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Energy-Efficient Communication Scheme for MANETs

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***Abstract*: Wireless ad hoc networks is a decentralized wireless network in which the network is ad hoc because it does not rely on a preexisting infrastructure. One of the most critical issues in mobile ad hoc networks (MANETs) is energy conservation. Mobile nodes operate on batteries which require power saving mechanism in order to guarantee the amount of lifetime. It also directly affects the network lifetime because mobile nodes themselves collectively form a network infrastructure for routing. Energy efficiency can be improved in two ways namely reducing energy used for active communication activities and reducing the energy spent during an inactive period. The proposed work tries to reduce such energy consumption by level the over hearing and avoids redundant rebroadcast.**

***Keywords*: Mobile ad hoc networks , energy balance, network lifetime, overhearing, power saving mechanism**

1. Introduction

MANETs is an infrastructure-less multihop network where each node communicates with other nodes through intermediate nodes. Thus all nodes in a MANETs basically acts as mobile routers participating in some routing protocol required for deciding and maintaining the routes. This decentralized nature of wireless ad hoc networks makes them suitable for a variety of applications where central nodes can't be relied on, and may improve the scalability of wireless ad hoc networks compared to wireless managed networks. Ease and speed of deployment and reduced dependence on fixed infrastructure makes it more attractive than the traditional wireless networks in the sense that it provides an instant network formation without the presence of fixed base stations and system administrators. The major problems associated with ad hoc networks are consumption of more power. Nodes in mobile ad hoc networks are powered by batteries. Energy is an indispensable but limited resource in such battery powered wireless networks. It is predicted that battery technology develops as rapidly as communication technology [1]. As wireless communication consumes significant energy of mobile computing devices, how to enable wireless communications to be energy efficient has recently attracted much research attention. This issue is particularly important in wireless ad hoc networks, because wireless devices in such networks serve not only as sources or destinations, but also as relay nodes.

Also energy efficiency continues to be a key performance metric as efficient utilization of energy increases the network longevity hence critical in enhancing the network capacity. So efforts are made to reduce the energy consumption in different ways. Different study suggests different techniques to handle energy issue in different way. The authors [2] proposed three techniques through which they have minimized route request message, optimized the transmission power at each node and increased network capacity by topology control mechanism. Energy can be conserved at different layers starting from physical layer to application layer. Each layer has its own techniques to conserve the energy. The main area where the research is going on how to conserve energy is on MAC level layer and network layer. Solutions addressing the power-saving issue in MANETs can generally be categorized as follows: Transmission Power Control: In wireless communication, transmission power has strong impact on bit error rate, transmission rate, and inter-radio interference. These are typically contradicting factors. In[4], power control is adopted to reduce interference and improve throughput on the MAC layer. How to determine transmission power of each mobile host so as to determine the best network topology, or known as topology control, is addressed in [5],[6],[7] . How to increase network throughput by power adjustment for packet radio networks is addressed in [8].

- *Power-Aware Routing:* Power-aware routing protocols have been proposed based on various power cost functions [9]-[11].In[7],when a mobile host's battery level is below a certain threshold, it will not forward packets for other hosts. In [10],five different metrics based on battery power consumption are proposed. Reference [11] considers both hosts' lifetime and a distance power metric. A hybrid environment consisting of battery-powered and outlet-plugged hosts is considered in[8]. Two distributed heuristic clustering approaches for multicasting are proposed in[9] to minimizing the transmission power.
- *Low-Power Mode:* More and more wireless devices can support low-power sleep modes. IEEE 802.11 [12] has a power saving mode in which a radio only needs to be awake periodically.

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The most frequently used protocol IEEE 802.11 support the Power Saving Mechanism (PSM) in its medium access control (MAC) layer specification [3]. Each radio can be in one of two power management modes: active mode (AM) or power save (PS) mode. A device in AM stays awake all the time. It can communicate at any moment but wastes energy during idling. A device in 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 sleep state during the subsequent data transmission period if it is not addressed, but stays awake otherwise to receive an advertised packet.

