Energy Aware and Stable Multipath Routing Protocol in Clustered Wireless Ad hoc Networks

Omar Smail, Bernard Cousin, Zoulikha Mekkakia, Rachida Mekki

HAL Id: hal-01183306

https://hal.science/hal-01183306

Submitted on 7 Aug 2015

Energy Aware and Stable Multipath Routing Protocol in Clustered Wireless Ad Hoc Networks

Omar Smail[1], Bernard Cousin[2], Zoulikha Mekkakia[1], Rachida Mekki[1]
[1] Faculty of Mathematics and Informatics. Computer Science Department.
University of Sciences and Technology, 'Mohamed Boudiaf' USTO-MB, Oran, Algeria
[2] IRISA / University of Rennes 1, France.
smailomar@ieee.org, bcousin@irisa.fr, {zoulikha.mekkakia, rachida.mekki}@univ-usto.dz

ABSTRACT

Ad hoc networks are wireless networks that can operate without infrastructure and without centralized network management; they may contain nodes with limited battery power; hence, energy conservation is a critical requirement in the design of routing protocols for ad hoc networks. Clustering has been proposed as a promising method for simplifying the routing process in mobile ad hoc networks when network size increases. In this paper, we propose an energy-efficient multipath routing protocol, called ES-CMR (Energy aware and Stable Clustered based Multipath Routing protocol), which preserves the residual energy of nodes and increases the network lifetime. To achieve this goal, we use a single objective model to select energy-efficient paths with stable links. Simulation results demonstrate that ES-CMR has better performance in terms of energy consumption, network lifetime, and end-to-end delay.

Keywords: Ad hoc network, wireless networks, clustering, multipath routing, energy efficiency, path stability.

1. INTRODUCTION

An ad hoc network is characterized by frequent changes in network topology, limited bandwidth availability, and limited power of nodes. Ad hoc network topology changes frequently as nodes are able to move collectively or individually and often in an unpredictable way. Hence these characteristics make route discovery complex. Several research studies have focused on routing protocols of ad hoc networks [1–5], these protocols have certain relevant characteristics, but they have also some limitations in the case of high mobility of nodes or high network density.

Traditional approach of routing in wireless ad hoc networks adopts a single active route between a source node and a destination node for a given communication. This usually uses proactive [6,7] or reactive (on demand) [8,9] routing protocols. In [10], it is shown that proactive protocols are very expensive in terms of energy consumption compared to the reactive protocols, because of the large routing overhead incurred in the former. But reactive protocols suffer from latency during the discovery process of fresh paths, especially in large networks and dense networks.

In recent years, the research community has focused on the improvement of ad hoc routing, with the development of several routing techniques. Multipath routing - which resists to frequent network topology changes - seems to be an effective mechanism in ad hoc networks with high mobility and high load, which mainly caused wireless link failures. In multipath routing, the source node is given the choice between multiple paths to reach a certain destination. The multiple paths can be used alternately; in this case the data traffic can follow either a single path at one time or several paths simultaneously.

The major disadvantage of multipath routing is the additional generated cost which increases significantly with the growth of network density, thus the scalability is compromised. Existing routing protocols for ad hoc network cannot solve this problem. A commonly proposed solution is to organize nodes into groups, called clusters. Clustering is a virtual organization of the network into groups of geographically close nodes. In clustering, a representative of each cluster is elected as a cluster head and a gateway the node which serves as intermediate for inter-cluster communication.

Several clustering techniques in mobile ad hoc networks have been proposed in the literature [11-15]. The main problem of these techniques is to maintain their cluster structure as stable as possible while the network topology may change. However each node in mobile ad hoc networks has a power battery and a limited energy supply. Over time, nodes deplete their energy supplies and are eventually removed from the network, which constrains the network connectivity. Some exhausted nodes may be critical for packet transmission mainly if they are cluster head node, because they are more suitable for supporting the ad hoc network functions (e.g., routing) than other nodes. A good routing protocol with clustering scheme will tend to preserve its structure by preserving its nodes energy power, principally the cluster head and the gateway nodes.

In this paper, we propose a novel routing protocol, called ES-CMR (Energy aware and Stable Clustered based Multipath Routing protocol), for wireless ad hoc networks based on the multipath principle, in order to use the energy of nodes efficiently, and minimize the end-to-end delay of the mobile ad hoc networks. It uses clustering structure to decrease routing control overhead. ES-CMR protocol is designed primarily for battery-limited nodes, where link failures and path breaks may occur frequently. The main idea of this

protocol is to discover multiple paths between a source and a destination in a clustered wireless ad hoc network and to select the path that ensures the least energy consumption with stable links. In order to combine energy efficiency and stability of links, we used a single objective function. This combination favours the energy efficient consumption because it has a strong impact on link breaks.

The paper is organized as follows. Section 2 provides a review of related works on known clustering techniques in wireless ad hoc networks. Section 3 presents a description of our proposed cluster creation and maintenance schemes. Section 4 gives the design details of the ES-CMR protocol. Section 5 provides the simulation results of its performance evaluation. Section 6 concludes this paper.

