

Recharge-As-Reward Mechanism to Incentivize Cooperative Nodes in Mobile Ad Hoc Networks

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Abstract—Cooperation in wireless multihop networks remains a significant research problem to be addressed as a node's selfishness can cause communication failure. Incentive mechanisms in the form of reputation or credit rewards have been proposed to stimulate nodes to cooperate. Complementing each other, a hybrid of the two types of schemes has been proposed to improve efficiency in mitigating selfishness, at the cost of high communication overhead. This paper proposes an alternative to reputation level incentive named Recharge-As-Reward (RAR) mechanism, as an explicit reward to strengthen motivation for nodes to cooperate. RAR is also combined with a Credit-As-Reward (CAR) mechanism that is based on centralized credit-based architecture, which makes our scheme a hybrid incentive mechanism. Through a comparison with another hybrid scheme, we show that RAR/CAR is able to increase nodes' forwarding rates while reducing message/communication overhead by being less reliant on a central agent.

Index Terms—Cooperation; reputation scheme; credit scheme; hybrid scheme; incentive; selfish nodes.

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) have evolved from scenarios involving network of nodes sharing the same authority and communication goal coming together to form an autonomous network domain (e.g. military and catastrophe recovery) to networks with nodes that no longer have common affiliation nor goals other than self-preservation; they also strive to conserve their own resources, like energy, while exploiting common resources like the wireless communication link. Such *selfish* behaviour is likely to happen in civilian applications because mobile devices/nodes (e.g. smartphones) have close relation with human usage paradigm, whereby decisions to cooperate can be very unpredictable.

Incentive-based mechanisms aim to stimulate node cooperation in wireless multihop networks by providing rewards to cooperative nodes in the form of reputation assessment or credit payment, both of which have their strengths and weaknesses [1]. In general, reputation-based schemes are good for motivating nodes to increase their reputation level by being cooperative, but incurring high communication overheads to collect behaviour data. Reputation alone does not provide a strong enough motivation for nodes to remain cooperative, something which credit-based schemes aim to address. Credit-based schemes are proven able to stimulate cooperation by having nodes aiming for credits as rewards, but at the cost

of processing delay and undetected selfish nodes, which if left unchecked can be detrimental to network operations. This motivated the development of hybrid schemes that combine desirable features of both schemes but not without overheads.

Our goal is to improve the efficiency of hybrid incentive scheme through a twofold approach: (1) acknowledging a node's forwarding effort through a new reward type besides assigning a reputation level, and (2) retaining the use of credit reward, but only when the reward in (1) is insufficient or when it is necessary to use the credit. Our contributions can be summarized as follows:

- i) Recharge-As-Reward (RAR) – to explicitly allow a cooperative node to suspend its operation (and resume later) by providing incentive in form of recharge flag/token such that it is able to rest and recharge without being judged as selfish and punished unnecessarily.
- ii) Credit-As-Reward (CAR) – combined with RAR, to efficiently stimulate node to cooperate with reduced dependency on a central agent. A node that has accumulated more than enough RAR flags can use them to send its packets, if it does not have enough CARs.

The remainder of this paper is organized as follows. Section II discusses related work on hybrid schemes. The system model and proposed mechanisms are presented in Section III and IV respectively. Section V presents the results from our performance evaluation before concluding in Section VI.

II. RELATED WORK

Hybrid schemes are motivated by the lack of a strong motive to cooperate through reputation, and the inability to detect and punish selfish nodes, and also credit-based approaches' heavy reliance on a central agent (CA). High communication/traffic overhead of reputation schemes due monitoring and information exchange is another concern [2]–[4]. On the other hand, overheads for credit schemes might be derived from communication bottleneck during message/receipt submission to CA, delay in verifying submitted information and the need to keep submitted receipts, incurring storage overhead [5]–[7].

