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LBTC: A Conceptual Energy Saving Framework for Mobile *Ad hoc* Networks

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ABSTRACT

Mobile *ad hoc* networks (MANETs), are more challenging due to their unique characteristics and wide applications. The main challenge of this network is its limited battery capacity as nodes are operated by battery. These batteries are limited in capacity and it is a cumbersome task to replace and recharge them in some environments like military operations, environment monitoring etc. Due to this limitation, proper utilization of battery power is very much essential for energy constraint mobile nodes. It is observed that transmission power is the major constitutes of energy consumptions. So to achieve significant energy saving, it is necessary to reduce transmission power at node level. Considering this facts present study has proposed a framework for energy saving using two techniques in MANETs. The proposed distributed topology control algorithm adaptively adjusts transmission power at node level based on nodes neighborhood information. For this, each node maintains a table and updates that periodically. A node reduces its transmission power based on information stored in its table. The second technique applies sleep scheduling approach to further reduce energy consumptions by putting some nodes in sleep state. A node goes to sleep state only when it has no pending traffic and it satisfies the connectivity constraints within its neighborhood.

Key words: Minimum energy transmission, energy efficiency, topology control, sleep scheduling, mobile *ad hoc* network

INTRODUCTION

Wireless technology has influenced the present society strongly through their inherent advantages and wide range of products. It has several applications in different fields which includes cellular data services (GSM, GPRS, CDMA and 3G), satellite communications, hotspot (Wi-Fi) technology, Bluetooth etc. These technologies are available in the door step by the help of different wireless networks. Some of these networks are infrastructure dependent while others are infrastructure independent. Cellular networks such as GSM, CDMA are belonging to first category while wireless *ad hoc* networks represent the second. Wireless *ad hoc* networks such as, mobile *ad hoc* network (MANET), Wireless Sensor Network (WSN), vehicular *ad hoc* network (VANET) are most interesting due to their unique characteristics and exclusive applications (Samara *et al*., 2011). They are getting more attentions in areas where infrastructure based networks are neither deployable nor economic, such as: military operations, environmental monitoring, disaster recovery, patient monitoring, search-and-rescue operations etc. The major difference between cellular network and wireless *ad hoc* network is the resource management and routing. Base stations in cellular network simplifies routing activity by taking the decision in a centralized manner (Amin and Islam, 2009) but in wireless *ad hoc* network routing decisions are made in a distributed manner at node level. All the nodes in *ad hoc* network coordinate to each other to enable communications among them. Each node acts like a host as well as router, for which nodes are more intelligent. However, due to lack of central arbitration they are more vulnerable to many challenges. They suffered some unmet challenges in form of contend for physical mediums, this in turn reduce the throughputs susceptible to collisions due to presence of hidden nodes, it is the major issues at MAC layer, limited battery power, also have to forward the data packets of others, unpredicted mobility, this issue aggravate when nodes frequently enter and leave the network and restricted bandwidth, etc. (Cheng and Li, 2008; Wu and Tseng, 2007; Qin and Chen, 2012; Meng *et al.*, 2008). These challenges motivate researchers to put their effort to tackle these issues. Continuous efforts are made and varieties of solutions are obtained but some problems are not considered in a concrete way under the umbrella of these solutions. Proper utilization of battery power is considered to be one of the key requirements in energy constraint wireless networks. It become a pervasive issue in all layers of communication protocols, until now, research and development in the field of communication networks was mainly targeted at their functionality and performance issue, but for battery-driven devices such as sensor nodes, energy efficiency is a significant consideration. The intensity of its importance has induced a new research area with energy efficient of communication networks as the main objective (Shi *et al.*, 2010; Atiq-Ur-Rahman *et al.*, 2011).

Energy conservation is considered to be one of the key performance metrics for wireless networks as network longevity and network capacity merely relies on it. Looking to its importance, efforts are being made to reduce the energy consumption at all layers of protocol stack. Researchers are focused mainly at routing and link layer to reduce power consumption at network level while very few works has done on other layer, also energy saving can be considered as a cross layer, approach (Lin *et al.*, 2006), where rather than focusing on one particular layer attention can be made on multilayer for the same objective. The proposed work considers the cross layer approach of energy saving. Two power saving techniques are introduced in this framework using power management and topology control approach. It has been observed that the overall performance of MANETs such as channel utilization, end-to-end delay, as well as life time of the network is enhanced if the transmission power of the nodes is properly adjusted to a lower level (Gomez and Campbell, 2007; Jayashree and Murthy, 2007; Wang *et al.*, 2011). Proper adjustment of transmission power is required not only to increase energy efficiency but also to reduce the network interference.

