

PAPER

Management of Energy Consumption on Cluster Based Routing Protocol for MANET

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SUMMARY The usage of light-weight mobile devices is increasing rapidly, leading to demand for more telecommunication services. Consequently, mobile ad hoc networks and their applications have become feasible with the proliferation of light-weight mobile devices. Many protocols have been developed to handle service discovery and routing in ad hoc networks. However, the majority of them did not consider one critical aspect of this type of network, which is the limited of available energy in each node. Cluster Based Routing Protocol (CBRP) is a robust/scalable routing protocol for Mobile Ad hoc Networks (MANETs) and superior to existing protocols such as Ad hoc On-demand Distance Vector (AODV) in terms of throughput and overhead. Therefore, based on this strength, methods to increase the efficiency of energy usage are incorporated into CBRP in this work. In order to increase the stability (in term of life-time) of the network and to decrease the energy consumption of inter-cluster gateway nodes, an Enhanced Gateway Cluster Based Routing Protocol (EGCBRP) is proposed. Three methods have been introduced by EGCBRP as enhancements to the CBRP: improving the election of cluster Heads (CHs) in CBRP which is based on the maximum available energy level, implementing load balancing for inter-cluster traffic using multiple gateways, and implementing sleep state for gateway nodes to further save the energy. Furthermore, we propose an Energy Efficient Cluster Based Routing Protocol (EECBRP) which extends the EGCBRP sleep state concept into all idle member nodes, excluding the active nodes in all clusters. The experiment results show that the EGCBRP decreases the overall energy consumption of the gateway nodes up to 10% and the EECBRP reduces the energy consumption of the member nodes up to 60%, both of which in turn contribute to stabilizing the network.

key words: energy consumption, MANETs, CBRP

1. Introduction

Mobile Ad hoc Networks (MANET), typically based on the IEEE 802.11 standard, are composed of mobile devices nodes which connect to each other via wireless connections to exchange data as well as to maintain the network connectivity among the nodes. These devices are free to move and roam unconstrained by the absence of network infrastructure. Therefore, this type of network is also called infrastructure-less network and nodes are required to cooperatively maintain the network topology [1]–[5]. Typical uses of MANET technology are found in: (i) Conferences;

(ii) Emergency Services; (iii) Military Operations; and (iv) Wireless Sensor Network. These uses are important factors that affecting protocol design and require more consideration in the design stage. We review four significant factors as follows:

• Energy limitation

In MANET all nodes are mobile with limited energy sources. On the other hand, any communication in a network involves energy consumption. So it is obvious that energy consumption is a critical parameter in MANETs and need to be prioritized when designing any protocol for this type of network. Due to differences in hardware technology network operational environments and usage scenarios, it is not possible to define universal criteria for managing energy consumption in MANETs. However, as a general rule the following should be followed [6].

1. Design hardware with minimum energy consumption.
2. Reduce the complexity of calculations involving CPU and RAM resources.
3. Employ efficient communication techniques for transmission and reception of data.

• Communications

All nodes in MANET connect to each other via wireless links and communicate through message exchanges. This messages exchange itself consumes the node's power.

• Scalability

Scalability is an important factor to be considered since increasing network population, traffic, and node mobility should not have adverse effects on efficiency and throughput of the network.

• Routing protocols

Since each node may act as a router in the network and nodes are openly mobile, routing in MANET is very challenging task.

In this paper we only focus on communication techniques for reducing energy consumption.

Cluster Based Routing Protocol (CBRP) has proven itself to be a robust and scalable routing protocol for ad hoc networks [12]–[14]. In this routing protocol each node belongs to a cluster. This paper aims to propose a robust, scalable, energy efficient and stable routing protocol for

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MANETs. In CBRP, the CHs and gateway nodes are critical nodes since they perform and control the communication between nodes in the whole network. Thus, we enhance the CBRP by introducing methods to select the CHs, to improve load balancing among the gateway nodes, and to force non-active gateway nodes into sleep state. We called this the Enhanced Gateway Cluster Based Routing Protocol (EGCBRP). Furthermore, to obtain a better energy efficient protocol we extend the EGCBRP into Energy Efficient Cluster Based Routing Protocol (EECBRP) which forcing all idle member nodes in the whole network into sleep state. Intuitively, the EECBRP will introduce more delay overhead.

This paper is organized as follows. Section 2 gives a brief summary of related works followed by Sect. 3 which discusses CBRP. In Sect. 4 we explain the detail of EGCBRP and EECBRP. Section 5 discusses simulation results while the conclusion is presented in Sect. 6.

2. Related Works

In communication techniques, energy efficient protocols can be categorized into two groups namely Network Layer power saving techniques, and Media Access Control (MAC) Layer power saving techniques [9], [10]. The MAC layer techniques have a little or no impact on throughput for IEEE 802.11 MAC [22]. Since we propose a Network layer based protocol to reducing the energy consumption, we do not consider the MAC layer techniques in this paper.

Network layer protocols are more effective in saving power. Scheduling of the physical network interface is controlled by Network layer by putting it into sleep state, active or idle states. Power saving techniques are based on three basic strategies [11].