ICARUS [8] is a hybrid scheme where reputation level of a node is evaluated using its average connectivity ratio (reported globally by nodes to a CA) and computed based on packet forwarding rate (locally observed by a node using promiscuous

mode and acknowledgment (ACK) packets). Nodes with reputation higher than a set threshold value will be rewarded with credit by the CA. A distinct feature of ICARUS is its treatment of distant nodes, forwarding their packets for free when these nodes run out of credits. ICARUS is shown to be able to detect and punish selfish nodes faster and improve packet delivery ratio of nodes in ad hoc networks, but suffers from high communication and message overhead which was justified as reasonable trade-offs to having good network performance.

The enhanced node cooperation technique (ENCT) [9] also relies on CA to manage both reputation and credit transaction to reward cooperative nodes. Nodes are rewarded with different amounts of credit based on different degrees of selfishness/cooperativeness to achieve fair incentive. Such processes incur high node-to-node and node-to-CA communication overheads. However, there is no analysis on overhead incurred by ENCT.

III. SYSTEM MODEL

A. Network and Communication Model

We consider a typical ad hoc network model which consists of mobile nodes and an offline trusted third party (TTP) as a CA. Key entities:

- Mobile nodes – wireless-equipped devices, like, laptops, smartphones, tablets, etc. with different hardware/ software and may belong to different service providers;
- Network – supporting civilian-based applications, hence its lifetime is long (if not indefinite) and accessible by mobile nodes when connection is available;
- TTP – holds valid certificate of connected nodes that will expire periodically and stores information like identity, public/private keys, credit accounts, transmission/forwarding histories, etc.

The communication model in this study is as shown in Fig. 1, which serves as a baseline for any node to initialize communication and perform data transmission.

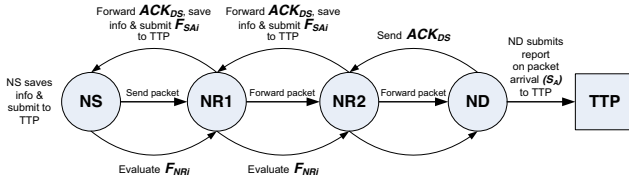


Fig. 1. Communication model.

B. Node Behaviour Model

We assume that nodes are rational, discard packets with no malicious intent, and can be encouraged to cooperate given the assurance that their resources can be preserved, while maintaining longer lifetime and trustworthiness in the network. We consider three types of selfish behaviour as follows:

- dropping packets (we aim to identify intentional and unintentional dropping packets behaviour);
- reluctance to reward cooperative node; and,
- not submitting reports/receipts to TTP that contain information on other nodes' forwarding behaviour.

C. Selfishness Detection

Selfishness detection is based on rate of packet forwarding that is measured differently for RAR and CAR mechanisms whereby the whole process of evaluating a node's forwarding behaviour is shown in Fig. 1. For RAR, we rely mainly on local observation using promiscuous mode of listening to evaluate the forwarding ratio, F_{NRi} , of a downstream node as a ratio of number of packets forwarded by downstream node (C_{Fi}) over number of packets sent to downstream node (C_{Ri}), i.e. $F_{NRi} = \frac{C_{Fi}}{C_{Ri}}$. The state of acknowledgment packet (ACK_{DS}) arrival is used only when a packet is not heard forwarded. Meanwhile, CAR mechanism adopts the same formula, except that the number of packets forwarded is counted after ACK_{DS} is received from destination node which we denote as (C_{SAi}) to obtain forwarding ratio, $F_{SAi} = \frac{C_{SAi}}{C_{Ri}}$.

In RAR, for each observed node i , if its F_{NRi} is found to be below a predefined threshold F_{th} , it will be labeled as a selfish node, but, unlike ICARUS (our benchmark scheme), nodes do not exchange F_{NRi} with one another to reduce message overhead. But, in rewarding CAR, we do rely on global selfish decision done by the TTP which receive reports on F_{SAi} from nodes and validate them, prior to sending the information to requesting nodes as opposed to network-wide broadcast in ICARUS; this is also one way to reduce message overhead.