RELATED WORK

Most of the energy management strategies for wireless networks rely on base-stations support, but base-stations are often not applicable in the MANETs. Due to this energy management strategies for mobile *ad hoc* networks are different from traditional infrastructure based wireless network. We classify the works reported in the literature as power management approach and topology control approach. In power management approach nodes in *ad hoc* network remain in one of the three possible states: (a) active (b) idle and (c) sleep. Active states consume more power in comparison to idle and sleep states. In this state mobile nodes actively participate in the network traffic by sending and receiving data and control packets. Idle state is the default state in MANETs as nodes stay most of the time in this state. Idle state power consumptions are nearly same as that of receiving power consumptions (Feeney, 2004). Nodes in idle state wait for the traffics to participate. However, nodes in sleep state switched off their radio transceivers for a particular period of time and wake up after the end of sleep time. Hence, they consume very less amounts of power as compare to other two states. Due to its power saving advantages sleep state is the desired state of power saving in mobile *ad hoc* networks. Power management based protocols tries to put nodes in sleep state to save substantial amount of energy. IEEE 802.11 standard (IEEE Std. 802.11, 1999) and its variants are the representatives of this approach.

Two types of power managements are used in IEEE 802.11 standard protocol. First type is used for infrastructure based wireless a network while second is for infrastructure less network. The second power saving approach is relevant to the *ad hoc* model and is known as IBSS power save. Synchronized beacon interval is established by the node which initiates the IBSS and is maintained in a distributed fashion. In this mode nodes remain within the radio range to each other. IBSS PS mode saves substantial amount of energy but its power saving for multi hop *ad hoc* network is a major issue. The power management scheme in IEEE 802.11 protocol has several challenges such as clock synchronization, beacon contention and neighbor maintenance, setting sleep duration etc. These challenges are more serious where the network is large and dense. To overcome these challenges and improve the energy efficiency Wu *et al.* (2005) proposed an asynchronous power management protocols for multi-hop *ad hoc* network. They suggested that their protocol provides better energy efficiency and throughput. Tseng *et al.* (2003) proposed a protocol called dominating-awake-interval by redesigning the IEEE 802.11 PS mode. However, the limitation of the protocol is node, remains awake for a longer period of time as compared to IEEE 802.11. Ray and Turuk (2009) discussed some energy efficient MAC protocols for wireless *ad hoc* and sensor network. They suggested that power management techniques are the main stay of power saving in all types of wireless networks.

In contrast topology control approach uses other way of power saving. Rather than putting the nodes in sleep state in reduces transmission power by implementing different techniques. It minimizes the maximum power used by nodes at node level and maximizes network longevity. It preserves major network constraints such as connectivity (bi-connectivity), k-neighbor set etc. Santi (2005) addresses several topology optimization problems where he analyses the problem of designing energy-optimal topologies for different communication patterns such as unicast, broadcast and multicast. SPAN (Chen *et al.*, 2002) is a distributed topology control 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 energy saving by selecting few nodes to work as a coordinator. Communication among the nodes takes place through these coordinator nodes. It gives guarantee of network connectivity by ensuring that every node has at least one coordinator node in its radio range. Sahoo *et al.* (2007) proposed a distributed transmission power control protocol to build the power saving tree topologies without taking the local information of the nodes. They maintain network topology by changing the transmission power. Most of the topology control protocols require certain information like location, direction, neighbour list, etc to construct final topology. Location information can be obtained through Global Positioning Systems (GPS) technology. However, it is associated with increase cost to support GPS technology. In order to reduce hardware cost some of the techniques assumes that a subset of the node are equipped with GPS receiver while other nodes get their location information by exchanging message with GPS enabled nodes. Direction based approaches requires direction information rather than location information. Cone based topology control (Li *et al.*, 2005) uses directional information to constructs the final topology. Some techniques for estimating the direction has been proposed in IEEE Antenna and propagation community (IEEE, 2004). The framework proposed here is based on location information rather than less accurate direction information.

