Secure Data Forwarding against Denial of Service Attack using Trust Based Evolutionary Game

Komathy K.,
Department of Computer Science and Engineering,
Anna University,
Chennai, India

Narayanasamy P.,
Department of Computer Science and Engineering,
Anna University,
Chennai, India

Abstract - Self-policing networks such as wireless ad hoc and sensor networks face a number of problems to retain trustworthiness and cooperation of the network. This paper presents an approach to build trust through an effective, dynamic and distributed framework using evolutionary game theory. Non-cooperative and evolutionary game theory has been utilized to model the dynamic behavior of selfish nodes in an ad hoc network, which demonstrates that it can increase the performance, even if the negotiations are absent. The proposed model learns and predicts the evolutionary behavior of neighbors. Investigation of the simulation results confirms that if nodes use trust based evolving strategies, maximum cooperation among the nodes is feasible during forwarding of data packets.

Key words: Cooperation, trust, genetic algorithm, evolutionary game theory, prisoner dilemma

I. INTRODUCTION

Secure routing protocols such as Ariadne [2], SEAD [1], SRP [7,15] and SAODV [14] are primarily designed for protecting routing information. A misbehaving node could behave well during the route discovery phase, but drop data packets later (Denial of Service attack). Moreover, if misbehaving nodes simply drop all packets including routing related packets, all these solutions can not detect and prevent such attacks, as they focus only on the detection of modification of routing control traffic or fabricating false routing information. Research works such as [3,12,13] examined a new type of attack during data transfer caused by misbehaving nodes called selfish nodes. In mobile ad hoc networks, nodes are generally resource constrained. The need to analyze the selfish behavior in a mobile ad hoc network arises because this self-organized network has no centralized authority to monitor the network performance and to take effective controls against misbehaving nodes. Free-riding attitude of selfish nodes use the network services for sending and receiving their own packets but drop others' packets when they are supposed to forward. The reasons behind this attitude are to conserve energy for sending and receiving packets that belong to them and to decrease the delay in transferring their own packets. Though packet drop attack is not malicious, it degrades the network performance and hence it needs to be corrected to improve the performance

II. RELATED WORKS

In order to deal with the security challenges related to data forwarding, especially for packet dropping due to selfishness, some solutions have been proposed by the research community. Srinivasan et al [9] propose an acceptance strategy called Generous TIT-FOR-TAT (GTFT) that leads to a pareto optimal Nash equilibrium. The acceptance algorithm used by the nodes is to decide whether to accept or reject a relay request. They show that GTFT results in Nash equilibrium and prove that the system converges to the rational and optimal operating point. But it is laborious to derive analytical results using the model. Srivastava and DaSilva [10] present a game theoretic analysis of a behavior-based scheme in which nodes adopt a grim trigger strategy to induce participation. Under the assumption of first order stochastic dominance of the public signal, they show this strategy to lead to equilibrium for nodes to participate. In [11], the authors developed a model based on game theory, capable of formally explaining characteristics of ad hoc networks. Each node is endowed with some information about its neighbors and their actions, which includes its neighborhood, the traffic it sent and has to send, and the traffic it received. Prior to choosing its next action, a node has an opportunity to analyze the past behavior of its neighbors and its priorities in terms of energy consumption and throughput, and to decide, consequently, how to act. Kimburg et al [4] present a co-ordination game where players learn and co-ordinate. Players in a Prisoner’s Dilemma (PD) game will learn a degree of cooperation and do much better than constant mutual defection. Nurmi [6] introduces a game-theoretical model on reputation for online auctions.

This paper attempts to study and analyze the evolutionary behavior of mobile nodes against selfishness. Genetic algorithm has been used to predict the best-fit neighbor based on its past behavior patterns thereby increasing the packet delivery of the network.