- The first and easiest strategy is a synchronized power saving mechanism. Nodes periodically go to sleep state and wake up to listen to announcements of pending traffic, and exchange it, if necessary.
- The second strategy is based on network topology. A set of nodes that interconnect the entire network is chosen. For example, in a cluster based routing protocol, this set contains all CHs and all gateway nodes because this set provides connectivity for the whole network. The remaining nodes can spend most of their time in the sleep state with minimal effect on network performance. This type of technique can be centrally synchronized or distributed. This paper uses this strategy.
- The third method is completely asynchronous. All nodes act independently, using independent schedules for going into sleep or wake up states.

Many protocols for energy efficiency in MANETs have been proposed. We classify these protocols as follows.

(i) Decreasing energy consumption via using sleep state and idle state. G. Schiele et al. in [15] proposed a network layer cluster-based power saving protocol. When each node joins

the network, it registers with the CH. After a member node was idle for t_{idle} time, it would send a message to the CH to request to enter sleep state. Based on its information, the CH sends an Acknowledgment (ACK) to the node. If the member node received an ACK, it would enter sleep state for t_{sleep} time. If there is a packet at the CH destined for a node currently in sleep state, the packet would be delayed for t_{delay} time defined as in Eq. (1):

$$t_{delay} = t_{sleep} - \text{time spend in sleep state} \quad (1)$$

G. Schiele et al. in [18] proposed a middleware named SANDMAN to control node behavior, where each node has two states, sleep or awake states. Any node after α sec in idle state can go to sleep state for β sec. After β sec, the node wakes up using an internal timer. Zhenxin et al. in [19] also used the idle and listening state to save energy. The wireless card is enabled every 5 seconds and if there is no information to communicate with, it goes into sleep state again. Although works in [15], [18], [19] proposed methods for energy saving, however, they create a quite high end to end delay which is one of the critical issues in MANETs. These works also do not consider cluster heads and gateway nodes or any bottleneck nodes which pass all cluster or zone traffics which are critical nodes. Network topology in [15] avoids the traffic flooding but in the other two protocols [18], [19] there is no consideration on it.

(ii) Second category refers to protocols that using methods for increasing stability of the life-time via algorithms such as error-aware or conditional max min battery capacity as follows. L. Tan et al. in [6] introduced Error-aware Candidate Set Routing Protocol (ECSR) that avoids over-using a given route. If there are multiple routes in the candidate set, ECSR employs a metric, trading off energy efficiency load balancing among the optimal routes. C.K. Toh et al. [16] proposed the Conditional Max-Min Battery Capacity Routing (CMMBCR). This technique chooses the shortest path if all nodes in all possible routes have sufficient battery capacity. When the battery capacity for some nodes goes below a predefined threshold, routes that go through these nodes will be reprioritized. Therefore, this algorithm extends the life-time of available routes. The proposed protocols in [6] and [16] help to stabilize the network. However keeping and updating the routes information to make a decision for choosing a route in MANETs create more messages overhead which in turn increase the energy consumption.

(iii) Using some other methods to decrease energy consumption as follows: One of the issues in decreasing the overhead that causes increasing the energy consumption is avoiding the flooding in MANETs. S.Y. Wang et al. in [17] proposed a technique to avoid flooding on a large scale network by: (a) merging several small flooding messages into a larger one, and (b) limiting the scope of flooding. It was shown that this method reduced the number of flooding messages without increasing the delivery failure rate. Consequently, this reduced the energy consumption as well. Vijay et al. in [20] found three facts regarding energy consumption in ad hoc networks: First, energy consumption is significantly

lower if the size of packet is greater than 100 bytes and the transmission rate is also high. Second, energy consumption is significantly higher when sending small packets of the size of packet less than 100 bytes. Third, Radio Frequency (RF) power levels do not have more impact on energy consumption if the packet size is greater than 500 bytes. Using this role for decreasing energy consumption is notable. M. Cardei et al proposed in [21] the division of the network nodes into some adjoining sets, where nodes participate to maximize network life-time.

3. Cluster Based Routing Protocol (CBRP)

CBRP is a robust and scalable routing protocol for MANETs and superior to existing methods designed for medium to large mobile ad hoc networks [12]–[14]. It has less overhead and better throughput compared to On-Demand Distance Vector (AODV) [23], [24]. CBRP has two main steps. Firstly CBRP performs cluster forming. It divides the nodes of the ad hoc network into a number of overlapping or disjoint 2-hop diameter clusters in a distributed and hierarchical manner with the purpose of minimizing on-demand route discovery traffic. Each cluster elects a head to maintain cluster membership information. The election algorithm is a variation of the “lowest ID” header election algorithm. The node with a lowest ID among its neighbors is elected as a cluster head (CH). Each node maintains a Neighbor Table and a Cluster Adjacency Table. The neighbor Table is used for link status sensing and maintaining cluster formation. The Cluster Adjacency Table keeps information about adjacent clusters for Adjacent Cluster Discovery. These tables are updated using periodic Hello Message (HM). The nodes in CBRP are differentiated into 3 types: member node, CH node and gateway node.

