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Improving Energy Efficiency in MANET by Topology Control

Bhavana S. Pansare[*1], Rajesh B. Singh[2]

[*1,2]Depatment of Computer Engineering, Sinhgad Institute of Technology, Lonavala, India

Bhavana.malvadkar@gmail.com

Abstract

The way to represent how the nodes are arranged in the MANET is referred as topology which is temporary or dynamically changed with time according to traffic conditions. The energy efficiency in MANET can be achieved mainly by dynamically adjusting the topology. The proposed technique On Demand Energy Efficient Topology (ODEET) is implemented to combine advantages of two different energy efficient topology approaches namely low traffic network topology and high traffic network topology. In routing process, topology is created dynamically involving smaller no. of nodes awake and other nodes are put into sleep mode by using AODV as routing protocol. The nodes which are acting as an active node are selected on the basis of different factors like stability, utility and energy. The proposed method dynamically adjusts the topology according to the network traffic conditions to conserve the energy of network and thus it prolongs the network lifetime without affecting node connectivity.

Keywords: Energy Management, Energy Efficient Topology, MANET, Routing, Topology Control

Introduction

Mobile Ad-hoc Networks also called as MANET is a group of mobile nodes connected via a wireless links to communicate with each other either directly or indirectly through other intermediate nodes without any infrastructure. The MANET is infrastructure-less, multi-hop, self organized, self configured, mesh network. The MANET because of these features can be used in many applications like: i) Battle fields ii) Disaster areas iii) Military applications iv) Mining operations v) Robot data acquisitions. Apart from these applications, the MANET has various challenges like: i) Limited energy ii) Dynamic topology iii) Low bandwidth iv) Security v) Energy saving vi) Routing vii) Packet loss due to transmission errors viii) Frequent network partitions. The description of the arrangement of nodes in the MANET is called as topology. The topology in MANET is generally temporary or dynamically changed with time because of the mobility of nodes is frequently happened in the network.

Now let's see some concepts related to MANET like topology control. For each device in MANET is provided with transmitting range. An ad-hoc network can be modeled as a (directed) graph whose nodes are the devices and there is an arc from node i to node j if and only if j is within i's transmitting range. Such graph is often termed as the communication graph.

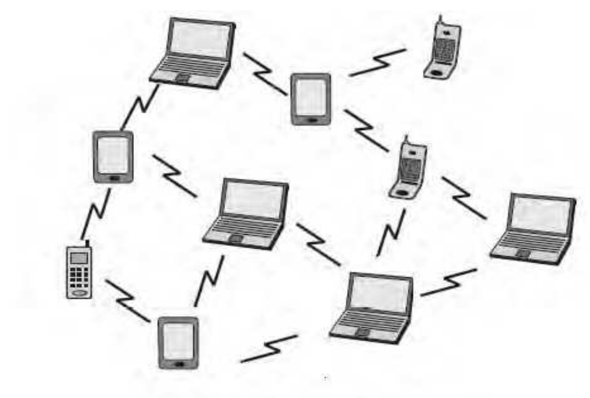

Fig. 1 Mobile ad hoc network

Topology control is the problem of establishing some desired connectivity property for the communication graph acting on the device's transmitting range. Depending on the application scenario and the traffic model, the required connectivity properties may vary, the most obvious is full-connectivity (graph must be strongly connected). the goal of topology control is to achieve the desired connectivity properties using the minimum possible transmitting powers. Because of the potential reduction in the nodes transmitting power, topology control may have positive effects on both network lifetime and channel capacity. Since a reduced range implies less contention on the wireless medium.

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Another concept related to MANET is the energy efficiency. Energy efficiency is a concern at all the levels of the protocol stack. In particular, topology control has the specific goal of determining a low consumption communication graph. As for routing, it is generally acknowledged that energy efficiency considerations must complement more traditional analysis based on packet loss rate, routing message overhead, etc. The ultimate goal is to increase the lifetime of individual devices and that of the network as a whole.

Conservation of energy is one of the challenge in front of MANET only because of limited battery resources available to each node. Various topology control schemes are proposed in most of the existing systems to save the energy and increase the network lifetime. These energy efficient topology control techniques are basically classified in two approaches: 1) A small number of nodes are keep awaked to maintain the network connectivity and remaining nodes are placed into the sleep mode to conserve the energy. This approach is suitable for the low traffic condition because the power required to keep node awake is much lesser than the power consumption for data transfer. 2) The topology is controlled by keeping minimum cost links in the network for its connectivity. This approach is effective for the high traffic conditions because here power required to data transfer is less than the power required to keep node awake.

