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ISSN 1727-6209
International Journal of Computing

ENERGY EFFICIENT BANDWIDTH CONSTRAINED QOS ENABLED MULTIPATH ROUTING FOR MANETs

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Abstract: *In mobile adhoc networks, node has a finite and decreasing energy. Energy saving mechanism is important for the efficient operation of the battery powered network. When a node is transmitting a packet, all the neighboring nodes overhear. Overhearing improves routing efficiency but consumes more energy. Overhearing is caused by the fact that when a unicast transmission is carried out in a node's immediate neighborhood, it does not have any mechanism for not to receive that packet. Energy consumption during overhearing is same as that during reception. Goal of this work is to develop an energy conserving mechanism due to overhearing. To minimize energy, probability method is applied to randomly select number of overhearing nodes. This probability based overhearing is incorporated into log based pipelined ABM (Available Bandwidth Measurement) and integrated with AOMDV routing protocol. This proposed approach is implemented in NS2 simulator. Simulation results are presented to demonstrate the performance metrics such as throughput, packet delivery ratio, end-end latency, routing overhead, energy and bandwidth consumption of the network.*

Keywords: *AOMDV, Bandwidth, Energy, Overhearing, QoS routing.*

1. INTRODUCTION

Mobile Ad hoc Networks (MANETs) is an autonomous collection of mobile nodes forming dynamic topology and communicating over wireless links. These nodes suffer from channel bandwidth limitation. The scarce bandwidth decreases even further due to idle time synchronization between source and destination, collision and backoff procedure. Moreover nodes operate on limited battery power, which will eventually be exhausted. They also have limited CPU and storage capacity. These nodes need to be energy conserved to maximize the battery life.

Energy management is done by MAC layer using local information while the network layer can take decisions based on topology information. The network interface has five physical states: transmit, receive, idle, sleep and switch-off. Energy consumed by the sleeping state node is significantly less than the other states. To minimize energy consumption, path consumes less power is chosen. The infrastructure less environment of ad hoc networks poses constraints on routing protocols. Ad hoc routing protocols can be broadly classified as proactive (table driven) and reactive (on demand) [17]. Proactive approach costs high to transmit the topology information. The reactive approach, on the other hand, reduces routing overhead so that bandwidth is saved. Therefore reactive routing protocols are given importance in this work.

Two mostly used reactive protocols are Ad hoc On-demand Distance Vector (AODV) [17] and Dynamic Source Routing (DSR) [9, 11, 16]. Both are uniform protocols, in which all nodes participate equally in the routing process: there are no distinguished nodes and no hierarchical structure is imposed on the network. The protocols differ primarily in the state information that they maintain. DSR is a source routing protocol. Ie only the source node knows the whole route to the destination. Each data packet stores the whole route information in the header which costs high and wastes bandwidth. There is a chance of using stale routes which cause loss of packets because there is no timer information. AODV is a destination-oriented protocol based on the distributed Bellman–Ford algorithm. Each node stores the information of the next hop and destination in its routing table. Timer is used to maintain the freshness of a route. It provides only one route reply. Also one route entry per destination is stored in the routing table. It maintains distance-vector routing information and uses a destination managed sequence number to avoid routing loops.

This paper is structured as follows. Section 2 describes related work on energy conserving techniques. Section 3 presents probability based overhearing concept and its integration with log based pipelined ABM and AOMDV routing protocol. Section 4 show simulation results and section 5 concludes the paper.

2. RELATED WORK

Mobile ad hoc networks use a wide range of energy conserving techniques. The PAMAS (Power Aware Multi-Access protocol with Signaling) protocol [25] uses a separate signaling channel to determine when and how long the nodes can power off themselves. In AFECA (Adaptive Fidelity Energy Conservation Algorithm), nodes sleep based on the size of their neighborhoods [27]. When number of neighbors is more, then node enters into sleep state without disconnecting the network. Reference from [4] provides different sleep patterns for the mobile nodes based on their residual energy and quality of service. But a special hardware, called Remote Activated Switch (RAS), is required to wake up the sleeping nodes.