Next, CBRP performs its routing mechanism as follows. It uses source routing that exploits the cluster structure to minimize traffic flooding during the route discovery phase. Furthermore, unidirectional links can be used for increasing

the network connectivity (See Fig. 1, between cluster C and D). Inter-cluster routes are dynamically discovered, based on cluster membership and information kept at each CH. Essentially, during Route Discovery, only CHs initiate and forward Route Request Packets (RREQ). Each CH node forwards an RREQ packet only once, and CH node never forwards it for a node already appearing in its routing table. It proactively acquires its intra-cluster topology information through the exchange of hello messages and reactively acquires the route information for inter-cluster routing. An example of a CBRP configured ad hoc network is shown in Fig. 1. Nodes are organized in four clusters, each of which has a CH.

The advantage of CBRP is that only CHs exchange routing information. Consequently the number of control messages transmitted through the network is far less than in traditional flooding methods. However, as in any hierarchical routing protocol, there are overheads associated with cluster formation and maintenance. This is because some nodes may carry inconsistent topology information due to long propagation delays [14].

A neighbor table in every node of CBRP keeps the information about link states (unidirectional or bidirectional) and the state of its neighbors. A CH keeps information of its neighboring clusters, in addition to the information of all members in its cluster. The information includes the CHs of neighboring clusters and gateway nodes connecting it to the neighboring clusters [13].

CBRP proposes a shortening route approach for performance optimization. Since CBRP uses a source routing scheme, a node gets all information about the route when receiving a packet. Nodes exploit route shortening to choose the most distant neighboring node in a route as next hop to minimize the hop number and adapt to network topology changes.

Another optimization method employed by CBRP is local repair. Whenever a node has a packet to forward and the next hop is not reachable, it checks the routing infor-

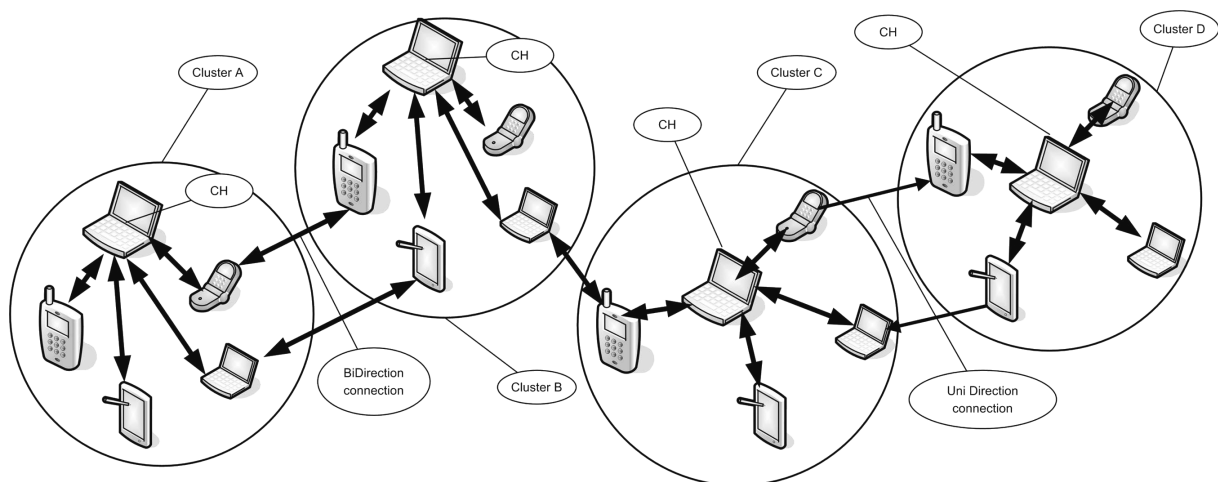


Fig. 1 A cluster based ad hoc network.

mation contained in the packet. If the next hop or the hop after next hop in the route is reachable through one of its neighbors, the packet is forwarded through the new route.

As an advantage, protocols that are implemented at the Routing/Network layer instead of in the Application layer significantly reduce the communication and energy consumption overheads [25].

4. Proposed Energy Consumption Management

As mentioned previously in Sect. 3, inter-cluster traffic is driven by CHs via gateway nodes. It is obvious that the energy consumption of these two types of nodes (CHs and gateway nodes) is high. In a network which having more data transmission, a part of network may go down after a CH or gateway node finishing their power, thus, it will be unreachable (See Fig. 1). Therefore, we focus on CHs and gateway nodes first and then we extend the idea into all nodes including member nodes. We propose Energy Efficient Cluster Based Routing Protocol (EECBRP) which enhances the CBRP in terms of: (i) electing the CH by taking into account its power; (ii) load balancing for gateway nodes; (iii) using sleep state for load balancing among gateway nodes; and (iv) using sleep state for all member nodes except active gateway nodes. We name the CBRP with the first three enhancements as Enhanced Gateway Cluster Based Routing Protocol (EGCBRP). The details of the enhancements are described in the following sections.

4.1 Electing the CH Based on Its Power

CHs are key nodes in a hierarchy type of network because they coordinate all inter-cluster traffic (See Fig. 1). Besides using criteria to elect CH in traditional CBRP, we also add the remaining available energy of a node as a parameter to control the election of CHs. In other words the CH election protocol would also check the available energy level and select the most appropriate node for CH with the maximum available energy among CH candidates.

