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Energy Efficient Techniques for Wireless Ad Hoc Network

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Abstract— **In Mobile ad hoc network, mobile devices are battery operated. The improvement in battery technology is slower as compared to advances in semiconductor technology. Although a lot of method has been suggested to conserve energy at different layer of the network protocol stack; many techniques are proposed by different study, however they have their own lacuna. Here efforts are made to have a glance over them and to summarize them in a technical way. We suggest three energy efficient techniques to reduce energy consumption at protocol level. The first technique conserves energy by reducing number of route request message while other two techniques suggest different approach to achieve that.**

Keywords— Minimum energy transmission, energy- aware protocol, power management, IEEE 802.11 PS mode, power control and topology control.

I. INTRODUCTION

Among the entire communication network available today the popularity of wireless networks has been appreciated recently due to its wide range of applicability and versatility. It has revolutionized the science and technology and added comfort and beauty to the modern life. The complex technology made simpler and more user friendly due to the amalgamation of the wireless technology with the traditional wired equipments. The wireless technology is blended with our personal and professional life in the form of mobile telephony, wireless fidelity (Wi-Fi), bluetooth, telemedicine and so on. Now a days, we are completely dependent on these type of device and applications for our comfort and necessity. Variety of wireless network exists ranging from most popular infrastructure based cellular networks, to most recent and advanced ad hoc and sensor networks [1].

A Mobile ad hoc network [MANET] is a decentralize network where mobile nodes are connected by wireless links without any pre-established infrastructure. A large degree of freedom and self organizing capability makes it completely different from other networks. It is one of the challenging and more innovative areas of wireless networking with many applications in different field. The applications are applicable in disaster management, rescue operations, vehicular network, agro sensing, pollution monitoring and many more. Ad hoc networking improves the efficiency of fixed and mobile internet access and enables totally new applications such as sensor and mesh networks. With its significant advantages over the traditional wired network there also exist unmet challenges [19] like unpredictable mobility, restricted battery power, limited bandwidth, multi hop routing, dynamic topology, security etc. Among all these, efficient utilization of energy is one of the important concerns as nodes are battery operated. Energy efficiency continues to be a key performance metric as efficient utilization of energy increases the network longevity hence critical in enhancing the network capacity. So efforts are made to reduce the energy consumption in different ways. Recently it is reported in the literature that energy conservation can be done at all layer of the network protocol stack. Different study suggests different techniques to handle energy issue in different way. In this paper we propose three techniques to reduced energy consumption at protocol level. The first technique reduces the energy consumption by logically portioning the network while second techniques apply power control at node level to reduce the transmission power of a node. In topology control techniques energy-inefficient links are removed to increase network capacity. The rest of the paper structured as follows. Section II focuses on related work on energy efficiency at MAC layer and network layer. Proposed energy efficient techniques are discussed in section III. Simulation results for power control are discussed on section IV and conclusions in section V.

II. RELATED WORK

This section is an exhaustive scientific study on energy efficient protocols published in different journals, conferences proceedings and book chapters. Since energy conservation is an open issue to all layer of the network protocols stack, so different techniques were suggested by different study and focus has been given on different layer design to conserve energy more effectively [13], [14], [15]. Here efforts are made to classify these works in different category such as power management based, power control based, and topology control based.

A. Power Management Based Protocols.

IEEE 802.11[2] standard protocols have two types of power managements. First type is known as power save (PS) mode for infrastructure based wireless network and the second type is known as IBSS PS mode, which is for infrastructure-less networks. In the former method nodes in PS mode consume less power compare to active mode operation. The access point buffered the MAC service date unit (MSDU) and transmits them at designated time by the help of traffic indication map (TIM) and delayed traffic indication map (DTIM). This type of power saving mechanism is not suitable for ad hoc network environment as there is no central coordinator like access point. On the other hand IBSS PS mode is applicable to fully connected single hop network where all the nodes are in the radio range to each other. Synchronized beacon interval is established by the node which initiates the IBSS and is maintained in a distributed fashion. All the nodes wake at the beginning of the beacon interval and wake till the end of the traffic window. The nodes participating in the traffic announcement remain awake till the end of beacon interval and the non-participator goes to sleep to conserve energy at the end of the traffic window. The amount of energy conserve by a node depends upon the time spent in the sleep state which can be affected by the state transition from sleep to active mode operation. The energy saving performance also depends upon the network size as well as on the length of the ATIM window and beacon interval duration. As clock synchronisation is difficult to achieve in ad hoc environment for which some study suggests alternate techniques [3] for multihop network.

