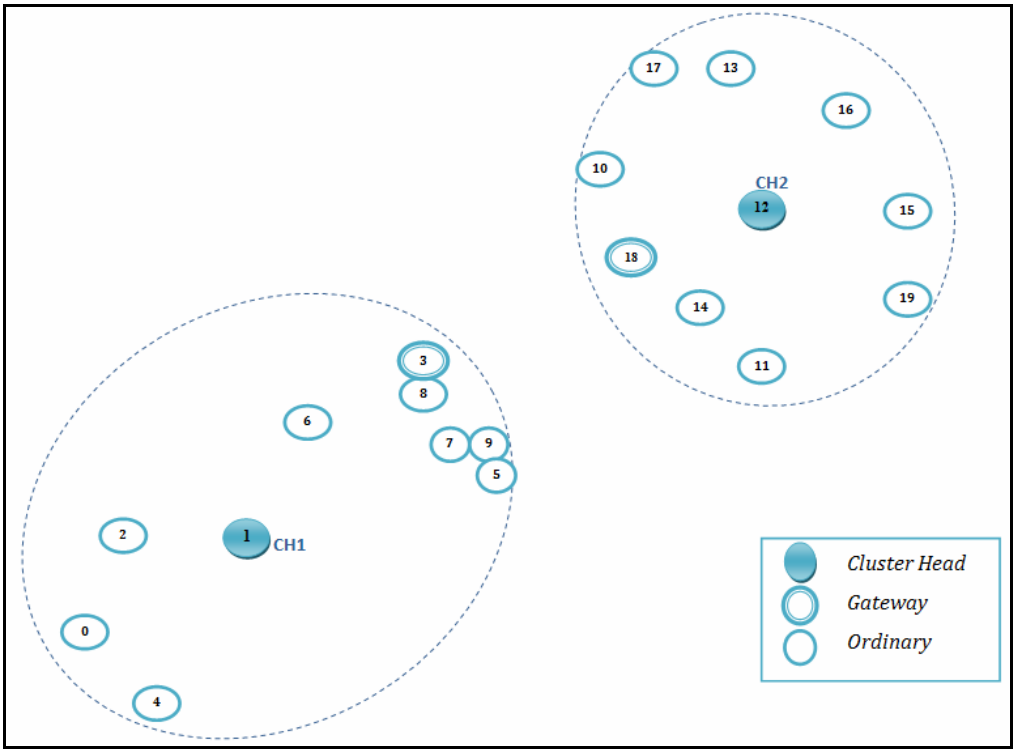


(b) Joining BNs with cluster 2

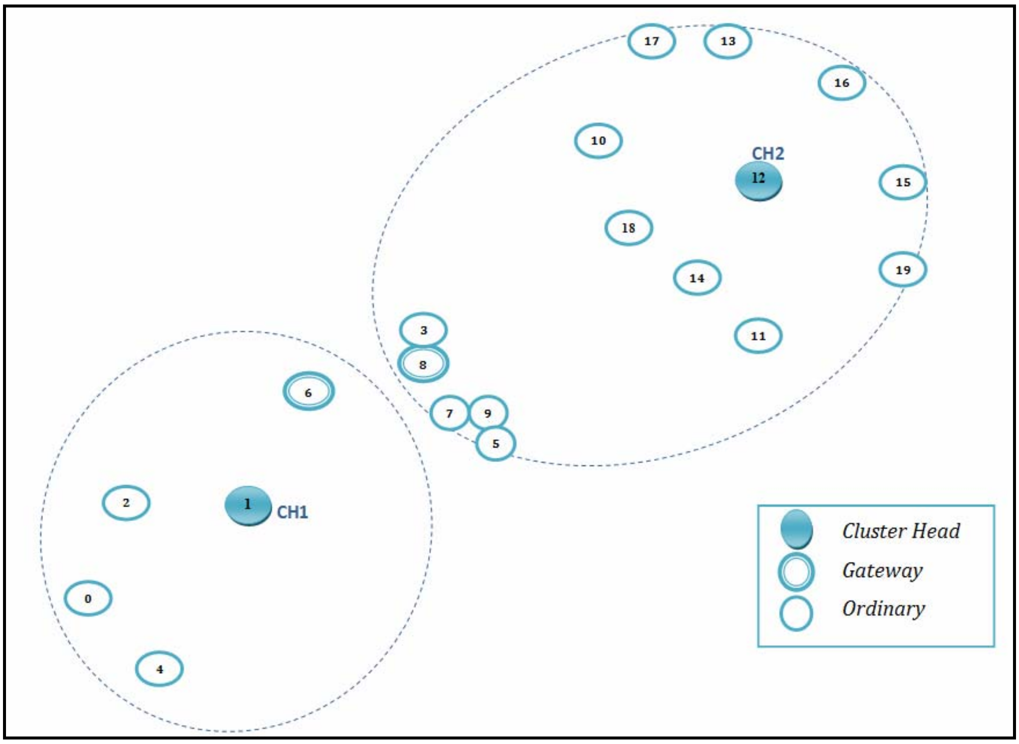
Figure 26. Third case for BNs placement: 352m distance from CH2

In this case of nodes placement, CH1 in Figure 26 part (a) need less power level to join the BNs than the previous case (Figure 25) because the BNs are now closer to CH1. In part (b), CH2 needs more power level than the previous case (Figure 25), and the BNs use the same power level to reach their CH.

