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Topology control in MANET for efficient energy conservation

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Abstract

The MANET is a Mobile Ad-hoc Network. Topology control is an important issue in design of MANETs, due to its nature of the node-mobility. Many solutions are available for topology control in ad-hoc networks, centralized or distributed algorithms like- i.e. GAF, LEACH, AFECA etc. The basic idea for topology maintenance is to elect the leader and all the moving node information is collected by it. This basically referred as clustering in ad-hoc communication. This paper proposes an energy conservation scheme for multi-hop ad-hoc wireless network, where it reduces energy consumption during idle-listening, without significantly diminishing the capacity or connectivity of the network. It is built on the observation that, when a region of a sufficient density of nodes, only a small number of them need to be ready at any time to forward traffic for active connections. It uses the clustering mechanism in a distributed manner. The main issue in design of such scheme is to choose the node status be- active or power save, in order to provide energy efficient communication. In this paper, we propose a schematic for the improved forwarding backbone mechanism, which reactively utilizes information about ongoing communication as well as the current power management mode of nodes along potential routes. This proposed design reduces the energy consumption for the overall network by almost 30%, and also with satiable network performance. By the results and their analysis, it can be concluded, that this algorithm preserves capacity and connectivity of network, decreases latency, and also provides significant energy conservation.

Keywords

MANET, Topology control, clustering, Ad hoc networks, routing, idle-time listening, energy efficient.

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1. Introduction

The MANET (Mobile Ad-hoc Network) is a self-configuring infrastructure-less network of mobile devices connected via wireless links.It is a multi-hop in nature, and is established only bynodes independent of any infrastructure. There are several issues for designing the MANETs, among which topology control is also essential design issue [3]. In order to extend the lifetime of the ad-hoc network, it requires designing energy-efficient protocols [4].

To create low power hardware design for mobile devices, it requires focusing on the power consumption of network interface at node level. Since the network interface may often be idle, this energy wastage can be saved by turning the radio off when not in use. But in practice, this approach is not easy to use: a node must arrange to turn its radio on, for both reasons- to receive packets addressed to it, as well as to participate in the high-level routing & control protocols.

A very basic issue in design and maintenance of ad-hoc network is the **Idle-time energy conservation**, which is the usage of same amount of energy even when the node/s are not involved in any communication activity, rather it is said to be idle. Thus due to such scenario, energy is wastage is occurring, which leads to less network lifetime [5]. The duty-cycle scheduling aims to prolong the network lifetime [4] by making some nodes sleep and wake up when packets transmission occurs. It is essential matter to coordinate the power-saving with routing in ad-hoc multi-hop networks and it should possess following characteristics:

- Interoperate correctly with any routing system in ad-hoc network
- Allow as many nodes to switch their radio off as possible, to reduce idle-time energy wastage
- Be able to forward packets between any source and destination
- Backbone formed by awake nodes in network should be having similar total capacity as original network with minimal congestion

- Have a proper prediction scenario with less assumption, to achieve proper network services rendered

Conventional routing algorithms concentrate on finding the shortest path, without much concern about critical issues such as energy efficiency and network lifetime. The problem we discuss here is how to route efficiently in a duty-cycled ad-hoc network.

The clustering is defined as division of the network into different virtual groups, based on rules in order to discriminate the nodes allocated to different sub-networks. Here the goal is to achieve scalability in presence of large networks and high mobility by using the information about routing and higher level (i.e. control). It is mainly used to provide better scalability and heterogeneity in the as-hoc network. It maintains the network in hierarchical manner by classifying the residing nodes and dividing the network region by assigning different roles to different nodes according to its current status [4]. But it is quite complex to design and more energy usage to just maintain and operate the network as well as its services, due to the regime design and longer modes of operation. To achieve such idle-time energy conservation is difficult to achieve in such scenario, since it requires proactive network maintenance

PSM 802.11

Wireless hosts are often powered by batteries and batteries provide a finite amount of energy. To make battery lifetime longer, it is important to design techniques to reduce energy consumption by wireless hosts. IEEE 802.11 specifies PSM (Power Saving Mechanism), one standard method of reducing energy consumption [5]. PSM prolongs ad-hoc network lifetime and may influence the performance of the other layers; for example, ad-hoc network routing protocol, TCP, UDP, and applications. PSM can be applied both the ways: Infrastructure- PCF (the Point Coordination Function) and Ad-hoc network- DCF (the Distributed Coordination Function) [5].