Dynamic power saving mechanism [DPSM] [6] is a variance of IEEE 802.11 PS, as it uses the concept of ATIM window and beacon interval. As discussed earlier during ATIM window all nodes are awake and those nodes have no traffic to receive or send are turn to sleep mode after the end of ATIM window. The study done by Freeny [5] suggests that if ATIM window is fixed then energy saving can be affected. DPSM improves this performance by using the variable ATIM window. It allows the sender and receiver node to change their ATIM window dynamically. The ATIM window size increased when some packets are pending after the current window is expired. The data packets carry the current length of the ATIM window and the nodes overhear this modify their ATIM window length. DPSM allows the sender and receiver node to switch of their radio immediately after their transmission is over. The energy saving performance of DPSM is better as compare to IEEE 802.11 DCF in term of power saving however it is computationally more complex.

In PAMAS [4] energy efficiency goal is achieved by using two separate channels, one for control and other for data. RTS/CTS signals are transmitted over the control channel while data are transmitted over data channel. Nodes with packet to transmit sends a RTS over the control channel, and waits for CTS, if no CTS they receives within a specific time then node enters to a backoff state. However, if CTS is received, then the node transmits the data packet over the data channel. The receiving node transmits a busy tone over the control channel for its neighbours indicating that its data channel is busy. The use of control channel allows nodes to determine when and how long to power off. The length of power off time is determined by different condition. After waking up, a node access the channel over the data channel and found multiple transmission going on. The node uses a probe protocol in this case to find how much time it will power off. Simulation results shows that good range of power saving is achieved in PAMAS.

B. Power Control Based Protocol

Power control MAC (PCM) [7] achieves energy saving without causing throughput degradation by implementing different type of transmission power. DATA and ACK packets are transmitted using minimum power while RTS/CTS packets are transmitted using maximum power. Receiver calculates the minimum power required by the sender to send data, depending upon the surrounding noise and interference. When the transmission takes place the neighbouring node defers their transmission. During data transmission same procedure are used for finding minimum required power level that should be enough for the transmission of DATA as well as ACK. PCM require an accurate estimation signal strength based upon which its power control works. Also factors like multipath propagation, fading and shadowing effects may degrade its performance.

Sahoo et al. [9] propose a distributed transmission power control protocol for wireless network to achieve energy conservation in the node level. The protocol uses distributed algorithm to build the power saving tree topologies without taking the local information of the nodes and provide a simple way to maintain network by changing the transmission power. The study on impact of power control performance on IEEE 802.11 wireless networks [12] describes about optimization of spectral reuse in large scale networks. This protocol shows that network with power control, avoiding hidden nodes can achieve higher overall network capacity as compared with minimum-transmit-power approach. The proposed distributed algorithm tries to achieve high spectral reuse by reducing expose node while entirely avoiding hidden node [16]. The pros and cons of common-range and variable-range transmission power control on the physical and network layer connectivity are nicely described by Gomic et al. [18]. The simulation result shown that variable-range transmission power control out-performs common-range transmission power control in term of energy saving and network capacity.

C. Topology Control Based Protocol

SPAN [8] is a distributed power saving protocol adaptively elects coordinator from all nodes in the network. Coordinator nodes stay awake continuously and perform multi-hop packet routing. Other nodes remain in power save mode to conserve energy. SPAN achieves four goals such as, it elects enough coordinator nodes, rotates the coordinator nodes to balance residual energy, attempts to minimize the numbers of coordinator and elects the coordinator using local information in a decentralize manner. SPAN gives guarantee of network connectivity by ensuring that every node has at least one active node in its radio range. Fairness among the nodes is based on the amount of residual energy and the additional neighbor pairs that a node can connect. It balances both fairness and network connectivity. The entire active node in SPAN form a connected backbone, each node periodically broadcast hello message which includes different information. From this, node constructs a table containing information like current state of the node, current state of the neighbor, residual energy of the neighbor, etc. When any inactive node found that its two of the neighbours cannot reach directly or through one or two active node then that node became an active node. On other hand any coordinator node can step down, if every pair of its neighbours can reach each other either directly or via other coordinators.

