



Power-Aware: An Optimal Energy Efficient Communication Scheme Using AODV Protocol in MANETs

Santhosh Reddy Tirumuru *
School of Information Technology & Engineering,
VIT University
Vellore, India.
Santhoshreddy539@gmail.com

Sakthi Ganesh . M
Assistant Professor,
School of Information Technology & Engineering,
VIT University,
Vellore, India.
sakthiganesh.m@vit.ac.in

Abstract: In wireless mobile ad hoc network (MANET) using a shared communication medium, every node receives or overhears every data transmission happening in its neighbourhood. However, this technique is not appropriate when a power saving mechanism (PSM) such as the one specified in IEEE 802.11 is working, where a packet advertisement period is alienated from the actual data transmission period. When a node receives an advertised packet that is not destined to it, it switches to a low-power state during the data transmission period, and thus, conserves power. However, since some MANET routing protocols such as Dynamic Source Routing (DSR) collect route information via overhearing, they would suffer if they are used with the IEEE 802.11 PSM. Allowing no overhearing may critically deteriorate the performance of the underlying routing protocol, while unconditional overhearing may offset the advantage of using PSM. This paper proposes a new communication mechanism, called Random Cast or Rcast, via which a sender can specify the desired level of overhearing in addition to the intended receiver by using (Adhoc On-demand Distance Vector) AODV protocol. Therefore, it is possible that only a random set of nodes overhear and collect route information for future use. Rcast improves not only the energy efficiency, but also the energy balance among the nodes, without significantly affecting the routing efficiency.

Keywords: Energy balance, energy efficiency, mobile ad hoc networks, overhearing, power saving mechanism.

I. INTRODUCTION

Adhoc networks are infrastructure less wireless networks. Here, mobile nodes communicate directly with each other. If two nodes are not within radio range of each other, they can use the forwarding functionality of another node to establish a connection, i.e., the message travels from one node to another until it reaches its destination. All nodes need to implement at least simple medium access mechanisms and need to detect collisions themselves. Therefore, nodes of ad hoc networks are much more complex than those of infrastructure based networks. However, ad hoc networks are easy to manage and establish. Since they do not require an infrastructure network, they are much more flexible and their use is possible in a broader range of scenarios, e.g. for disaster relief. Depending on the frequency of structural changes in the network, ad hoc networks can be subdivided into mobile ad hoc networks, or MANETs, and sensor networks.

One of the most critical issues in mobile ad hoc networks (MANETs) is energy conservation [6]. Since mobile nodes usually operate on batteries, a prudent power saving mechanism (PSM) [11, 12, 13] is required to guarantee a certain amount of device lifetime. It also directly affects the network lifetime because mobile nodes themselves collectively form a network infrastructure for routing in a MANET. Energy efficiency can be improved in two different ways: Reducing the energy used for active communication activities and reducing the energy spent during an inactive period.

IEEE 802.11 standard, which is the most popular wireless LAN standard, exploits this hardware capability to support the power management function in its medium access control (MAC) layer specification. Each mobile

device can be in one of the two power management modes: active mode (AM) or power save (PS) mode [13]. A device in the PS mode periodically wakes up during the packet advertisement period, called Ad hoc (or Announcement) Traffic Indication Message (ATIM) window to see if it has any data to receive. It puts itself into the low-power state if it is not addressed, but stays awoken to receive any advertised packet otherwise. However, this IEEE 802.11 PSM [11, 12] is difficult to employ in a multihop MANET because of routing complexity not alone the difficulty in synchronization and packet advertisement in a dynamic distributed environment

The main goal of this paper is to make the IEEE 802.11 PSM applicable in multihop MANETs when the popular (Adhoc On-demand Distance Vector) AODV [10] is used as the network layer protocol. A major concern in integrating the AODV protocol with the IEEE 802.11 PSM is overhearing. Overhearing improves the routing efficiency in AODV by eavesdropping other communications and gathering route information. It incurs no extra cost if all mobile nodes operate in the AM mode because they are always awake and idle listening anyway. However, if mobile nodes operate in the PS mode, it brings on a high energy cost because they should not sleep but receive all the routing and data packets transmitted in their vicinity. A naive solution is to disable overhearing and let a node receive packets only if they are destined to it. However, it is observed that this solution reduces network performance [7] significantly because each node gathers less route information due to the lack of overhearing, which in turn incurs a larger number of broadcasts flooding of route request (RREQ) messages resulting in more energy consumption. In short, overhearing plays an essential role in disseminating route information in

AODV but it should be carefully re-designed if energy is a primary concern.

