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A Stable Payoff Allocation Protocol for Controlling the Selfishness and Managing the Power Consumption in Mobile Ad Hoc Networks

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Abstract—**We present a model to control the mobile nodes' selfish behavior in Mobile Ad Hoc Networks using the cooperative game. We design the model such that a path from a source node to a destination node is a stable coalition among the nodes. We achieve this by compensating the nodes using virtual currency to take part in the coalition formation. The incentive provided to a node taking part in the coalition is determined using the Shapley value of the coalition formed. We also design the model to use minimum power to reach the one-hop node in the communication path. We achieve each node's dynamic power control while forming the coalition among the nodes in the path from the source node to the destination node. In addition to these, we design the model where a node in the path should be truthful regarding the power requiring to reach a one-hop node. Finally, we perform a rigorous simulation to check the performance of the model.**

Index Terms—**Cooperative Game, Dynamic Power Control, Mobile Ad Hoc Network, Selfish Node, Shapely Value, Truthfulness, Virtual Currency.**

I. INTRODUCTION

Mobile ad hoc networks (MANETs) are the infrastructure-less communication systems comprising mobile nodes control by rational agents. These agents may be either human or intelligent non-human entities. Because of this, we treat a mobile node as an independent logical entity. Also, because of the infrastructure-less ad hoc nature, each node in the networks has to forward the messages/packets to other mobile nodes. Such nature of the ad hoc networks makes them suitable for any emergency communications that require minimal configuration. However, despite their promising nature, the networks often cannot serve the purpose. When a node relays a message for another node in the ad hoc networks, it depletes resources. To preserve mobile nodes' resources, they are often reluctant to participate in the communication process unless adequately motivated. We commonly call such nodes showing this behavior as selfish nodes. They have an immense impact on the performance in the communication networks (14).

Another essential aspect of MANET is that a node would act as a transmitter, receiver, and relayer while its power is fed from a limited capacity source. Because of such functionality, the need for controlling power consumption while participating in communication becomes an essential nature (3). The power control mechanism also helps in reducing the interference and fading effects in connections. It maintains the transmitter to use the minimum transmission power necessary to have communication with the receiver. It makes sure the use of only necessary and sufficient transmission power for sustaining the communication link. This mechanism will reduce the interference for the transmission to other nodes nearby. Thus, it enhances both energy and bandwidth consumption. However, the problem with the mobile ad hoc networks is that the power control settings need to be handled distributedly by each node itself.

In this paper, we concentrate on defining a power control mechanism besides controlling the selfish nature with the tools from game theory (15). Here, a rational agent will represent a mobile node; therefore, we analogy it to an intelligent agent who participates in a game's rational decision-making. Like in the game, we model each agent in the MANET to interact and conclude whether to join relaying messages or not until it gets sufficient motivation. We model the system such that energy consumption corresponds to the utility of participating in the communication. We achieve it by designing a coalition game, a class of mathematical game theory. Another class game called non-cooperative game theory may be used to analyze the interaction between nodes and derive the strategy that motivates the node to participate in the communication process (19). The coalition game helps determine the actual incentive amount (virtual currency in our case) for simulating the nodes to participate in the communication process. This paper aims

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to carefully draft a path formation process to minimize the power loss during the data transmission and determine a stable incentive allocation mechanism through the coalition game among relay nodes to reduce selfishness. Finally, after studying these objectives, we propose an algorithm that uses the cooperative game to handle dynamic power control and selfish nature.

In Section II, we review the related work with this paper, in Section III-A, we define the problem, and in Section III-C, we discuss the formation of path preserving the energy. The coalition formation method is explained in Section III-C. The Payment procedure is analyzed in Section III-D. Simulation and Results are analyzed in Section IV with the conclusion in Section V.

II. LITERATURE REVIEW

Many researchers have shown that selfish nodes in ad hoc communication networks have an immense impact on network performance until and unless a mechanism is used to simulate these relaying nodes' cooperation. The mechanisms are broadly classified into two principles. One is based on rewarding the cooperative nodes using a virtual currency (7), and the other is based on punishing the non-cooperative node using a reputation mechanism (13). These mechanisms are analyzed using game theory approaches (21), (20), (11).