4.2 Load Balancing for Gateway Nodes

Example of MANET shown in Fig. 1 exhibits that nodes are organized in four clusters; each one has a CH. There is at least one link between two clusters. For example, there are two links between cluster B and cluster A. In this case, all traffics from cluster B and cluster C toward cluster A should be sent via B's gateways. Since there is no rule for using these links, traffic over these links is not load balanced. If the gateway nodes of cluster A, which are critical nodes, run out of energy, routing between cluster A and other cluster can no longer be achieved. This may penalize some nodes that happened to be in a location that causes it to be part of several routing paths. In order to optimize the energy consumption and to increase the gateway life-time, we propose a load balancing method for gateway nodes as follows.

Based on the information of adjacency tables, we can

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B = 0;
for each ( l ∈ L1,2 ) {
    if ( LE(l) ≥ B ) {
        B = LE(l); sl = l;
    }
}
return sl;
    
```

Fig. 2 The best link algorithm.

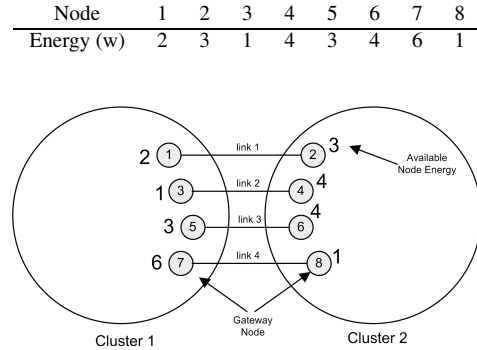


Fig. 3 Cluster inter-link selection example.

recognize a number of links between two clusters. Here, we add a function into the CBRP for arranging and managing the usage of these links in turn. This strategy assists the cluster gateway nodes in maximizing their life-time, improving link stability and prolonging network reachability. We use the standard deviation of node's available energy level as a parameter to select the inter-cluster-link. Let $L_{1,2}$ be a set of inter-cluster-links between two clusters, cluster 1 and cluster 2. First, we define the average energy level of gateway nodes as the Eq. (2).

$$Av = \frac{1}{2|L_{1,2}|} \sum_{l \in L_{1,2}} \sum_{i=1}^2 E(g_i^l) \quad (2)$$

where $|L_{1,2}|$ is the number of links between the two clusters, g_1^l and g_2^l are gateway nodes of link $l \in L_{1,2}$, and $E(g_i^l)$ are their energy levels. Next, we define the energy level of a link $l \in L_{1,2}$ as the Eq. (3) as follows.

$$LE(l) = \sum_{i=1}^2 E(g_i^l) - \sum_{i=1}^2 |Av - E(g_i^l)| \quad (3)$$

We compute the energy level LE periodically and update the adjacency table and perform the proposed algorithm shown in Fig. 2 to select the inter-cluster-link with the maximum energy level as the link activated at the next step.

To illustrate how our proposed method works, let us consider the following example. Assume, we have four links between two clusters as shown in Fig. 3 and the value of the available energy on each node is as follows:

The best link is link 3 because the available energy of nodes of the link ($\sum_{i=1}^2 E(g_i^3) = 3 + 4 = 7$) is the maximum and the standard deviation ($\sum_{i=1}^2 |Av - E(g_i^3)| = 1$) is the minimum, where $Av = 3$. In other word $LE(3) = 7 - 1 = 6$

maximized the value of energy. Having done electing the link 3 as inter-cluster-link, we force the other links to go to sleep state.

4.3 Using Sleep State for Load Balancing

As mentioned in Sect. 2, one of the methods for saving energy is using sleep states. This means that the node is forced into sleep state periodically. After some time, for example, α (based on internal timer) the node wakes up and transmits any existing packets, and the best inter-cluster-link election is conducted again. The steps are as follows.

1. Select the best inter-cluster-link as the active inter-cluster-link using the best link algorithm