PROPOSED ENERGY EFFICIENT TECHNIQUES

The main objective of the proposed Location Based Topology Control (LBTC) framework is to achieve energy efficiency by controlling the transmission power and putting nodes in sleep state when they are idle i.e., when they have no traffic to carry and their absence do not create any local partitioning in their neighborhood. The LBTC controls the topology by adaptively adjusting transmission power using local information of the nodes.

Network structure and assumptions: Following assumptions are made here:

- Nodes communicate through Omni-directional antennas and are identified by their ID
- Nodes are aware of their locations and the source knows the ID and location information of the destination
- Signal from neighboring nodes is received accurately and the received signal strength can be measured with the help of radio interface in each node

Let G = (V, E) be the topology of the network, where V is the set of nodes and E is the set of links which can change dynamically as nodes move with a random speed. Let P_{uv} denotes the minimum power required for node u to communicate directly to node v. A node u can determine the power P_{uv} when v sends a message to u and v's maximum transmission power P_{max} is known to u by using received signal strength calculation as given below. Suppose u receive a message with power P_r and P_{min} denotes the node's smallest possible receiving power. Then:

$$P_{uv} = \frac{P_{max} * P_{min}}{P_r} \tag{1}$$

P_r is given by the free space propagation model:

$$P_r = P_t \left(\frac{\lambda}{4\pi d}\right)^n g_t\, g_r \tag{2}$$

where, P_t and P_r denote the signal power at transmitting and receiving antenna, respectively λ denotes the carrier wavelength, d denotes the distance between the sender and the receiver and g_t and g_r denotes the antenna gains at the sender and receiver, respectively n is the path loss coefficient which depends on the environment.

The LBTC framework consists of two phases: (i) link determination phase and (ii) sleep scheduling phase. The network structure of LBTC is shown in Fig. 1.

Link determination phase: In this phase a node randomly broadcast a Hello message using maximum power P_{max}. A node that listen this Hello message computes P_{uv} since transmission power (P_{max}) of Hello message is constant. Hello message contains the identity of the sender, SenID and its location information, LocInfo. Each node maintains a vicinity table having six fields as shown in Table 1. The purpose of each field is explained below:

- SenID: Records the ID of the node which has sends the Hello message
- LocInfo: Location information of the sender
- DirCost: Communication cost between the node and the sender, computed as P_{uv}, where, u is the current node and v is the node from which it has received the Hello message

Table 1: Structure of vicinity table

SenID	LocInfo	MinCost	ComNode	DirCost	LinkType

Table 2: Vicinity table at Node X after receiving Hello message from node Y

SenID	LocInfo	MinCost	ComNode	DirCost	LinkType
Y	(101, 96)	1	-	1	d

Table 3: Vicinity table of node X after receiving hello message from its neighbor

SenID	LocInfo	MinCost	ComNode	DirCost	LinkType
Y	(101,96)	01	-	01	d
Z	(102, 98)	08	-	08	d
M	(100,99)	09	-	09	d
N	(98, 94)	08	-	08	d
O	(99, 92)	17	-	17	d

- MinCost: Minimum cost between the node and the sender
- ComNode: This field contains a node between the current node and the node which identity is SenID. Communication from the current node to SenID through the ComNode shall consume less energy
- LinkType: Indicates whether the node is direct or indirect. For one-hop neighbor the entry is d and for multi-hop neighbor the entry is i

Initially the vicinity table is empty and is calculated when a node receives Hello message from its neighbor. For example when node X with its current location (100, 96) receives the Hello (Y, (101, 96)) message from node Y, it updates its vicinity table as shown in Table 2. The co-ordinates (101, 96) is the current location of node Y. DirCost is computed as in Eq. 1 and MinCost is set to DirCost. LinkType is d as X is the neighbor of Y and ComNode is set to null.

Vicinity table of node X after receiving Hello message from all its neighbors is shown in Table 3.

After gathering initial information about its entire neighbor, nodes X determines whether there exist any *ComNode* between itself and its neighbor.