Reliable routing procedures use the incentive system with coalition game approaches to provide a stable incentive to the participating nodes. The coalition game approaches like (10), (8) provide motivation to mobile nodes for allying to work together as a single unit. In such approaches, the coalition's stability plays an important role and becomes critical for the network's nodes. Otherwise, the node may break from the collision. Such a condition, too, happens if links of the networks change frequently.

The paper (16) uses the core of the coalition game to derive the stable price for each node contributing to the communication process. This paper finds the most cost-effective path and assumes that the path is stable for a fixed unit of time. During this fixed period, the algorithm finds a stable and cost-effective path. However, this may not be valid for the extremely dynamic networks, as pointed out by (12). The paper (12) defines the method to mitigate the drawback of topology changes in the cooperation of the wireless ad hoc networks. It uses the coalition game theory to establish a stable coalition among the nodes by proving that the links established in the coalition are pair-wise stabled. The paper defines the benefit of a node in the coalition as its reachability to other nodes when it joins that coalition. This collision may be stable as long as all the nodes in the communication networks have some data to transfer. So, every node will maximize the utilization of the coalition at that point. However, once a node has empty data to transmit, the best strategy is to break from the collision to reduce its resources' depletion.

The paper (4) uses VickreyClarkeGroves (VCG) auction to compensate for selfish nodes in the ad hoc networks. According to this paper, a node must submit the true cost-of-energy and emission power to reach its one-hop neighbor or is compensated with negative rewards. The problem with the paper is the dynamic topology of the MANET. For instance, if any new node arrives in the path chosen by this mechanism, although the new node may compensate for the energy loss, it will not be used in the path already set up. Briefly, we can say that the paths established by such mechanisms are assumed to be static for a while. Another problem in the convolution among the nodes in this mechanism may bring MANET down, as shown in (16).

This paper presents a model based on cooperative game theory approaches to handle MANET's dynamic topology. The coalition game will help form a stable coalition among the nodes by providing adequate compensation for the service provided. We will use the method defines by (5) for the payment of incentives. The model we design assures that the node in the path is truthful regarding the minimum power consumption as the payment will be based on it. So, like in (4), we ensure that the nodes are truthful while forming the path. We also define a dynamic power control mechanism to reduce unnecessary power drain during the data transmission. In short, we try to control the selfishness among the nodes and the dynamic adaptation of the power consumption. Thus, here we try to increase networks' overall lifespan by controlling the power consumption among the rational mobile nodes.

III. MODEL AND PROBLEM

A. Problem Overview

To define the problem of power management with the reduction in the selfish behavior of the mobile nodes, we take an example of a mobile ad hoc network, as shown in Figure 1. In this example, five nodes are distributed randomly with s and d as the source and destination nodes. The source node s needs to use node A, B, and C to reach d. This will reduce the energy consumption and reduce the transmission's delay compared to the path without these relay nodes. This is because d may be unreachable using the maximum power of s, or the power consumption in the transmission of this network will increase if some relay nodes are not involved in the path from s to d. In brief, the path to d from s with all these nodes reduces the power consumption and improves the overall communication network's performance. However, the problem is that the relay nodes are the rational agent, and providing services to s reduces their resources. So, it is not wise for them to provide service until they are incentivized for the service to s.

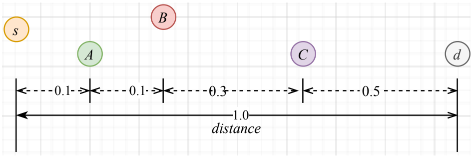

Fig. 1: An example network between s and d. We normalize the distance between s and d to 1. The label below each node defines the distance between the source and the destination node. Accordingly, s and A is separated by 0.1.

If we use the incentive to reward nodes in the path from s to d, s has to design a tool to provide a stimulus to the nodes. In short, s node has to define how much a relay node should get for the service rendered by it. The cooperative game provides a natural solution to this problem. We can assume that the source node's path to the destination node forms a coalition, where the relay nodes are free to join the coalition. Initially, in the path, we assume a single-member coalition of the source node. Gradually, when the source node searches the route to a desirable destination, the coalition is joined by the relay nodes in the path and finally forms a grand coalition with all the potential relay nodes. Once they establish the coalition, we can analyze the coalition's stability and provide the mechanism to reward them. The reward for each node will be based on the solution concept of the coalition game.