2. CLUSTERING TECHNIQUES

We present below different clustering techniques, that are categorized into different approaches based on theirs distinguished features. We focus on mobility and energy of nodes because in ad hoc networks a node is mobile and has a limited battery; when it moves out of range of its neighbours or it runs out of battery power, some wireless links between nodes may fail. These failures increase the intensity of changes in the network topology and make routing difficult. Two types of clustering schemes are considered: single metric and combined metric based clustering.

Combined metrics based clustering or weight based clustering takes several metrics into account for cluster configuration. One advantage of this clustering scheme is that it can flexibly adjust the weighting factors for each metric to adapt to different scenarios. We choose two metrics (energy and mobility of nodes) because they affect the reliability of the packet delivery service of ad hoc network.

The Weighted Clustering Algorithm (WCA) proposed in [16] takes into consideration the ideal degree, transmission power, mobility, and battery energy of mobile nodes. Depending on specific applications, any or all of these parameters can be used in the metric to elect the cluster heads. This method could have a fully distributed system where all the nodes in the mobile network share the same responsibility and act as cluster heads.

WCA does not invoke re-clustering when a member node changes its attaching cluster. Even though this mechanism can enhance the stability of cluster topology, this also implies that cluster heads keep their status without considering the attribute of minimum weight factor in later cluster maintenance. For instance, in relatively static networking environments, WCA will hardly ever be invoked, hence cluster heads service time will be prolonged and elected cluster heads will soon suffer from battery exhaustion. WCA has improved performance compared with other previous clustering algorithms. But it fails to capture the correlation that may exist among the movements of neighbouring mobile hosts as in the case of group movement. Another drawback of this method, the high mobility of nodes will lead to high frequency of cluster re-association which will increase the network overhead. To solve this problem, an entropy-based WCA (EWCA) was proposed [17] which can improve the stability of the network.

In CEMCA (Connectivity, energy & mobility driven weighted clustering algorithm) [18], the election of the cluster head is based on the combination of several significant metrics such as the lowest node mobility, the highest node degree, the highest battery energy and the best transmission range. This algorithm is completely distributed and all nodes have the same chance to act as a cluster head. CEMCA is composed of two main stages. The first stage consists in the election of the cluster head and the second stage consists in the grouping of members in a cluster. Normalized value of mobility, degree and energy level is calculated and is used to find the quality for each node. The node broadcasts its quality to their neighbours in order to select the better among them. After this, a node that has the best quality is chosen as a cluster head. In the second stage the creating of the cluster member set is done. Each cluster head defines its neighbours at two hops maximum. These nodes form the members of the cluster. Next, each cluster head stores all information about its members, and all nodes record the cluster head identifier. This exchange of information allows the routing protocol to function into the cluster and between the clusters. Drawback of this method is that, energy consumption in cluster increases when one node is located far from its cluster head but it remains available and so it is still a member of cluster.

In [19] the authors proposed an adaptive weighted cluster-based routing for mobile ad-hoc networks. The cluster head selection is performed by assigning a weight value based on the following factors: energy level, connectivity and stability. The cluster head selection in the proposed approach uses the above weight value (W). The node having minimum W is chosen as the cluster head. When a node is selected as a cluster head, this node and the members of this node are marked as "considered". Then the election process is carried out within the set of all "unconsidered" nodes. Once all the nodes have been considered, the election algorithm gets terminated. AWCBRP is an energy efficient and is an adaptive weighted cluster based routing protocol which amends swiftly to the topological changes and establishes the routing efficiently. This involves high link failure rate and so partitioning rate of the network is considerably high, this leads to increase the computational overhead.

3. CLUSTER CREATION AND CLUSTER MANAGEMENT

In this section we describe the clustering scheme. Before proceeding with the presentation of the various steps of the algorithm we describe the network model.

3.1 Network model

An ad hoc wireless network is represented by an undirected graph, $G = (V, E)$, where V is the set of network nodes and E is the set of network bidirectional links. Node s is the source node and the node d is the destination node. In our scheme, there are three possible states for nodes: cluster head, gateway and ordinary. A cluster is denoted by $Ci = \{Nij\}$, where Nij are members of the cluster i. CHi is the cluster head of cluster Ci and CGi is the gateway set of the cluster Ci. Routing for large-scale ad hoc network requires k-hop clusters, where k represents the maximum number of hops between any cluster node and its cluster head. We call k as the cluster radius. By adjusting the parameter k, we can control the number of cluster heads. A large value of k means fewer cluster heads. This reduces the cluster number of ad hoc network which, in turn, may minimize the inter-cluster connectivity problems. To facilitate the description the clustering scheme and routing protocol, $k = 2$ is adopted throughout the remainder of this study.

3.2 Cluster creation

In clustering scheme, a representative node of each cluster is elected as a *cluster head*. Cluster heads hold routing and topology information, relaxing ordinary mobile hosts from such requirement; however, they represent network bottleneck points and are prone to fast battery exhaustion, thus the choice of cluster head is very crucial for the cluster stability and its lifetime. For our cluster formation, we have selected the Entropy-based Weighted Clustering Algorithm (EWCA) [17], which is an improvement of the basic protocol WCA [16]. We have selected this algorithm because an entropy-based model is considered a very good indicator of the stability and mobility of the ad hoc network [20].