GAF [17] uses location information to determine node equivalence by the help GPS. The algorithm divides the whole network area into small virtual grids. The nodes present in one virtual grid can communicate to the nodes present in its neighbouring virtual grid. Virtual grid mechanism applies power management techniques to put some of the node to sleep state to conserve energy. The nodes can be in any of the states such as: discovery, active or sleep. It applies load balancing strategy to balance the residual energy in a distributed manner. Any active node after staying for a particular time changes the state from active to discovery giving chance to other node to become active in the same grid. Any node with maximum residual energy became the active node while its surrounding node goes to sleep state. As it is based on GPS for which it introduces more computation delay, extra messaging overhead and more energy consumption at each node.

Ramanathan et al. proposes two centralized topology control algorithm [10] for ad hoc network. They have proposed two centralized algorithms called CONNECT and BICONN_AUGMENT for use in static network. Algorithm CONNECT is a greedy algorithm similar to minimum spanning tree (MST). The BICONN-AUGMENT is also a greedy based algorithm whose objective is to identify the biconnected components in the network. For mobile network they have proposed two distributed heuristic, namely *local information no topology* (LINT) and *local information link-state top*ology (LILT).

Sheu et al. proposes a location free topology control algorithm [11] for faster access. The algorithm has two phases, link determination phase to determine the power required to send data packet while interference announcement phase to handle the hidden terminal problem.

III. PROPOSED ENERGY EFFICIENT TECHNIQUES

In this section we are proposing three energy efficient techniques for ad hoc network environment. The first technique minimizes route request message. Second technique optimizes the transmission power at each node and third techniques increases network capacity by topology control mechanism.

A. Techniques to Minimize Route Request

Let us consider a multi-hop homogeneous wireless network in which nodes are randomly deployed over certain geographical area. In this mobile ad hoc networking environment each mobile node can access the internet applications via one or more numbers of gateways. The mobile nodes communicate with the gateways directly (single hop) or through multi hop depending upon the transmission range of the node as shown in the figure 1.

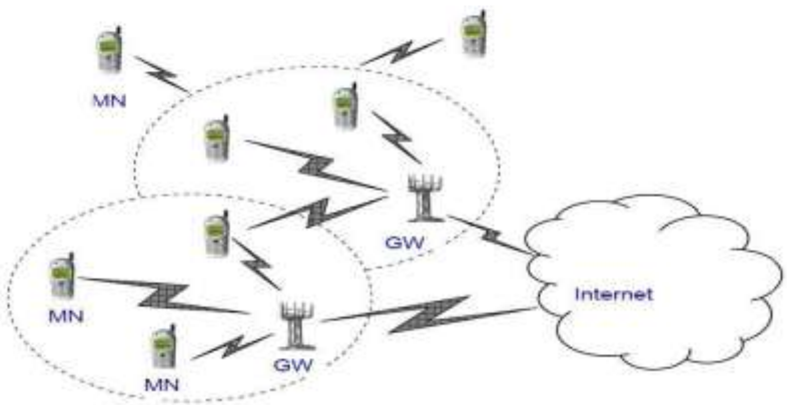

Fig.1 Single Hop and Multihop Communication with Gateways

Besides the internet access nodes can also transmit data among themselves. It is assume that the gateways are stationary. The geographical area covered by gateway is partitioned into different logical group with unique group number assigned by the gateways. Groups are overlapping and there are some nodes present in the overlapping area. The partitioned is based upon the number of nodes present in it. Nodes are categorised into active node (AN) and common node (CN). Nodes present in the overlapping area of groups are called common nodes while nodes belonging to any particular group called active node of that group. It is assumed that overlapping area of the different group contains enough number of common nodes (CN) as inter- group communication will takes place through them. When any active node wants to send route request (RREQ) message it append its group number in the packet and broadcast the message. Message will forwarded by the other node if they belonging to the same group otherwise message will be dropped. When a CN prepares the RREQ message it add one group number from the group it belonging depending upon the share index (SI) calculation. SI is calculated by the CN for the all groups it belongs to and appends the group number to the RREQ based on maximization value of SI. The SI is calculated as