The coalition game thus provides a tool to incentivize the nodes taking part in the routing process. However, we also need to define the procedure to form the coalition to reduce overall power consumption. For example, in Figure 1, every node adjusted its power requires to transmit up to a single hope, i.e., s adapt its transmission power such that it reaches A only, A also adjust its transmission power such that it reaches only B. Thus, all nodes in the path should adapt their transmission power once they become coalition members.

Hence, we designed an ”A Stable Payoff Allocation(SPA)” model to solve the above problems. There are two phases in the algorithm; in the first phase, we derive the path from the source to destination, and in the second part, we define how to form the coalition in the path. For the convenience of modeling the algorithm, we normalize the distance between s and d to 1, as shown in Figure 1.

B. Path Finding Phase

The source node using SPA sends a route request (RREQ) packet using Algorithm 1. The RREQ packet consists of all information used in on-demand routing algorithms like Ad Hoc On-demand Distance Vector (AODV) (6). However, the difference from AODV is that the RREQ includes transmission power PT_X currently used in sending the RREQ packet. This RREQ packet has a structure of Figure 2. As the route creation is based on minimum energy requirement (checks Section III-C), we are allowing the reply for an RREQ only from the destination node in this model.

It is assumed that the threshold (P_{Thres}) is standard for all mobile nodes, which denotes the minimum signal power level requires for the incoming message to be accepted by a receiver. If the received message has a power level below the threshold value, it is discarded by the receiver. So, when the receiver receives the RREQ packet, it checks whether a duplex link can be established or not with the transmitter. To check it, we need to calculate the power loss (P_{Lost}) of the RREQ packet, and it is calculated using equation (1).

$$P_{Lost} = PT_X - PR_X \tag{1}$$

where PR_X is the amount of power received by the receiver. So, P_{Lost} is the loss in the signal power during the propagation from the transmitter to the receiver.

After checking the P_{Lost}, it checks whether a duplex transmission link can be established between them or not, i.e., verify if it has a transmission power more than minimum $P_{t_{min}}$ power calculated by equation (2).

$$P_{t_{min}} = \alpha(P_{Lost} + P_{Thres}) \tag{2}$$

where α is some constant which value is adjusted based on the signal noise.

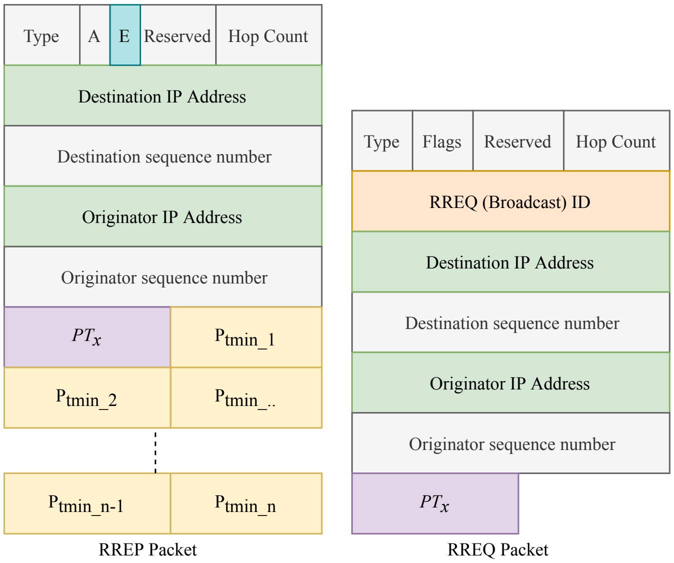

Fig. 2: Route Request (RREQ) and Route Reply (RREP) Message of the model.

Once it confirms its power level, the node enters the RREQ in a routing table like other routing protocols and decides whether to forward or reply to the RREQ message. The node forwards RREQ to the next node if the node is not the destination. It is forwarded by modifying the RREQ with its transmission power through Algorithm 2. If the receiver is the destination node then, it sends a route reply (RREP) message adding PT_x. It adds extra power information to adjust the transmission power for the mobile agent that receives RREP using Algorithm 3.

Algorithm 1: Source: Broadcast of Route Request Packet (RREQ)

```
Result: Succesfull/Failure in Broadcasting
Get $PT_X$ from Physical Layer ;
Add $PT_X$ in the RREQ Header ;
Broadcast RREQ packet to all the neighboring mobile
nodes.
```

C. On-Fly Coalition Formation Phase

Coalition formation of the network links happens in one of the two possible cases.