Technique to combine power management and power control for wireless cards is presented in [23]. Another centralized approach is discussed in [5], where an RF wake-up channel is used to design a protocol which minimizes energy consumption to meet QoS requirements. GAF (Geographic Adaptive Fidelity) discussed in [29] uses GPS to form a grid such that adjacent boxes are guaranteed to be within the communication range of each other. Then, selected nodes in each box remain on to keep the network connected.

In [11], a node enters into the doze state if it overhears RTS/CTS for data transmission. However, this approach incurs more transition costs associated with a doze-to-active transition. SPAN [3] selects a set of coordinators to form a virtual backbone which forward traffic for active connections. This concept increases network life time but decreases throughput.

STEM (Sparse Topology and Energy Management) uses an independent control channel to avoid clock synchronization and variant of STEM achieves greater power savings by periodically listening on the data channel and buffering packets [19]. In PSM (Power Saving Mode) of 802.11, when a node transmits or receives an ATIM (Adhoc Traffic Indication Map) frame during an ATIM window, it must be in active mode during the entire beacon interval that results in much higher energy consumption [7]. In DPSM [7] (Dynamic Power Saving Mechanism) scheme, the ATIM window size is adjusted dynamically based on current network conditions. A NPSM (New Power Saving Mechanism) introduces some parameters indicating amount of data in each station [8]. Power-saving mechanism is hard to implement in partial connected like mobile multi-hop network. In [22], off-the-shelf hardware is used to wake up wireless devices in a centralized environment. In [28], energy is saved by integrating routing and MAC layer functionality. However, the timers do not adjust to the traffic rate, so if traffic is not frequent enough to refresh the timers, the benefits of the protocol are lost. Even though GEAR (Global Energy Aware Routing) can save energy and maximize the system lifetime [1], it has two major disadvantages (difficulty in utilizing route cache and the blocking property) that can be avoided with Local Energy-Aware Routing (LEAR) protocol. In (ODPM) (On Demand Power Management), soft state timers are set or refreshed on-demand, based on control messages and data transmission [28]. Nodes that are not involved in data transmission may enter into sleep state to save energy.

The protocol discussed in [26] extends doze time and reduces contention, retransmission and improves channel utilization. It also provides quality of service support. In [21], author described distributed power control algorithm which incorporates group mobility patterns, group traffic patterns and blockage models. In [10], author discussed an algorithm to improve the system life time and balanced energy consumption rates in proportion to energy reserves among the nodes.

In [13], number of AM nodes is reduced based on backbone probability. TITAN (Traffic-Informed Topology-Adaptive Network) improves ODPM in which PS nodes sleep for longer duration and saves energy [20]. Rcast [14] implements randomized overhearing but not randomized rebroadcast. Dorsey and Siewiorek [6] discussed a fast wakeup mechanism so that latency for route discovery is reduced. Randomcast [15] uses no/unconditional/ randomized overhearing depending on the packet type and introduces randomized rebroadcast to improve performance. This technique improves energy balance. This algorithm is integrated into DSR routing protocol. In DSR, overhearing leads to bad situation because stale route concept is applied to all unconditional overheard nodes and wastes energy resource while transmitting, receiving packets. DSR broadcasts control packets which waste channel capacity because it generates redundant rebroadcasts. Hence AODV routing protocol is proposed for energy efficient method.

3. ENERGY EFFICIENT PIPELINED ABM

3.1. LOG BASED PIPELINED AVAILABLE BANDWIDTH MEASUREMENT (ABM)

Available bandwidth of a node can be improved by considering channel utilization ratio, idle period synchronization and bandwidth loss due to the collision probability. The steps in ABM are

1. Evaluate the capacity of a node and estimate the available bandwidth (ABM).
2. Estimate the link's available bandwidth and integrate into ABM. It depends on channel utilization ratio and idle period synchronization.
3. Estimate collision probability and integrate into ABM.
4. Collision leads to retransmission of same frames. When collision occurs, backoff procedure is executed. This is an additional overhead which affects the available bandwidth. To reduce this overhead, log based implicit pipelined backoff algorithm (IPBA) is executed [24] which is explained below. Bandwidth loss due to this backoff is evaluated and integrated into ABM.
5. Finally estimate the available bandwidth and store it in all the nodes with the help of Hello packets.
6. Routing protocol called enhanced link disjoint AOMDV (Ad hoc On demand multipath Distance Vector) finds the route based on this available bandwidth [18].