The next case is when the BNs move closer to CH1 to be 243 meters from it. This case is the same as the previous one (Figure 26). Figure 27 part (a) represents SR and PECD algorithms where the BNs are joined to CH1. In contrast, part (b) represents joining the BNs to the second cluster. As in the previous case (Figure 26), BNs here are closer to CH1 than to CH2, so the power level needed for BNs in part (a) is less than the power level used in part (b).



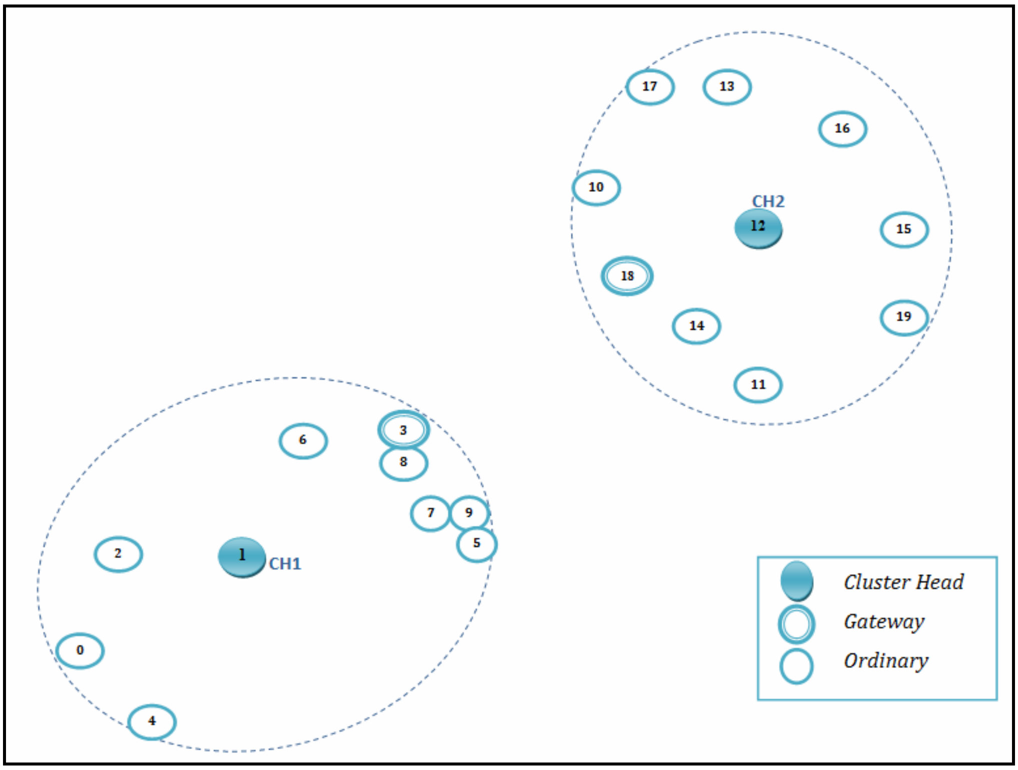
(a) SR and PECD algorithms



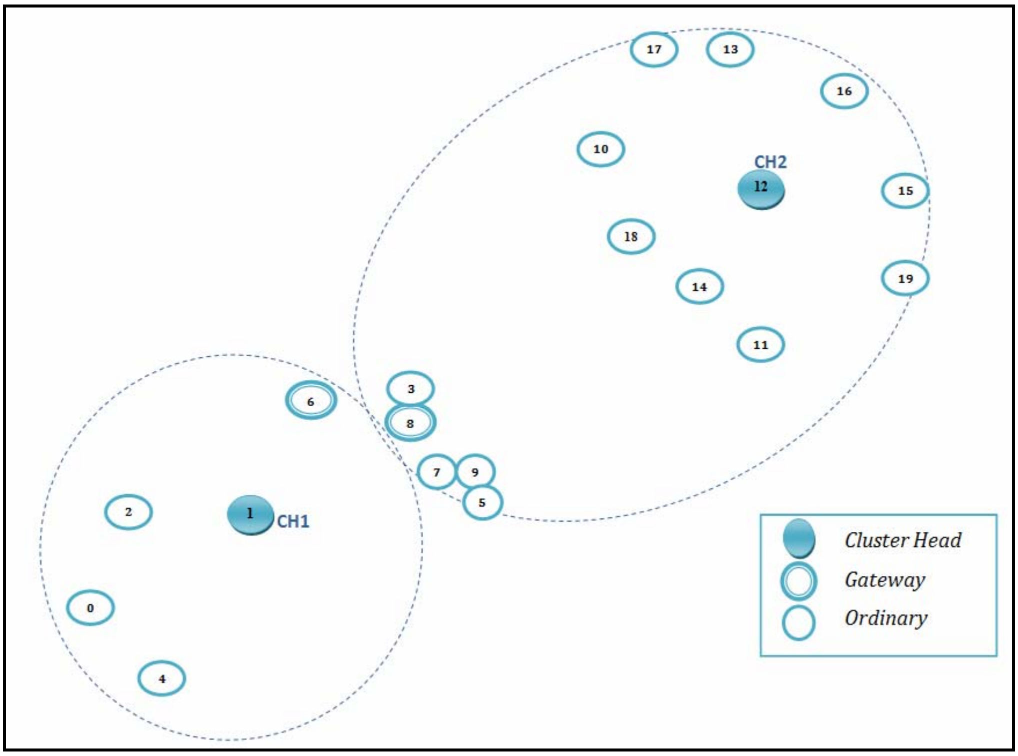
(b) Joining BNs with cluster 2

Figure 27. Fourth case for BNs placement: 420m distance from CH2

The last case is when the five BNs are 177.5m far from CH1. They are very close to CH1 and very far from CH2, so CH1 needs small power range to join them. As shown in Figure 28 part (a), when BNs are joined to cluster 1, all the nodes use a moderate power level. There are only two nodes which use different levels from others. These nodes are the GWs (nodes 3 and 18).