The main goal of this paper is to make the 802.11 PSM applicable in a MANET with Dynamic Source Routing (DSR) [13] and to achieve an additional energy saving by identifying and eliminating unnecessary communication activities. Key contributions of this paper are threefold: 1) It presents the RandomCast 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 RandomCast. This has not been studied elsewhere in the literature to the best of authors' knowledge. 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. For example, in DSR, when a node transmits a unicast packet, it in fact expects that all of its neighbors overhear it as if it is a broadcast packet. This is not the case in the proposed RandomCast protocol. 3) Compared to our earlier work [14], 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 performance of the proposed RandomCast scheme is evaluated using the ns-2 network simulator [15] in comparison to 802.11 PSM. The rest of the paper is structured as follows : Section 2 presents the background information on the DSR routing protocol and IEEE 802.11 PSM. Section 3 presents the proposed RandomCast protocol and its integration with DSR. Section 4 is devoted to extensive performance analysis. Section 5 draws conclusions.

2. Background

We assume that mobile nodes employ the IEEE 802.11 PSM for energy-efficient use of the shared medium and DSR for discovering and maintaining routing paths. Section A summarizes the DSR routing protocol. It also discusses the effect of overhearing in DSR and argues that unconditional overhearing and rebroadcast is the main reason behind energy inefficiency. Section B explains 802.11 PSM.

A. *DSR routing protocol*

1) *Route discovery and maintenance*

When a node has a data packet to send but does not know the routing path to the destination, it initiates the route discovery procedure by broadcasting a control packet, called route request (RREQ). When an RREQ reaches the destination, it prepares another control packet, called route reply (RREP), and replies back to the source with the complete route information. Upon receiving an RREP, the source saves the route information in its local memory, called route cache, for later uses. Since nodes move randomly in a MANET, link errors occur and a route information that includes a broken link becomes obsolete. When a node detects a link error during its data transmission, it sends another control packet, called route error (RERR), to the source and deletes the stale route from its route cache. Overhearing improves the network performance by allowing nodes to collect more route information. Nodes in the vicinity of a transmitter would learn about the path to the destination via overhearing.

2) *Effect of overhearing*

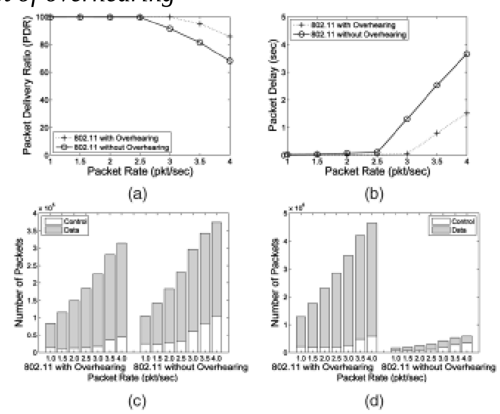

Fig. 1. Effect of overhearing. (a) Packet delivery ratio (PDR), (b) packet delay, (c) number of packets transmitted (traffic implication), and (d) number of packets received or overheard (energy implication)

To better understand the effect of overhearing in terms of routing performance and its implication on energy consumption, Fig. 1 compares 802.11 with and without overhearing. Figs. 1a and 1b compare the two in terms of packet delivery ratio (PDR) and packet delay, respectively. As can be inferred from the figure, overhearing improves the network performance, pronounced more at higher traffic condition. To identify the cause of the performance difference, the number of packets transmitted and that received/overheard is compared in Figs. 1(c) and 1(d), respectively. In both figures, data packets are dominant. However, the number of control packets (RREQ, RREP, and RERR) increases when packet rate increases as shown in the figure. In Fig. 1(c), 802.11 without overhearing results in more control packets and a slightly larger number of data packets than with overhearing. Total traffic in the network is not significantly different as in Fig. 1(c). However, the number of packets received or overheard shows the opposite trend and the gap is quite significant as shown in Fig. 1(d). Although less traffic is generated, nodes receive or overhear more packets when overhearing is enabled. Note that energy consumption of a node is usually dominated by the packets received/overheard because they are much more than those

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transmitted. Note that the scale in Fig. 1(d) is 10 times larger than in Fig. 1(c). In short, overhearing increases traffic (and energy consumption) but improves network performance. It is, therefore, important to know how to make a prudent trade-off between the two and how to control the level of overhearing.

(50 nodes in 300 _ 1500 m2, 30 CBR streams generated by 21 nodes, pause time of 100 seconds, and the maximum node speed of 5 m=s. Note that the scale in (d) is 10 times larger than in (c).)

B. IEEE 802.11 power saving mechanism (PSM)

According to the IEEE 802.11 standard, there are two medium access methods depending on the existence of an access point (AP). They are referred to as Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The DCF uses a contention algorithm based on the principle of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and delay, known as Inter Frame Space (IFS). The PCF is an optional access method implemented on top of DCF and provides a contention free service coordinated by an AP. 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 will not 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. Random Cast not only reduces the overall energy consumption but also improves the energy balance among the nodes leading to a longer network lifetime.