In a heavily contended network, the collision probability increases which degrades the performance. Pipelining technique is applied to backoff algorithm to reduce collision rate and channel idle time. When two nodes are using the channel, the remaining nodes start the channel contention procedure in parallel to solve channel contention for the next packet transmission. It implicitly pipelines the channel contention stages as stage1 and stage2. Stage1 functions as a filter to select few nodes to contend for channel in Stage2. The channel contention can be solved effectively because the number of nodes in stage2 is small. It reduces collision probability and improves channel utilization. Log based pipelined backoff hides channel idle time and reduces collision probability. It is also used to control number of contending nodes. This procedure consumes less bandwidth and improves the performance.

3.2. ENERGY EFFICIENT METHOD

In the log based pipelined method (LPABM), all the neighboring nodes overhear when a node is transmitting a packet. Overhearing is caused by receiving information that is not intended to it. Energy consumption during overhearing is same as that during reception. Goal of this work is to develop an energy saving mechanism to reduce energy consumption due to overhearing. To minimize energy, probability method is applied to randomly select number of overhearing nodes. This probability based overhearing is incorporated into log based pipelined ABM and integrated with AOMDV routing protocol.

Overhearing improves network performance since nodes collect more route information. Nodes in the range of source learn about path to destination. But overhearing increases traffic and consumes energy. The proposed algorithm controls the level of overhearing. It reduces energy consumption without affecting quality of route information.

Overhearing and redundant rebroadcast problems are controlled using ATIM window. RTS, CTS, ATIM, Beacon and ACK frames are allowed to transmit during the ATIM window. At the beginning of each ATIM window, each host will contend to send a beacon frame. During ATIM window, an ATIM frame is sent. ATIM frame consists of frame control, destination address, source address, sequence control etc. Subtype field in frame control helps to set the overhearing level.

Subtype: 1001 for unconditional overhearing
1101 for probability based overhearing
1110 for no overhearing

Number of overhearing nodes is controlled by probability based overhearing method.

The main aim is to limit the level of overhearing and forwarding of broadcast packets without affecting the network performance. Three possibilities such as probability overhearing, no overhearing, and unconditional overhearing are considered while finding the routes. No overhearing is one in which only a very minimum number of nodes (sender, receiver and intermediate nodes) can overhear and the others would go to low-power sleep state. Unconditional overhearing is one in which almost all one hop neighbor nodes in a network can overhear. Unconditional overhearing or probability overhearing is set based on the types of messages are exchanged. A) Probability overhearing is used for DATA packet and RREP messages. B) RERR messages will be assigned unconditional overhearing. The reason is that the link failure should be informed to all the nodes, so that the nodes will not use it for the next time until it gets ready. C) RREQ is a broadcast message. Based on overhearing level and rebroadcast probability (Pr) values, ATIM frame is sent. Each node receives ATIM and ATIM-ACK during an ATIM window and depending on its sub type, node is either in awake or sleep state.

Probability based overhearing method controls the level of overhearing and forwarding of broadcast messages. Sender is able to specify the level of overhearing. Sender may choose no or unconditional or probability overhearing which is specified in ATIM frame control. Node is awakened if unconditional overhearing or probability overhearing is set or it is a destination node. Each node maintains overhearing probability P_o and rebroadcast probability P_r. These values depend on number of neighbors.

$$P_o = \frac{1}{n} \quad (1)$$

$$P_r = \frac{cn}{N^2} \quad (2)$$

where *c* is a constant, *n* – number of neighbors and *N* – average number of neighbor's neighbors.

$$\text{Energy consumption} = \sum \frac{(\text{Initial energy - residual energy})}{\text{no. of pkts sent}} \quad (3)$$

If a node's subtype is 1101, it generates a random number between 0 and 1 and compares it with P_o. If it is greater than P_o, node decides to overhear. If it is greater than P_r, node decides to rebroadcast. Fig. 1 shows that A and B are overhearing nodes. They overhear the transmissions between the nodes S and D. Other neighbor nodes are in sleep state.