2. Force other gateway nodes into sleep state
3. When other gateway nodes wake up, repeat step 1.

As a general rule, the implementation of the sleep state for gateway nodes in the EGCBRP is as follows. If a non-active gateway node is idle for t_{idle} sec, it sends a packet to CH to request to go to sleep state. If this node receives an ACK from the CH, it goes to sleep state for t_{sleep} second, where $t_{sleep} = \frac{1}{2} * t_{idle}$.

Furthermore, we define a link-active timer and a link-sleep timer which represents the activation time and sleeping time, respectively. Link-active timer represents the time that an inter-cluster link is active and all information passes through it. Link-sleep timer represents the time that other inter-cluster links are sleep. The state diagram for gateway nodes that constitute inter-cluster-links is shown in Fig. 4.

The gateway nodes' sleep state change into active state when the 'sleep timer over' event occurs. The best link algorithm is performed to elect a new active inter-cluster-link. The gateway nodes' active state change into sleep state if a 'Link active timer over' event has happened. It will reset sleep timer.

This proposed protocol has three main advantages: (i) saving the energy, because the gateway nodes go to sleep state periodically; (ii) stability of the network, because lifetimes of the active gateway nodes increase. This approach complements the load balancing mechanism in the gateway nodes. (iii) does not impose any delay to the network.

4.4 EECBRP, An Enhancement of EGCBRP

Reasonably if we can force all idle member nodes (except active gateways nodes) go into sleep state then we able to save more energy. In the EECBRP, the CHs and active gateway nodes (we named them as the backbone of the network) are always active for any communication.

We define idle timer which represents the time that node was in idle state and sleep timer which represents the time that node was in a sleep state. Having sent or received a packet, the idle timer resets itself. Based on pause time and traffic by user, the value of idle timer and sleep timer is changeable. The state diagram for member nodes with

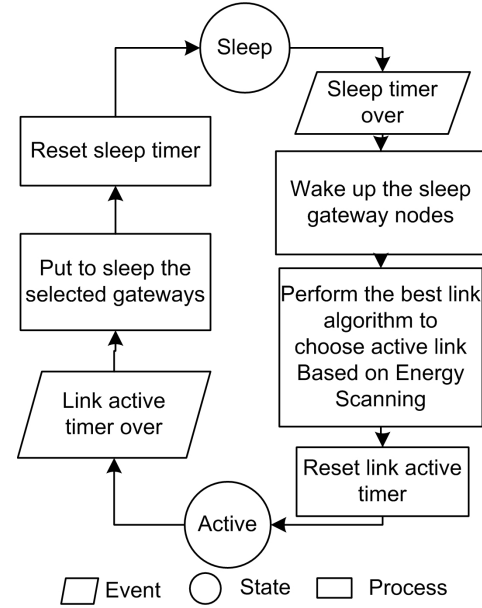


Fig. 4 Gateway node's state diagram.

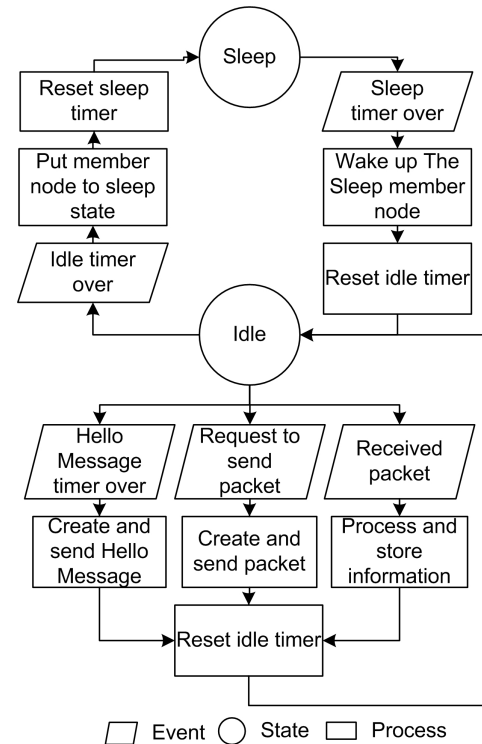


Fig. 5 State diagram for member nodes with concern to energy.

concern to energy is shown in Fig. 5.

A node with idle state changes to sleep state if 'idle timer over' event occurs. It will resets the sleep timer. There are another three events may occur which do not change the sleep state. They are: HM timer over, Request to send packet, and Received packet events. The HM timer over event will trigger Creating and send HM module. The Re-

Table 1 Power consumption measurements for LUCENT IEEE 802.11 2 Mbps WAVELAN PC CARD 2.4 GHz.

Parameter	M (μ W.sec/byte)	D (μ W.sec)
Broadcast Send	1.9	266
Point to point Send	1.9	454
Broadcast Receive	0.50	56
Point to point Receive	0.50	356
Idle Power	843 (mW)	
Sleep Power	66 (mW)	

quest to send packet event will activate Create and send packet module, while the Received packet event will execute the Process and store information module. The three events will execute Reset idle timer module.

4.5 Energy, Idle Time and Sleep Time Computation

There are many network states that influence the energy consumption pattern, they are: sending packet, receiving packet, discarding packet, idle time and sleep time [7]. Energy consumption for sending and receiving packet is calculated using formula in Eq. (4) [8]:

$$\text{Energy Consumption}(EC) = M * \text{SIZE} + D \quad (4)$$

SIZE is the size of sending or receiving packet in byte. M and D are two constant parameters which are determined by hardware specification, protocol used, and speeds of data transmission. Table 1 shows the value of M , D and energy consumption for idle and sleep states (*Idle Power* and *Sleep Power*), for the LUCENT IEEE 802.11 2 MBPS WAVELAN PC CARD 2.4 GHz [9]–[11]. In this device, energy consumption for sending 1024 byte of data as a packet is calculated as follows:

$$EC = 1.9 * 1024 + 266 = 2211.6 \mu\text{W.sec.}$$

Total energy consumption for packet transmission $EC_{\text{packet-trans}}$ is calculated by formula in Eq. (5), where n is the population and EC_i is energy consumed during the simulation and calculated by Eq. (4).

$$EC_{\text{packet-trans}} = \left(\sum_{i=1}^n EC_i \right) \quad (5)$$

The idle time and sleep time are total length of times that a node experienced in idle state and sleep state, respectively. The total energy consumed during idle time EC_{idle} and the total energy consumed during sleep time EC_{sleep} for all nodes in the network are calculated by Eq. (6) and (7), where $(\text{idle time})_i$ and $(\text{sleep time})_i$ are the idle and sleep time for each node respectively, *Idle Power* and *Sleep Power* are given in Table 2. Finally, overall energy consumption is shown in Eq. (8).

$$EC_{\text{idle}} = \left(\sum_{i=1}^n (\text{idle time})_i \right) (\text{Idle Power}) \quad (6)$$

$$EC_{\text{sleep}} = \left(\sum_{i=1}^n (\text{sleep time})_i \right) (\text{Sleep Power}) \quad (7)$$

$$EC_{\text{total}} = EC_{\text{packet-trans}} + EC_{\text{idle}} + EC_{\text{sleep}} \quad (8)$$

Table 2 Simulation setting and parameters.

Parameter	Values
Simulation duration	900 sec
Broadcast interval	2 sec
Pause time	2 sec
Maximum Speed of the node	10 m/s
Background Traffic	CBR
CBR Max pkts	1100 Byte
Max connection	16
Sending rate	packets/sec
Seed	1.0
Number of nodes	15,20,30,40,50,60,70,80,90
Area	Max x = 500 m max y= 500 m
Node sleep time	300 ms
Node idle time	600 ms

4.6 Rotating CHs of a Cluster Periodically

As highlighted in Sect. 3, all traffics in cluster based networks are monitored and controlled by the CH nodes. As such, the energy consumption in these nodes is high. One idea that helps the stability of network is to rotate periodically the CHs among all nodes in a cluster. This method would also help the stability of network, however it has more overhead, and consequently we do not consider to implement it in our proposed protocols.

5. Simulation and Results Evaluation

We conducted experiments in the Network Simulator 2 (NS2) [26] in order to evaluate the proposed protocols with considering energy consumption in the sending, receiving, idle and sleep states. The scenario files are created by the SetDest tool of the NS2 and the traffic files are created by cbrgen.tcl. The simulation setting and parameters are given in Table 2. We ran our simulation for different network populations with the purpose of evaluating the scalability of the proposed protocols as well as for different pause time to see the impact of mobility level to the proposed protocols. The same traffic pattern and mobility is used for all simulation experiments. We employ CBR for background traffic in the network with 16 links and each link sends 4 packets per second.

5.1 Energy Saving and Load Balancing on the Gateway Nodes