III. REPEATED PACKET FORWARDING GAME MODEL

The proposed framework for repeated packet forwarding (RPF) using evolutionary game theory is a random one based on the genetic algorithm for learning and predicting the best response during every game. The concept of the evolution of behavior using game theory and genetic algorithm in a random encounter scheme was used in the past in the Iterated Prisoner’s Dilemma under Random Pairing game (IPDRP) [5]. Our problem models a dilemma in an environment in which the interaction sequences are short and also it devises payoff terms, which is different from classical Prisoner Dilemma(PD) payoffs. Core function of normal AODV routing [8] is modified to include the proposed game model that learns and predicts the behavior of neighbors to achieve better packet
delivery ratio. Every node along the route of the packet will be engaged in: learning the behavior of neighbors through direct monitoring; predicting the behavior of neighbors based on the game model; selecting the best-fit next-hop neighbor; and forwarding the packet. Fitness is applicable only for forwarding packets and not for sourcing and receiving the packets. AODV routing protocol is also modified to provide multiple paths to the destination.

A. Evolution of Cooperation

Dynamic strategy profiles are considered to study the evolutionary behavior of the selfish neighbors using genetic algorithm (GA). AODV routing assisted by genetic model is referred as AODV-GA. The evolutionary model is expected to furnish the behavior of network under different scenarios such as:

- Evolution of cooperation among the nodes without selfish nodes.
- Change in the behavior of network with selfish nodes when the selfish nodes do not evolve: The selfish nodes characterize themselves strictly as non-cooperative in nature.
- Under a new selection operator in genetic algorithm: A simple but effective selection method is introduced and the performance of different selection methods is compared for the above two situations. A suitable selection method for an ad hoc network is recommended.
- Change in the behavior of network with selfish nodes when the selfish nodes evolve: Evolving selfish nodes are cooperative in nature.

The random strategy is specified through a 16-bit chromosome. Chromosome represents the past behaviors of neighbor, which are attributes of the fitness of an individual. The fitness function \( f_i(.) \) evaluates the fitness value of neighbor after every generation. Genetic algorithm starts with the population of \( N \) strategies.

Genetic operators of selection, crossover, mutation and reproduction are applied on the current population of strategies after obtaining the fitness value of the population. The process is repeated for a predefined number of generations. Random selection methods namely roulette wheel (RW), tournament and stochastic random roulette wheel (SR-RW) selection mechanisms are applied and the performances are compared. A simple and effective selection method is introduced into the genetic algorithm, which normalizes the absolute fitness of the individual, \( f_i \) as:

\[
\text{fi}^\prime = \frac{fi - \mu}{s \cdot \sigma}
\]

(1)

where \( s \) is the sigma scale factor, \( \mu \) is the mean fitness of the population and \( \sigma \) is the standard deviation. Negative fitness values (\(\text{fi}^\prime < 0\)) are set equal to zero, which means that participants with fitness more than standard deviation and below the mean value produce no offspring. Fitness function is provided as:

\[
\sum_{i=1}^{n} \text{fi}^\prime_{\text{neighbor}} = \text{Trust_Weightage} \cdot \text{Payoff}(M_{\text{neighbor}}, M_{\text{node}}) \]

(2)

where \( \text{Trust_Weightage} \) is defined as:

\[
\text{Trust_Weightage} = \frac{\text{trust_class_acquired}}{\text{trust_class_maximum}} \cdot \text{positional_weightage}
\]

Positional_weightage is the level of importance given to the behavior history with respect to time. Payoff(.) is a payoff function and it evaluates the payoff as per the move of the neighbor, \( M_{\text{neighbor}} \) and the move of the respective node, \( M_{\text{node}} \). Table I defines the payoff terms as per classical Prisoner’s Dilemma (PD). Both players will receive rewards (R,R) if they forward (F) packets and penalties (P,P) if both drop (D) packets of each other. Temptation (T) and sucker (S) are scored when player1 differs from player2. For example, (S,T) is the payoff when player1 forwards the packet and player2 drops the packet. Similarly, if player1 drops the packet of player2 and player2 forwards the packet of player1 they get (T,S). The payoff terms assigned for the repeated packet forwarding (RPF) game are: \( R=4; T=0; S=3; P=1. \)

<table>
<thead>
<tr>
<th>TABLE I. PAYOFF FUNCTION OF REPEATED PACKET FORWARDING GAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player1</td>
</tr>
<tr>
<td>Forward (F)</td>
</tr>
<tr>
<td>Forward (F)</td>
</tr>
<tr>
<td>Drop (D)</td>
</tr>
</tbody>
</table>