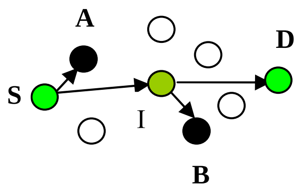

Fig. 1 – Probability based overhearing

Algorithm to set subtype and send ATIM

When a node is ready to transmit a frame, check its overhearing level (OL) for broadcast and unicast transmission.

1. For a broadcast transmission
   If (OL = unconditional)
   send ATIM.
   Else if (OL= probability overhearing)
   If (rand(0,1)≤ P_r) send ATIM.
2. For a unicast transmission
   If (OL = unconditional)
   subtype=1001.
   Else if (OL= no overhearing)
   subtype =1110.
   Else if (OL= probability overhearing)
   subtype =1101.
   Send ATIM with subtype.

After receiving an ATIM frame, node decides to receive or overhear or to be in sleep mode in the following data transmission period based on destination address and subtype values.

Algorithm to receive messages and decide overhearing level

1. For broadcast transmission
   Receive packet
2. For unicast transmission
   If it is a destination node then
   Receive packet
   else check its subtype
   a. If subtype =1001 // unconditional
   Overhear transmission
   b. If subtype =1101 // probability overhearing
   If(rand(0,1) ≤ P_o
   Node decides to overhear the transmission
   c. If subtype =1110 // No overhearing
   Go to sleep state.

This probability based overhearing is combined with pipelined ABM to improve its energy. Hence the name Energy Efficient Log based Pipelined ABM (EELPABM). This concept is integrated into a routing protocol called enhanced link disjoint AOMDV to find the route based on available bandwidth from a given source to destination.

3.3. ROUTING PROTOCOL

Enhanced Multipath AODV modifies the base AODV protocol's route discovery mechanism, to find multiple link-disjoint paths for a particular source node [17]. To discover link-disjoint paths, each node forwards a route request towards the destination during the route discovery process; however, it maintains a queue of the previous hop nodes for each RREQ received from a unique neighbor of the source. When a link failure occurs, the node upstream of the link detects the failure, invalidates its routing table entry for that destination and unicasts an RERR message towards the source. Once the source node receives the RERR, it switches its primary path to the next best alternate link-disjoint path. It is designed mainly for highly dynamic ad hoc networks when route breaks and link failures occur frequently.

Route discovery procedure of AODV finds the route between sender and receiver that satisfies the bandwidth requirement. This routing protocol finds the route from source to destination by comparing the bandwidth stored in nodes with the requested bandwidth. Route discovery is responsible for generating all possible routes between source and destination. Source transmits RREQ packet with bandwidth extension. This extension field indicates the minimum bandwidth needed between source and destination. A node receiving a RREQ for the first time creates an entry in its routing table. Before forwarding RREQ packet, each intermediate node compares its available bandwidth to bandwidth field of RREQ.

If the required bandwidth is available, then the node forwards the RREQ to its neighbors. Otherwise the packet is discarded. RREQ packets have unique sequence number. When the RREQ reaches the destination, its information is extracted and it is destroyed. Then, RREP (Route REPly) is created with same sequence number and sent towards the source with the available bandwidth measured on the link. Finding multiple routes is beneficial in mobile wireless networks where routes are disconnected frequently because of node mobility and poor link quality.

4. SIMULATION RESULTS

The proposed algorithm is implemented using NS2 simulator tool [30]. Performance analysis of energy efficient log based pipelined ABM is carried out by setting simulation time to 200 s with a grid size of 1000×1000 m. Random way point mobility model with CBR (Constant Bit Rate) traffic is used to simulate nodes movement. Nodes move toward a randomly selected destination, pause there for a predefined interval and travel towards another randomly selected destination. This algorithm is tested for 50 nodes. The parameters used to measure the performance are throughput, latency, energy consumption, routing overhead and packet delivery ratio. Results are compared with two schemes: ABM-AODV and LPABM-AOMDV. In these schemes, nodes are always awake and hence consume more energy. To achieve optimum result, system parameters must be selected according to traffic condition. Table 1 shows simulation parameters.

Fig. 2 shows the throughput performance Energy efficient method improves the throughput almost twice than that of ABM.