IV. THE RAR AND CAR MECHANISMS

A. Recharge as Reward (RAR)

RAR functions as an instant reward, so that nodes can maintain longer operational lifetime in the network without having to wait for too long for their rewards to be verified and approved, which may degrade motivation to cooperate. **Algorithm 1** presents the communication and evaluation process in RAR. E_{DATA} is set as a guideline to estimate a node's energy level and its honesty in declaring battery status upon agreeing to setup route. At the start of data transmission, source node N_S sends its data packets towards its downstream neighbour, N_{Ri} and overhears its forwarding activity. The same process applies to successive downstream nodes until the last N_{Ri} which forwards packets to N_D . If a packet is heard forwarded by a particular relay node, its forwarding counter (C_{Fi}), packet received counter (C_{Ri}) and energy counter (C_{Ei}) are incremented by the observer. If the forwarding ratio (F_{NRi}) exceeds a predefined threshold (F_{TH}), the node is considered cooperative and eligible to get one RAR flag/token (RAR_C). This flag/token is in form of a receipt that is verified by its corresponding observer node. Unlike ICARUS, the confirmation of forwarded packet and thus, the provision of RAR does not depend on successful reception of ACK packet, except when packet is not heard forwarded.

B. Credit as Reward (CAR) – Credit is Given When It is Due

With CAR, we aim to retain the use of credit payment to stimulate cooperation, but being less reliant on TTP. This is to alleviate issues like delay in getting expected rewards and communication overhead. The workflow of our CAR mechanism is presented in **Algorithm 2**. Based on the same

flow of RAR mechanism, the difference in the CAR mechanism is that, we set a more stringent criterion to increase the *credit counter* (CAR_C) that is based on confirmation of successful rate of packet arrival (S_A) by using both passive and active acknowledgment monitoring techniques as implemented in ICARUS. Unlike RAR, a node earns one CAR (also interchangeably referred to as “credit”) per successful packet arrival that surpassed the threshold value SA_{th} . This is to ensure fair charging of the source node such that it only needs to pay for successfully arrived packets and that relay nodes are stimulated to help forwarding packets above threshold level to gain credit rewards. ICARUS also uses these two monitoring techniques for credit reward, but it assumes that ACK packets are always successfully sent, which is not realistic in a wireless environment and situation where nodes need to be motivated to cooperate.

Thus, in this work, we set four conditions of dependability between the two monitoring techniques that will be evaluated by N_S and N_R to validate S_A . When N_D receives the intended packets sent by N_S , it will send an ACK_{DS} to N_S for verification of packet reception. We note, in **Algorithm 2**, that both C_{Fi} and ACK_{DS} values are used together to evaluate S_A whereby value “1” denotes successful packet forwarding/reception and “0” otherwise. There is a case of $C_{Fi} = 0$, but since $ACK_{DS} = 1$, which denotes successful packet reception at N_D , hence, $S_A \leftarrow 1$. The S_A value is used to determine whether a packet is forwarded, such that, C_{SAi} is incremented by 1 when $S_A = 1$. Using C_{SAi} as input, the ratio of packet forwarded F_{SAi} is calculated, and if the value surpasses threshold SA_{th} , CAR_C is incremented by 1 and reports are submitted to TTP by observer and relay nodes for credit provision.

Algorithm 1 RAR Mechanism

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1: Set  $E_{DATA}$  = minimum number of packets that should be relayed for
   source node in time slot  $m$ 
2: Data transmission starts
3: while (node is not destination node ( $N_D$ ) &&  $C_{Ei} \leq E_{DATA}$ ) do
4:    $N_S$  sends /  $N_{Ri}$  forwards packet to next downstream node and
   overhears its forwarding effort
5:    $C_{Ri} + 1$ 
6:   if Packet is heard forwarded then
7:      $C_{Fi} + 1, C_{Ei} + 1$ 
8:   else
9:     Wait for  $ACK_{DS}$ 
10:    if  $ACK_{DS} = 1$  then
11:       $C_{Fi} + 1, C_{Ei} + 1$ 
12:    end if
13:  end if
14: end while
15: if ( $F_{NRi} > F_{th}$ ) then
16:   Node is cooperative
17:    $RAR_C + 1$  // increment  $RAR$  counter
18:   Upstream node sends a signed RAR receipt with expiry period ( $T_{ex}$ )
   and timestamp of rewarding ( $T_S$ ) to  $N_{Ri}$ 
19:   Upstream node resets  $F_{NRi}$  of downstream node
20: else
21:    $N_{Ri}$  is selfish (local detection)
22: end if
23: if  $N_{Ri}$  uses RAR then
24:    $N_{Ri}$  broadcasts RAR flag to upstream and downstream nodes or to
   any new nodes requesting service
25:    $RAR_C - 1$ 
26:   Record  $T_{Sout}$ 
27: end if