$$SI = \frac{\left[\sum_{i=1}^{G} g_i\right]^2}{G \sum_{i=1}^{G} g_i^{\,2}}$$

$$\text{Where } SI = \begin{cases} 1; & \text{when each group contains equal number of source node} \\ <1; & \text{for other case} \end{cases}$$

Here G is the number of group of the common node and gi is the numbers of node present in ith group. The SI calculations are done for load balancing purpose. When SI value is one, it indicates groups contain equal number of nodes. If it is less than one, then groups don't contain equal number of nodes. In that case common node will join to that group which will maximize the SI.

The objective of proposed technique is to reduce the number of route request by putting restriction on inter-group communication. The node of one group will not forward the RREQ message to other group. Only common node will support inter-group communication to reduce the number of RREQ. The algorithms for SI calculations and sending procedure are given below.

<u>Algorithm ROUTE REQUEST</u>

Step1: Calculation SI

$$SI = \frac{\left[\sum_{i=1}^{\mathbf{G}} g_i\right]^2}{G \sum_{i=1}^{G} g_i^{\,2}}$$

Step2: Procedure_SENDING (node)

1. if (node == CN)
2. Calculate SI
3. RREQ = RREQ || gn
   /* append the group number (gn) depending upon the max.value of SI */
4. Broadcast (RREQ)
5. else if (node == AN)
6. RREQ = RREQ || gn /* RREQ containing group number of AN */
7. Broadcast(RREQ)
8. end if
9. end if

B. Power Control Technique

In this technique we choose an environment where, nodes are deployed randomly in a two dimensional area. It is assumed that each node has at least two power levels such as P*max* and P*min*. Former is the power required to reaches farthest node while latter is the power required to reach the nearest node. The objective of power control here is to minimize the power consumption of a node. It is assumes that there may exist some intermediate power level between P*max* and P*min*. Let P(*uv*) be the power needed to support communication from node u to v, we called it symmetric if P(*uv*) = P(*vu*). The power requirement is called Euclidean if it depends upon Euclidean distance $\|uv\|$. It can be calculated as $P(uv) = c + \|uv\|^{\beta}$ where c is a positive constant real number, and β € [2,5], depends upon transmission environments. P*max*(*u*) and P*min*(*u*) are the maximum and minimum power level of node u. When $P(uv) \geq P_{min}(u)$ and $P(uv) \leq P_{max}(u)$ then communication between u and v is possible otherwise it is not possible. When some intermediate energy efficient path exists between node *u* and *v* via intermediate node w then node u will transmit with P(*uw*) rather than P(*uv*). In the figure 2, if $P(uv) \leq [P(uw)+P(wv)]$ and $[P(ux)+P(xv)]$ then communication from u to v will take place through P(uv) otherwise communication will through intermediate node w or x by the help of P(*uw*) or P(*ux*) respectively.

