Power – Aware Routing in Manet using Randomized Casting

B. Siva kumar, K. Tharani, S. venkatasen

Abstract— In a typical wireless mobile ad hoc network (MANET) using a shared communication medium, every node receives or overhears every data transmission occurring in its vicinity. However, this technique is not applicable when a power saving mechanism (PSM) such as the one specified in IEEE 802.11 is employed, where a packet advertisement period is separated 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 802.11PSM. 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.

Index Terms— **Energy balance, energy efficiency, mobile ad hoc networks, network lifetime, 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 adhoc 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 adhoc networks (MANETs) is energy conservation. Since mobile nodes usually operate on batteries, a prudent power saving mechanism (PSM) 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. A device in the PS mode periodically wakes up during the packet advertisement period, called Adhoc (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 awaken to receive any advertised packet otherwise. However, this IEEE 802.11 PSM 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 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 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.

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Sivakumar.B, Assistant Professor in Vel Tech Multi Tech Engineering College, Tamil Nadu, India. (e-mail: sivablack@gmail.com).

Tharani.K, pursuing Master of Information Technology in Vel Tech Multi Tech Engineering College. (e-mail: tharukannan@gmail.com).

Venkatesan.S, Assistant Professor in Vel Tech Multi Tech Engineering College, Tamil Nadu, India. (e-mail: svsan_81@yahoo.co.in).

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, 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 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. 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) Compared to earlier work, this paper shows that the problem of unconditional or unnecessary forwarding of broadcast packets can also be taken care of in the RandomCast 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 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,

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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.

C. 802.11 PSM IN MULTIHOP NETWORKS

Recently, a number of research groups have studied how to utilize the PSM in multihop networks. SPAN [6] mandates a set of nodes to be in AM, while the rest of the nodes stay in the PS mode. AM nodes offer the routing backbone so that any neighboring node can transmit a packet to one of them without waiting for the next beacon interval. A drawback of this scheme is that it usually results in more AM nodes than necessary and degenerates to all AM-node situation when the network is sparse. More importantly, it does not take the routing overhead into account because it uses geographic routing and assumes that location information is available for free.

Zheng and Kravets suggested a similar approach, called On-Demand Power Management (ODPM), in which a node switches between the AM and PS mode based on communication events and event-induced time-out values. For example, when a node receives an RREP packet, it is better to stay in AM for an extended period of time (RREP ime-out) because it will most probably need to forward data packets in the near future. However, this scheme asks for each node to switch between the AM and PS mode frequently, which may incur non-negligible overhead. Moreover, each node needs to know and maintain the power management mode of its neighbors. This may not be trivial as it requires either an additional energy cost or an extended packet delay if the information is not accurate. Also, its performance greatly depends on time-out values, which need fine tuning with the underlying routing protocol as well as traffic conditions. For example, consider that a node stays in AM for five consecutive beacon intervals upon receiving a data packet (Data time-out). If data traffic is infrequent, say once every six beacon intervals, the node stays in AM for five intervals without receiving any further data packets and switches to a low-power sleep state. It receives the next data packet while operating in the PS mode, and thus, decides again to stay awaken for another five intervals. Packet delay is not improved but it consumes more energy than unmodified 802.11 PSM. Each node makes an AM-node (backbone) decision based on the number of neighbors; i.e., the backbone

Probability (P) is inversely proportional to the number of neighbors (say, n). This is based on the observation that having more neighbors usually means more redundancy in terms of connectivity. The backbone probability is then adjusted based on the average number of neighbors of its neighbors (say, _n). In other words, when a node has more neighbors than its neighbors, its backbone probability is increased because it can help reduce the number of AM nodes by electing itself as an AM node, i.e., P ¼ cn _n2 , where c is a tunable constant .

Traffic-Informed Topology-Adaptive Network (TITAN) is another probabilistic algorithm that improves over ODPM. It favors AM nodes when selecting routing paths at the network layer. It can be easily accomplished when PS nodes delay forwarding RREQ packets. Discovered routes could be a long way around compared to the shortest ones, but they utilize more AM nodes for delivering traffic. PS nodes would sleep for a longer duration than in ODPM and save more energy. The backbone decision (AM node) depends on the number of neighbors as well as the number of neighboring AM nodes.

Our approach in this paper is different from the aforementioned schemes in that every node operates in PS mode and is not required to switch between AM and PS mode. This means that any node won't fall in a potential danger to be an AM node for an extended period of time and die earlier than others. This could affect the network lifetime too. RandomCast not only reduces the overall energy consumption but also improves the energy balance among the nodes leading to a longer network lifetime.