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Algorithm 2 CAR Mechanism

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1: Set  $E_{DATA}$  = minimum number of packets that should be relayed for
   source node in time slot  $m$ 
2: Data transmission starts
3: while (node is not destination node ( $N_D$ ) &&  $C_{Ei} \leq E_{DATA}$ ) do
4:    $N_S$  sends /  $N_{Ri}$  forwards packet to next downstream node and
   overhears its forwarding effort
5:    $C_{Ri} + 1$ 
6:   if packet is forwarded by  $N_{Ri}$  then
7:      $C_{Fi} + 1, C_{Ei} + 1$ 
8:   end if
9:    $N_S$  and  $N_{Ri}$  wait for  $ACK_{DS}$  by  $N_D$ 
10:  if  $N_D$  receives intended packet by  $N_S$  then
11:     $N_D$  sends  $ACK_{DS}$  to upstream nodes
12:     $N_D$  submits packet arrival ( $S_A$ ) report to TTP
13:     $N_S$  and  $N_{Ri}$  evaluate  $S_A$  of downstream nodes
14:  end if
15:  if  $C_{Fi} = 1$  AND  $ACK_{DS} = 1$  then
16:     $S_A \leftarrow 1$ 
17:  else if  $C_{Fi} = 1$  AND  $ACK_{DS} = 0$  then
18:     $S_A \leftarrow 0$ 
19:  else if  $C_{Fi} = 0$  AND  $ACK_{DS} = 1$  then
20:     $S_A \leftarrow 1$ 
21:  else if  $C_{Fi} = 0$  AND  $ACK_{DS} = 0$  then
22:     $S_A \leftarrow 0$ 
23:  end if
24:  if  $S_A = 1$  then
25:     $C_{SAi} + 1$ 
26:  end if
27: end while
28: if ( $F_{NRi} > F_{th}$ ) then
29:   RAR provision (refer to Algorithm 1)
30:   if ( $F_{SAi} > SA_{th}$ ) then
31:      $CAR_C + 1$  // increment  $CAR$  counter
32:     Observer and relay nodes submit report to TTP for CAR provision
33:   end if
34: else
35:    $N_{Ri}$  is selfish
36: end if

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V. PERFORMANCE EVALUATION

In comparison to ICARUS, the performance evaluation of our proposed mechanisms is divided into two parts: (1) cooperation stimulation, and (2) overhead analysis.

A. Simulation Setup

Using OMNeT++ simulator, we evaluate the effectiveness of our proposed mechanisms on the AODV routing protocol, in an area of $800m \times 800m$ whereby nodes are within 60m radio transmission range of one another. The traffic source for each node is based on constant bit rate (CBR) with channel capacity of 2Mbps. Each node sends packets of size 512 bytes. Forwarding thresholds of F_{th} and SA_{th} to evaluate nodes' cooperativeness/selfishness from observer nodes and TTP's perspectives respectively, are set to 0.5.