PSM mobile hosts having at least one frame buffered at the Access Point. PSM mobile hosts are synchronized with the Access Point, and wake up to receive Beacons. They are indicated in the TIM. Specifically, the PSM mobile host sends a special frame (ps-poll) to the Access Point by means of the standard DCF procedure. Upon receiving a ps-poll, the Access Point sends the first data frame to the PSM mobile host, and receives the corresponding ack frame. If appropriate, the Access Point sets the More Data bit in the data frame, to announce other frames to the same PSM mobile host. To download the next frame, the mobile host sends another ps-poll. When, eventually, the mobile host has downloaded all the buffered frames, it switches to the sleep mode.

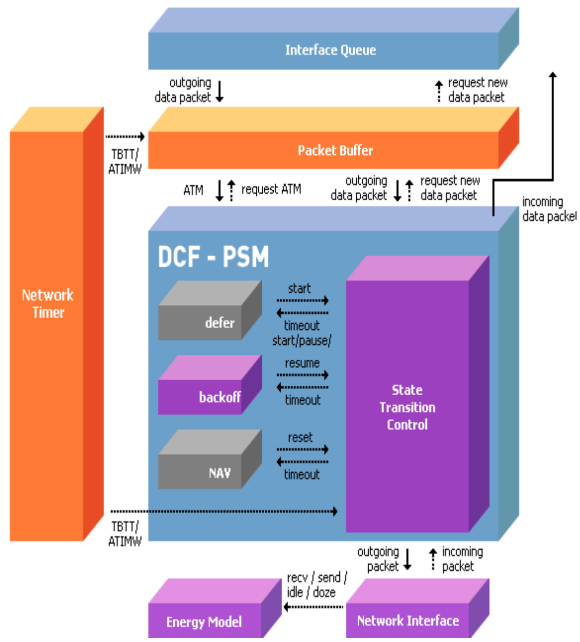

Fig 1- IEEE802.11 PSM (DCF)

This paper proposes cluster-head election algorithm and compatible maintenance mechanisms, in which election of CH by considering energy availability and connectivity. This algorithm is distributed and randomized over the network.

This paper is divided in 8 sections, first is the introduction to basic concepts regarding this paper, second section the related work done so far, third section provides with prerequisite notations and calculations of this paper, fourth section gives detailing of proposed design and algorithm, fifth & sixth sections are about the performance evaluation of proposed design and finally in the seventh section it concludes the paper. A last section contains references, acknowledgement, and profile of author.

2. Related work

To decrease idle-time energy consumption while maintaining efficient communication standard, there exist 2 approaches: Proactive and Reactive, that selects a set of active nodes to support network, while other nodes are conserving energy by power-saving mode.

In Proactive approaches i.e. topology management protocols, it builds a forwarding backbone, mostly based on connected dominating set-CDS, over the MANET, reducing the number of nodes involved in route computation and eliminating broadcast storms [1]. To build suck backbone, CDS protocols requires, either location or topology information. In GAF, it uses GPS for identifying geographical location information to divide the network region into fixed square grids. Such virtual grid maintains the nodes residing in it irrespective of node density, and at least 1 node needs to stay awake to route on-going traffic.
In Reactive approaches, i.e. topology control algorithms, it ties power management decisions with current node routing information [6]. It is built on the idea of, whether the completely connected backbone is not necessary for supporting the forwarding i.e. multi-hop. For such algorithms only some selective number of nodes needs to stay active, while other nodes may switch to sleep or power-save mode. In PAMAS, it turns off the radio when it is overhears a packet not addressed to itself. It follows a system in which mobile nodes wakes-up periodically and poll a base station for newly arrived packets. It reduces both power and delay.