So, the proposed approach ODEET combines the advantages of both the two approaches mentioned earlier to adjust the network topology dynamically for various network traffic conditions. The proposed approach uses the AODV as routing protocol.

The rest of the paper is organized as follows: The second section provides a brief review of related studies. The third section gives the design details of the proposed system. The performance evaluation criteria is provided in section four. The last and the final section concludes the paper with using same pointer to future research direction.

Need for Energy Management in MANET

The ratio of the amount of data delivered by the node to the total energy expended is known as the energy efficiency of a node in ad hoc network. Higher energy efficiency denotes that the greater number of packets can be transmitted by the node with a given amount of energy reserve. There are some important reasons for energy management in ad hoc wireless networks like MANET which are as follows :

1. Reservation of limited energy : The main reason behind the implementation of MANET is to provide a communication environment where a fixed infrastructure is not possible. MANET have limited energy resources. Though the battery technologies are advances but are negligible as compared to the recent advances in the field of mobile communication. So, the increasing gap between the power consumption and power availability adds to the importance of energy management.
2. Battery replacement difficulties : It is quite difficult in some cases to repalce or recharge the batteries such as battlefields where it is almost impossible. So, in such scenarios the conservation of energy is essential as much possible.
3. Lack of cenral coordination : As the cellular networks have base station as central coordinator, the MANET does not introduces multihop routing and requires that some of the intermediate nodes act as a relay nodes. If the propogation of relay traffic is large, it may lead to a faster depletion of the power source for that node. But if no relay traffic is allowed through a node, it may lead to a partitioning of a network.
4. Battery constraints : Batteries are tend to maximize the size and weight of the mobile node. If we reduce the size of battery , it will results in less capacity which in turn reduces active lifetime of the node. Hence, in addition to reducing the size of the battery, energy management techniques are necessary to utilize the battery capacity in the best possible way.
5. Optimal transmission power selection : The transmissionn power selected determines the reachability of the nodes. The consumption of battery charge increases with an increase in the transmission power. An optimal value for the transmission power decreases the interference among nodes, which in turn, increases the number of simultaneous transmissions.
6. Utilization of channel : A reduction in the transmission power increases frequency reuse which leads to better channel reuse. Power control becomes very important for CDMA-based systems in which the available bandwidth is shared among all the users. Hence, power control is essential to maintain the required signal to interference

ratio (SIR) at the receiver and to increase the channel reusability.

Energy Management Schemes

The need for energy management in MANET discussed in the previous section, points to the fact that energy awareness needs to be adopted by the protocols at all the layers in the protocol stack and has to be considered as one of the important design objectives for such protocols. Energy conservation can be implemented using following techniques :

1. Battery management schemes : The systems which are designed taking into consideration mainly battery and its internal characteristcs are called as battery-driven. These systems try to maximize the amount of energy provided by the power source by exploiting the inherent property of batteries to recover their charge when kept idle. There are some characteristics of battery such as i) Battery technologies ii) Battery discahrge principles iii) Impact of discharge characteristics on battery capacity iv) Battery models v) Battery scheduling vi) Smart battery standards.

   So, according to these characteristics of battery, the Device-Dependent approach increase the battery lifetime by exploiting the internal characteristics of battery. Another approach is given by considering the data link layer. In this approach, the solution is designed by considering the battery characteristics while designing the protocol. Some battery aware scheduling techniques and maximizing the number of packets being transmitted are some issues that are hard to implement. The network layer approach for battery management aim mainly at increasing the lifetime of the network by developing routing protocols that use routing metrics such as low energy cost and remaining battery charge.
2. Transmission power management schemes : The components used in the communication module consume a major portion of the energy in ad hoc networks. So, this scheme basically investigate some of the means of achieving energy conservation through efficient utilization of transmission power such as selection of an optimal power for communication. The variation in transmission power greatly influences the reachability of a node. Increasing the transmission range not only increases coverage but also the power consumption rate at the transmitter. Another solution is provided at the data link layer. Because the power control can be effected at data link layer by means of topology control and constructing a power control loop. This approach proposed some solutions to calculate the optimum transmission range like Dynamic power adjustment policies, Distributed topology control algorithm, Constructing distributed power control loop, Centralized topology control algorithm etc.