The total energy consumption of gateway nodes for both CBRP and EGCBRP is shown in Fig. 6. The difference between energy consumption in EGCBRP and CBRP is significant. The graphs in Fig. 6 and Fig. 7 show that the energy consumption and the saved energy are suddenly steep in 70 nodes population, because we found in our experiment result, the number of gateway nodes in 80 node population is less than in the 70 node population. As such, logically, less gateway nodes can be forced into sleep state. Nevertheless, overall the graph shows almost monotone linearly increases

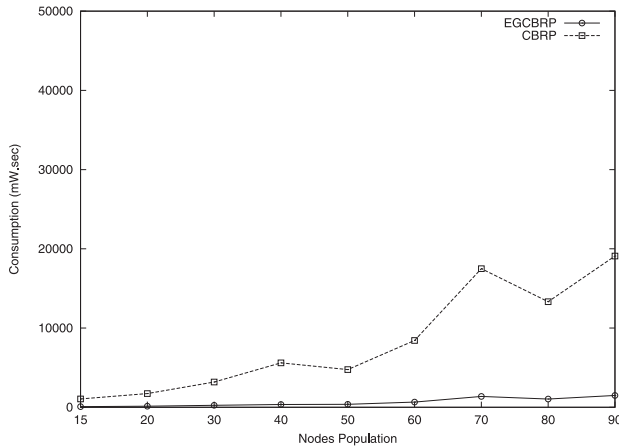


Fig. 6 Energy consumption of gateway nodes.

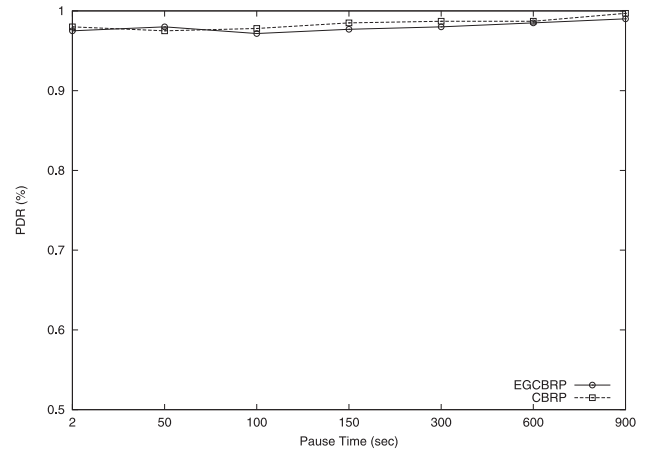


Fig. 8 Packet delivery ratio based on pause time.

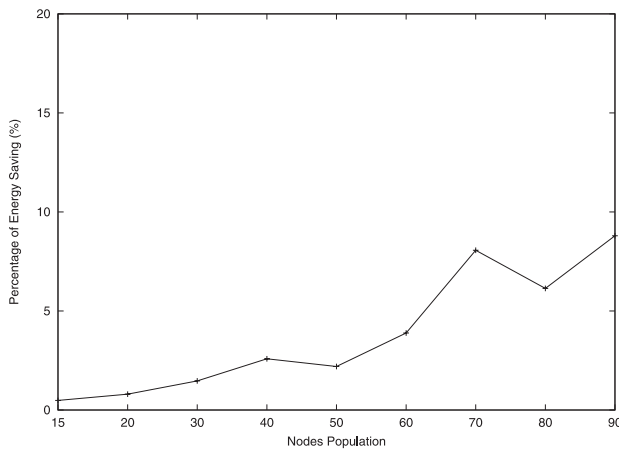


Fig. 7 The percentage of saved energy in EGCBRP.

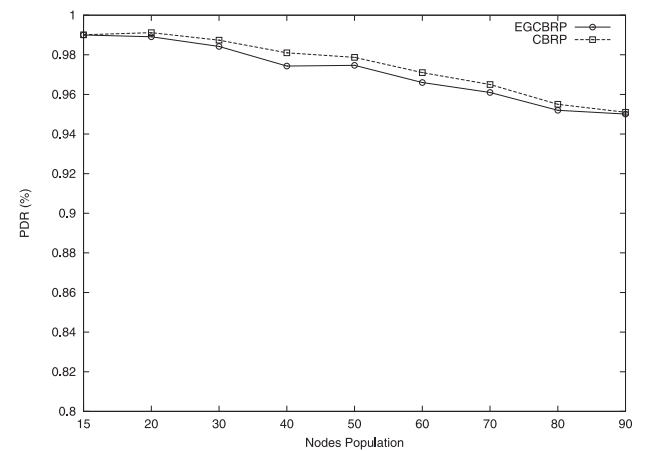


Fig. 9 Packet delivery ratio based on nodes population.

when the number of node population increases.

Figure 7 shows the percentage of saving energy in the gateway nodes for various node populations. The percentage is based on the ratio of energy consumed by nodes and the total available energy in the whole network. In general, when the number of nodes population increases, the density of the population increases and naturally the number of gateway nodes increases. The more gateway nodes we force into sleep mode, the more energy can be saved. However, there are cases where the number of gateway nodes does not increase due to the mobility of the nodes.

Basically, energy efficiency protocols try their best to save more energy and prevent irregular energy consumption so that it does not have any effect on throughput and route latency. Furthermore, the important side effects of this strategy are packet delivery latency and throughput. However, in the EGCBRP (with load balancing), we found there was no significant delay or throughput change compared to the CBRP (without load balancing). This is shown in Fig. 8 where the Packet Delivery Ratio (PDR) in both protocols CBRP and EGCBRP are not so different for various pause times and this shows EGCBRP supports mobility. Pause

time is length of time a node resides in one location/position. It is used to measure the mobility of nodes in a network. Network pause time is an important parameter in network mobility. By increasing the pause time, the mobility decreases. In other words, by zero pause time we have high mobility in the network. Moreover, we also consider the packet delivery ratio from another point of view which is scalability aspect. We set the pause time to 2 seconds for this experiment with nine various nodes populations. The packet delivery ratio based on nodes population and fixed pause time is shown in Fig. 9. The graph in Fig. 9 shows that there is no significant difference between the packet delivery ratio of CBRP and EGCBRP (after and before adding the balancing load algorithm). Thus, based on the results from Fig. 8 and Fig. 9, we conclude that the EGCBRP does not incur significant packet delivery ratio, at the same time considers the mobility support and scalability aspect as well.

The other experiment on the proposed protocol evaluation considers the packet delivery latency. The packet delivery latency is calculated based on the number of nodes population. It is shown in Fig. 10 that there is no significant latency between CBRP and EGCBRP. This means that our

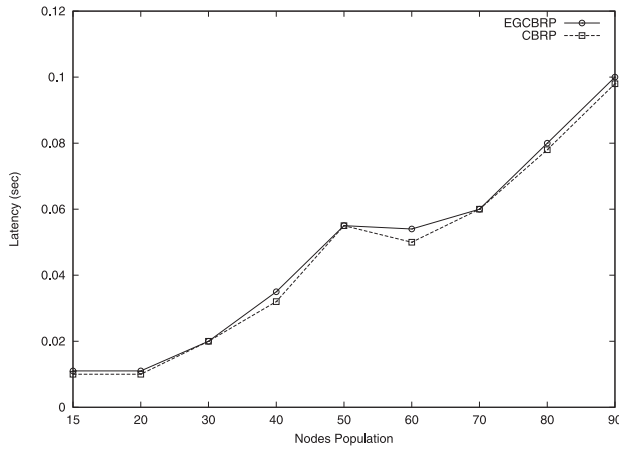


Fig. 10 Packet delivery latency.

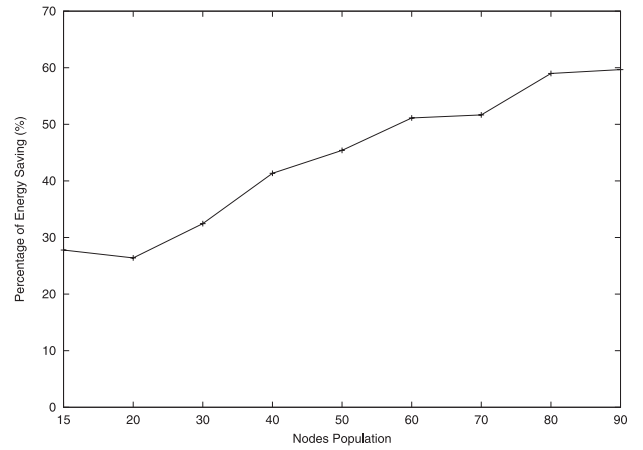


Fig. 12 The percentage of saved energy in EECBRP.