The term, fitness in GA is alternatively referred as average payoff in RPF game. Average payoff per neighbor is given by dividing the total payoff earned by an individual neighbor divided by the number of neighbors during a single game. Mean fitness of the population is arrived as total payoff earned by all nodes involved in forwarding divided by the population size in the tournament. The objective function of GA is to get the best-fit neighbor with optimal behavior. The optimal behavior is decided based on the maximum value of mean fitness of the population obtained while playing RPF game. In other words, the objective of AODV-GA game model is to maximize the mean fitness of population, so that the network is maintained with its optimal behavior. Maximum value of fitness expected from playing the game is estimated from (2) as 40.

B. Simulation of Non-Cooperative Selfish Players

Cooperative players will behave according to their strategy that evolves in the evolutionary process. A selfish node portrays as rational and non-cooperative. Using a pseudo random number generator, a rational selfish node is simulated. The non-cooperative behavior of selfish players is simulated by genetically excluding them from selection and reproduction. The evolutionary algorithm has been modeled in such way that it does not allow the population of strategies representing the selfish nodes in selection and reproduction.
After each generation, the number of selfish players remains the same. Simulation is done with parameters such as: Number of players=100; Crossover probability=0.8; Mutation probability=0.001; Unknown/new nodes with default trust class=2.

Selfish strategies are introduced in the population and the evolutionary behavior of the population is observed. Cooperation level and average fitness of the population are estimated after every generation under roulette wheel (RW), stochastic random roulette wheel (SR-RW), tournament and normalized selection methods. The observations show that tournament and normalized selection methods compete with each other to give better stability and both perform better compared to RW and SR-RW.

An average player in the population attains a maximum fitness value of 40 as per (2). Various sigma scale factors, say 1,2 and 4 are used in the case of normalized selection method as per (1) and it is found that they do not produce significant variation in the results. Therefore, the results discussed in this paper are pertaining to sigma scale factor $s$, equal to 1. Observations from the simulation show that the level of cooperation under normalized selection is comparable to tournament selection. The roulette wheel (RW) and stochastic remainder roulette wheel (SR-RW) methods perform also poorly under selfish neighborhood. The cooperation level rises up to 100% when every node in the population is altruistic. Normalized selection shows overall better performance against selfishness and the maximum cooperation level achieved is approximately as 75%, 50% and 23% respectively for 25%, 50% and 75% selfishness introduced in the population. The mean fitness of the population using normalized selection relatively fares well compared to other methods. As selfish nodes follow neither the evolved strategies nor the trust mechanism, the level of cooperation reachable is due to that of cooperative nodes. Since the genetic algorithm generally is not intended to impose any cooperation enforcement, these free riders stay permanently to represent the behavior of a real scenario of an ad hoc network in practice.

C. Simulation of Cooperative Selfish Players

Simulation is also done to study the evolutionary behavior of the network when the selfish nodes are allowed to evolve along with the cooperative nodes. Genetic algorithm is implemented with normalized selection operator. Fig.1 compares the behavior of cooperative selfish players against non-cooperative selfish players using normalized selection. This graph displays the behavior of the network and the convergence of the algorithm during initial 500 generations. The selfish nodes, at different proportions say 25%, 50% and 75%, are able to evolve and reach the maximum cooperation along with cooperative players. The illustration in Fig.1 clearly points out that the cooperation of selfish nodes could reach to that of altruistic nodes, if and only if they strictly follow the evolved strategies along with the trust mechanism. Mean fitness of an individual is also estimated.

![Figure 1. Comparison of cooperation level achieved with evolving selfish nodes against non-evolving selfish nodes during initial 500 generations](image)

IV. PERFORMANCE ANALYSIS OF AODV ROUTING WITH GA

Section 3 encompasses features stimulating cooperation during forwarding of packets when the evolutionary game model assists AODV routing. Further, it is essential to investigate the overall network performance due to the introduction of game model into AODV routing. Fig. 2 and Fig. 3 display the comparison of network performance under normal AODV routing against that of AODV-GA.