D. PROBLEM STATEMENT

The PS mode of IEEE 802.11 is designed for a single-hop (or fully connected) ad hoc network. When applied to a multi-hop ad hoc network, three problems may arise. All these will pose a demand of redesigning the PS mode for multihop MANET.

A) Clock Synchronization: Since IEEE 802.11 assumes that mobile hosts are fully connected, the transmission of a beacon frame can be used to synchronize all hosts' beacon intervals .So the ATIM windows of all hosts can appear at around the same time without much difficulty. In a multi-hop MANET, clock synchronization is a difficult job because communication delays and mobility are all unpredictable, especially when the network scale is large. Even if perfect clock synchronization is available, two temporarily partitioned sub-networks may independently enter PS mode and thus have different ATIM timing. With the clock-drifting problem, the ATIM windows of different hosts are not guaranteed to be synchronous. Thus, the ATIM window has to be re-designed.

B) Neighbor Discovery: In a wireless and mobile environment,

a host can only be aware by other hosts if it transmits a signal that is heard by the others. For a host in the PS mode, not only is its chance to transmit reduced, but also its chance to hear others' signals. As reviewed above, a PS host must compete with other hosts to transmit its beacon. A host will cancel its beacon frame once it hears other's beacon frame. This may run into a dilemma that hosts are likely to have inaccurate neighborhood information when there are PS hosts. Thus, many existing routing protocols that depend on neighbor information may be impeded.

C) Network Partitioning: The above inaccurate neighbor information may lead to long packet delays or even network partitioning problem. PS hosts with unsynchronized ATIM windows may wake up at different times and may be partitioned into several groups. These conceptually partitioned groups are actually connected. Thus, many existing routing protocols may fail to work in their route discovery process unless all hosts are awaken at the time of the searching process.

E. POWER-SAVING PROTOCOLS FOR MANET

In this section, we present three asynchronous power-saving protocols that allow mobile hosts to enter PS mode in a multihop MANET. According to the above discussion, we derive several guidelines in our design:

More Beacons: To prevent the inaccurate-neighbor problem, a
mobile host in PS mode should insist more on sending beacons.
Specifically, a PS host should not inhibit its beacon in the ATIM window even if it has heard others' beacons. This will allow others to be aware of its existence. For this reason, our protocols will allow multiple beacons in a ATIM window.
Overlapping Awake Intervals: Our protocols do not count on clock synchronization, to resolve this problem, the wake-up patterns of two PS hosts must overlap with each other no matter how much time their clocks drift away.
Wake-up Prediction: When a host hears another PS host's beacon, it should be able to derive that PS host's wake-up pattern based on their time difference. This will allow the former to send buffered packets to the later in the future. Note that such prediction is not equal to clock synchronization since the former does not try to adjust its clock. Based on the above guidelines, we propose three power saving protocols, each with a different wake-up pattern for PS hosts. PS hosts' wake-up patterns do not need to be synchronous. For each PS host, it divides its time axis into a number of fixed-length intervals called beacon intervals. In each beacon interval, there are three windows called active window, beacon window, and MTIM window. During the active window, the PS host should turn on its receiver to listen to any packet and take proper actions as usual. The beacon window is for the PS host to send its beacon, while the MTIM window is for other hosts to send their MTIM frames to the PS host. Our MTIM frames serve the similar purpose as ATIM frames in IEEE 802.11; here we use MTIM to emphasize that the network is a multihop MANET. Excluding these three windows, a PS host with no packet to send or receive may go to the sleep mode.

III. RANDOM CAST IMPLEMENTATION WITH AODV

A. *No, Unconditional, and Randomized 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. When node receives a RREP from node B, it obtains a new route (S→ D) and stores it in its route cache. 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 → 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.