We denote the position of node m at time t as $\vec{p}(m,t)$.

The positions of nodes are calculated periodically every time interval Δ_t. The distance between node m and n at time t is defined as :

$$\vec{p}(m,n,t) = \vec{p}(m,t) - \vec{p}(n,t) \qquad (1)$$

The relative position between two nodes, m and n is defined as

$$a_{m,n,t} = \frac{1}{N} \sum_{i=1}^{N} \left| \vec{p}(m,n,t_i) \right| \qquad (2)$$

Where t_i refers to the time instant of the i-th calculation and N is the number of discrete times t_i within the time interval Δt.

Then the entropy of Fm at time t is denoted as $H_{Fm}(t,\Delta_t)$. We have

$$H_{Fm}(t,\Delta_t) = \frac{-\sum_{k \in Fm} P_k(t,\Delta_t) \log P_k(t,\Delta_t)}{\log(\overline{Fm})} \qquad (3)$$

where $P_k(t,\Delta_t) = (a_{m,k,t} / \sum_{i \in Fm} a_{m,i,t})$.

Fm denote the set of the neighbour nodes of node m, and by $\overline{Fm}$ the cardinality (degree) of set Fm. Fm refers to the potential cluster centred on node m, hence H_{Fm} presents the stability of this cluster, the set of all nodes that can reach node m in one hop. It should be noted that the entropy, as defined here, is small when the change of variable values in the given region is severe and large when the change of the values is small. One term in replaced in the combined weighted sum of node v (W_v) described in [16]: the average speed of nodes M_v by the entropy H_{Fv} defined in (3). Simulation study given later will indicate that this replacement can effectively reduce the frequency of cluster re-association, especially for those networks consisting of high-speed moving nodes [17]. Hence, our new formula to calculate W_v becomes:

$$W_v = c_1 \Delta_v + c_1 D_v + c_3 (-H_v) + c_4 P_v \qquad (4)$$

where Δ_v is the degree between the number of members of the cluster centred on node v and the number it can handle under ideal condition, Dv is the sum of the distances of the members to node v, H_{Fv} is the entropy of the node, and Pv is the accumulative time of node v being a cluster head. P_v implies how much battery power has been consumed. We assume that the energy consumption of a cluster head is more than an ordinary node. c_1, c_2, c_3, c_4 are the respective weighing factors.

The node with the minimum W_v is chosen to be the cluster head. Once a node becomes a cluster head, that node and all its cluster members are marked as "considered". Then the election process interacts on all "unconsidered" nodes (Initially, all nodes are "unconsidered"). The election algorithm will terminate once all the nodes have been considered.

3.3 Inter-cluster links maintenance

A routing path may break due to a broken link, especially due to the high mobility of nodes. In the case of an ad hoc network organized in clusters, the most critical links are the links between the gateways nodes. Thus, we need an effective mechanism for maintaining connectivity between clusters despite disruptions of some of these critical links to ensure the success of routing. We propose two variants: distributed and centralized solutions.

3.3.1 Distributed solution

When the moving of a gateway node breaks the inter-cluster link, the gateway node sends a *RELG* query (Request Error Link Gateway) to the gateway node of the neighbour cluster associated with the link. *RELG* query contains information of the new gateway node relays, noting that each gateway node has information about all gateway relay nodes in the same cluster. Finally the cluster head node is informed of this update.

3.3.2 Centralized solution

When a gateway node moves, the inter-cluster link can break, the moved gateway node sends a request to its cluster head so that it is replacing the gateway node (in this case the gateway node have no information about the topology of the cluster). In case of a broken inter-cluster link, the gateway node sends an error packet *RERR* (Request Error) to its cluster head node. The cluster head designates a new gateway node which uses a replacement link which replaces the broken inter-cluster link.

We opted for a centralized solution because it is compatible with the proposed clustering technique, which is based on a cluster management by an elected node, called cluster head.

4. THE ES-CMR MULTIPATH ROUTING PROTOCOL

In this section, we present our efficient routing protocol, named ES-CMR (Energy aware and Stable Clustered based Multipath Routing protocol), its based on the topology constructed by the clustering algorithm [17]. Our protocol has two parts: intra-cluster and inter-cluster routing. In case of a request for a path between a source *s* and destination *d*, the cluster head associated to the cluster of the source *s* checks if the destination node *d* is a member of its cluster, if that is the case an intra-cluster routing is launched. Otherwise, cluster external research is initiated to locate *d*, it is the inter-cluster routing. In all cases, two packets are used: RREQ (Route Request) is sent from the node source for the path discovery and RREP (Route Reply) is sent by the destination as a response to the request.