Algorithm to determine ComNode: Given 3 points A (a_1, a_2), B (b_1, b_2) and C (c_1, c_2):

(i) First check for co-linearity of three given points A(a_1, a_2), B(b_1, b_2) and C(c_1, c_2)
If A, B and C are collinear and B lies between A and C go to Setp (ii), else go to Step (iii)
(ii) If ($a_1<b_1<c_1$) and [cost (AB)+cost (BC)<cost (AC)] then B is the common node. End
(iii) No common node exits between A, B and C
(iv) End

Based on information available in its vicinity Table 3, node X computes, Y to be the ComNode between itself and node Z and N to be the ComNode between itself and node O. Updated vicinity table at node X after computation of ComNode is shown in Table 4. The MinCost between node X and Z is computed as be 6 instead of 8 and between X and O is 13 instead of 17. The link type is

Table 4: Modified vicinity table at node X after determining ComNode

SenID	LocInfo	MinCost	ComNode	DirCost	LinkType
Y	(101, 96)	01	-	01	d
Z	(102, 98)	06	Y	08	i
M	(100, 99)	09	-	09	d
N	(98, 94)	08	-	08	d
O	(99, 92)	13	N	17	I

Table 5: Vicinity table at node X

SenID	LocInfo	MinCost	ComNode	DirCost	LinkType
Y	(101, 96)	01	-	01	d
Z	(102, 98)	06	Y	08	d
M	(100, 99)	09	-	09	d
N	(98, 94)	08	-	08	d
O	(99, 92)	13	N	17	I

modified from d to i indicating that there is an indirect path from node X to Z through Y and from node X to O through N. Cost of communication through this indirect path will be lesser than the DirCost.

After computing the ComNode, X selects the farthest direct node. Farthest direct node is the neighbor of node X for which MinCost is maximum. Transmission range of node X is set to this MinCost and data is transmitted from node X using this power. Setting transmission range of node X to the cost of farthest direct node, each and every direct node is reachable from node X.

Node X from its vicinity table can determine the appropriate transmission power with which it can transmit to its neighbor. As given in Table 5, if node X has a data packet to be transmitted to node Z, it can use the minimum cost 1 to transmit to node Y which can relay it to node Z. Thus, the total energy consumed at node X is reduced.

Sleep scheduling phase: In this phase nodes which do not take part in the traffic are put into the sleep state based on criteria as described below. The nodes work in three states such as: active (A), watching (W) and sleep (S). The state transition diagram of the three-state is depicted in Fig. 2. Initially a node is in active state and exchange the Hello message, the duration of Hello message is T_H. After expire of Hello message, node enters to the watching state for taking decision for the next state. When the node finds that it has some pending traffic, it comes back to active state, otherwise it runs sleep-scheduling algorithm. Other traffic aware power saving protocol (Belghith, 2007) saves energy at link layer by adaptively adjusting the beacon window but in our approach an intended node goes to save power only when its connectivity in its surroundings is preserved.

Sleep-scheduling algorithm: The algorithm determines the sleep eligibility for a node. When a node founds it has no traffic to send in the next clock cycle, before entering to sleep state, it checks the connectivity in its neighborhood by running sleep-scheduling algorithm. A node decides not to sleep if it found that any two of its neighbors are not reachable directly or through any other ways within its two-hop communications. That means node only enters to the sleep state if connectivity