1) Case 1: When a Node is in a path to the Destination.: When a relay node receives RREP, it checks whether it will benefit from being a part of the path. For example, consider a node M reply RREP to a node L through a node Y. Knowing the minimum transmission power ($P_{t_{min}LM}$) of L to reach M, node Y calculates the minimum transmission power to reach

```
Algorithm 2: Relay Node: Receiving and Broadcasting of Route Request Packet (RREQ)
  Result: Broadcasting or Droping of RREQ
  Get $PT_X$ from received RREQ. ;
  Calculate $PR_X$ for the receiving RREQ packet.;
  Calculate $P_{Lost}$ and $P_{t_{min}}$ using equation 1 and 2.;
  if $P_{t_{min}}$ is satisfiabled then
      Add $PT_X$ itself in the RREQ Header ;
      Broadcast RREQ packet to all the neighboring mobile nodes.;
  else
      Drop the RREQ;
  end
```

```
Algorithm 3: Destination: Receiving RREQ
  Result: Drop or Return RREP
  Get $PT_X$ from received RREQ. ;
  Calculate $PR_X$ for the receiving RREQ packet.;
  Calculate $P_{Lost}$ and $P_{t_{min}}$ using equation 1 and 2.;
  if $P_{t_{min}}$ is satisfiabled then
      Set Hop Count in RREQ with Hop Count of RREQ;
      Make entry of $P_{t_{min}}$ in routing table including other routing details.;
      Add $PT_X$ to the RREP Header ;
      Send RREP packet to last node that forward RREQ packet;
  else
      Drop the RREQ;
  end
```

from L ($P_{t_{min}LY}$) and the minimum transmission power to reach $M(P_{t_{min}YM})$. It checks whether the following condition (equation (3)) is satisfied or not, and if satisfies, Y forwards the RREP to L else drops the RREP (Figure 3).

$$P_{t_{min}LY} + P_{t_{min}YM} < P_{t_{min}LM} \tag{3}$$

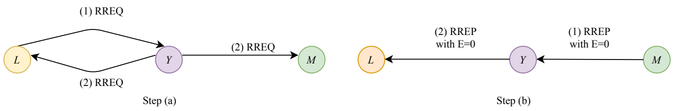

Fig. 3: Coalition Formation Case 1.

2) Case 2: When a Node comes in between relaying Nodes.: When a relay node receives an RREP signal (promiscuous mode On), which is not destined for it (e.g., X move in between Y and M) as shown in figure 4, the node calculates its minimum power $P_{t_{min}XM}$ to reach M using equation 1 and 2. Before forwarding the RREP to Y, X sets RREP bit E to 1 and appends the $P_{t_{min}XM}$. After that, X forwards the RREP package to Y. It gets the address of Y from the internet protocol destination address from the previously received RREP. It sets the bit E to 1 for informing a possiblerelay node in the routing path to Y from M.

When node Y receives RREQ with E $= 1$, it checks whether the path specified in the RREQ exists in its routing table. Each node has a routing table of the structure given by Figure 6. If the route already existed, Y decides whether or not to update its original routing path. To update, it compares the minimum energy requires reaching the previous mobile node in (backward) route to the destination, as shown in Algorithm 4.

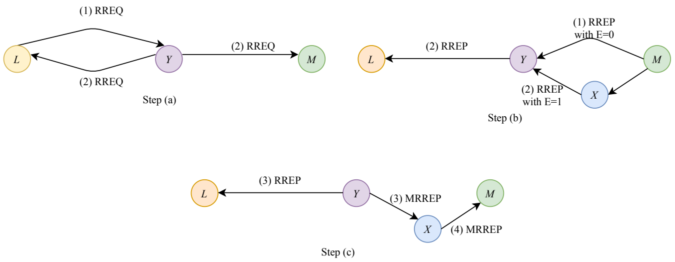

Fig. 4: Coalition Formation Case 2

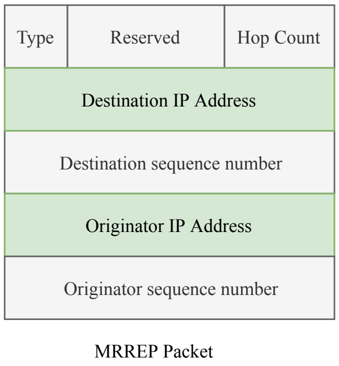

Fig. 5: Modified Route Reply

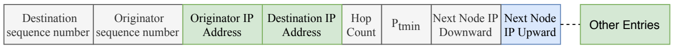

Fig. 6: Routing Table Structure for the Proposed Algorithm

In the algorithm, Y extracts $P_{t_{min}XM}$ from the received RREP, and calculates $P_{t_{min}YX}$ using equation (1) and (2). After getting these value, Y gets the value of $P_{t_{min}YM}$ from the routing table for the same RREQ sequence number and compares it using the following condition.