The RREQ packet has the following structure:
RREQ = (src_id, dest_id, b_id, seq_nbr_s, n_id, gats_id, seq_d, ttl) with
- src_id : source node identifier
- dest_id : destination node identifier
- b_id : broadcast identifier
- seq_nbr_s: sequence number of the transaction given by source node
- n_id: neighbor identifier
- gats_id : gateway node identifier
- path_seq_d : sequence of identifiers of the intermediate nodes toward the destination node
- ttl : time to live

The RREP packet has the following structure:
RREP = (src_id, dest_id, seq_nbr_d, seq_r, e_{ij}_cumul, s_{ij}_cumul, ttl) with
- src_id: source node identifier
- dest_id: destination node identifier
- seq_nbr_d: sequence number of the transaction (given by the source node)
- path_seq_r: sequence of identifiers of the intermediate nodes toward the node source s
- e_{ij}_cumul: cumulative value of the energetic coefficient

- s_{ij}_cumul: cumulative value of the stability coefficient
- ttl: time to live

4.2 Intra-cluster routing

When a source *s* of a cluster C_i searches to establish a path with a destination *d* of the same cluster C_i, node *s* sends first a *RREQ* packet to the cluster head CH_i. Since the cluster head contains information about its member nodes, CH_i responds to the request of node *s* by sending a reply packet RREP containing the sequence of intermediate nodes between *s* and *d*. Thus, the node *s* can communicate with the node *d* using this path.

4.3 Inter-cluster routing

Inter-cluster routing allows a node source *s* to reach a destination *d* belonging to another cluster. The cluster head and gateways manage the communications between clusters.

4.3.1 Multipath routing discovery

When a cluster head receives a request for a path from a source *s* of its cluster C_i to a destination *d*, first it consults its cluster nodes set containing information about all nodes belonging to its cluster C_i. It notes that destination node *d* does not belong to cluster C_i. In this case, it sends a request RREQ to each gateway node listed in its gateway set CG_i. Gateway nodes receiving the request RREQ send requests to neighboring gateway nodes (gateways of the neighboring clusters). Then gateway neighboring nodes send the request RREQ to their cluster head which verifies the presence of the destination node in its own cluster.
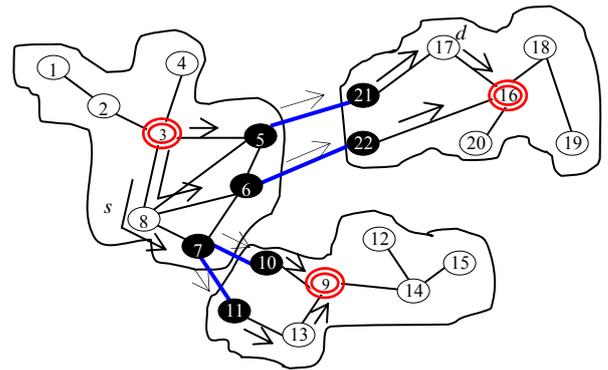
→: Request packet RREQ, s : Source node, d : Destination node
◎ Cluster head ● Gateway ◯ Ordinary node

Fig.1. Discovery requests paths

In Fig. 1. node 8 sends a request RREQ to its cluster head node 3. Cluster head 3 broadcasts the query to all gateway nodes 5, 6 and 7. Each gateway node sends the query to their neighboring gateway nodes. Thus the gateway nodes 21, 22, 10 and 11 receive the request and they will send it to their respective cluster head nodes 16 and 9. The path sequence is inserted in the request

RREQ and is updated at each intermediate node. This solution guarantees loop-free paths, since a RREQ request is simply deleted by a node when the node identifier is listed into the path parameter of the RREQ request.

4.3.2 Reverse paths

Once a cluster head node locates in its own cluster the destination node d, it completes the path sequence by the path segment from the gateway node to the destination node d and then it sends RREP packet to the sender gateways nodes. Return paths used by the RREP packet are not necessarily the same paths used by the request RREQ, as the RREQ requests are sent by the intermediate cluster head/gateway node to the destination node d, so the RREP packets using reverse paths indicated by the cluster head which are necessarily better than the paths traversed by the RREQ requests. Using the previous example, in Fig. 1. cluster head node 16 finds destination node d in its own cluster and sends a RREP packet to gateway nodes 21 and 22. These nodes broadcast reply packets to their neighbouring gateway nodes, in our example; these are gateway nodes 5 and 6. The RREP packets follow the sequence of the intermediate nodes indicated in the *path_seq_r* field to reach the source node 8. Cluster head node 9 does not return RREQ requests to gateway nodes 10 and 11 as they are sender's RREQ requests. However, source node may not receive any RREP packet; in this case, after a certain waiting time (a timeout is set - with the value *RREQ_Wait_Time* - each time a RREQ packet is sent), the source node initiates path discovery process and repeats the search process until a path is found. After three attempts, the route discovery process is canceled.