(a) SR and PECD algorithms



(b) Joining BNs with cluster 2

Figure 28. Last case for BNs placement: 489m distance from CH2

Scenario Parameters

The main parameter in this experiment is the distance between BNs and the two CHs. The scenario is evaluated for different values of distances. It begins with 5 BNs placed close to CH2. In each of the following cases, the BNs are put in places farther from CH2 and closer to CH1. Additional parameters for this scenario are listed in Table 8.

Table 8. Scenario3 Parameters

Parameter	Value
Number of nodes	20 nodes
Simulation Time	15 minutes
Traffic Generator	FTP/GENERIC
Packet size	1460
Maximum cluster size	10

5. Results and Discussion

5.1 Power Consumption Results

This section discusses the results for different scenarios using the following parameters: simulation time, traffic load, packet size, number of Boundary Nodes (BNs), and BNs location. The simulation experiments were performed to evaluate the total power consumption for Size Restricted (SR) and Power Efficient Clustering Distribution (PECD) algorithms. The simulation results are discussed in sections 5.1.1, 5.1.2 and 5.1.3. The first scenario measures how the energy consumption is affected by varying simulation time, traffic load and packet size. The second scenario evaluates the differences of power consumption when the number of Boundary Nodes (BNs) changes. The last scenario shows how to choose the effective cluster formation depending on BNs locations.

5.1.1 Power Consumption Results for First Scenario

In the first scenario, each parameter is examined using two application layer protocols: Constant Bit Rate (CBR) and File Transfer Protocols (FTP/GENERIC). The simulation time is the first parameter which used to evaluate its effect on the consumed power for each algorithm. The packet size here is fixed which is 1460 bytes.

Figure 29 shows the consumed power in milliWatt/hour (mWhr) for SR and PECD algorithms when time is changing. As we can see from the figure, the consumed power increases while increasing the simulation time in the two algorithms. When the simulation time increases that enables the nodes to send more packets and hence consume more power.

The results show that the proposed PECD algorithm consumes less power than SR algorithm. In general, PECD algorithm uses less power ranges when joining the BNs to the closest Clusterheads (CHs), which leads to decrease in the power consumption for this algorithm. The difference in terms of power consumption between the two algorithms is also increasing with time. For example, when the simulation time is 25 minutes, then PECD algorithm is better than SR algorithm by 186.6 mWhr.

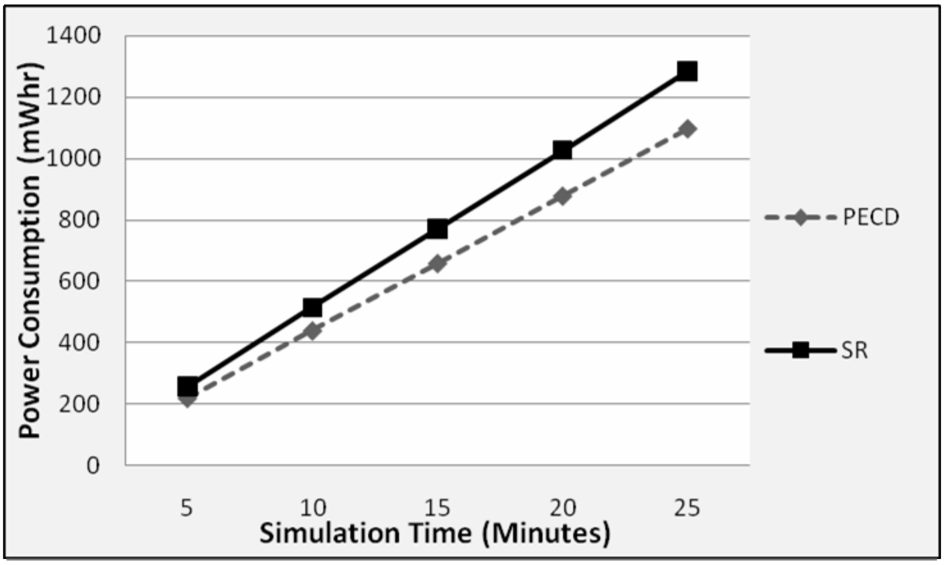


Figure 29. Power consumption results for variant simulation time using CBR Protocol

Using FTP/Generic shows the same result, that is PECD algorithm saves more power than SR algorithm. Power Efficient Clustering Distribution algorithm joins the BNs to the closest CHs not to clusters with small sizes and that decreases the transmission power levels used by these nodes. The Power consumed is also increasing by time, and the difference also increases. Results are summarized in Table 9.