$$P_{t_{min}YX} + P_{t_{min}XM} < P_{t_{min}YM} \tag{4}$$

If the condition is satisfied, Y sends a Modified Route Request Packet (MRREP) (shown in figure 5) to the destination through new downstream node M to inform the new route to source from M by setting Hop Count to the hop count of the original RREQ. Meanwhile, it forwards the RREQ to L setting E to 0, appending the new $P_{t_{min}YX}$.

The two cases of the coalition formation phase are represented in a single unit by Algorithm 4.

Algorithm 4 guarantees that reporting the exact power requirements by any intermediate node joining the path from s to d is only the strategy that maximizes its incentive.

In Case 1 and 2 of the coalition formation phase, if the intermediate nodes Y and X, respectively, report the power

Algorithm 4: Relay Node: Collision formation while forwarding RREP packet

```
Result: Joining the Collision: Case 1 and Case 2
if RREQ Destination is Own Address then
    if RREQ with E=0 then
        Calculate $P_{t_{min}}$ for reaching previous node using equation 1 and 2.;
        if Constraint of equation 3 is satified then
            Update routing table ;
            Add $PT_X$, Append $P_{t_{min}}$ to RREP Header ;
            Forward the RREP to next node based on routing table entry;
        else
            Drop the RREP;
        end
    else if RREQ with E=1 then
        Calculate $P_{t_{min}}$ for reaching previous node using equation 1 and 2;
        $P_{t_{min}}$_PreviousEntry = ReadEntryInRoutingTable(RREQ);
        $P_{t_{min}}$_NewNode = ReadEntryFromLastAppendPower(RREQ);
        if $P_{t_{min}}$_PreviousEntry < $P_{t_{min}}$_NewNode+ $P_{t_{min}}$ then
            Update routing table ;
            Generate and Unicast MRREQ to original Destination through New Node;
            Increasing Hop Ccount by 1 and Set E=0 in RREP packet;
            Forward RREP to upstream Node (Check Route Entry);
        else
            Drop the RREP;
        end
    end
else
    Calculate $P_{t_{min}}$ for reaching previous node using equation 1 and 2.;
    Update routing table ;
    Add $PT_X$, Append $P_{t_{min}}$ to RREP Header ;
    Forward the RREP with E=1 to address specifiy by IP header destination of the RREP;
end
```

requirement below the exact power required for communicating the next one-hop node, these two nodes will not be a reachable neighbor. Similarly, if they report the maximized power requirement, they will not include in the coalition formation by equation (3) and equation (4). Hence, reporting the power's truth value requires communicating its one-hop node by an intermediate node while joining the coalition is the best strategy that maximizes its incentive.

We further analyze Algorithm 4 using the coalition game to derive the payment of nodes involved in the path. We begin by defining the power requirement by a node in transmitting a packet over the network. Following a two-ray ground propagation model ((17)), a minimum power required to transmit is proportional to the transmitter's distance and the receiver. If τ is the distance between them, then according to the two-ray propagation model, we have

$$c_{ij} \propto \tau^4 \tag{5}$$

where i is the transmitter and j is the receiver (19). As the algorithm follows the power control mechanism using coalition formation, we assume that all the nodes in a path from a source to a destination form a collision structure. Accordingly, each node in the path should be incentivized base on their contribution. However, the problem is designing an effective incentive distribution system such that every node in the path would not leave without providing the service.

To determine the incentive, we treat the coalition formed by the path as a game $G(N, v)$, where N represents a set of relay nodes in the path and v as the characteristic of G, which defines the benefit of the coalition.

Consider a path C such that $C \subseteq N$ than the characteristic function of $G(C, v)$ is

$$v(C) = c_{sd} - \sum_{i,j \in C} c_{ij}$$

where c_{sd} is the cost of transmission from a source s to a destination d without relay node, and $c_{i,j}$ is the cost of transmission from a node $i \in C - \{d\}\}$ and $j \in C - \{s\}$ in the path from s to d and i and j are separated by one hop. Thus, $v(C)$ gives the benefit that thrives the communication network when relay nodes offer service to s, satisfying the power control mechanism.