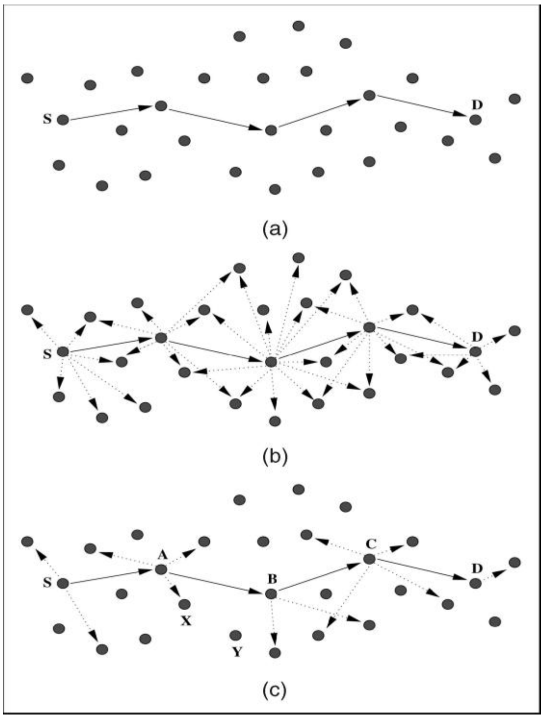

Fig. 1 Delivery of a unicast message with different overhearing mechanisms. (a) no overhearing, (b) unconditional overhearing, and (c) randomized overhearing.

B. *RandomCast Probability*

A key design issue in the Random Cast implementation is randomization. Basically, each node maintains an overhearing (rebroadcast) probability, PR (PF), determined using the factors listed below.
Sender ID: The main objective of RandomCast is to minimize redundant overhearing. Since a node would typically propagate 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 ATIM frame with subtype 1101_2, it determines to overhear it if the sender has not been heard for a while. This means that the traffic from the sender happens rarely or the node skips too many packets from the sender.
Number of neighbors: When a node has a large number of neighbors, there potentially exists a high redundancy. For example, when a node asks for a routing path by sending an RREQ, it is possible that a neighbor offers one.
Mobility: When node mobility is high, link errors occur frequently and route information stored in route caches becomes stale easily. Therefore, it is recommended to overhear more conservatively (a higher PR) but to rebroadcast more aggressively (a lower PF) in this case.

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Each node can estimate its mobility based on connectivity changes with its neighbors.

Remaining battery energy: This is one of the most obvious criteria that helps extend the network lifetime: less overhearing (a lower PR) and less rebroadcast (a lower PF) if remaining battery energy is low. However, it is necessary to take other nodes' remaining battery energy into consideration in order to achieve balanced energy consumption. Overhearing decision can be made based on the criteria mentioned above, but in this paper, we adopt a simple scheme using only the number of neighbors (PR ¼ 1= number of neighbors) to show the potential benefit of RandomCast.

RandomCast at a node (MAC address MA, overhearing probability P_R and rebroadcast probability P_F)

```
/* When it receives a frame */
Upon receiving an ATIM frame (receiver MAC address DA, subtype ID)
    if (DA == BROADCAST) continue to wake up and receive;
    else { /* unicast */
        if (DA == MA) /* the node is the intended destination */
            continue to wake up and receive;
        else if (ID == 1001) /* unconditional overhearing */
            continue to wake up and overhear;
        else if (ID == 1101) { /* randomized overhearing */
            if (rand(0, 1) ≤ P_R)
                continue to wake up and overhear;
            else switch to sleep;
        }
        else switch to sleep;
    }

/* When packet queue is not empty */
Upon being ready to transmit a frame (receiver MAC address DA,
overhearing/rebroadacst level OL requested by DSR/ARP)
    if (DA == BROADCAST) {
        if (OL == unconditional) send an ATIM;
        else if (OL == randomized) {
            if (rand(0, 1) ≤ P_F) send an ATIM;
        }
    }
    else { /* unicast */
        switch (OL) {
            case unconditional: ID = 1001;
            case randomized: ID = 1101;
            case no: ID = 1110;
        }
        send an ATIM with subtype ID;
    }
```

Fig 2. The RandomCast algorithm.