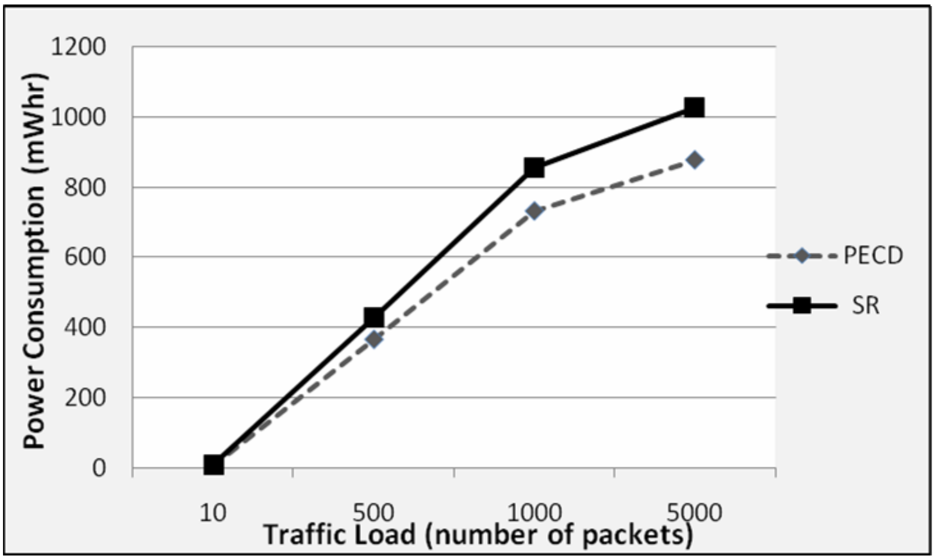
Table 9. Total consumed power for variant simulation time using FTP/Generic Protocol

Time / Minutes	PECD/ mWhr	SR /mWhr
5	411.2784	424.831
10	821.997	848.4378
15	1235.3918	1273.1268
20	1648.5166	1697.0038
25	2062.589	2122.0128

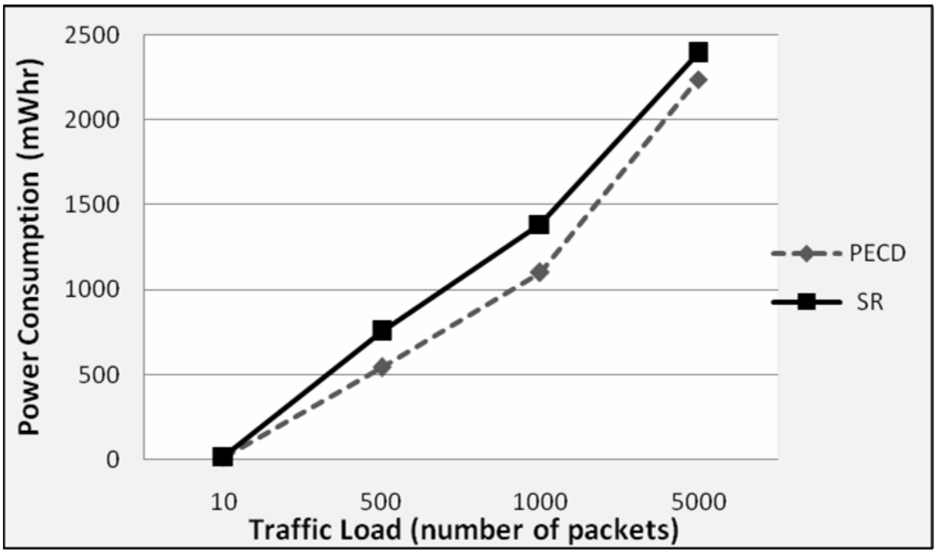
The second parameter in this scenario is the traffic load. Different numbers of packets are used to measure how the energy consumption is affected by varying the traffic load. In this experiment the simulation time and packet size are fixed which are 20 minutes and 1460 bytes, respectively.

Figure 30 part (a) presents the consumed power in 20 minutes with different numbers of packets. The consumed power increases when traffic load increases, and the difference between the two algorithms increases too. For example, when the number of packets is 5000 packets, then PECD Algorithm is better than SR algorithm by 148.7 mWhr. Part (b) also shows that PECD algorithm gives slightly better results in general than SR algorithm.

Increasing the traffic load means that each node sends more packets and consumes more power in all its modes. More packets in the channel means more collisions too. In SR algorithm, the packets are sent to large area because of using more power levels. Therefore, if the area is dense populated, the number of receiving and sensing nodes is more and thus the number of collisions and dropped packets increases. In addition, the dropped packets in SR algorithm are retransmitted in large power levels which makes this algorithm consume more power than PECD algorithm.