To simplify the characteristic function, from here onward we normalize the distance between s and d to 1 such that $c_{sd} = 1$, and τ_{si} + $\tau_{id} \leq 1$, where i is any relay node joining the collision C. So,if i is only the coalition member in C then

$$v(C) = 1 - (c_{si} + c_{id})$$

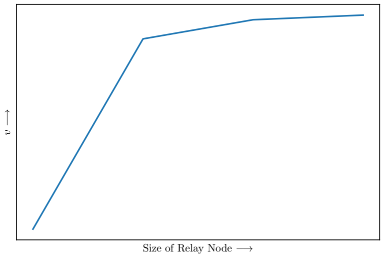

Fig. 7: Behavior of the Characteristic Function

Figure 7 represents the characteristic function against the size of relay nodes. It shows that with an increase in relay nodes, the benefit in the system increases.

If $C \subset N - \{j\}$ is a path from s to d then, $v(C) \leq v(C \cup j)$ when. j is a relay node selected by Stable Payoff Allocation (SPA) algorithm.

If distance τ_{sd} is divided into N relay nodes, then each individual relay node requires a cost(c) of

$$c_{sd} \propto (\frac{\tau_{sd}}{N})^4$$

This is a factor N^4 less than a long single transmission. Thus, overall end-to-end reduction in the transmission power is N^3 obtains by dividing total factor N^4 by N relay nodes.

The coalition game $G(N, v)$ is a convex game.

Let m_i be the marginal contribution of a node $i \in N$ such that

$$m_i(C) = v(C \cup i) - v(C) \quad \forall \quad C \subset N - i$$

Let T be a set such that $T \subset C \subset N - i$ then we have

$$m_i(T) = v(T \cup i) - v(T)$$

Due to Proposition III-C2,

$$m_i(T) \leq m_i(C)$$

Thus, according to (9), the game G is a convex game. Convexity property reflects that as the size of relay nodes grows in the path as per the SPA model, the system's benefit increases. This property also leads us to solve the problem of dividing incentives among relay nodes in the path. Because of the convexity of the game G, we have a fair and stable incentive allocation method. This method is called Shapley's value (18).

D. Payment Procedure: Using Shapley's Value

We allocate the incentive using Shapley's value to A, B, and C when they form a collision in the path between s and d for the example path in Figure 1. From Shapley's value obtained, we show that C gets more incentive as it contributes more than other nodes.

Fig. 8: Shapley's Value for Three relay Nodes (A,B, and C).

So, in this model, on receiving the RREP for the requested route, the source node extracts the minimum power required to transmit or reach the destination. Based on the possible contribution from the relay node calculates the characteristic function combining all the relay nodes. The source node derives a stable and fair allocation rule using Shapley's value for each node. Each allocated value corresponds to monetary benefits that the relay node will obtain.

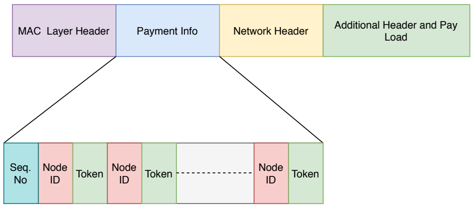

Fig. 9: Payment Packet Model

In our model, benefits are attached in the header of the data message as a token for each relay node, as shown in Figure 9 for each data packet transmitted ((5)). The token must be presented to clear some monetary benefits from some credit clearance center (CCC). However, CCC will clear the monetary benefit only after getting acknowledgment from the destination.

IV. SIMULATION AND RESULT ANALYSIS OF THE ALGORITHM

We use INET (1) in the OMNET++ (2) environment to simulate the proposed model. To simulate the proposed algorithm, we took a source node hostA, three relay nodes hostR1, hostR2, hostR3, and receiver node nodeB. Relay nodes are distributed randomly and move with a low speed of 5 meters/second. The hostA generates the User Datagram Protocol (UDP) messages of length 1000 bytes each, at an exponential rate to nodeB. There are two options for hostA to deliver the message to nodeB, i.e., either by using relay nodes or directly to the nodeB. Here nodeA will use the relay node to transmit the information to nodeB to minimize its power consumption.