   The network layer solution deals with reduction in the power consumed for two main operations, namely, communication and computation. The communication related power consumption is mainly due to the transmit-receive module present in the node. The computation power refers to the power spent in calculations that take place in the nodes during routing and power adjustment. The higher layer solutions deals with some power aware techniques handled at TCP/IP and the application layers of the protocol stack. The protocols used at these layers incorporate in them power control and energy conservation.
3. System power management schemes : This scheme deals with the power control in the peripheral and processor of nodes in MANET. Efficient design of the hardware brings about significant reduction in the power consumed. This can be effected by operating some of the peripheral devices in power saving mode by turning them off under idle conditions. System power consists of the power used by all hardware units of the node. This power can be conserved significantly by applying 2 schemes namely : Processor power management scheme and Device power management scheme.

Apart from these schemes, transmission power management scheme proposed some solutions related to topology control. So, the next section covers all the literature study related to topology control.

Related Work

We briefly provide the description of various techniques related to our work topology control. Different approaches of topologies have been proposed in the literature to minimize the energy consumption. So these methods can be classified according to centralized controlling and distributed controlling methods. For the mobile ad-hoc network, a topology should be computed and managed in distributed, asynchronous and localized manner.

The author Li and Wan [5] describe the protocol that uses the local information only. This protocol is distributed in nature and is used to derive or design the topology called as minimum power topology. The proposed protocol finds the direct path whose length is not crossing the limits of constant factor of shortest path. The length of path is calculated by the energy consumption of that path.

The LMST stands for Local Minimum Spanning Tree based on minimum spanning tree topology control algorithm. The LMST protocol was proposed by Ning Li et al [7]. This protocol have 3 properties like: 1) LMST maintains the network connectivity in pact. 2) Maximum allowable node degree of each node is 6. 3) After removing asymmetric links (uni-directional), the topology can be derived as symmetric (bi-directional) without affecting connectivity of the network.

The simple XTC topology control algorithm was proposed by Wattenhoper [8] that works without location or directional information. The algorithm works in three steps. In first step, each node in the network broadcasts packet at its maximum power. Then it takes ranking between entire neighbor depending on its link quality to it. The link quality would be Euclidian distance, signal attenuation or packet arrival rate depending on various conditions. In second step, each node transmits its ranking result to neighboring nodes. In third step, each node verifies the ranking results of its neighbor. Depending upon this result it selects neighbor to be linked directly. This algorithm uses symmetry and connectivity feature of topology control.

The X-AODV protocol [10] is a protocol where AODV uses XTC algorithm to create topology and to reduce transmission range of node to improve the lifetime of network. This protocol is enhancement in XTC used by AODV. It does not assume the network graph to unit disk graph. This protocol works on weighted network graphs and does not require the node position information.

In AODV [1] each node is acting as a router and routes are decided as per the requirement (on demand). AODV provides loop free routes even after repairing faulty links. The AODV protocol takes different steps for its working like path discovery, route table management, path maintenance, local connectivity management. AODV is one of the reactive protocol that discover route on demand when packet is to be sent.

The LFTC protocol stands for Location Free Topology Control proposed by Ping et al [11]. The collision caused by hidden terminal problem is also avoided along with constructing power efficient network topology. It works in two steps. First by link determination and second by interference announcements. In the first step, vicinity table helps node to broadcast hello message. The vicinity table is attempted by each node in the network. Each node adjusts its transmission power to interact with all its direct neighbors. The second step deals with the avoiding data collision due to hidden terminal.

Power Control-based Locally customized Routing (PCLR) approach proposed by H. P. Gupta and S. V. Rao uses the dynamic path optimization technique to select the energy efficient path dynamically as per the need of dynamic topological changes in the network. Due to the mobility in existing path, the goal of energy efficiency is not achieved, so each node in data path dynamically update its path by adjusting its transmission power. Each node in such type of network determines its power for data transmission and controls the packet transmission according to the beacon messages it receives from its neighbor.

The LINT and LILT protocols proposed by Ramnathan and Hain [3] are distributed topology control protocols. Both are zero over-headed that is they do not use any special control message for their operation. Both the protocols calculate the new transmit power based on the currently used values.

The K-Neighbors (K-NEIGH) protocol [9] not only focuses on reducing energy consumption but it also handles the topology control with the aim of limiting interference as much as possible while at the same time keeping the network that is communication graph connected with higher probability. The protocol is based on the principle of keeping the number of physical neighbors of energy node equal to or slightly below a specific value k. It connects each node with its k closest neighbor and requires the knowledge of all the neighbors. The resulting network is symmetric by removing asymmetric edges which has k-upper bound neighbors. So, in short the issue of critical neighbor number is discussed by the author.