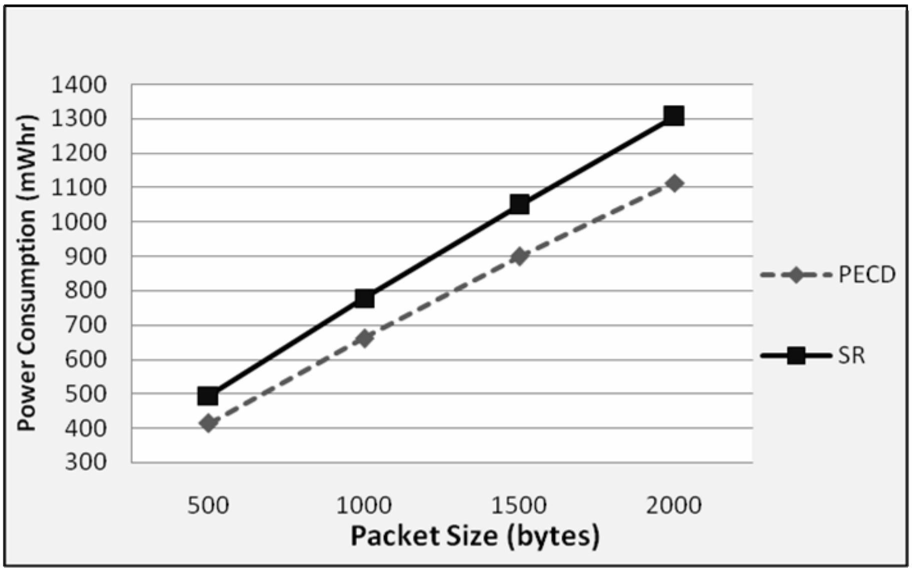
(a) Using CBR Protocol



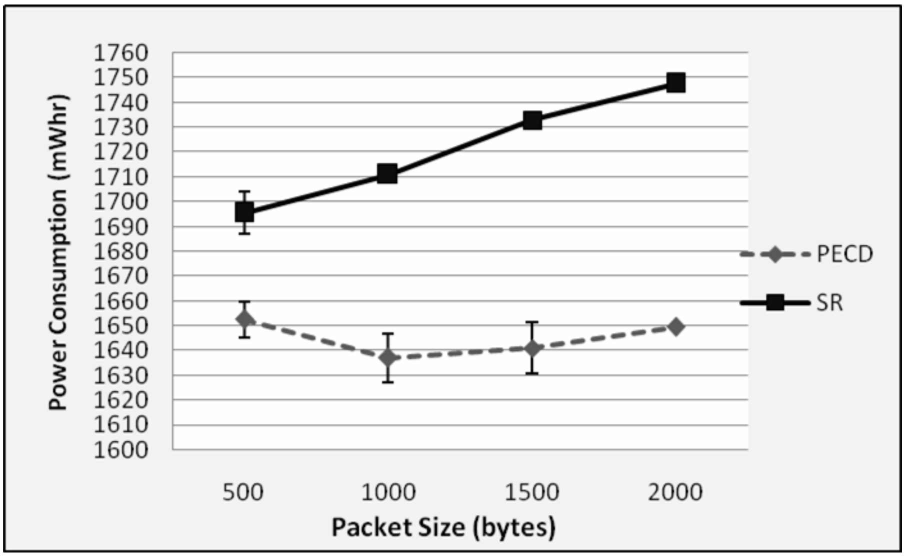
(b) Using FTP/Generic Protocol

Figure 30. Power consumption results for variant traffic load

The last Parameter in this scenario is the packet size, where four packet sizes are used 500, 1000, 1500 and 2000 bytes. The simulation time here is 20 minutes. Figure 31 part (a) presents the simulation results using CPR application layer protocol. The consumed power increases when packet size increases, and the difference between the two algorithms increases too. When the packet size increases, it needs more duration to be sent because the transmission time for the node depends on the packet size. If the packet size increases, the duration for transmitting will increase and that consumes more power (Margi and Obraczka, 2004). In SR algorithm, large packet sizes need more duration and more transmission levels when the BNs are distant from CHs. That consumes more power than in PECD algorithm. PECD joins the BNs to the closest CHs and that decreases the transmission power levels used by these nodes, so for large packet sizes the packet need more duration but less power level compared with SR algorithm. In FTP/Generic protocol, the best difference happened when using 2000 bytes packet size, where PECD is better than SR algorithm by 98 mWhr, as shown in part (b).



(a) Using CBR protocol



(b) Using FTP/Generic Protocol

Figure 31. Power consumption results for variant packet sizes

It is clear from the results that using FTP/Generic protocol consumes more power than CBR in the two algorithms. The File Transfer protocol (FTP) consists of two parts, control part and data transfer part. In the control part a TCP connection is established between client and server. Client TCP entity sets up a logical connection with the TCP entity in the server. It is a reliable three-way handshake procedure includes error free transmission and flow control procedure (Halsall, 2005). Using the control connection increases the throughput and the number of transmitted packets. Moreover, more throughput means that nodes take more time in transmitting mode and consumes more power compared with the CBR protocol.

5.1.2 Power Consumption Results for Second Scenario

The second scenario evaluates the power consumption of the network for SR and PECD algorithms while changing the number of BNs. The results of this experiment are illustrated in Figure 32. The results show that PECD algorithm outperforms SR algorithm by an order of magnitude. The network with this algorithm consumes less power in five cases: one, two, three, four and five boundaries. The largest difference in power happens in the last case when the network has five boundaries. The difference in this case is 139 mWhr.

In general, the consumed power increases while the number of boundaries is increasing. The reason for that is the large power needed for distant BNs to reach their CH. As the number of these nodes increases, the number of nodes which use large power increases too, this yields to increasing in the total power consumption for the network. However, the dashed line represents the PECD algorithm. In PECD algorithm the BNs are joined to the closest CH, so they use less power level and thus save the power consumption for the network.