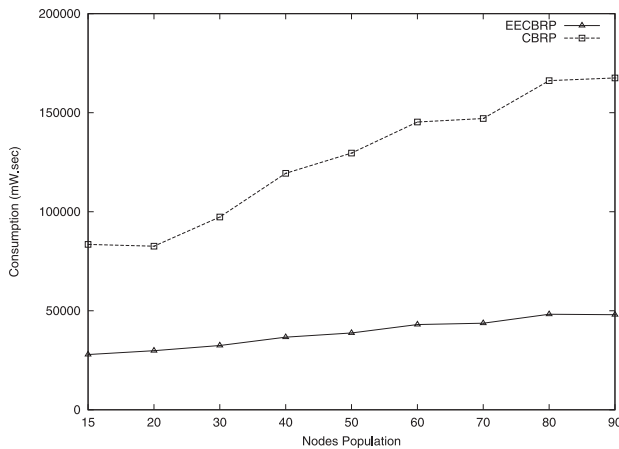


Fig. 11 Total energy consumption for several nodes populations.

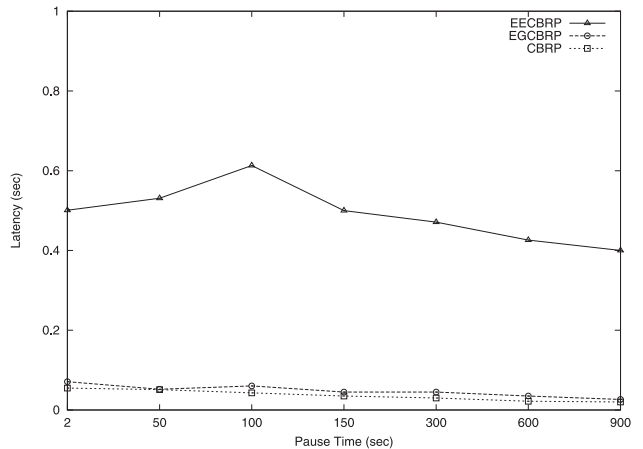


Fig. 13 Packet delivery latency.

protocol does not impose any delay to the network. This experiment and the two above experiments (Fig. 8, Fig. 9) show that our protocol is an efficient protocol.

5.2 Energy Saving on All Member Nodes

We carried out experiments on the total energy consumption on all member nodes (for the idle, sleep, sending and receiving states). Figure 11 shows the total energy consumption for the CBRP and EECBRP (with forcing idle state nodes into sleep state nodes) in various numbers of nodes populations. The simulation results show that to maximize the energy saving, the nodes should be put in sleep state instead of idle state. Figure 12 shows the percentage of saved energy on EECBRP which is considerable.

With the purpose of investigating the overhead delay of the proposed protocols we carried out the experiment with regard to packet delivery latency and throughput, based on various pause times. In this experiment we set the nodes populations to 50. The packet delivery latency for CBRP, EGCBRP, and EECBRP are shown in Fig. 13. From the graph in Fig. 13, we can see that packet delivery latency in our proposed EECBRP is about 4 times over the conven-

tional CBRP. This is the tradeoff that we need to consider for gaining more energy saving.

6. Conclusion and Future Work

CBRP is a robust and scalable routing protocol for MANETs. However, as a hierarchical protocol the CBRP consumes high energy to maintain the routing mechanism. Thus, an enhancement for the protocol which takes into account the energy consumption management in MANET is mandatory. We proposed EGCBRP and EECBRP as robust, scalable, energy efficient and stable routing protocols for MANETs. The EGCBRP modifies the CBRP in electing the Cluster Head (CH) by taking into account the available energy in candidate nodes. The EGCBRP defines a function to control and manage the use of inter-cluster links by turns with the aim of performing load balancing on these links. The EGCBRP forces the non-active gateway nodes to sleep state in order to save the energy. Since the active gateway nodes are connectors of two clusters, these nodes have a main role to network connectivity and stability and are not forced into sleep state. The experiment results showed that EGCBRP reduces the energy consumption up to 10%

compare to the conventional CBRP. The EGCBRP does not have any significant latency in the network due to connectivity interruption because nodes on backbone of the network keep alive during simulation. The experiment results furthermore showed that the EGCBRP optimizes the life-time of gateway nodes, which in turn improves the stability and connectivity of the MANETs.

In addition, with the intention of optimizing the energy consumption in the whole network we introduced EECBRP. In this protocol, instead of only forcing non-active gateway nodes, the sleep state mechanism is employed for all idle member nodes as well. Our experiment results showed that the energy consumption is saved up to 60%. In fact, this amount of the saved energy is obtained with the impact of significant increment on the packet delivery latency. Finally, the experiments results also showed that the protocols (EGCBRP and EECBRP) are scalable.

We plan to conduct further research on reducing packet delivery latency as a future work.

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