The critical neighbor number approach [6] was proposed by the Feng Xue and P. R. Sharma. This algorithm deals with the problem of choosing how many nodes acts as a neighbors to connect to affect not only connectivity of network but also the capacity of the network.

Another approach for topology control is the MPR that is Minimum Power Routing [2]. The goal of MPR is to route a packet on path that will require the least amount of total power expended and for each node to transmit with just enough power to ensure reliable communication.

The unnecessary energy consumption can be carried out by node when it is in idle mode. So, to save the energy its better to put the node in sleep mode without affecting network connectivity. The SPAN protocol [4] selects a coordinator (master) node that takes the decision to which node put into sleep mode or not. This procedure is carried out by using the distributed approach. The node is master/ coordinator if two of its neighbors cannot interact with each other directly or via other coordinator nodes which are in existence. But the master nodes get easily overloaded. So, to reduce this the master node any time quits its position as a master and give chance to its neighbor node to act as a master if it satisfy the criteria for eligibility of as a master.

Here, we present a demand based energy efficient topology (ODEET) for MANET that dynamically changes the topology as per network traffic requirements. Initially, we compute a small set of nodes, which forms a backbone connected network, where the other nodes are put into the sleep mode to conserve the energy. This connected backbone network is used to pass the packets under the low traffic conditions. When there is a large quantity data to transfer between two nodes, the topology dynamically changes along the path between these nodes by power control and path optimization technique to minimize the power consumption.

Proposed Design

The proposed system is divided into five phases which are discussed in the following as:-

Phase A: Selecting the nodes

This phase selects a minimum set of nodes that form connected backbone of networks. This selection of nodes is done in distributed and localized manner by using the neighbor's information available with the network layer. If node i becomes a coordinator role to forward the packet, then following criteria is used in this phase.

i. *Stability factor* -- More preference is given to that nodes which had relatively more stability than other nodes. The node's stability is measured as the ratio of number of link failures and new connection establishment per unit time to the total number of nodes surrounding that nodes. As the values of new connection established per unit time and number of link failures increases, the stability of nodes decreases.
ii. *Utility factor* -- More preference is given to that nodes which has higher number of neighbors without an active neighbor. It is derived from the fact that such nodes, if elected, can help a large number of nodes which can then put in sleep mode.
iii. *Energy Factor* -- More preference is given to that nodes that have higher amount of percent remaining power over others to be elected as active node.

Phase B: Connecting the nodes

The nodes that are selected in the first phase are not connected with each other because there is only one active node in the given locality. So here in the second phase, more nodes are elected to ensure that the selected nodes can form a connected network. All nodes that have one two or more active nodes as neighbors which are not connected directly or through one or two active node are eligible to become active in this phase.

Phase C: Coordinator withdraw

Every active mode periodically checks if it should go to sleep mode or not. The need of a node to be an active may also cease to exist due to the dynamics of the system. This may happen due to one of the following reasons:-

i. If first phase active nodes may move into region that already has another first phase active node so that the region now has more than one first phase active nodes. These active nodes recognize this situation and one of them withdraws.
ii. If the withdrawal of a first phase active node may mean that the second phase active nodes in the locality no longer serve their purpose and hence withdraw.

In the above scenarios the respective active nodes withdraw, as their need no longer exists. However, when an active node withdraws by virtue of completion of its quota of time it needs to be awaked until another node is elected in the locality.

Phase D: Local route customization with power control techniques

The energy consumption per data packet from source to destination is high when each node uses full transmission power. It will be reduced by choosing a lower energy cost path. The minimum transmission power is required to send data through a node at distance d and for some constants a and c. The receiving power (Pr) by surface reflection model where ht, Gt, hr and Gr are respectively antenna height and gain of sending and receiving nodes. The actual power Ei, j required for sending data from a node I to node J at a distance d with the energy consumption by receiving node.

The minimum required energy for the data transmission can be calculated as follows:

Each node in the network has fixed default full transmission power Pt, when a node I receives control message from node J with power Pr it can calculates the distance between nodes I and J, then node I can find minimum energy Pt (d) required for transmitting the data to node J.

The proposed ODEET uses this power optimization technique locally along the routing path to minimize the energy consumption during the

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transmission. Whenever a new node satisfied the above criteria it remains awake to participate in the high traffic flow path. A new node can come either a sleeping node wakes up near high traffic flow path or awake node moves closer to high traffic flow path.

Phase E: Integration of ODEET with routing protocol

The proposed approach ODEET can be integrated with any of the routing protocol but here in this paper we are describing the way of integrating the proposed system with the AODV protocol. In this approach all the control packets and data packets are transmit on low traffic path with full transmission power and data packets on high traffic path with minimum required energy.

i) *Route Discovery* -- Route discovery uses route cost in place hop count as route metric. We use the notation C(I,J) denotes the cost of least cost path from the node I to the node J.

