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Modelling and Optimising a New Hybrid Ad-Hoc Network Cooperation Strategy Performance Using Genetic Algorithm

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Abstract: The lifetime of an ad-hoc network depends on a mobile device's limited battery capacity. In ad-hoc multi-hop communication, source nodes use intermediate nodes as a relay to communicate with remote destinations. As cooperation between nodes is restrained by their battery resources, it might not be in their best interests to always accept relay requests. Therefore, if all nodes decide how much energy to spend for relaying, selfish or non-cooperative nodes reduce cooperation by rejecting to forward packets to others, thereby leading to a dramatic drop in the network's throughput. Three strategies have been founded to solve this problem: tit-for-tat, live-and-let-live, and selective drop. This research explored a new strategy in ad-hoc cooperation which resulted from the combination of the live-and-let-live and selective drop strategies. This new strategy is based on the suggestion to select fewer hops with a low drop percentage and sufficient power to stay alive after forwarding the data packets towards the destination or other relays at the route path. We used a genetic algorithm (GA) to optimise the cooperative problem. Moreover, the fitness equation of the GA population was designed according to the mixing of the two strategies, which resulted in a new optimized hybrid dynamic-static cooperation.

Keywords: Ad-Hoc, Power Consumption, GA, Cooperation Strategy, Optimisation.

1 Introduction

Wireless technology is currently an enormously significant field in communications and computing. The use of wireless applications, such as mobile phones, began in the 1970s. Since the 1990s, the popularity of wireless networking technology has only increased. Moreover, when wireless networks

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and mobile devices began to popularise, ad-hoc – as a dynamic field within networks and communication – received much academic interest. [1, 2]

Mobile wireless networks have two implementation methods: *infrastructure* network and *infrastructure-less* network (ad-hoc). For the former, mobile nodes are merely communicated with base stations that have internode routing and specified network connectivity. For the latter, every node interconnects, directly or indirectly, with the others throughout intermediate or relay nodes [1].

'Ad-Hoc network stands for a group of mobile nodes'. These nodes develop temporal mobile nodes which dynamically form a temporal network without any traditional infrastructure of the central administration [3].

Due to ad-hoc networks' lack of base stations, each mobile node runs as an 'end system' in addition to a 'router' for each node in the network. Since nodes are free to move arbitrarily in an ad-hoc network, dynamic topologies can lead to problems. Indeed, the network topology (which is typically multi-hop) may vary arbitrarily and rapidly at irregular periods [3 – 6].

The battery resources failure of mobile devices severely impacts communication systems in fatal communication environments as well as during natural disasters.

Topology is also impacted by the adjustment of reception and transmission parameters, such as power sources. Accordingly, nodes in wireless ad-hoc networks are energy constraining and possibly operate inconsiderately, meaning that they decline to progress packets for other nodes [3, 7, 8].

This research examines energy efficiency and cooperation in multi-hop ad-hoc networks. For the purposes of this article, we assume that every mobile node creates traffic for other nodes in the network and that the established route for each source-destination pair is known. Every source node opts for the potential routes and requests the relay nodes (intermediate nodes) on the route to relay traffic. Due to the inherent value of energy as a resource, the intermediate nodes may not wish to deplete their energy by relaying the source node's traffic. This research seeks to solve the selfishness of uncooperative nodes and to enhance the network's throughput by improving the cooperation of network nodes. In order to achieve this, we suggest the combination of the live-and-let-live and selective drop strategies to form a novel hybrid dynamic-static strategy. According to the selective drop cooperation strategy, every mobile node in a network has a dropping table for its neighbour nodes. Consequently, when a source node needs to direct several packets, it directs a request to a nearby node with a low drop percentage. It does so as a node with a low drop percentage will forward a huge amount of packets, in accordance with the live-and-let-live strategy. Each node maintains a connection with nodes that have a low drop percentage, or those known as 'behaviour nodes'. A GA is used to optimise the new hybrid dynamic-static cooperation strategy. The fitness function identifies behaviour nodes according to its expectation of lifetime, energy constraints, and average power constraints. Roulette wheel selection is used to select the behaviour or cooperative nodes, which are later used to forward the source node's traffic to a particular destination. Single point crossover is used when a sleep node becomes active and another active node becomes dormant. Single point mutation is used when the lifetime power of the parent node drops or rises.