Packet delivery ratio (PDR) of the network is defined as the ratio between the total packets received by all destinations and the total packets sent by all sources within the network. Average end-to-end delay of a packet is defined as the sum of delay of all packets that are delivered successfully at the destinations divided by the sum of packets delivered successfully to the destinations. Network traffic load refers to the number of data sources connected to the source nodes. To simplify the representation of traffic load, grouping is done such as: low load=5 number of data sources; medium load=10 and 15; and high load=20 and 25 number of data sources.

From Fig. 2, it is observed that the percentage of PDR for normal AODV at low load is comparable to AODV assisted by GA (AODV-GA) and it goes to a very low value for medium and high loads. While exploring the behavior of selfish nodes, the reduction in PDR is due to (i) increase in the proportion of selfish nodes (ii) increase in the network load. At low load, AODV-GA tries to improve PDR by selecting the best-fit neighbor to forward the packets and thereby avoiding the highly malicious neighbors. At medium and high loads, cooperative neighbors are loaded further by GA apart from network load and hence the drop rate increases. However, the packet delivery has been improved compared to that of normal AODV especially at high loads.
With cooperative selfish nodes, AODV-GA improves the packet delivery even in the presence of high percentage of selfishness as seen in Fig. 3. The variations in PDR up to medium load are minimal. AODV-GA with evolving selfish nodes performs the network functions better than its counterpart, i.e., AODV-GA with non-evolving selfish nodes. At low and medium loads, AODV-GA improvises the situation by selecting the best-fit neighbors and avoiding the highly misbehaving neighbors to forward the packets.

When every neighbor evolves to become a cooperative one, the network attains a stable state, which resembles a network without selfishness. As per Fig. 3, PDR is trying to reach 100% for low load. But, at higher loads, both GA and network load more on the cooperative neighbors and hence the drop rate increases. 75% selfishness leave very few and sometimes nil cooperative neighbors and therefore, selecting the best of worst neighbor would be the only way to forward and hence the drop rate is high.

Fig. 4 gives the average end-to-end delay of the network under AODV-GA with evolving selfish nodes. Due to the additional computational load for providing genetic operators and for finding alternate paths to forward packets, the average end-to-end delay increases for AODV-GA compared to normal AODV. From Fig. 4, it is also noted that the delay steadily increases for AODV-GA up to 15 data sources and further increase in delay for 20 data sources is very nominal. For 25 data sources, either the delay stays on or it reduces because of heavy packet drop. The reasons are due to (i) network load and (ii) additional increase in packets that are forwarded by GA. More traffic keeps the packets waiting in queue, even though the delivery of packets is guaranteed at the respective ratio. Except for 75% selfishness, delay for AODV-GA with 25% and 50% selfishness is more than that of AODV-GA with no selfishness, which is contrary to normal AODV. Normal AODV has the highest delay for no-selfish situation and gradually the delay reduces as selfishness increases. As the selfishness level increases, searching for well behaving nodes also increases thereby increasing the delay.
V. CONCLUSION

This paper has introduced an evolutionary game model to study the dynamic cooperative behavior of selfish nodes under AODV routing. Using randomized model deployed with genetic algorithm, the cooperative behavior of selfish neighbors is dynamically observed. This work has attempted to show that tournament and normalized selection methods in genetic algorithm converge faster and they are more appropriate to stabilize the network functions especially, cooperation in wireless ad hoc network. Moreover, a short sequence of chromosome is used to model the problem as to make the convergence faster.

Non-cooperative and rational selfish neighbors perform poorly compared to cooperative selfish neighbors. Simulated results show that if nodes use evolving strategies and trust evaluation mechanisms, then the cooperation level is able to reach the maximum. In other words, AODV assisted by the evolutionary game model demonstrated that it could stimulate cooperation among selfish neighbors if they are cooperative without using any additional cooperation enforcing mechanism. Whereas non-cooperative selfish nodes definitely need some enforcing mechanism if the stability of the network is to be concerned about. AODV-GA model with non-evolving selfish nodes confirms to be a punishment model for selfish nodes as to arrest them from forwarding packets. Performance of the network such as packet delivery ratio and average end-to-end delay is dependent on the network load rather on the proportion selfishness except at very high selfishness. Additional delay caused due to game model on AODV routing is to be born for achieving higher packet delivery ratio.

REFERENCES