When a source node S wants to find a route to a destination D, it broadcasts the route request packet (RREQ) to its neighbors. The route request packet contains the least route cost from source node S, which is initially zero. An intermediate node J receiving the route request packet from another intermediate node I, it calculates the cost of the path form node S to nodes J as C(S,I) + L(I,J). The node J update its routing table if the calculated cost is less than the cost in its routing table and forward the route request packet to its neighbors with updated cost. In order to avoid another cost update, node J waits for the time (propositional to the cost to C(S,J)) before forwarding.

When a destination node D receives first route request packet (RREQ), it calculates the route cost and update its routing table. It waits for a fixed time interval to receive more route request packets and find the least cost route among them. The node D uni-cast a route reply packet (RREP) back to its neighbor from which it received the least cost route. The neighbor nodes uni-cast RREP towards the source node S.

ii) *Local Route Customization* -- Due to the dynamic nature of the network new node may come closer to existing path, which may reduce the existing route cost, if it participates in forwarding the data.

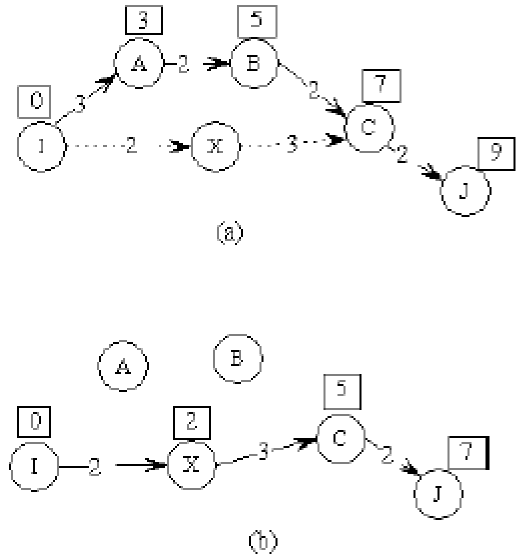

Fig. 2 Local Path Customization

Let consider the example network given in the Fig. 1(a) with the existing path cost from the node I to the node J is 9 units. If a node is in data transmission path, it sends the (Source address, Destination address, Route cost from source to itself) as a piggyback with periodic hello messages in full transmission path. After receive the hello messages from the node I and the node C, along with piggyback information, node X calculate the link cost L(I,X) and L(M,X) and checks whether it can participate in the ongoing data transfer. The node X can participate in data forwarding, if it reduces the cost of the path from the node I to the node M. That is, if L(I,X) + L(M,X) less than C(I,M) then the new node X participate in the routing by sending route update control message (RUP) to the node I and the node M with route cost C(I,M). When the node I and the node M receive (RUP) messages and then update their routing tables.

Performance Evaluation

Energy Consumption

From the comparative study it is observed that energy consumption by ODEET is same as that of SPAN in low traffic however ODEET perform better in high traffic than SPAN because of power controlled transmission. From literature it is also observed that AODV without using any topology control consumes very high energy as compared to ODEET.

End To End Delay

The end-to-end delay is the average time between data packets sent out from the sources and received at the destination. The delay can be denoted with respect to number of nodes and mobility rate. As the mobility rate increases the end-to-end delay is always increases because the network topology changes more

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frequently. In high traffic network ODEET performs better as compared to SPAN and AODV because the low transmission power implies low queuing delay and reduced interference.

Packet Delivery Ratio

Packet delivery ratio is the ratio of the data packets received at the destination to the data packets sent out from source. The delivery ratio can be denoted by mobility rate. As the mobility rate increases, the delivery ratio always decreases.

Conclusion

In this paper, we have done a detailed study of topology control approaches like centralized or distributed in nature. Each approach has its own consideration, goals and different performing methods in their implementation. Like some approaches perform better when degree of node is less (low traffic network) while others are performing better in high degree of nodes (high traffic network). The ODEET approach is different from the other approaches because it focuses on on-demand dynamic topology which is energy efficient. This approach is combining the advantages of both low traffic network and high traffic network approaches. It dynamically changes the topology according to network traffic requirements to increase the network lifetime and to reduce the energy consumption. The work is going on to denote that the proposed scheme is performing better in terms of energy, delay and delivery ratio than the existing systems. It would be interesting to investigate the use of direct antenna to further reduce the energy consumption in future.

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