Alternative approach for energy-conservation communication is LEACH protocol, which selects cluster-heads to collect information and transmit it to a base-station in a WSN. It sensors randomly select themselves as cluster heads with some probability and broadcast their decisions [7]. The remaining sensors join the cluster of the cluster head that requires minimum communication energy. LEACH is one of the most popular clustering routing algorithms for sensor networks and is completely distributed. However, LEACH uses single-hop routing where each node can transmit directly to the cluster head and the sink. Besides, there are a number of clustering algorithms constructing clusters not more than 1-hop away from a cluster head, such as DCA [8] and DMAC [9]. It takes advantage of WSN aspect, of possibility of compressing and aggregating data, which isn't available in general-purpose networks.

In general, the basic idea that a path with many short-hops is sometimes more energy-efficient than one with few long hops could be applied to any MANET with variable power radios and knowledge of positions. This technique is orthogonal to our proposed algorithm, so their benefits could be combined.

3. Notations and calculations

Notations

i) NT= neighborhood-table of the chosen node, contains list of current neighbor nodes
ii) CH= proximal cluster-head-table of the chosen node, contains list of proximal-CH nodes
iii) x,y= any 2 nodes residing in the network area
iv) two-hop-CH= CH of the local-CH element
v) HOP-FEAS= ensures whether local-contention while CH-role election
vi) n= value of node-connectivity
vii) state-table= maintains list of backbone nodes, CHs
viii) N(i) = number of neighbors for node-i
ix) $N_{NT}(i)$ = if node-i may become CH, number of additional-pairs of nodes which can be added to the local-NT

Calculation
${}^{N(i)}C_2$ - possible paired combination, reachable at distance of 2 units.
$P(i)=N_{NT}(i)/{}^{N(i)}C_2$, (equation-a)
where P(i) – probability of prominence of a node to become the CH
$E^i_{active} = \{ (t^i_{idle} * P_{idle}) + (t^i_{rx} * P_{rx}) + (t^i_{tx} * P_{tx}) \}$, (equation-b1)
$E^i_{power\text{-}save} = t^i_{sleep} * P_{sleep}$, (equation-b2)
where P- measure of power mW, t- duration of certain power consumption, E- measure of energy Joules

4. Proposed Design

The proposed algorithm adaptively elects CH (clusterheads) by the backbone information of the network. The CHs stay active and awake continuously, until it withdraws, and also perform multi-hop packet routing within the ad-hoc network. The remaining nodes stay inactive and accept the power-save mode.

Here it proposes a proactive scheme, where each node performs periodical broadcasts of either “hello” messages or snooping MAC headers, that contains current status of the node, i.e. mode of operation, list of current proximal-CHs & neighbors etc. This way it manages the list neighbors and CHs at node level. Below is shown the framework of operation for this proposed type:

As shown in the figure our proposed algorithm works between the link-MAC layers & routing layer and also interacts with the routing layer such that it can incorporate the power-save mechanism 802.11. Thus it can manage the PSM as well as affect the routing process. A node switches its roles/states from time to time as being a CH or PSM.

This proposed model uses 3 mechanisms to support the efficient data-forwarding via the elected backbone nodes of the ad-hoc network.

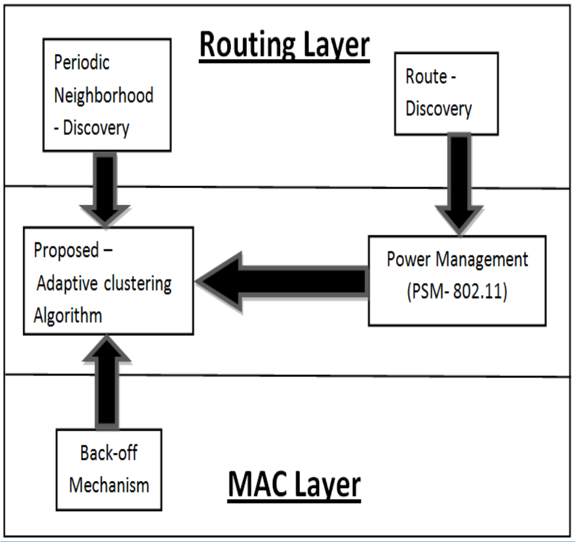

Fig 2- System model of the proposed type

- CH-election mechanism
- Back-off mechanism

Neighborhood discovery mechanism

CH-election mechanism

Periodically, a non-CH node determines whether it should alter itself to CH or not by verifying a