IV. PERFORMANCE EVALUATION

A.*SIMULATION TEST BED*

The performance of Random Cast is evaluated using ns-2, which simulates node mobility, a realistic physical layer, radio network interfaces, and the DCF protocol. Since ns-2does not support 802.11 PSM, we modified the simulator based on suggestions in [7]. Our evaluation is based on the simulation of 50 mobile nodes located in an area of 1500 _ 300m2. The radio transmission range is assumed to be 250 m, and the two-ray ground propagation channel is assumed with a data rate of 2 Mbps. The data traffic simulated is constant bit rate (CBR) traffic. Twenty nodes out of 50 generate CBR streams at the data rate of 0.2-2.5 256-byte data packets every second (Rpkt). Random waypoint mobility model is used in our experiments with a maximum node speed of 5 m/s and a pause time (Tpause) of 0-900 seconds. With this mobility model, a node travels (at 5 m/s) toward a randomly selected destination in the network. After the node arrives at the destination, it pauses for the predetermined period of time (Tpause) and travels toward another randomly selected destination. Simulation time is 900 seconds, and each simulation scenario is repeated 10 times to obtain steady state performance metrics. We compare four different schemes: 802.11, 802.11 PSM, ODPM, and RandomCast. 802.11 is unmodified IEEE 802.11 without PSM. ODPM is one of the most competitive energy-efficient schemes developed for multihop networks. For ODPM, a node remains in AM for 5 seconds if it receives an RREP (RREP time-out). It remains in AM for 2 seconds if it receives a data packet or it is a source or a destination node (Data time-out). RandomCast uses no/unconditional/randomized overhearing depending on the packet type. We additionally evaluate RCAST, which employs randomized overhearing like RandomCast but not randomized rebroadcast. This is introduced to see the additional performance enhancement due to randomized rebroadcast. ATIM window size and the beacon interval are set to 0.02 and 0.4 seconds in ODPM. On the contrary, they are 0.05 and 0.25 seconds in PSM and RandomCast. Since nodes are allowed to send packets without prior announcements in ODPM, they require a smaller ATIM window than in 802.11 PSM and RandomCast. Nonetheless, considering the relative overhead due to ATIM windows, ODPM is advantageous in terms of energy consumption. However, our simulation results show the opposite, which tells the superiority of the proposed RandomCast protocol.

In short, RandomCast performs on par with other schemes in terms of PDR but achieves a significant energy saving as well as a better energy balance in comparison to existing schemes. The benefit of RandomCast is significant when traffic is light. This is because nodes stay in low-power sleep state more intelligently in RandomCast. It consumes less energy at high traffic condition as well, but the benefit in this case comes from less Rx energy. This is credited to more judicious overhearing decisions than other schemes.

B.*SIMULATION RESULTS*

The average energy consumption per node, and energy good puts for the five different schemes mentioned above with varying packet injection rate (0.2- 2.5 packets/second). In the high packet injection rate, both 802.11 and ODPM show a higher PDR than 802.11 PSM, RCAST, and RandomCast because all (802.11) or more (ODPM) nodes are in AM and participate in the packet transmission. On the otherhand, 802.11 and ODPM consume more energy than RCAST and RandomCast. It is important to note the performance difference between RCAST and RandomCast. RandomCast achieves a higher PDR, particularly when packet rate is high.

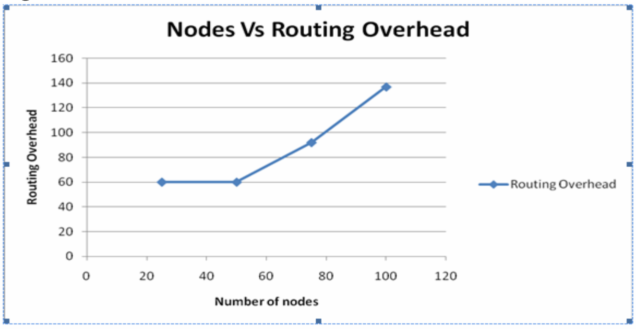

Fig.3 Graph between number of nodes vs routing overhead.

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

V.CONCLUSION

In power-controlled wireless ad-hoc networks, battery energy at conventional routing objectives was to minimize the total consumed energy in reaching the destination. However, the conventional approach may drain out the batteries of certain paths which may disable further information delivery even though there are many nodes with plenty of energy. 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. RandomCast also improves energy good put by as much as 56 percent, that is, an integrated measure of energy and PDR. The performance results indicate that the proposed scheme is quite adaptive for energy-efficient communication in MANETs. In particular, applications without stringent timing constraints can benefit from the RandomCast scheme in terms of power conservation.

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AUTHORS PROFILE

Sivakumar. B, He is working as Assistant Professor in Vel Tech Multi Tech Engineering College, Tamil Nadu, India. He did his Bachelor degree in Computer Science. He finished his Master of Engineering in Computer Science department. Area of interest is Wireless Network. Attended four three Conferences and one international conference. Published a paper in one international conference. (e-mail: sivablack@gmail.com).

Tharani. K, She is pursuing Master of Information Technology in Vel Tech Multi Tech Engineering College. She did her Bachelor degree in Information Technology. Her area of interest is MANET and Adhoc Network. Attended three national conferences and one international conference. (e-mail: tharukannan@gmail.com).

Venkatesan. S, He is working as Assistant Professor in Vel Tech Multi Tech Engineering College, Tamil Nadu, India. He finished his Master of Information Technology in Computer Science department. Area of interest is MANET. (e-mail: svsan_81@yahoo.co.in).

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