4.4 Multipath routing selection

This section describes path selection routing based on the works [21-27]. When the node source receives the first RREP packet, it waits for a certain amount of time (*RREP_Wait_Time*) to receive more RREPs before selecting the best path. The choice of the best path between a source node s and destination node d, is done according to energy consumption and link stability. In this approach, two functions that are defined : the coefficient $e_{ij}(t)$ which characterizes a node from an energetic point of view and the coefficient $s_{ij}(t)$ which represents the stability of link (i,j) at time t, formally:

$$e_{i,j}(t) = \frac{P_{i,j}(t)}{PR_j(t)} \cdot \frac{DR_j(t)}{E_j^0} \cdot T_{i,j} \tag{5}$$

Where E_j^0 represents the initial energy level of node j and $T_{i,j}$ is the time required to send a data packet from node i to node j. The power load rate, PR_j, is used, in conjunction with the transmission power, $P_{i,j}$, and drain rate, DR_j, to define the coefficient $e_{i,j}$. They are defined as follows:

$$PR_j(t) = \frac{E_{resj}}{E_j^0}$$

$$P_{i,j}(t) = c_{i,j} \cdot f_{i,j}$$

$$DR_i(t) = \alpha . DR_i(t-1) + (1-\alpha) . DR_{curr,i}$$

E_{resi} denotes the residual energy of node i. $f_{i,j}$ is the bandwidth of the data stream sent from node i to j and the coefficient $c_{i,j}$ represents the power consumption cost per bit associated with link (i, j). Each node i monitors its energy consumption caused by the transmission, reception and overhearing activities and computes the energy drain rate, denoted by DR_i, for every T seconds sampling interval by averaging the amount of energy consumption and estimating the energy dissipation per second during the last T seconds. The value of DR_i is calculated by utilizing the well-known exponential weighted moving average method [28], applied to the drain rate values $DR_i(t-T)$ and $DR_{curr,i}$, which represent respectively the previous and the newly calculated values : $DR_i(t)=alpha. DR_{curr,i}+ (1-alpha).DR_i(t-T)$;
The coefficient $s_{ij}(t)$ is defined as follows :

$$s_{i,j} = \frac{d_{i,j}^{avg}}{R_{i,j}(a_{i,j})k} \qquad \forall (i,j) \in A \tag{6}$$

where $d_{i,j}^{avg}$ the average among the movement distances of each node under the Random Way Point (RWP) mobility model.
The coefficient $R_{i,j}$ is the ratio between the sum, on all links belonging to the set of links A with age equal or greater than the age (duration) between two nodes i and j ($a_{i,j}$), of the products of the age a and the number of links with age equal to a, over the total number of links with age greater or equal to $a_{i,j}$. k is a scaling factor, defined in such a way that the link stability can be compared to the energy consumption.
The coefficient $R_{i,j}$ is given by:

$$R_{i,j}(a_{i,j}) = \frac{\sum_{a=a_{i,j}}^{A_{max}} a d[a]}{\sum_{a=a_{i,j}}^{A_{max}} a.d[a]} - a_{i,j} \forall (i,j) \in A \tag{7}$$

where a_{max} represents the maximum observed age of the links and d is an array used to store the observed data. Path selection principle is very important for ensuring stable data communication. As mentioned above, several paths can be discovered between a ordered pair of nodes (source and destination). So we design our multi-path selection principle on the ordering of paths according to the energy consumption of their path nodes and the link stability of their path links. To satisfy this, we use a single objective model using arbitrary importance weights for each criterion (p_1 and p_2). The corresponding objective function f_{tot} is defined as:

$$f_{tot} = p_1 \sum_{(i,j) \in A} e_{i,j}(t).x_{i,j} + p_2 \sum_{(i,j) \in A} s_{i,j}(t).x_{i,j}$$

$$= \sum_{(i,j) \in A} (p_1 . e_{i,j}(t) + p_2 . s_{i,j}(t)).x_{i,j} \tag{8}$$

where

$$\sum_{(i,j)\in A} x_{i,j} - \sum_{(j,i)\in A} x_{j,i} = \begin{cases} 1 & if & i = s, \\ 0 & if & i \in N - \{s,d\}, \\ -1 & if & i = d, \end{cases}$$

$$x_{i,j} \in \{1,0\} \qquad \forall (i,j) \in A$$

Where <il manque quelchose ici> represents the flow conservation constraints that are used to ensure that each feasible solution of the proposed model is a path from s to d. Our idea is based on sorting all paths between a source node s and destination node d by the ascending value of f_{tot}. The path with the minimum $f(t)$ is chosen to forward the data packets. We note that this model [21] can be used to address many applications, with different QoS constraints when we choose appropriate values for the parameters p_1 and p_2. For instance, with applications that require energy saving, more importance is given to the coefficient p_1 ($p_1 >> p_2$), since it is the weight associated to the path energy in the model. Weights p_1 and p_2 are chosen such that the condition $p_1 + p_2 = 1$ is satisfied.

4.5 Route management

Route error detection in ES-CMR is launched when a link fails between two nodes along a path from a source to a destination. When a neighbor node does not respond to three successive HELLO packets sent by a node, the link is considered to have failed. If a node detects a failure of a link in an active path, it erases the route from its routing table and then sends an RERR (Route ERRor) packet to the source node of the path to select another path. Each intermediate node forwards this RERR packet along the reverse path to the source node. When a source node receives an RERR packet, it erases the path from its routing table and looks for an alternative path towards the destination node, if one is available; otherwise it initiates a path discovery process to resume the data transmission. An alternative path is selected as described in Section 4.4.