Proposed CH-election algorithm

```
OnWakeUp()
{
//check-announce-CH()
        if(! all neighbors can reach each other directly or via one or two CHs)
        {
        //back-off
        n=0; //# of common-connected CHs
        HOP-FEAS==false;
        wait T-delay;
        for each x in NT
        {
                for each neighbor y in NT, y>x //connect-pairs()
                {
                        for each CH in x's NT, CH!=x //share-other-CH?(x,y)
                        {
                                if(CH in y's NT)
                                        HOP-FEAS==true;
                                else-if(CH in NT)
                                {
                                        for each two-hop-CH in NT of CH, two-hop-CH!=CH
                                        {
        if(two-hop-CH in y's NT)
        HOP-FEAS==true;
                                        }
                                }
                        }
                        if(HOP-FEAS==false)
                                n++;
                }
        }
        if(n>0)
        {
                sent out HELLO announcement;
        }
        if( no announcements from other neighbors received during the back-off and n>0)
        {
                accept CH-role;
                sent out HELLO announcement;
        }
        else
        {
                if(! all neighbors can reach each other directly or via one or two CHs)
                {
                        accept CH-role;
                        sent out HELLO announcement;
                }
        }
        update state-table;
}
```

In this algorithm a node uses information from its neighbor-table, in order to determine whether it should announce or withdraw itself as CH. It doesn't determine the minimum number of clusters required to maintain the overall connectivity of MANET, but it ensures that every populated radio-range in the ad-hoc network contains at least single CH, since the aim is to attain better capacity of network by routing the packets via elected CH/s.

Back-off mechanism

When multiple nodes discover the lack of connectivity over the network at the same time and all nodes decides to become CHs, which is referred to as problem of contention. The above mentioned CH-election algorithm may encounter several problems during maintenance of such ad-hoc network, i.e. contention over CH-announcements, management of density & energy-level/s etc. Thus, it requires to alter the back-off mechanism of PSM-802.11 as well. This mechanism aims to achieve a balanced CH-node distribution by using neighborhood information, to decide about alteration of the mode of operation for the current backbone-nodes. For the solution of this problem, it delays the CH-announcements with randomized delay, then reevaluates the validity of the node should be elected as CH or not. Here the main goal is to elect CHs, with higher energy-level and more connectivity.

Basically this mechanism attempts to solve 2 different cases regarding the announcement contention, by evaluating the delay value for both cases:

1) Assume the energy-level is almost same for all nodes.

Here the topology-information is used to decide whether a node should be elected as CH, or not. It uses a probabilistic-evaluation by using equation(a)- $P(i)=N_{NT}(i)/{}^{N(i)}C_2$ for each node to evaluate the comparative measure for need to select least possible nodes as CHs.

When all the above-mentioned evaluated node parameter is of similar-value for the feasible nodes, then in order to avoid the CH-announcement contention another parameter of time-delay ismeasured. This delay is introduced in the proposed algorithm.

T_{delay} = [{ (1- P(i)) + RND } *N(i) * T] , where RND= random value-calculated uniformly at random between [0,1], T=normal roundtrip delay to send a packet over network

2) Assume the nodes have unequal energy left in their batteries.

In this case, it requires considering the remaining energy at each prominent-nodes that should become a CH. The time-delay, for announcement of a list of nodes that it is to be elected as a CH, is evaluated by an equation mentioned below:

T_{delay} = [{ (1- (E_r/E_m)) + (1- P(i)) + RND } *N(i) * T] , where RND= random value, T=normal roundtrip delay to send a packet over network, E_r=remaining node-energy, E_m=maximum node-energy

Neighborhood discovery mechanism

The proposed algorithm requires each node to forward the related information via the “hello” message. The geographical forwarding is used for transmission-simplicity. The “hello” packet format is shown in figure below:

Source ID
Location of node
If node==CH?
If node==PSM?
CH-Table
Neighbor-nodes-Table

Fig 3– “hello” message header format

For reduction of protocol-overhead piggybacking of the “hello” messages is used onto the broadcast updates, necessary in forwarding. In general the packet is forwarded via elected backbone nodes. While forwarding a packet is if it encounters that no further CH is available to ford the node, then the packet is forwarded to another proximal non-CH node, if available, otherwise packet is dropped.