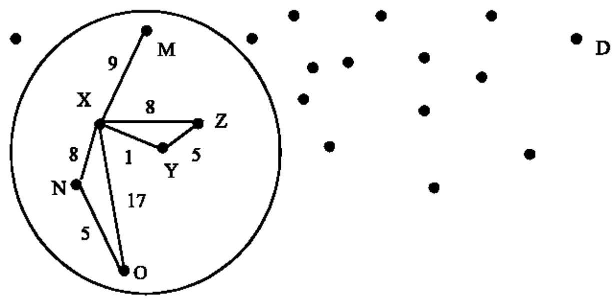

Fig. 1: Network structure LBTC

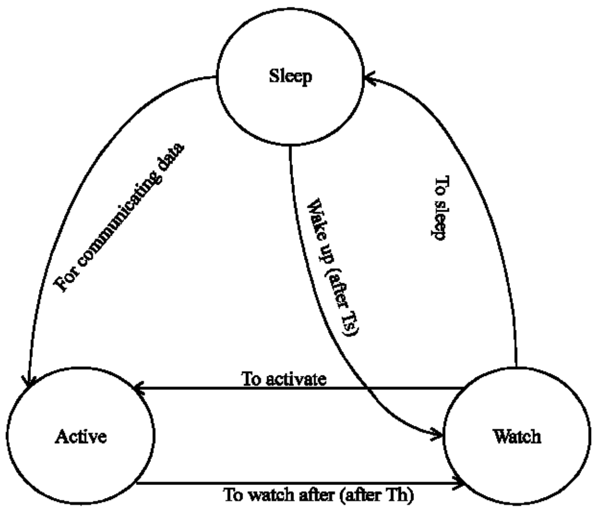

Fig. 2: State transition diagram of sleep scheduling phase

in its neighborhood is preserved without being its active participations. The node in the sleep state periodically wakes up after sleep time T_S and enters to watch state for determining which state to enter next. If the node has any data to send then it goes to active state and exchange the Hello message. The nodes take their own decision regarding their sleep and wake up strategy. The node executes a procedure called Local-connectivity to find connectivity in its neighborhood before going for sleep. If the procedure returns connectivity-retain the node goes to sleep for the duration of T_S.

Consider the network structure of LBTC, as depleted in Fig. 1. When node X has no traffic to participate it waits for T_H period when it conformed that it has no traffic to participate in the next clock period it wants to enter sleep state. Before entering sleep state node runs the Local-connectivity procedure. When it found that it's absent will break network connectivity and create network partition it doesn't enter to the sleep state. So, node X can't goes for sleep even if it has no traffic pending. Like that when node N runs the procedure it found that its neighbors are reachable even it goes to sleep state. So, N will enter to sleep state and will wake up after T_S period. At the end of T_S the node N will come to watch state to check the status of traffic. In this way, all intended node will run local connectivity procedure to find their sleep eligibility.

Procedure Local-Connectivity (Graph G, Node V):

States {1, 2, 3 | ready = 1, waiting = 2, process = 3}, counter = k, n = number of nodes

begin

(I) Initialize all the nodes to ready state (i.e state = 1)and k = 0
(ii) Find an adjacent node V and initialize it to V-NEB
(iii) Change status of V-NEB to 3
(iv) Push node V-NEB to STACK and change status to waiting state(status = 2)
(v) Repeat (vi) and (vii) until STACK is empty
(vi) Increment counter k and POP the top node N of STACK,
Process N and change its status to the processed state i.e Status = 3
(vii) Push onto STACK all the neighbors of N that are still in the ready state (STATUS = 1) and change their status to the waiting state
(viii) End(loop)
(ix) If value of k is n-1 write Connectivity Retains
else write Connectivity Lost
(x) Exit

End

CONCLUSIONS

In this study, we proposed LBTC framework for energy saving in mobile *ad hoc* network using two methodologies. We propose link determination and sleep scheduling procedure for this purpose.

In LBTC nodes adjust transmission power adaptively using link determination phase and runs local-connectivity procedure to determine sleep eligibility. We believe that our proposed framework not only conserve more power but also increase network throughput as it guaranty network connectivity at worst case. The node reduces the energy consumptions by transmitting with a low transmission power by calculating the link cost in link determination phase. The most common problem of low transmission power communication is to maintain the network connectivity which can affect the network life time. Previous work in this directions only considers energy saving as the time spend by the node in sleep state by sacrificing some throughput and they does considers the connectivity which are normally addressed at higher layer but our algorithm consider the same at node level in a distributed manner. In sleep scheduling phase nodes tries to keep the local connectivity, therefore, sleep in LBTC does not produce any local network partition. However, the Hello message time (T_H) and sleep time (T_S) must be adjusted properly otherwise, if T_H is so large then more number of node will participates in the traffic it may results increase in idle power consumption. If T_S period is large then more energy may be saved but its impact can affects throughput. Like that if these values are kept low they can hamper energy saving for which threshold must be calculated otherwise its fruitfulness cannot be redeem. Another area of concern is to reduce the message complexity which is a key challenge in energy constrained wireless network.

We are now validating our proposed methodology and comparing its performance with ESATC (Tian *et al*., 2009) and XTC (Wattenhofer and Zollinger, 2004), UDCA (Abidoye *et al*., 2011).

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