3. Proposed techniques

This section describes the proposed Random Cast protocol. It is designed to improve energy performance by controlling the level of overhearing and forwarding without a significant impact on network performance. Compared to the algorithms presented in Section 2 (B), the proposed scheme assumes that mobile nodes employ 802.11 PSM and consistently operate in the PS mode. Section A presents the basic idea of Random Cast and its advantages. Sections B and C discuss the Random Cast mechanism for unicast and broadcast packets, respectively. Randomization algorithm is described in Section D.

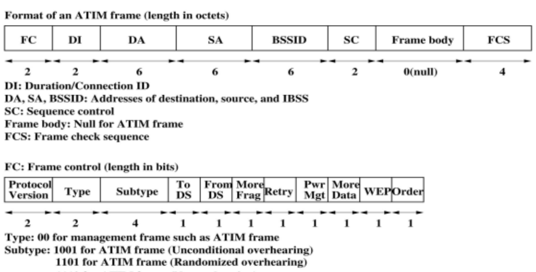

Fig. 2. ATIM frame format

Fig. 2. ATIM frame format. (Note that RandomCast additionally defines subtypes 11012 and 11102 to specify randomized and no overhearing, respectively. IBSS: Independence Basic Service Set, DS: Distribution System, and WEP: Wired Equivalent Privacy).

A. No, unconditional, and randomized overhearing

In RandomCast, a transmitter is able to specify the desired level of overhearing. Consider that node S transmits packets to node D via a precomputed routing path with three intermediate nodes as shown in Fig. 3.

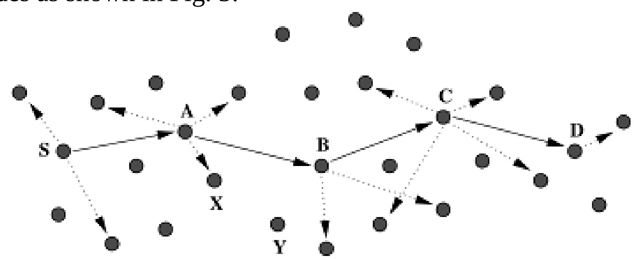

Fig. 3. Delivery of a unicast message with randomized overhearing.

Randomized overhearing adds one more possibility in between the two. As shown in Fig. 3c, some of the neighbors overhear but others do not. Those that chose not to overhear will switch to a low-power sleep state during the following data transmission period, saving substantial amount of energy compared to unconditional overhearing. With respect to route information, this does not necessarily deteriorate the quality of route information due to its spatial and temporal locality of route information. Consider an example in Fig. 3c, in which nodes A and B are two intermediate nodes along the path from node S to D. Node B forwards an RREP to node A (and ultimately to node S) and later node A forwards a number of data packets to node B (and ultimately to node D). Nodes X and Y are two neighbors of A and B, and they will learn about the routing path (S! D) by overhearing any one of the communications between nodes A and B.

B. Random cast for unicast packets

The Random Cast protocol enables a transmitter to choose no, unconditional, or randomized overhearing for its neighbors. It is specified in the ATIM frame and is available to its neighboring nodes during the ATIM window. For practicality, it is implemented in the context of IEEE 802.11 specification by slightly modifying the ATIM frame format as shown in Fig. 2 ATIM frame is a management frame (type 002) and its subtype is 10012 according to the 802.11 standard. The RandomCast protocol utilizes two unused subtypes, 11012 and 11102, to specify randomized and no overhearing, respectively. An ATIM frame with the original subtype 10012 is recognized as unconditional overhearing and thus conforms to the standard. When a node (its MAC address MA) wakes up at the beginning of a beacon interval, it receives an ATIM frame for a unicast packet. The ATIM frame contains the receiver address (DA) and subtype (ID). The node decides whether or not to receive/overhear the advertised packet in the following data transmission period based on DA and ID. It would remain awaken to receive it if one of the following conditions is satisfied:

- The node is the intended destination (DA = MA).
- The node is not the destination but the sender wants unconditional overhearing (DA is not equal to MA but ID = 10012).
- The node is not the destination, but the sender wants randomized overhearing, and the node randomly decides to overhear the packet (DA is not equal to MA, ID = 11012, and decides to overhear).