This paper proposes a message overhearing mechanism, called Random Cast or Rcast [4, 14], via which a sender can specify the desired level of overhearing when it advertises a packet. Upon receiving a packet advertisement during an ATIM window, a node makes its decision whether or not to overhear it based on the specified overhearing level. If no overhearing is specified, every node decides not to overhear except the intended receiver and if unconditional overhearing is specified, every node should decide to overhear. Randomized overhearing achieves a balance somewhere in between, where each node makes its decision probabilistically based on network parameters such as node density and network traffic. Rcast helps nodes conserve energy while maintaining a comparable set of route information in each node. Since route information is maintained by sequence number in AODV, Rcast effectively avoids unnecessary effort to gather redundant route information and thus saves energy. The key idea behind the Rcast scheme is to explore the temporal and spatial locality of route information, as is done in the CPU cache. Overheard route information will probably be overheard again in the near future and thus it is possible to maintain the same quality of route information, while overhearing only a small fraction of packets. Even though a node misses particular route information, it is highly probable that one of its neighbors overhears it and can offer the information when the node asks for it. Note that we have chosen AODV in this paper because other MANET routing algorithms [3, 9, 15] usually employ periodic broadcasts of routing related control messages, and thus tend to consume more energy with IEEE 802.11 PSM.

Key contributions of this paper are threefold: 1) It presents the Random Cast protocol that is designed to employ the IEEE 802.11 PSM in multihop MANETs. Unlike previous approaches, where nodes need to switch between AM and PS mode, they consistently operate in the PS mode in Random Cast 2) In Random Cast, a transmitter can specify the desired level of overhearing to strike a balance between energy and throughput. More importantly, it helps avoid the semantic discrepancy found in most of MANET routing protocols. 3) This paper shows that the problem of unconditional or unnecessary forwarding of broadcast packets can also be taken care of in the Random Cast framework.

The rest of the paper is structured as follows: Section II presents the background information on the AODV routing protocol and IEEE 802.11 PSM. Section III presents the proposed Random Cast protocol and its integration with AODV. Section IV draws the simulation progress of this study.

II. BACKGROUND

We assume that mobile nodes operate as the IEEE 802.11 PSM for energy-efficient medium access and use AODV for discovering and maintaining routing paths. Section A summarizes the AODV routing protocol. It also discusses the stale route and load unbalance problem in AODV and argues that unconditional overhearing is the main reason behind them. Section B explains the IEEE 802.11 PSM.

A. AODV Protocol Overview

The AODV routing protocol is a reactive routing protocol; therefore, routes are determined only when needed. Hello messages may be used to detect and monitor links to neighbors. If Hello messages are used, each active node periodically broadcasts a Hello message that all its neighbors receive. Because nodes periodically send Hello messages, if a node fails to receive several Hello messages from a neighbor, a link break is detected. When a source has data to transmit to an unknown destination, it broadcasts a Route Request (RREQ) for that destination. At each intermediate node, when a RREQ is received a route to the source is created. If the receiving node has not received this RREQ before, is not the destination and does not have a current route to the destination, it rebroadcasts the RREQ.

If the receiving node is the destination or has a current route to the destination, it generates a Route Reply (RREP). The RREP is unicast in a hop-by-hop fashion to the source. As the RREP propagates, each intermediate node creates a route to the destination. When the source receives the RREP, it records the route to the destination and can begin sending data. If multiple RREPs are received by the source, the route with the shortest hop count is chosen. As data flows from the source to the destination, each node along the route updates the timers associated with the routes to the source and destination, maintaining the routes in the routing table. If a route is not used for some period of time, a node cannot be sure whether the route is still valid; consequently, the node removes the route from its routing table.

If data is flowing and a link break is detected, a Route Error (RERR) is sent to the source of the data in a hop-by-hop fashion. As the RERR propagates towards the source, each intermediate node invalidates routes to any unreachable destinations. When the source of the data receives the RERR, it invalidates the route and reinitiates route discovery if necessary.

B. IEEE 802.11 PSM

In the IEEE 802.11 PSM, a node can be in one of two different power modes, i.e., active mode when a node can receive frames at any time and power-save mode (PS) when a node is mainly in low-power state [5] and transits to full powered state subject to the rules described next. The low-power state usually consumes at least an order of magnitude less power than in the active state.