Each mobile node is assigned State-Based Energy Consumer (StateBasedEnergyConsumer) (1) having Simple Energy Storage (SimpleEpEnergyStorage). State-Based Energy Consumer is an energy consumption model based on the transmitting or receiving state of the radio. Simple Energy Storage is the model showing the difference between consumed energy and the total energy generated with time. To make a realistic mobile node, we assume each node's battery has a nominal capacity of 0.05J with initial power assigns with the nominal power. Table I is the radio and network interface card configuration for the simulation.

TABLE I: Configuration used during the simulation

Property	**Value**	**Property**	**Value**
Path Loss	Two Ray Ground	MAC	802.11
Radio type	APSK Scaler	Background Noise	$-90dBm$
Initial Transmitter power	$1.4mW$	Radio sensitivity	$-85dBm$
Preamble Duration	$10\mu s$	energy Detection	$-85dBm$
Radio snirThreshold	$4dB$	Antenna Type	Constant Gain
Antenna Gain	$3dB$	Ground	Flate

During the simulation, the routing algorithm much knows the following parameters:

- The power uses by its neighbor while transmitting the packet.
- The energy at which it receives.
- The power threshold of its radio receiver unit.

All conditions are achieved in the simulation through a cross-layer communication. In the cross-layer communication, the protocols inside the network node pass meta information along with the packet. This is done by adding a tag (see Figure 10). So, our routing model attaches meta information. This meta information comprises the information about the amount of power requires to transmit as calculates by the routing protocol. The physical layer reads the meta information from

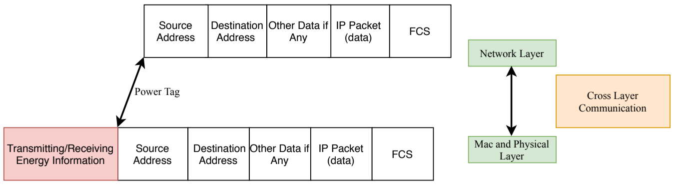

Fig. 10: Tagging information for cross layer communication in the proposed algorithm.

the added tag. Similarly, the physical layer protocol adds the information for parameters required by the routing algorithm as the tag and passes to the routing protocol.

To analyze the performance of the proposed method, we implement three Scenarios.

- **First Scenario:** In the first scheme, we reproduce Stage 1 and Stage 2 of the Stable Payoff Allocation Algorithm without payment procedure. In this setup, relaying nodes have a 70% chance of dropping other data packets without motivation for their service. We refer to this case as a Power Saving method, as it takes care of the power requirement during the transmission of packets. We set relay nodes so that all the nodes take part in themselves during the routing procedure. However, in the data transmission phase, every selfish node verifies whether the approach data packet is for its own or requires forwarding. If thedata packet requires forwarding, the relay node discards the data packet.
- **Second Scenario:** We reproduce Phase 1 and Phase 2 of the Stable Payoff Allocation model with the payment procedure in the second scheme. In this setup, relaying nodes have a 70% chance of dropping other data packets without incentive for their work. We name it as the Proposed Algorithm,and it takes care of the power requirement during transmission of packets and the payment for the service by relay nodes.
- **Default Scenario:** In this setup, relaying nodes have a 70% chance of dropping other data packets without motivation for their help. We fix the power of each mobile node to 1.4 mW (default simulator value). All the setup is the same as the first and second scenarios except for payment and power control. In fact, the default scenario is running the AODV routing protocol.

A. Result Analysis: Residual Energy

During the simulation, each mobile node uses the IEEE 802.11 radio that operates in different modes. The mode of operation includes off mode, sleep mode, receiving mode, and transmitting mode. The externality factor does not affect these modes of radio. Besides modes, each communication radio in the simulation also has three states. States are listening, receiving and transmission, and transmitting states. The mode, state, and time spent in the state influence each mobile node's energy consumption.

To check the energy efficiency of each node in the simulated environment, we track changes in the radio state of the hostA (Sender's Node). We keep track of the node transmitter/receiver radio state when it changes from busy (Radio State No. 2 in the simulation) to idle (Radio State No. 1 in the simulation) and to sleep (Radio State No. 0 in the simulation). For each simulated scenario, we plot the time average of the transmitter and receiver radio state in Figure 11a and Figure 11b.