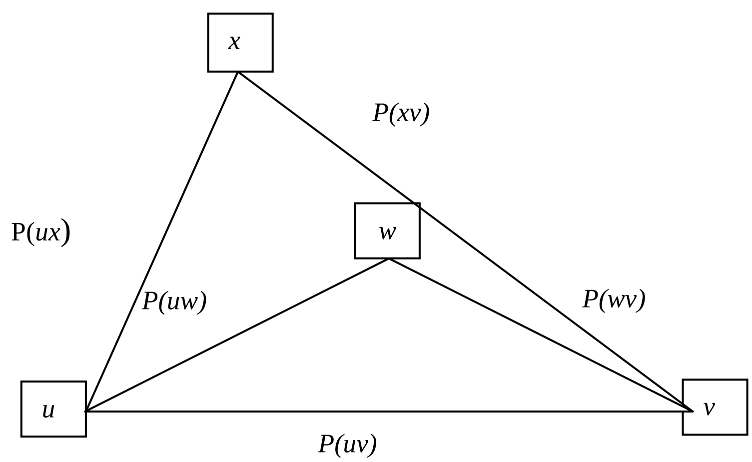

Fig.2 Power control technique through intermediate node

<u>Algorithm POWER CONTROL</u>

Input: (1) Multihop wireless network N

Output: power levels p for each node for communicating to other node

begin

1. for each (u, v) do
2. calculate Pmin(u) and Pmax(u) /* for node u */
3. calculate P(uv) by Euclidean distance
4. if P(uw) + P(wv) ≤ P(uv) /* u finds any energy efficient path to v via w */
5. then transmit with P(uw) for v
6. else transmit with P(uv) for v
7. end if

end

C. *Topology Control Technique to Increase Network Capacity*

Topology control can be defined as the techniques by which network device takes their own decision regarding their transmission range, in order to satisfy some network constraints. A network topology can be modeled as a graph G=(*V*,*E*), where *V* represents the set of nodes and *E* represents the set of edges. Cover (*vi*,*vj*) means node *vj* is within transmission range of *vi* . Initially all nodes are transmitting with maximum power P*max*. Depending upon the P*max* value node *u*, (u€V) has a direct communication set known as DCS(*u*). P(*uv*) denotes the minimum power required for node u to communicate directly to node *v*. By applying topology control we have to get sub graph G'= (*V*, *E'*) of G, in G' the node has shorter and fewer numbers of edges as compare to G. The objective of topology control here is to remove the energy-inefficient link from the network.

Initially all the node in the network will calculate their DCS depending upon their maximum transmission power. Each node will maintain a *node information table* containing information like *neighbor_id (NI)*, *direct_communication_cost (DCC)*,and *energy_efficient_cost (EEC)*. Each node has a unique NI. DCC represents the minimum transmission power required for a specific neighbor node. DCC of node u to neighbor node v is represented as DCC(uv) which is same as P(uv) as described earlier. EEC is initially same as DCC but when any energy efficient path is obtained through alternate path ECC is updated. Each node periodically updates their node information table and broadcast the information to other node. After a specific time each node will calculate their DCS by removing energy-inefficient link (if any).

Algorithm LINK REMOVAL

Input: (1) Multihop wireless network G=(*V*,*E*),
(2) Maximum transmission power

Output: G'= (*V*, *E'*) , G' has shorter and fewer numbers of edges as compare to G

begin

1. Each node broadcast a “hello” message with its *node information table*.
2. If a node u receives the “hello” message from its neighbor
3. If *u* has a power efficient path to node *v* via *k* /* *k* is a node in alternate path */
4. update (v, P(uv), P(uk) + P(kv)) into u’s *node information table*.
   /* energy_efficient_cost =(P(uk) + P(kv)) ≤ P(uv) */
5. Else Insert (v, P(uv), P(uv) into u’s *node information table*.
   /* as energy_efficient_cost= direct_communication_cost*/
6. End if.
7. End if.

end

IV. Simulation Results

In order to evaluate our power control approach simulation area of 500mt×500mt were taken. We consider scenario1 with six numbers of nodes and scenario2 with five numbers of nodes. Nodes are randomly deployed and are in transmission ranges of each other. In the first scenario different nodes are placed in different position as shown in the figure 3. In scenario 1, it is assumed that one hop communication between sources to destination exists. It means that source to destination path exist through only one intermediate node other than direct path. In scenario 2 multi hop communication has been taken into consideration. In both scenarios node4 is taken as the source and node2 is the destination, it is founds that five alternate paths exists in scenarios 1 and sixteen in scenarios 2. The energy consumption of each path is measured and it is found that path through node3 is least. In the scenario 2 five nodes are placed as shown in the right hand side figure 3. From the simulation results we measure the energy consumption of all paths. In both scenarios energy efficient path is the through node3 although the position of the node3 is different. It is also observed that in single hop count when the angle of the intermediate node is more than ninety degree the alternate path through intermediate node is always energy efficient. In the first scenario the direct path consumes energy proportional to 3.200000e+001. and the path through node3 consumes energy proportional to 1.600000e+001.In the second diagram direct path consume the energy same as first scenario but the energy efficient path through node3 consumes less which is measured and found proportional to 18. From the both scenario we shows that energy consumption in intermediate path is better in comparison to direct path in most of the time.