Now, as a transmitter, let us consider which level of overhearing is desirable for various types of unicast packets. DSR employs three control packets: RREQ, RREP, and RERR. RREQ is a broadcast, and RREP, RERR, and data are unicast packets. For each of the unicast packets, DSR uses the following overhearing mechanism:

- Randomized overhearing for RREP packets: An RREP
  Includes the discovered route and is sent from the destination to the originator of the corresponding RREQ packet. For example, in Fig. 3c, node D sends an RREP to node S. Unconditional overhearing of RREP is not a good idea because DSR generates a large number of RREP packets, as discussed in Section 2.1. Therefore, intermediate nodes as well as node D will specify the randomized overhearing for
- *RREP packets:* Randomized overhearing for data packets: In DSR, every data packet includes the entire route from source to destination. Each intermediate node (e.g., nodes A, B, and C in Fig. 3) as well as the source node (e.g., node S in Fig. 3) will demand randomized overhearing for these packets so that neighboring nodes (e.g., nodes X and Y in Fig. 3c) can overhear them probabilistically.
- *Unconditional overhearing for RERR packets:* When a link (e.g., link B _ C in Fig. 3c) is detected broken, an upstream node (e.g., node B in Fig. 3c) transmits an RERR to the source. It is better for nodes in the vicinity to overhear this message unconditionally because the stale route information must be propagated as soon and wide as possible.

C. Random cast for broadcast packets

Note that the RandomCast algorithm can also be applied to broadcast packets such as RREQ to allow randomized rebroadcast as mentioned earlier. This is to avoid redundant rebroadcasts of the same packet in dense mobile networks. On the other hand, the rebroadcast decision must be made conservatively. This is because a broadcast packet may not be delivered to all nodes in the network when randomized rebroadcast is used. For example, an RREQ packet may not reach the specific destination node. For this reason, rebroadcast probability (PF) is set higher than overhearing probability (PR).

In RandomCast, when a node sends an ATIM for a broadcast packet, all of its neighbors receive the packet in the following data transmission period but probabilistically rebroadcast it. Note the difference between the randomized overhearing of a unicast packet and the randomized rebroadcast of a broadcast packet. In the former, the decision is whether to remain awake and receive the data packet after receiving an ATIM. However, in the latter, the decision is whether to rebroadcast or not. Receiving a broadcast packet is mandatory because the ultimate receiver of the broadcast packet could be in the neighbourhood of the transmitter. As in overhearing, different broadcast packets are treated differently.

Randomized rebroadcast for RREQ packets: DSR requests a randomized rebroadcast of an RREQ packet to the MAC and the MAC forwards it probabilistically based on PF . If the node is the source of the RREQ, it will ask the MAC to broadcast it unconditionally.

- Unconditional rebroadcast for ARP (address resolution protocol) request packets: ARP request packets are typically single-hop communication. Since the destination node is expected to exist in the transmitter's vicinity, unconditional rebroadcast must be requested to the MAC.

Note that randomized rebroadcast is more effective when node density or node mobility is high as described in Section 2.1. Note also that randomized rebroadcast of a broadcast packet is requested by an upper layer protocol (such as DSR or ARP) to the MAC as described above. The overall Random Cast algorithm is summarized in Fig. 5. More details regarding PR and PF are followed in the next section.

D. Random Cast 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. In other words, if a randomly generated number is higher than PR, then a node decides to overhear (rebroadcast).

- *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 11012, 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 neighbour 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. 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 a balanced energy consumption.

Table 1
Protocol behavior of two schemes

Scheme	Behaviour	Expected Performance
802.11 PSM	Nodes incorporate PSM and overhear unconditionally. Packets are deffered until it is announced in the next beacon interval	Saves energy but consumes more energy than necessary due to unconditional overhearing and unconditional rebroadcasts.
Random Cast	All nodes consistently operate in PS mode and the level of overhearing and rebroadcast is controlled. Packets are deffered until it is announced in the next beacon interval.	No switches between AM and PS mode.

4. Conclusion and future work

This proposed work integrates 802.11 PSM with a multihop routing protocol such as DSR. 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 DSR. Similarly, the use of RandomCast for broadcast messages in order to avoid redundant rebroadcasts and thus save additional energy. This proposed work concentrates routing using remaining battery level. After each hop each node's battery level is measured. When it reaches the [16] threshold level the node is not used as router and different path is identified for communication. In future this paper compares the performance of RandomCast with two other schemes in terms of PDR, energy consumption, energy goodput, and energy balance through simulation.

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