In the power-save mode, all nodes in the network are synchronized to wake up periodically to listen to beacon messages. Broadcast/multicast messages or unicast messages to a power-saving node are first buffered at the transmitter and announced during the period when all nodes are awake. The announcement is made via an ad hoc traffic indication message (ATIM) inside a small interval at the beginning of the beacon interval called the ATIM window. If a node receives a directed ATIM frame in the ATIM window (i.e. it is the designated receiver), it sends an acknowledgment and stays awake for the entire beacon interval waiting for data packets to be transmitted. Immediately after the ATIM window, a node can transmit buffered broadcast/multicast frames, data packets and management frames addressed to nodes that are known to be

active (by reception of acknowledgment to ATIM frames). Otherwise, the node can switch to the low-power state to conserve energy. In IEEE 802.11, a node's power management mode is indicated in the frame control field of the MAC header for each packet. In the IEEE 802.11 PSM, the length of a beacon interval and the size of an ATIM window are configured by the first node that initiates the network in IBSS. A mobile station can choose to wake up every multiples of the beacon intervals for further energy saving.

III. RANDOM CAST IMPLEMENTATION WITH AODV

A. No, Unconditional, And Randomised Overhearing

The unicast packet is delivered only to an intended receiver if the IEEE 802.11 PSM is employed. Consider that a node S transmits packets to a node D via a pre-computed routing path with three intermediate nodes as shown in Fig. 1(a). Only five nodes are involved in the communication and the rest would not overhear it (*no overhearing*). However, if each neighbor is required to overhear as in AODV, each sender should be able to "broadcast" a unicast message. i.e., it specifies a particular receiver but at the same time asks others to overhear it as shown in Fig. 1(b) (*unconditional overhearing*). *Randomized overhearing* adds one more possibility in between unconditional and no overhearing. As shown in Fig. 1(c), some of the neighbors overhear, but others do not and these nodes switch to the low-power state during the data transmission period. Randomized overhearing saves substantial amount of energy compared to unconditional overhearing. With respect to route information, it does not deteriorate the quality of route information by exploiting the spatial and temporal locality of route information dissemination as explained in the introduction. Consider an example in Fig. 1(c), in which nodes X and Y are two neighbors of the communicating nodes A and B. Their communication and overhearing activities are drawn in Fig. 3.

When node A receives a RREP from node B, it obtains a new route ($S \rightarrow D$) and stores it in its route cache [8]. Nodes X and Y do not overhear the RREP as shown in the figure but, since there will be a number of data packets transferred from node A to B, they will obtain the route information ($S \rightarrow D$). In this figure, node X overhears the second data packet and node Y overhears the second from the last packet. Fig. 1 also shows when the route becomes stale and gets eliminated from the route cache.

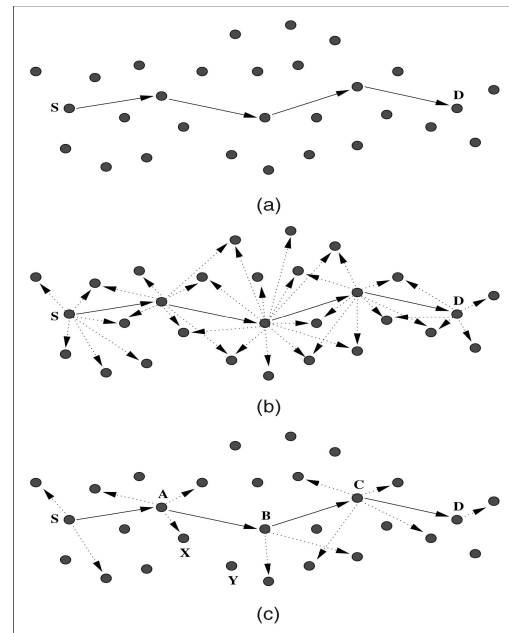


Fig. 1 Delivery of a unicast message with different overhearing mechanisms. (a) no overhearing, (b) unconditional overhearing, and (c) randomized overhearing.