The ability to deliver a high percentage of packets to a destination increases the overall utility of the system. Energy efficient method delivers more number of packets successfully under high load. PDR is high because most of the nodes are participated in packet transmission as shown in Fig. 3. PDR is reduced due to the mobility of nodes and link failures. It is observed that proposed method maintains a significantly high PDR than the existing one. Because the most active path is selected, this has less probability to fail. And in turn increases the PDR.

Table 1. Parameters for Simulation

Parameter	Value
Transmission range	250 m
Carrier Sensing range	550 m
Packet Size	512 bytes
Channel Capacity	2 Mbps
Grid Size	1000×1000 m
No. of nodes	50
CWmin-CWmax	31-1023,15-1023
Mobility Model	Random way point
Mobility Speed	20 s
Simulation Time	200 s

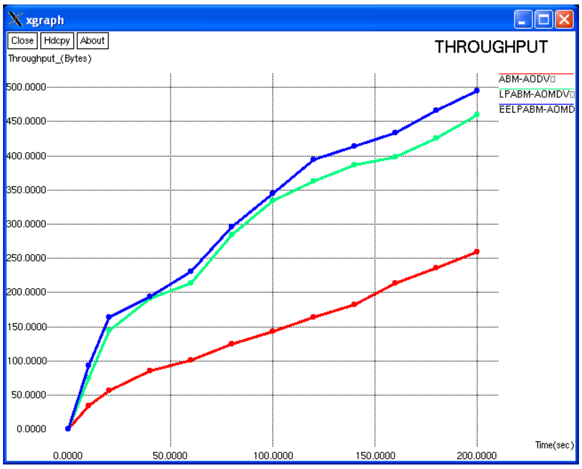

Fig. 2 – Throughput

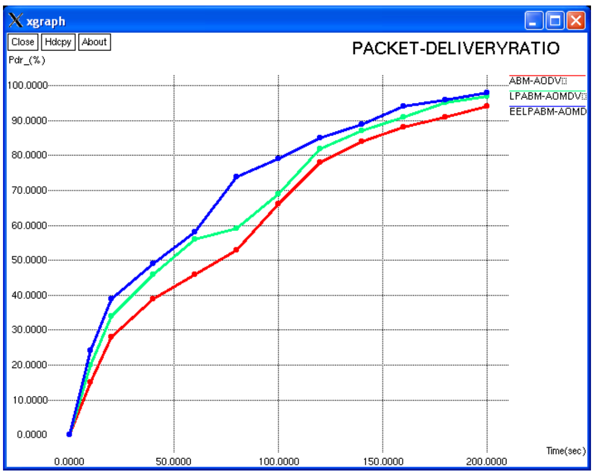

Fig. 3 – Packet Delivery Ratio

Fig. 4 shows bandwidth consumed by all methods. Energy efficient method saves bandwidth by 65% compared to ABM and 19% compared to LPABM.

Probability based overhearing method

outperforms other algorithms with respect to energy consumption. Energy efficient pipelined ABM shows less energy consumption than other schemes as in Fig.5. Energy efficient scheme achieves better energy performance under high traffic condition.

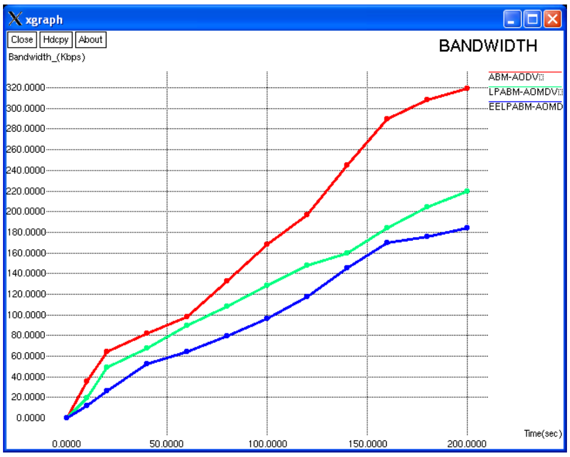

Fig. 4 – Bandwidth Utilization

Performance gap is not dramatic under low traffic condition. Pipelined scheme consumes more energy since nodes keep awake during the entire period of simulation time. In energy efficient scheme, nodes in the range of active communication overhear probabilistically. Effective energy management is obtained in proposed work. This is due to the variation of the transmit power between two nodes and also reduction in the number of overhearing nodes. This proposed approach with energy management still reduces the energy consumption. There is not much change in PDR and throughput before and after energy management.