5. PERFORMANCE EVALUATION OF ES-CMR

In this section, we present simulation results to demonstrate the efficiency of our proposed protocol. First we present the metrics used for performance evaluation and then we evaluate our protocol by comparing it with one protocol in the literature, namely EWCA [17]. This evaluation comes with an analysis and discussion of results.

5.1 Performance metrics

We evaluate three key performance metrics: energy consumption, network lifetime and end-to-end delay. Energy consumption is the average of the energy consumed by nodes participating in packet transfer from the source node to the destination node during the whole simulation. The network lifetime can be defined in three ways [29]: the time taken to exhaust the battery of the first network node, the time required to drain the battery of a certain portion of network nodes, and the time when the battery of the last network node is exhausted. We choose the second way; this allows to see the evolution of the lifetime of the network. End-to-end delay is the average transmission delay of data packets that are delivered successfully over the total duration of the simulation.

5.2 Performance evaluation

In our protocol, the choice of the path made by a source node to transmit data packets toward a destination node is based on the energy of nodes and the path stability. This is mainly affected by the value of two weights p_1 and p_2. Our protocol promotes energy conservation, so the choice of the coefficient value for p_1 (associated to the energy) must be greater than p_2 coefficient (associated to the stability). Thus p_1 is set to 0.7 in our performance evaluation.

We carried out simulations to determine the effectiveness of our protocol. The principal goal of these simulations is to analyze our protocol by comparing it with the protocol EWCA [17]. The values of simulation parameters are summarized in Table 1.

TABLE 1. Simulation parameters

Communication Model	Constant Bit Rate (CBR)
MAC type	IEEE 802.11
Mobility model	Random Waypoint
Terrain range	840 m × 840 m
Transmission range	250 m
Number of mobile nodes	90, 120, 150 and 180
Data payload	512 bytes
RREQ_Wait_Time	1.0 s
RREP_Wait_Time	1.0 s

To evaluate ES-CMR, we use the network simulator ns-2 [30]. Each simulation has duration of 200 seconds, this duration gives significant results. During each simulation, constant bit rate (CBR) connections are generated, each of which produces four packets per second with a packet size of 512 bytes. The values of *RREQ_Wait_Time* and *RREP_Wait_Time* are set to 1.0 seconds.

We vary the number of network nodes from 90 to 180 to obtain different scenarios in an 840 m × 840 m environment. The Random Waypoint model is used to simulate node movement; each node moves with a speed randomly (uniform distribution) chosen from 0 to 5 m/s. The radio model uses characteristics similar to a commercial radio interface, Lucent's Wave LAN. Wave LAN [31] is a shared-media radio with a nominal bit-rate of 2 Mbit/s and a nominal radio range of 250 m, which is compatible with the IEEE 802.11 standard. Each simulation is carried out under a different number of network nodes and the performance metrics are obtained by averaging over 10 simulation runs. We assume that a node consumes 281.8 mW while receiving and 281.8 mW while transmitting [32], the

energy consumption during the idle state is not considered because no real node energy optimization can be achieved in the idle state [33]. In our simulations, we initialized the energies of the nodes randomly between 10 and 60 Joules (uniform distribution), which corresponds to the usual capacity of a battery. Fig. 2. shows the energy consumed by the ES-CMR and EWCA protocols. Initially, ES-CMR is not better than EWCA, because initially the majority of packets are not yet transmitted, so the total energy of sending and receiving packets is not important. But as time increases, there is some imbalance of energy which is noted and then the impact of our protocol is significant. The energy consumed in ES-CMR is less than the energy consumed by ES-CMR. In Fig 2. the energy consumed of ES-CMR is lower than EWCA, by at least 39%, on average.
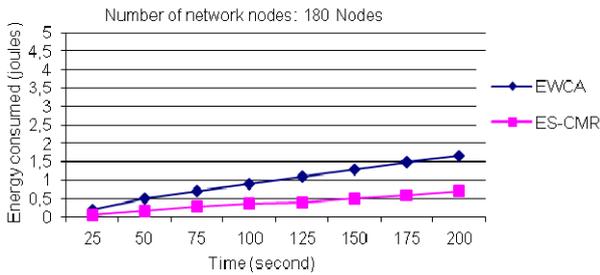

Fig. 2. Energy consumed versus time

ES-CMR consumes less energy than EWCA, firstly because ES-CMR favours paths with a high energy based on paths selection (a higher weight is associated to the energy aware metric). Secondly, ES-CMR is a multipath routing protocol unlike EWCA; in EWCA a new path discovery process is required once a path failure is detected, this additional path discovery generates an additional cost in energy caused by the sending of additional control packets. The network life depends on the node expiration which in turn depends upon energy consumption. The network lifetime metric is shown in Fig. 3. in different pauses times for number of network nodes between 50 to 200. The network lifetime of ES-CMR is longer than EWCA, in all different pause times, ES-CMR has a smaller number of nodes that is exhausted compared to EWCA.
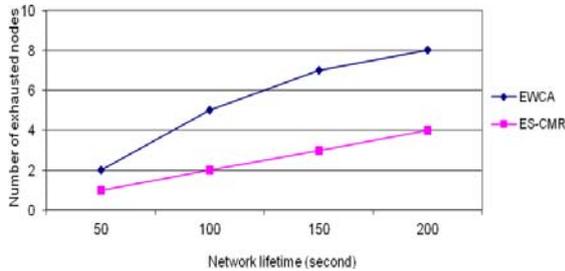

Fig. 3. Network lifetime versus number of exhausted nodes

Thus ES-CMR balances the energy among all the nodes and prolongs the path nodes lifetime and hence the network lifetime.