B. Rcast Implementation

The Rcast mechanism enables a node to choose no, unconditional, or randomized overhearing when it has a unicast packet to send. Its decision can be specified in the ATIM frame so that it is available to its neighboring nodes during the ATIM window. For practicality, implementation in the context of IEEE 802.11 specification is considered by slightly modifying the ATIM frame format as shown in Fig. 4. An ATIM frame is a management frame type and its subtype ID is 10012. The Rcast mechanism utilizes two reserved subtype IDs, 11012 and 11112, to specify randomized and unconditional overhearing, respectively. A frame with subtype 10012 is recognized as no overhearing, and thus, conforms to the standard.

Consider an example when a node (its MAC address MA) wakes up at the beginning of a beacon interval and receives an ATIM frame. It decides whether or not to receive or overhear the packet based on the destination address (DA) and subtype ID. It would remain awoken if one of the following conditions is satisfied.

1. The node is the intended destination ($DA = MA$).
2. The node is not the destination but the sender wants unconditional overhearing ($DA \neq MA$ but subtype ID = 11112).
3. The node is not the destination, but the sender wants randomized overhearing, and the node randomly decides to overhear the packet ($DA \neq MA$, subtype ID = 11012 and decides to overhear).

A key design issue in the Rcast implementation is the mechanism of overhearing when the sender specifies node maintains a probability, PR, determined using the factors listed below and probabilistically makes the overhearing decision based on PR. In other words, if a randomly generated number is $> PR$, then a node decides to overhear.

- *Sender ID*: The main objective of Rcast is to minimize redundant overhearing as much as possible. Since

a node usually repeats the same route information in consecutive packets, a neighbor can easily identify the potential redundancy based on the sender ID. For instance, when a node receives an ATIMframe with subtype 11012, it determines to overhear it if the sender has not been heard or overheard for a while. The former condition means that the traffic from the sender happens rarely or the packet is for a new traffic. The latter condition holds when the node skips too many packets from the sender.

- **Mobility:** When node mobility is high, link errors occur frequently and route information stored in the route cache becomes stale. Therefore, it is recommended to overhear more conservatively in this case. Each node is not knowledgeable about mobility of every other node, but it can estimate its own mobility based on the connectivity changes with its neighbors.

- **Remaining battery energy:** This is one of the most obvious criteria that helps extend the network lifetime: Less overhearing if remaining battery energy is low. However, it is necessary to consider other nodes' remaining battery energy in order to make a better balance.

- **Number of neighbors:** When a node has a large number of neighbors, it is possible that one of them offers a routing path to the node when it asks for it by sending a RREQ. Therefore, the overhearing decision is related inversely to the number of neighbors. Overhearing decision can be made based on the above four criteria, but in this paper, we adopt a simple scheme using only the number of neighbors ($P_R = 1 / \text{number of neighbors}$) to show the potential benefit of Rcast. In other words, if a node has five neighbors in its radio transmission range, it overhears randomly with the probability P_R of 0.2.

C. Rcast With AODV

AODV employs three control packets, RREQ, RREP and RERR, in addition to data packets. RREQ is a broadcast and RREP, RERR and data are unicast packets. For each of these unicast packets, AODV uses the following overhearing mechanism.

- **Randomized overhearing for RREP packets:** A RREP includes the discovered route and is sent from the destination to the originator of the corresponding RREQ packet. For example, in Fig. 1(c), node D sends a RREP to node S. Intermediate nodes as well as node D will Rcast this message to allow randomized overhearing. Unconditional overhearing of RREP is not a good idea because AODV generates a large number of RREP packets as discussed in Section 2.1.

- **Randomized overhearing for data packets:** In AODV, every data packet includes the entire route from the source to the destination. Each intermediate node (e.g., nodes A, B, and C in Fig. 1(c)) as well as the source node (e.g., node S in Fig. 1(c)) will demand randomized overhearing for these packets so that neighboring nodes (e.g., nodes X and Y in Fig. 1(c)) can overhear them randomly.

- **Unconditional overhearing for RERR packets:** When a broken link is detected, an upstream node (e.g.,

nodeB in Fig. 1(c)) transmits a RERR to the source. Nodes will overhear this message unconditionally because the stale route information must be invalidated as soon as possible from nodes' route caches.

Note that a broadcast packet such as RREQ can also be Rcasted to allow randomized receiving as mentioned in the introduction. This is to avoid redundant rebroadcasts of the same packet in dense mobile networks. In this case, the overhearing decision must be made conservatively to make sure that the broadcast packet such as RREQ is propagated correctly until it reaches the final destination. Note also that the randomization approach described above can avoid the occurrence of preferential attachment, discussed in Section III (B), and lead to a more balanced network with respect to packet forwarding responsibility and energy consumption.