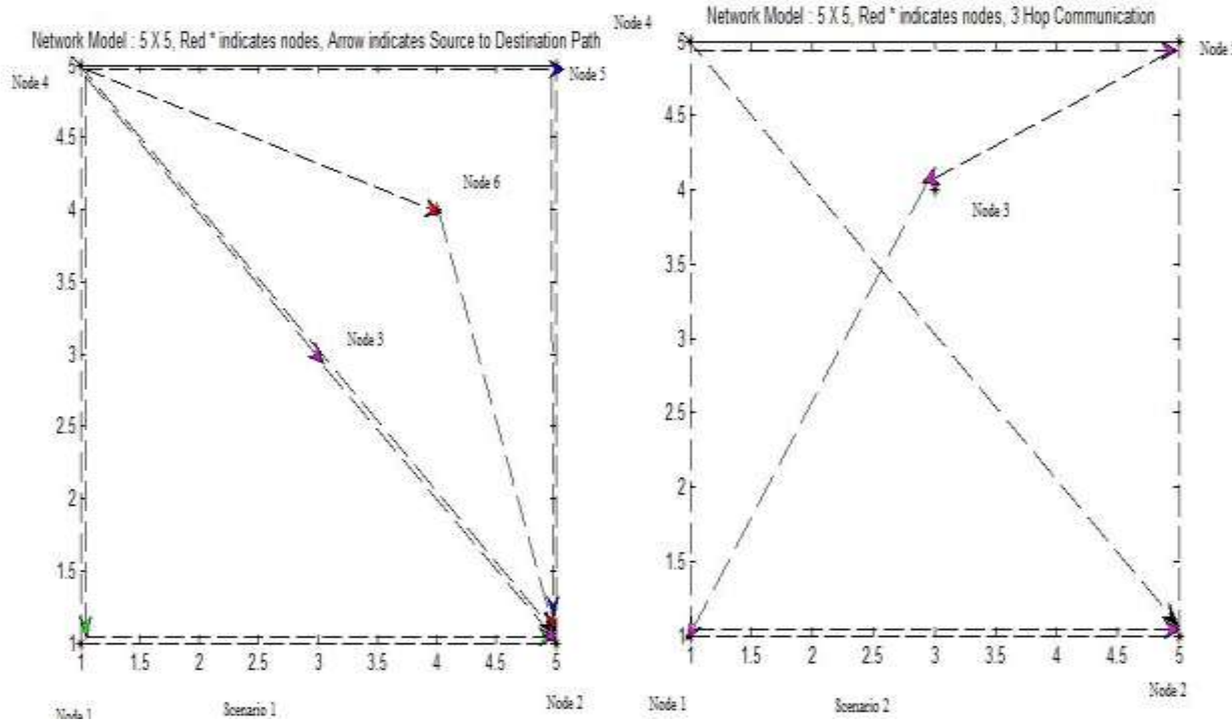

Fig.3 Energy efficient path through intermediate node.

V. CONCLUSIONS

In this paper, we reviewed some of the recent work done in mobile ad hoc network considering energy as the key issue. It is found that most of the study discusses the energy issue at data link and network layer. We discuss different energy efficient protocol based on power management, power control and topology control approach. We suggest three energy efficient techniques for MANET point of view. Route request minimization technique can be done by implementing logical grouping; power control techniques reduce the transmission power of a node while topology control approach increases the network longevity by satisfying network constraints. The simulation results presented in section IV, suggests that multi-hop is ideal for energy point of view but the limitation is the increase chance of link failure.

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