Fig. 4. shows the average end-to-end delay. The average end-to-end delay for all tested protocols increases as the network size increases, but the average end-to-end delay of ES-CMR is lower than EWCA. When the number of nodes of a network is between 60 and 120, the delay of the ES-CMR protocol is nearly 58% lower than that of the EWCA protocol and nearly 61% when the network number of nodes is between 120 and 180.
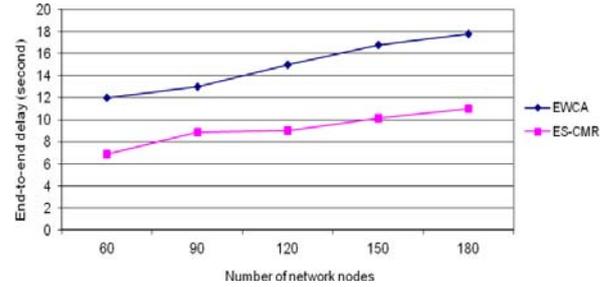

Fig. 4. End-to-end delay versus number of nodes

Indeed our ES-CMR protocol favors energy efficient paths which ensures less path failures. Moreover, ES-CMR protocol is a multipath routing protocol which can use alternative paths when wireless links fail so it reduces the delay of rerouting and overhead consumption.

6. CONCLUSION

In this paper, we propose ES-CMR which is an energy aware and stable clustered based multipath routing protocol for wireless ad hoc networks, in order to reduce nodes energy consumption and end-to-end delay and extend network lifetime. ES-CMR is a cluster based protocol which improves the performance of ad hoc networks. The proposed protocol is a multipath routing protocol which uses an energy-aware mechanism which exploits the residual energy of nodes and link stability to select the best discovered paths. We conducted simulation experiments to measure the performance of our protocol and demonstrate that it performs significantly better than well known protocol proposed in literature such as EWCA. ES-CMR reduces energy consumption by at least 47% compared to EWCA for a network size of 90 to 120, and nearly 39% when the network size is between 150 and 180 on average. ES-CMR outperforms EWCA by extending the node lifetime and has a lower average end-to-end delay, because paths are computed depending on the energy of their nodes, and the best path is selected.

REFERENCES

[1] S. R. Das, C. E. Perkins, and E. M. Royer, "Performance comparison of two on-demand routing protocols for ad hoc networks," Proc. of the IEEE Conf.. on Computer Communications INFOCOM, 2000.

[2] T. Clausen and P. Jacquet, "Optimized link state routing protocol," RFC 3626, 2003.

[3] D. B. Johnson and D. A. Maltz, "Dynamic source routing in ad-hoc wireless networks," Mobile Computing, T. Imielinski, H. Korth, and Eds., Kluwer Academic Publishers, Chapter 5, pp. 153–181, 1996.

[4] D. Murthy and J. J. Garcia-Luna-Aceves, "A routing protocol for packet radio networks," Proc. of the 1st ACM International Conf. on Mobile Computing and Networking MOBICOM'95, pp. 86–95, 1995.

[5] V. D. Park and M. S. Corson, "A highly adaptive distributed routing algorithm for mobile wireless networks," Proc. of 1997 IEEE Conf. on Computer Communications INFOCOM, April 1997.

[6] E. M. Belding-Royer , S. Basagni, M. Conti, S. Giordano and I. Stojmenovic, "Routing approaches in mobile ad hoc networks," Mobile Ad Hoc Networking, IEEE/Wiley, pp. 275–300, Sept. 2004.

[7] C. E. Perkins and P. Bhagwat, "Highly dynamic destination sequenced distance vector routing (DSDV) for Mobile Computers," Proc. of ACM SIGCOMM'94, pp. 234–244, Sept. 1994.

[8] S. Mueller, R.P. Tsang, and D. Ghosal, "Multipath routing in mobile ad hoc networks: issues and challenges," Performance Tools and Application to Networked Systems, Lecture Notes in Computer Science, vol. 2965, pp. 209–234, Apr. 2004.

[9] C. E. Perkins, E. M. Royer, and S. Das, "Ad hoc on-demand distance vector (AODV) routing," RFC 3561, July 2003.

[10] T. X. Brown, S. Doshi, and Q. Zhang, "Optimal power aware routing in a wireless ad hoc network," Proc. of IEEE LANMAN, pp. 102–105, 2001.

[11] R. Agarwal and M. Motwani, "Survey of clustering algorithms for MANET," International Journal on Computer Science and Engineering vol.1, issue: 2, pp. 98-104, 2009.