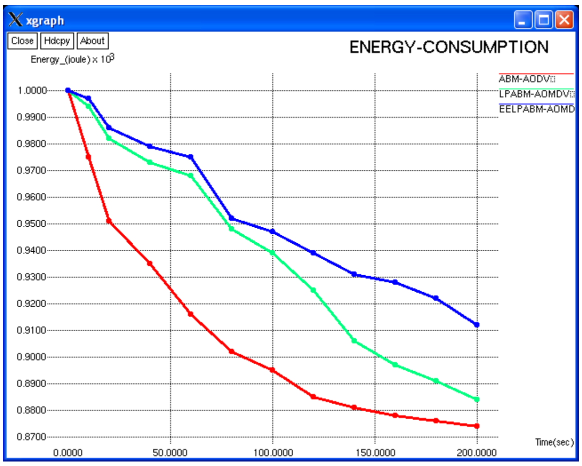

Fig. 5 – Energy Consumption

Routing overhead depends on number of hello messages, RREQs, RREPs and RERRs. Due to the incorporation of energy efficient method, routing overhead is comparatively reduced as shown in Fig. 6. Fig. 7 shows latency caused by energy efficient method varies upto is 0.8 ms. It is less compared to other methods.

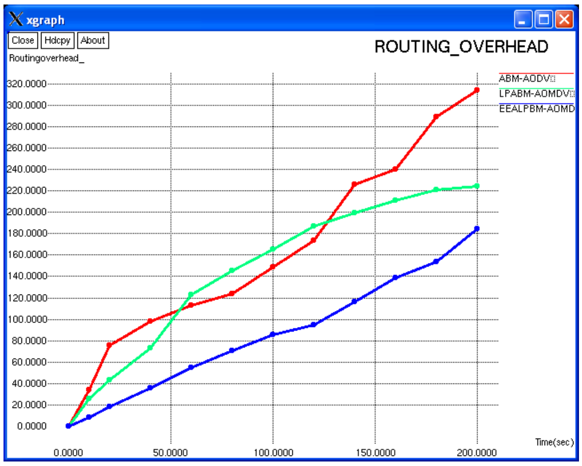

Fig. 6 – Routing Overhead

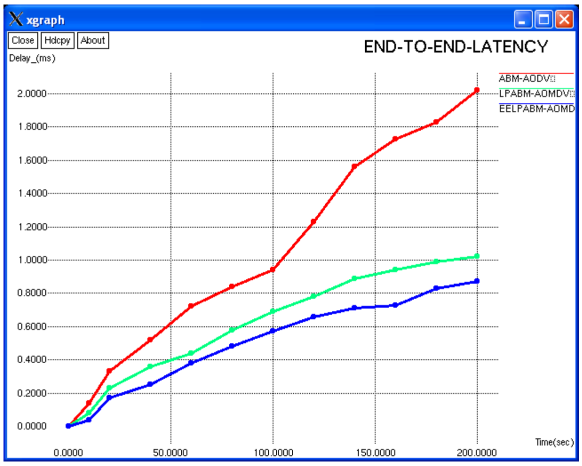

Fig.7 – End-End Latency

5. CONCLUSION

Because of the mobility characteristic of the network, devices use battery as their power supply. As a result, the advanced energy conservation techniques are very necessary in designing a system.

Energy is saved by integrating MAC layer functionality with routing. In order to save energy, probability based overhearing method is applied. Sender can specify the desired level of overhearing based on overhearing probability. Number of overhearing nodes is reduced probabilistically. Hence the energy consumed by overhearing nodes is reduced. Problem of unconditional or unnecessary forwarding of broadcast packets are considered. This energy efficient scheme is incorporated into pipelined ABM to gain the benefit of existing work without degrading performance metrics. This paper compares the performance of energy efficient pipelined ABM with other schemes in terms of throughput, PDR etc. Its performance is close to pipelined scheme in terms of throughput and PDR but achieves a significant improvement in energy saving.

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