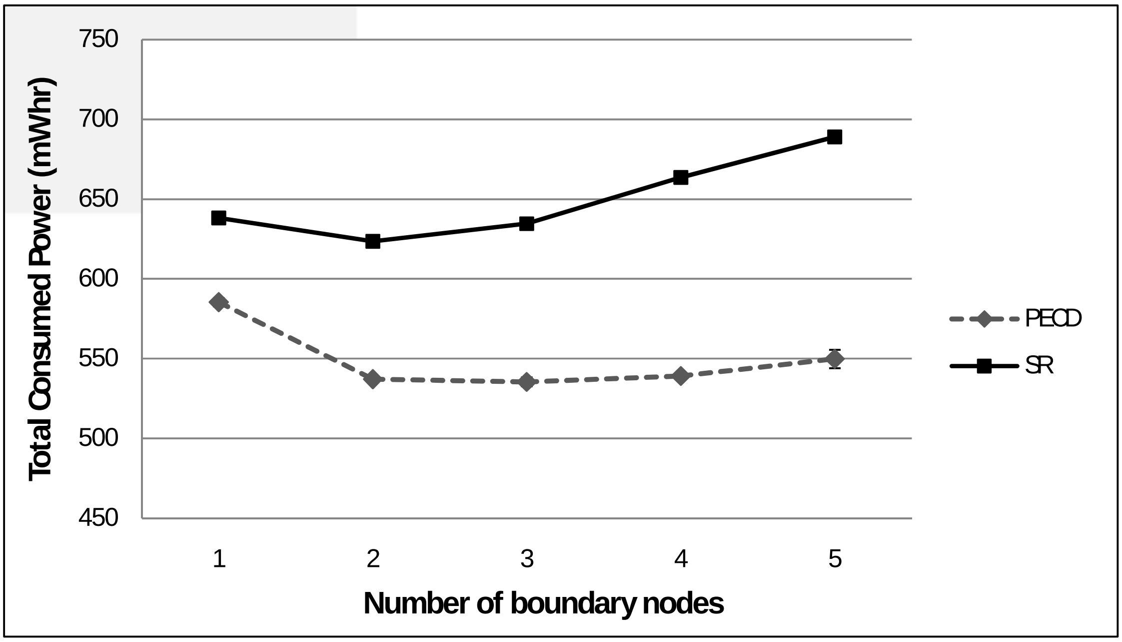


Figure 32. **Power consumption results for variant numbers of boundary nodes**

5.1.3 Power Consumption Results for Third Scenario

This scenario evaluates the total power consumption of the network while changing the position of the BNs. The proposed algorithm is compared with SR algorithm and shows better performance in saving power consumption of the network.

The result of this experiment is illustrated in Figure 33. Results show that in the first two cases, it is better to join the BNs to cluster 2 not to cluster 1, which are shown in Figure 24 and Figure 25 part (b). Joining BNs to CH2 in these cases consumes less power than joining them to CH1. In the other three cases, the Figure shows that joining the BNs to the first cluster is more efficient, which are shown in Figure 26 part (a), Figure 27 part (a) and Figure 28 part (a).

Note that the cross point of the two lines in Figure 33, presents the distance where the two cases consume the same power. This point is the midpoint between the two CHs which is 325 meters (the distance between the two CHs divided by 2). So when the average distance of the BNs is 325 meters from the two CHs, then joining the BNS to CH1 or CH2 give the same results for power consumption.

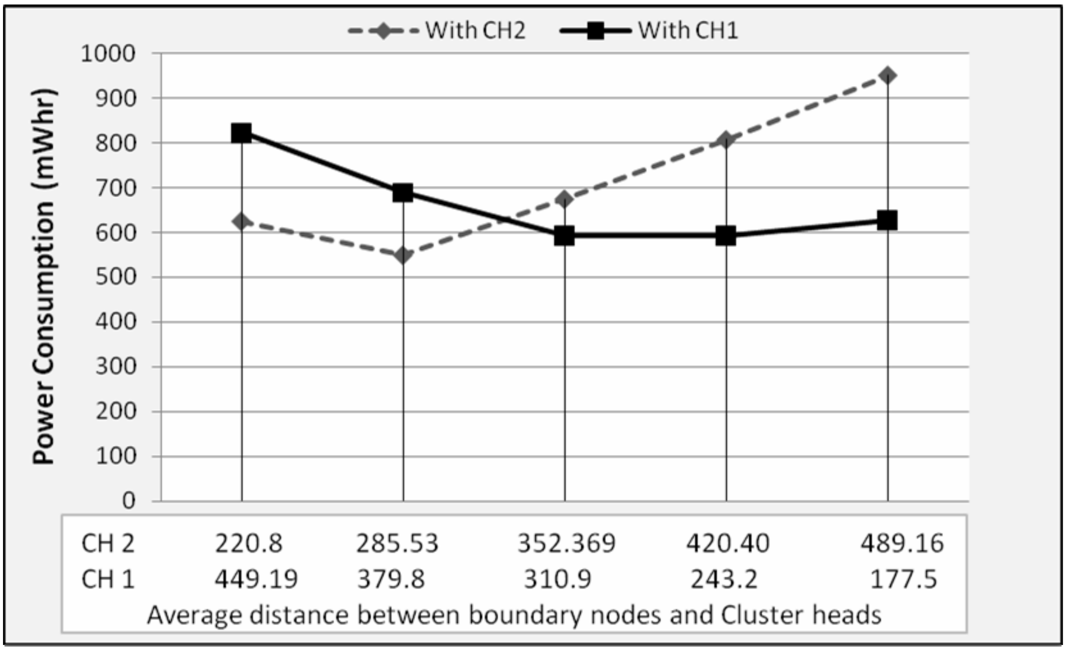


Figure 33. Power consumption results for variant distances of boundary nodes

As described in section 4.6.3, if SR algorithm is used, then it will give good results for the last three cases. In the first two cases, the BNs will be joined to CH1, as shown in Figure 23 and Figure 25 part (a). In contrast using our proposed PECD algorithm gives a better choice for all cases. It joins the BNs to CH2 in cases 1 and 2 because the BNs are closer to CH2 than to CH1, as shown in Figure 24 and Figure 25 part (b). In cases 3, 4 and 5, the BNs are closer to CH1 so they will be joined to it.