(a) Radio States of hostA while simulating the Power Saving Algorithm (first scenario) in the presence of selfish nodes.

(b) Radio States of hostA while simulating the Proposed Algorithm (second scenario) in the presence of selfish nodes.

Fig. 11: Radio states of hostA following first scenario and second scenario.

From the figures, we observe that in Scenario 1, the time average radio transmitter state throws up beyond 1.5 initially, after which it distributes around 1. In contrast, in the second scenario, its average state amount remains between 0.3 to 0.85. It means the hostA in the second scenario has a lesser amount of busy state (State 2) compared to the hostA of the first scenario.

(a) Residual Energy for all the nodes involve in the First Scenario (Power Saving with the uncontrolled selfish behavior)

(b) Residual Energy for all the nodes involve in the Proposed Algorithm (Second Scenario)

(c) Residual Energy for all the nodes involve in the simulation with the Default Parameters.

Fig. 12: Residual Graph of all three Scenarios.

It signifies a frequent transmission of the data packets in the source node of the first scenario compared to the source node of the second scenario. After discovering the route to its destination through the RREQ, the source node sends the data packets through the newly created course. However, because of the selfish nature of the relay node in the recently discovered path, the relay node discards whatever the data packets forwarded to it. This prompts retransmission as the source node receives an acknowledgment of the error from the relay node. An increase in the busy state in the beginning signifies that the queue buffer of the source node contains lots of data packets as it was waiting for the route to its destination. Because of this, it transmits lots of packets out to the relay node at the beginning of the simulation. With time, however, the transmission of the packets becomes proportional to packet generation from the application layer. Because of this, the transmission state line in Figure 11a flattens at around 1.

Let's compare the radio state representation of the Proposed algorithm with the first scenario. The radio state seems to normalize at around 0.2 with a slight spike at the beginning of the simulation. It explains that the sudden bursting of the data packet happens just after the route discovery phase. The state of the radio signal makes the amount of energy consumed by a node varied. Figure 12a and 12b shows the residual energy of all the nodes that take part in mobile communication for the first and second scenario, respectively. In Figure 12a, the source node consumes its power faster than other nodes in the network environment and lasts only for 100 seconds of the simulation time. In contrast, the source node in the second scenario lasts its battery for up to 500 seconds of the simulation time (shown in Figure 12b). From the two figures, we conclude that without controlling the selfish node, the power consumption increases, thus decreasing the node's lifetime by four times than the node on the environment without selfishness.

Besides the proposed algorithm, we simulate another scenario with a fixed transmitting power of 1.4mW (Default of the simulator). We check the power consumption performance of all the mobile nodes that take part in the simulation by adding the selfish nodes. Figure 12c defines the residual energy of the simulated environment. We observe that the source node exhausts all its power at around 65 seconds of the simulated time. From all these observations, we found that all mobilenodes directly used for forwarding/relaying data packets in the second scenario consume their energy uniformly, unlike the nodes in the first and default scenarios.

B. Result Analysis: End to End Delay

Fig. 13: End-to-End Delay Histogram for the Default and Second Scenario.

Besides the throughput, we measure the end-to-end delay report for each data packet. Based on the measurement, we plot the representation of the information in Figure 13. The left side of the figure defines the end-to-end delay for the default scenario, and the right side of the graph represents the end-to-end delay for the second scenario. From the chart, we observe that the proposed algorithm has more delay than the default scenario. In the default scenario, there is a direct transmission of the data packets from the source node to the destination node without any relay node. As the proposed algorithm used the relay nodes by compensating them with some incentive, there are delays in delivering packets.

V. CONCLUSION

All nodes in wireless mobile ad hoc networks need to work cooperatively. So, the avoidance of selfish behavior is a crucial issue for an efficient network system. In this paper, we analyze the performance based on the energy consumption of a mobile node. Because of the constraint of resources, the networks node tends not to be altruistic. This paper has shown that in the presence of selfish nodes, the power-controlled algorithm failed miserably. It also showed that if we use fixed transmitter energy for each node, there is a decrease in the network's lifetime. So, we have proved that only controlling selfish behavior is the way to achieve the system's efficiency by efficiently using the power resources of each mobile node.

This paper shows a trade-off between power consumption and the effectiveness of networks in terms of throughput. There is also the possibility of a security issue in the credit distribution system used in the proposed work. However, we will deal with it in the near future.

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