B. Analysis of RAR/CAR in stimulating cooperation

We compute the average forwarding ratio, F_{NRi} and F_{SAi} , of nodes as a measure of cooperativeness. A total of 50 nodes involved, whereby 15 nodes are selfish and 10 cooperative nodes will be under stress after half of 400-second simulation time due to participation in more than one routing paths. As shown in Fig. 2, the forwarding ratio for cooperative nodes are higher for RAR/CAR mechanisms than ICARUS, especially towards the end of simulation period. This can be justified by the fact that, cooperative nodes which are rewarded with RAR manage to avoid being mis-judged as selfish; longer simulation

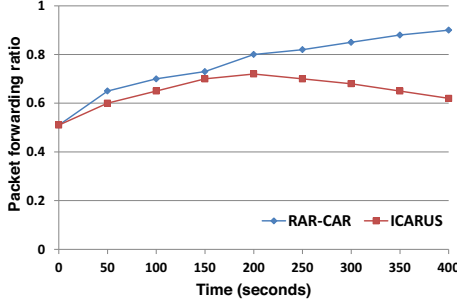


Fig. 2. Packet forwarding ratio.

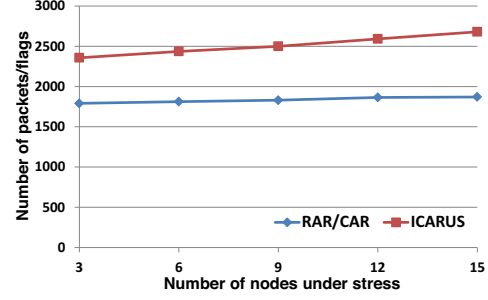


Fig. 3. Message/communication overhead.

time allows nodes in idle mode to be back online and help in forwarding.

In the case of ICARUS, nodes do not have a mechanism to promptly save themselves from being mis-judged as selfish which affects their motivation to cooperate as reflected by the packet forwarding ratio. The case for nodes under stress is always neglected in many existing schemes when in reality, these are the nodes that are much more likely to be regarded as being selfish, thus, get wasted. Our scheme proves otherwise.

C. Overhead analysis

We compare the message and communication overheads of RAR/CAR and ICARUS. This can be viewed from two ways: (1) node-to-node and (2) node-to-TTP communications. For the former, this may come from the dissemination of ACK packets, the exchange of node behaviour information among nodes, award of RAR flags and RAR flags broadcast to announce energy state. For the latter, overhead may come from communication with TTP for report submission, CAR/credit provision and global selfishness report broadcast by TTP. To achieve this, we total up the number of packets/flags/reports that need to be produced (e.g. ACK and RAR) together with data packets that have to be dropped when certain nodes are running out of energy. We use the same simulation settings as the previous evaluation, but different number of nodes under stress $n_{us} = 3, 6, 9, 12, 15$; these nodes will go offline after half-time and start broadcasting RAR flags to their respective upstream and downstream nodes, in order to avoid being accused as selfish. To assess the impact of broadcasting RAR flags in the network, we measure the total number of packets produced during the communication session for both schemes.

Fig. 3 shows the message and communication overhead for ICARUS being significantly higher than our RAR/CAR mechanisms, due to two major reasons: (1) nodes in ICARUS need to exchange behaviour information with one another to rate the reputation level for determination of credit rewards by TTP. Our scheme does not require such information exchanges as nodes submitting behaviour information to TTP is sufficient for global selfish detection where reputation level can be determined by the TTP itself. Besides, with our RAR mechanism, nodes are motivated to pursue such explicit rewards, other than just being reputed as good nodes; (2) in ICARUS, the TTP periodically broadcasts global selfish decision to all nodes

in the network although not all nodes would actually need such information. Our mechanisms work by letting TTP share the global selfish list to requesting-for-information-nodes only, which avoids flooding the network with too many packets.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have proposed the Recharge-As-Reward (RAR) mechanism to reward a node with an explicit recharge session that can be advertised to other nodes to prevent false judgment and unnecessary punishment. RAR is also combined with Credit-As-Reward (CAR) to reward nodes with some credits but with less reliance on TTP, an offline central agent, to process the credits. Performance evaluations have shown that our proposed mechanisms are able to increase nodes' forwarding ratio and reduce message/communication overhead. Future work will cover issues like: (1) a node recycles the same flag with the intention to cheat from carrying forwarding tasks, and (2) node collusion during RAR's implementation.

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