So our proposed PECD algorithm outperforms SR algorithm in terms of power consumption by an order of magnitude.

5.2 Improvement Ratio

The results of the three scenarios show that PECD algorithm outperforms SR algorithm in term of power consumption. The Improvement Ratio (IR) of PECD algorithm is evaluated by the following equation:

$$IR = (Max\_Val - Min\_Val)/Max\_Val, \qquad (8)$$

where *Max_Val* is the total power consumption when using SR algorithm, and *Min_Val* is the total power consumption when using PECD algorithm.

Figure 34 presents the improvement ratio for the first scenario. Each part shows the improvement ratio for different parameters, such as simulation time, traffic load and packet size, using two different traffic generators, as applications: CPR and FTP/Generic protocols. The first experiment compared PECD algorithm with SR algorithm under different simulation time (5, 10, 15, 20 and 25 minutes). As shown in Figure 34 part (a) and part (b), PECD algorithm shows better results and decreases the power consumption by 14% when using CBR protocol, and by 3% when using FTP/Generic Protocol. The second parameter used to compare these algorithms is the traffic load. Under different numbers of packets, our proposed PECD algorithm saves power consumption by 14% when using CBR protocol, as shown in Figure 34 part (c), and by 18% when using FTP/Generic Protocol, as shown in Figure 34 part (d). The last experiment compared the algorithms for different packet sizes. The PECD algorithm outperforms SR algorithm by 15% when using CBR protocol, as shown in Figure 34 part (e), and by 4% when using FTP/Generic Protocol, as shown in Figure 34 part (f).

Consequently, the proposed PECD algorithm decreases the power consumption by 14%, 14% and 15% when using CBR protocol, and saves power by 3%, 18% and 4% when using FTP/Generic protocol compared to SR algorithm. That introduces reasonable decrease of power consumption which is (in average) 11% less than SR algorithm.

Time (minutes)	IR
5	14%
10	14%
15	14%
20	14%
25	14%
average	14%

(a) Results for variant simulation time using CBR Protocol

Time (minutes)	IR
5	3%
10	3%
15	2.9%
20	2.8%
25	2.8%
average	2.9%

(b) Results for variant simulation time using FTP/Generic Protocol

No. of packets	IR
10	15%
500	14%
1000	14%
5000	14%
average	14%

(c) Results for variant traffic load using CBR Protocol

No. of packets	IR
10	18%
500	28%
1000	20%
5000	6%
average	18%

(d) Results for variant traffic load using FTP/Generic Protocol

Packet size	IR
500	16%
1000	15%
1500	14%
2000	14%
average	15%

(e) Results for variant packet sizes using CBR Protocol

Packet size	IR
500	2%
1000	4%
1500	5%
2000	5%
average	4%

(f) Results for variant packet sizes using FTP/Generic Protocol

Figure 34. Improvement Ratio for the first scenario

The improvement ratio for the second scenario is shown in Table 10. In this experiment, PECD algorithm is compared with SR algorithm under different numbers of BNs (one to five nodes). As shown in the table, the PECD algorithm gives better results for power consumption in the five cases: one, two, three, four and five boundaries. The largest improvement in power happens in the last case when the network has five boundaries. The improvement of power consumption in this case is 20%. As the number of BNs increases, the number of nodes which use large power in SR algorithm increases too. Therefore the SR algorithm consumes more power when the number of BNs increases and that increase the difference between the two algorithms. The average percentage in this scenario is 15 % better than SR algorithm.

Table 10. Improvement ratio of the second scenario

Number of BNs	IR
1	8%
2	13.8%
3	15%
4	18.7%
5	20%
average	15%

6. Conclusions and Future Work

6.1 Conclusions

This thesis presents the Power Efficient Clustering Distribution (PECD) algorithm which reduces the effect of Boundary Nodes (BNs) on power consumption. The PECD algorithm decreases the power needed for communication with BNs by joining them to the closest cluster not to that with less members. Different scenarios were designed and implemented using GloMoSim simulator.

The first experiment evaluates the power consumption to compare PECD with SR algorithm under different simulation time, traffic loads and packet sizes. For the two traffic generators (FTP/Generic and CBR), PECD algorithm consumes less power than SR algorithm. In general, PECD algorithm uses less power ranges when joining the BNs to the closest CHs. That decreases the power consumption for this algorithm by 3-18% compared with SR algorithm.

The second experiment compared SR and PECD algorithms for different numbers of BNs (one to five nodes). The PECD algorithm gives better results for power consumption by 15%. The last experiment shows how to choose the effective cluster formation depending on BNs locations. The network power consumption was evaluated for SR and PECD algorithms when the placement of BNs is changing. Our proposed PECD algorithm outperforms SR algorithm and makes the efficient cluster formation choice in term of power consumption.

6.2 Future Work

This study compares the PECD algorithm with SR algorithm and evaluates the power consumption for them. We propose as a future work to compare the proposed PECD algorithm with another algorithm which distributes the nodes evenly between clusters and balance the load on CHs. Also, other important performance metrics will be taken into account. Besides evaluating the power consumption, the network throughput, collisions and dropped packets will be measured. The experiments can also be evaluated using multihops by taking larger values of k (number of hops inside the cluster).