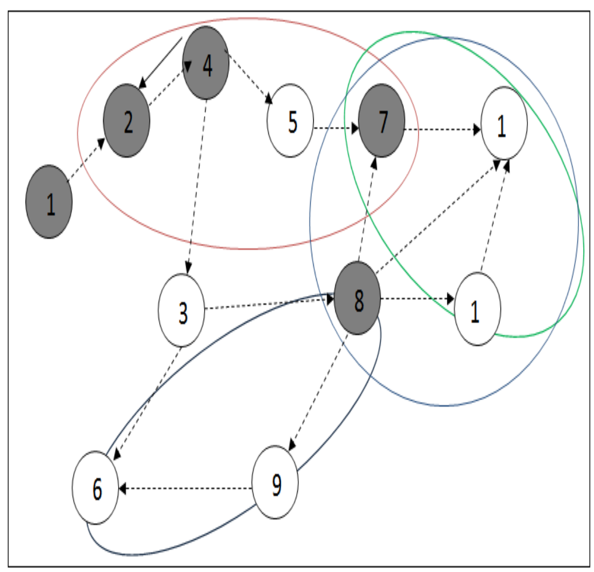

Fig 4- Illustration of the proposed design

As shown in the illustration of proposed algorithm, each CH-node manages the cluster containing neighboring node which are 1-hop or 2-hop away from the CH-node. As per the figure node 6 and 9 can communicate only via their respective CH-nodes over a forwarding backbone only but in occurrence of certain critical-conditions, i.e. low battery in CH-node, maintain fairness of CH role distribution for balanced battery usage etc., if they need to communicate directly then the CH-election algorithm is re-invoked at that node-level.

5. Simulation Scenario

The prototype of proposed algorithm and respective mechanisms of proposed design are implemented in NS2 network simulator using the CMU wireless extension [11]. The PSM module is implemented in well-known ns-2 simulator. The goal of evaluation is to show that proposed algorithm provides better energy conservation compared to other solutions, i.e. 802.11, PSMechanism 802.11-DCF(Infrastructure-less) etc., without the degradation of communication quality, i.e. per-packet delivery latency, delivery ratio or delay.

Network model

In our simulations, every node communicates with-half-duplex 802.11-based wireless-radio having bandwidth of 2 mbps and a nominal transmission radius of 250m. 10 source and destination nodes are placed, uniformly at random, on each of two 50m-wide full height strips located at both sides of the network, a source on left-side must send to a destination on the right-side and vice-versa. The traffic is CBR, and the start-time for each flow is determined randomly between 20s and 120s, each node chooses a speed uniformly at random between 0-20m/s and moves there with chosen speed, after determining the destination uniformly at random in the simulated region and let the pause-time be of 60s. The number of rotating-nodes per radio-range, i.e. ($250^2 * \pi$)sqr-mtr, is referred to as the node density. The node-density table is shown below for various values of area.

Table 1: Average node density values for selected area

Area	Node-Density
500m * 500m	78.5
750m * 750m	34.9
1000m * 1000m	19.6
1250m * 1250m	12.6

We experiment this simulation scenario with simple 802.11 non-infrastructure wireless network and802.11 PSM-DCF networks, with our proposed algorithm. Our simulation results represent average of 5 runs with identical traffic models, but different randomly generated topologies.

Energy model

It can be derived by analysis, that in order to model accurate energy-measures, we the Cabletron 802.11 DSSS High-Rate NIC (Network Interface Card) with base-station operation mode at 2mbps rate. The power consumption measurement of energy-model is shown in below table:

Table 2:802.11 Power scheme

P_{tx}	P_{rx}	P_{idle}	P_{sleep}
1400 mW	1000 mW	830 mW	130

Results and analysis

Energy conservation

In this section we evaluate the performance of our proposed algorithm, in terms of energy. The evaluation metric used be, various power evaluation of the forwarding-backbone. For accurate analysis the node-density is used as comparative parameter, so that energy conservation analysis performed as shown in the figure below:

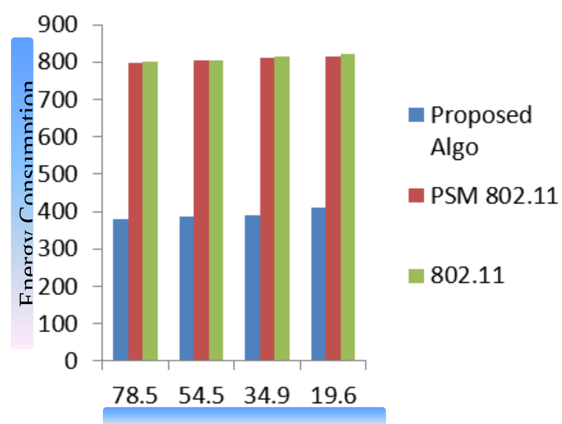

Fig 5 –Energy conservation, average power usage vs. node density, i.e. traffic

Each value is the average of 5 simulation-results. As the node-density increases, our algorithm retrieves better energy conservation than other networks.

Communication performance

We use 2 metrics, for measurement of communication performance:

1) Data delivery-ratio, which is to measure the ease of capacity of the underlying network. The below shown figure gives the analysis of PDR (packet delivery ratio) with respect to the CBR send-rate.In cases of higher traffic our algorithm delivers better performance, by delivering more packets than others destination receiving it, or **round-trip**: the one-way latency from source to destination plus the one-way latency from the destination back to the source. Round-trip latency is more often quoted, because it can be measured from a single point. It contributes to network speed, low latency network connection is one that generally experiences small delay times, while a high latency connection generally suffers from long delays. The results are shown in the figure below:

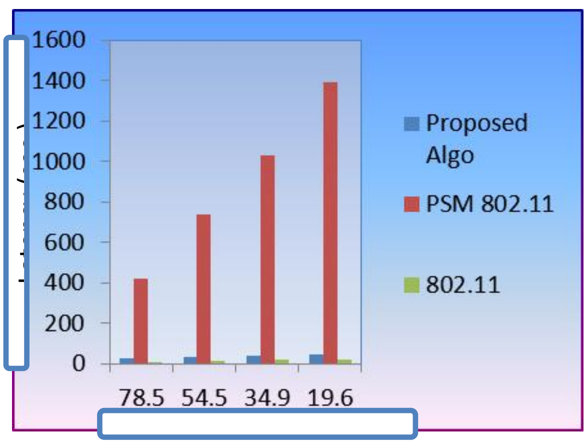

Fig 6 –Latency of the network here our proposed design has satiable improvement over PSM-802.11, even though it lacks than simple 802.11.

Network-lifetime

Since this algorithm provides better energy conservation it can prolong the lifetime of the network, by default. Here the algorithm also makes sure to distribute the node-roles periodically, so that the load is balanced between residing nodes.

The energy-conservation is inversely proportional to the communication-performance, but due to the back-off mechanism this proposed design maintains energy-conservation as well as makes sure of that the ad-network performance is not compromised by any means. Thus, it ensures to provide a satiable communication performance with improved power-save mechanism, with extended network-lifetime, due to conserved energy.

6. Conclusion

Conserving energy in MANET is challenging due to its mobility, changing topology, and mainly due to trade-off between keeping nodes in power-save mode and maintain efficient & effective communication. This paper presents and elaborates a distributedcluster-head election algorithm and a compatible design to support algorithm effectively for MANET, which improves overall energy consumption as well as provides with satiable communication performance. This algorithm adaptively elects cluster-heads (CHs), based on periodical analysis of topology information of network, where the elected CHs stays awake for providing communication-backbone and the other nodes remain in power-save mode. Each node periodically checks, whether it should become a CH or not.

By the results and their analysis, it can be concluded, that the algorithm provides energy conservation without incurring decrease in overall network capacity or connectivity, rather it manages both of them properly using the back-off mechanism. With the increase in node-density the algorithm saves only little increase in energy conservation. This algorithm preserves capacity and connectivity of network, decreases latency, and also provides significant energy conservation.

For our future work, the back-off mechanism can be improved by incorporating a load-balancing algorithm, to distribute network traffic more fairly. Additionally neighborhood-discovery can be improved by using an on-demand mechanism to reduce the protocol overhead.

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