IV. SIMULATION PROGRESS

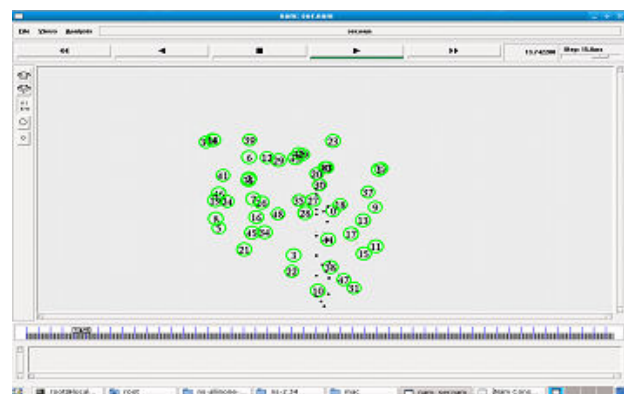


Fig. 2 NAM window for implementing AODV with 50 nodes.

Fig 2 shows the NAM window [1, 2], the AODV routing protocol is simulated by using fifty nodes and the working progress of protocol is analyzed.

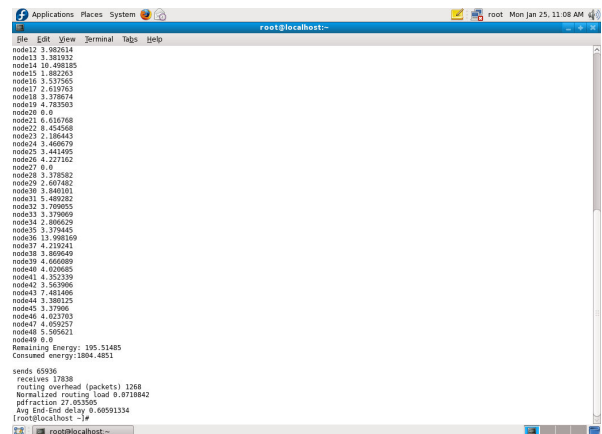


Fig.3 Tracefile calculation for energy consumed in AODV

Fig.3 shows the trace file for calculating energy consumed in AODV routing protocol with scenario generated for fifty nodes. The increased network structure and node create the overhead. The simulated graph for the routing overhead is shown below.

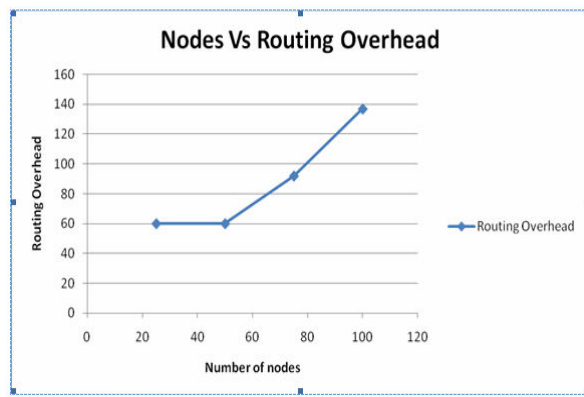


Fig.4 Graph between number of nodes vs routing overhead.

In the graph it is clear that after certain extent the overhead increases exponentially with increase in number of nodes.

V. CONCLUSION

Little effort has been devoted to integrate 802.11 PSM with a multihop routing protocol such as AODV. This study addresses this important problem and suggests an efficient solution based on RandomCast. The key observation is that unconditional overhearing, which is taken for granted without PSM, is not freely available with PSM. In RandomCast, when a packet is transmitted, nodes in the proximity should decide whether or not to overhear it considering the trade-offs between energy efficiency and routing efficiency. Routing efficiency comes into picture because overhearing is an important tool to gather route information in AODV. Similarly, we explored the use of RandomCast for broadcast messages in order to avoid redundant rebroadcasts and thus save additional energy.

VI. FUTURE ENHANCEMENT

RandomCast opens many interesting directions of research to pursue. First, this study identifies four factors that must be considered for the overhearing/rebroadcast decision. These are sender ID, number of neighbors, mobility, and remaining battery energy. We implemented the RandomCast scheme using only the second factor (number of neighbors), but plan to investigate the effect of other three factors (sender ID, mobility, and remaining battery energy) for making the decision.

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