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APPENDIX

1. About GloMoSim

GloMoSim is a scalable environment for wireless and wireline communication networks. It uses a parallel discrete-event simulation which provided by Parsec (Nuevo, 2004). "GloMoSim simulates networks with up to thousand nodes linked by a heterogeneous communications capability that includes multicast, asymmetric communications using direct satellite broadcasts, multi-hop wireless communications using ad-hoc networking, and traditional Internet protocols" (Nuevo, 2004). Table 11 lists the GloMoSim models which are available at each layer.

Table 11. The GloMoSim models currently available at each of the major layers (Nuevo, 2004)

Layer	Models
Physical (Radio Propagation)	Free space, Two-Ray
Data Link (MAC)	CSMA, MACA, TSMA, 802.11
Network (Routing)	Bellman-Ford, FSR, OSPF, DSR, WRP, LAR, AODV
Transport	TCP, UDP
Application	Telnet, FTP

2. GloMoSim Installation on Windows XP

Before installation, the following software must be installed correctly:

- Microsoft VC++ version 6.0 (Essential)

- JAVA JRE version 1.2 or higher (For VT)

- JAVA SDK version 1.2 or higher (For VT)

This is a step-by-step installation guide for GloMoSim on Microsoft Windows XP

1. Copy "glomosim" and "parsec" directories to the "c:\" directory: C:\glomosim and C:\Parsec

2. Set *pcc* environmental variables (For Parsec)

1) My Computer -> Properties -> Advanced -> Environmental Variables

2) New "PCC_DIRECTORY", value = "C:\parsec"

3) Set *path* "C:\parsec\bin;C:\glomosim\bin;C:\Program Files\Microsoft Visual Studio\VC98\Bin;C:\Program Files\Microsoft Visual Studio\Common\MSDev98\Bin;C:\Program Files\Microsoft Visual Studio\Common\Tools;C:\Program Files\Microsoft Visual Studio\VC98\Include;"

3. Set VC6.0 environmental variables (for both user variables and system variables)

1) Set *include*:

"C:\Program Files\Microsoft Visual Studio\VC98\MFC\Include;C:\Program Files\Microsoft Visual Studio\VC98\Include"

2) Set *lib*:

"C:\Program Files\Microsoft Visual Studio\VC98\MFC\Lib;C:\Program Files\Microsoft Visual Studio\VC98\Lib"

4. Check pcc environment by "set pcc" in DOS prompt (cmd)

You should get: " PCC_DIRECTORY = C:\parsec"

5. GloMoSim Installation

1) Go to glomosim\main, do "makent.dat"

2) Go to glomosim\bin, find "glomosim.exe"

3) Test glomosim. Under DOS: "glomosim config.in"

6. GloMoSim is now ready to use.

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العنقدة المعتمدة على توفير الطاقة في الشبكات المتنقلة العشوائية

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ملخص

يعتبر التحكم بالطاقة من أهم القضايا في الشبكات المتنقلة العشوائية (MANET). لقد تم تطوير مجموعة من الأبحاث التي تهدف لإطالة عمر الشبكة والتحكم بالطاقة، وذلك لأن الأجهزة اللاسلكية تعتمد في عملها على طاقة محدودة. تعتبر العنقدة (clustering) من أحد الطرق المستخدمة للتحكم بالطاقة وإدارتها في الشبكات اللاسلكية.

في الشبكات المجمعة تقسم الأجهزة اللاسلكية إلى مجموعات، وتحتوي كل مجموعة على جهاز خاص يسمى رأس التجمع (clusterhead). كلما زاد حجم المجموعة يتم الاتصال بشكل أسرع، وكلما قل الحجم يكون استغلال واستخدام الوسط الناقل بشكل أفضل. وبالموازنة بينهما يتم الحصول على الحجم الأفضل للمجموعة. استخدمت مجموعة من الخوارزميات حدا أعلى لعدد الأجهزة داخل كل عنقود (cluster)، وذلك للتحكم بحجم المجموعة و توزيع الأجهزة بشكل متزن على المجموعات وتجنب تكوين مجموعات كبيرة الحجم. ولكن في حال أن حجم بعض المجموعات وصل للحد الأعلى، فإن باقي المجموعات ذات الحجم الأقل عليها ضم باقي الأجهزة حتى لو كانت بعيدة وتحتاج لطاقة كبيرة لضمها. تعرض هذه الرسالة طريقة جديدة لتكوين المجموعات تسمى " العنقدة المعتمدة على توفير الطاقة في الشبكات المتنقلة العشوائية "(PECD)، التي تقلل تأثير الأجهزة الحدودية البعيدة (Boundaries) على الطاقة المستهلكة. تهدف هذه الطريقة إلى إطالة عمر الشبكة بغض النظر عن عدد الأجهزة أو الطاقة المستهلكة في كل مجموعة.

في طريقة PECD يتم ضم الأجهزة الحدودية للمجموعة الأقرب وليس للمجموعة الأقل عددا، وهذا يقلل من الطاقة التي نحتاجها للاتصال بهذه الأجهزة. لقد تم تصميم مجموعة من النماذج(Scenarios) ونفذت بواسطة برنامج المحاكاة (GloMoSim). وقد أظهرت النتائج أن طريقة PECD تزيد في عمر الشبكة وتوفر الطاقة المستهلكة بالمقارنة مع الطرق الأخرى التي تحدد حجم المجموعة.