[12] M. Anupama and B. Sathyanarayana, "Survey of Cluster Based Routing Protocols in Mobile Ad hoc Networksm," International Journal of Computer Theory and Engineering, vol. 3, no. 6, pp. 806-8015, Dec. 2011.

[13] R. Agarwal, R. Gupta, and M. Motwani, "Review of Weighted Clustering Algorithms for Mobile Ad hoc Networks," GESJ: Computer Science and Telecommunications, vol. 33, no.1, pp. 71-78, 2012.

[14] S. Basagni, M. Mastrogiovanni, and C. Petrioli, "A performance comparison of protocols for clustering and backbone formation in large scale ad hoc networks," Proc. of The 1st IEEE International Conf. on Mobile Ad Hoc and Sensor Systems, MASS, pp. 70–79, pp. 25–27, Oct. 2004.

[15] F. Sharmila and R. Elijah Blessing, "Performance Analysis of Clustering Protocols in Mobile Adhoc Networks," Journal of Computer Science, vol. 4, Issue 3, pp.192-204, 2008.

[16] M. Chatterjee, S. Das, and D. Turgut, "Wca: A weighted clustering algorithm for mobile ad hoc networks," Cluster computing Journal,vol. 5, no. 2, pp. 193–204, 2002.

[17] Y. Wang and F. S. Bao, "An Entropy-Based Weighted Clustering Algorithm and Its Optimization for Ad Hoc Networks," Third IEEE International Conf. on Wireless and Mobile Computing, Networking and Communications WIMOB, 2007.

[18] F. D. Tolba, D. Magoni, and P. Lorenz, "Connectivity, energy & mobility driven Weighted clustering algorithm," Proc. of IEEE GLOBECOM, 2007.

[19] S. Karunakaran and P. Thangaraj, "An adaptive weighted cluster based routing (AWCBRP) protocol for mobile ad-hoc networks," WSEAS Trans. on communications, vol. 7, Issue 4, pp 248-257, April 2008.

[20] B. An and S. Papavassiliou, "An entropy-based model for supporting and evaluating route stability in mobile ad hoc wireless networks," IEEE Communications Letters, vol. 6, no. 8, August 2002.

[21] F. De Rango, F. Guerriero, and P. Fazio, "Link Stability and Energy Aware Routing Protocol in Distributed Wireless Networks," IEEE Trans. on parallel and distributed systems, vol.23, no 4, pp. 713-726, April 2012.

[22] N. Meghanathan and A. Farago, "Looking at Protocol Efficiency from a New Angle: Stability-Delay Analysis," Proc. Second Int'l Conf. Mobile Computing and Networking, pp. 51-55, 2004.

[23] Y. Colletter and P. Siany, "Multiobjective Optimization: Principles and Case Studies, Decision Engineering," Springer-Verlag, 2003.

[24] A. J. V. Skriver and K. A. Andersen, "A Label Correcting Approach for Solving Bicriterion Shortest Path Problems," Computer and Operations Research, vol. 27, pp. 507-524, 2000.

[25] T. Tanino, T. Tanaka, and M. Inuiguchi, "Multi-Objective Programming and Goal Programming," Theory and Applications. Springer, 2003.

[26] F. De Rango, M. Gerla, and S. Marano, "A Scalable Routing Scheme with Group Motion Support in Large and Dense Wireless Ad Hoc Networks," Elsevier Computers and Electrical Eng. J., vol. 32, no. 1-3, pp. 224-240, 2006.

[27] K. Fall and K. Varadhan, "The ns Manual: formerly ns Notes and Documents," The VINT Project, UC Berkeley, LBL, USC/ISI, and Xerox PARC, http://www.isi.edu/nsnam/ns/ns-documentation, May. 2010.

[28] K. Dongkyun, J. J. Garcia-Luna-Aceves, K. Obraczka, J.-C. Cano, and P. Manzoni, "Routing Mechanisms for Mobile Ad Hoc Networks Based on the Energy Drain Rate," IEEE Trans. Mobile Computing, vol. 2, no. 2, pp. 161-173, Apr.-June 2003.

[29] M. Bheemalingaiah, M. M. Naidu, D. Sreenivasa Rao, and G. Varaprasad, "Energy aware node disjoint multipath routing in mobile ad hoc network," Journal of Theoretical and Applied Information Technology, vol.2, no.2, pp. 416-431, 2009.

[30] The Network Simulator ns-2, available online at http://www.isi.edu/nsnam/ns.

[31] L. M. Feeney and M. Nilsson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment," IEEE INFOCOM, pp. 1548–1557, Apr. 2001.

[32] E. S. Jung and N. H. Vaidya, "A power control MAC protocol for ad hoc networks," Proc. of the ACM International Conf. on Mobile Computing and Networking MOBICOM, pp. 36–47, Sept. 2002.

[33] D. Kim, J. J. Garcia-Luna-Aceves, K. Obraczka, J-C. Cano, and P. Manzoni, "Routing mechanisms for mobile ad hoc networks based on the energy drain rate," IEEE Trans. on Mobile Computing, vol. 2, no. 2, pp. 161–173, 2003.