The remainder of this study is structured as follows. We provide a review of the relevant literature in Section 2. Section 3 depicts cooperation strategies. Section 4 discusses the GA used for the ad-hoc network. In Section 5 we present the proposed cooperation modelling. Section 6 outlines simulation details of the new hybrid ad-hoc cooperation strategy. We then present and discuss the simulation's results in Section 7, before providing our main conclusions in Section 8.

2 Literature Survey of Related Works

In [3], the authors presented a combination of two cooperation strategies and compare the resulted throughput with that of the Tit-for-Tat cooperation strategy. Their results indicated that the merging of two cooperation strategies is more productive than solely relying on the Tit-for-Tat strategy.

In [9], the authors used an analytical method and a mathematical framework to study cooperated wireless ad-hoc networks. Additionally, the researchers defined strategies leading to optimal user behaviour based on a Tit-for-Tat cooperation named the Generous Tit-for-Tat (GTFT) strategy.

[10] Sought to find the shortest pathway between the source and destination using a GA with a backup of routes and authentication, while having minimum power consumption and congestion levels.

An accurate model of energy consumption for wireless ad-hoc networks was addressed in [11]. The authors developed models for considered energy consumption based on transmission, and data and control packets. Furthermore, their paper showed that the routing protocol of minimum energy based on an accurate model yields better results than those based on existing models.

Moreover, a GA could be used for ad-hoc security, as in [12], where the authors used the GA for a cryptanalysis of the affine cipher. They reported that their work could be used to break the ciphertext of an encrypted message by the affine cipher in various wireless and ad-hoc networks.

In [13], two researchers applied energy consumption optimisation to ad hoc networks. They implemented the modified Greedy Perimeter Stateless Routing (GPSR) algorithm to enable altruistic behaviour to device's energy saving energy in ad hoc networks.

3 Cooperation Strategies

Each mobile node in a wireless ad-hoc network can be set to adopt one of the following three cooperation strategies [3, 6, 7]:

1. *Tit-for-tat cooperation strategy*: A mobile node is programmed to drop or forward packets based on the pragmatic performance of its neighbour nodes. This requires the node to mimic its neighbour's behaviour after having closely examined its actions.
2. *Live-and-let-live cooperation strategy*: A mobile node employing this approach should follow the following behaviours:
    a. Reduce the connection with its neighbour nodes by maintaining a logical active connection to only one neighbour, selected according to the reachability of the network's residual nodes.
    b. Adopt a monitoring mechanism to identify and detach misbehaving neighbours.
3. *Selective drop cooperation strategy*: A mobile node undertaking this strategy drops packets with an abiding percentage (set anywhere between 0–100%) of the packets it is requested to forward. A node maintains a list of all destination nodes and their corresponding drop percentages.

The third strategy is static, while the first two are dynamic. These cooperation strategies are a subset of those employed by the contestants of the 2007 MANIAC challenge. The teams counted the effects of these strategies on real-time and non-real-time traffic. In non-real-time data, the performance was reflected in terms of packet delivery ratio and throughput. For real-time data, the behaviour was shown in terms of packet delivery timeliness [3].

4 GA for an Ad-Hoc Network

The ad-hoc network under consideration can be characterised as a connected graph by N nodes. The optimising metric in this paper is the cooperation between nodes and their related power consumption. The entire power consumption is the summation of the power consumption of all packets that require being forwarded by the relay node and the power lifetime of the relay node. The goal here is to find the relay node at the route path with a sufficient amount of lifetime power to forward the packets (either in part or in their entirety) of the source node and to stay alive after having done so. This section presents an effective and optimising GA with which to search for, and ultimately find, the most appropriate relay node. The details of this endeavour are specified in subsequent subsections. On the other hand, the performance analysis is achieved via the simulation work in the following section.

4.1 Evaluation of Fitness Function

The fitness function was applied on the nodes of the population under the condition of the selective drop percent (specifically, on those nodes with a low selective drop). The fitness function of used in this paper is defined in the following equation (1) related to the selective drop cooperation strategy:

If $node_i$ selective drop ≤ 50%, then

$$\text{Forwarded\_Packets} = \left(P_i - \sum_{j=1}^{n} (P_j) \right) \times L_i \times Sd_i\,\% \tag{1}$$

where

$$P_i = \frac{E_i}{L_i}\,. \tag{2}$$

The number of the node in the population is represented by i, while j is the number of packets that need to be forwarded to the destination.

According to the fitness function in the above equation, it is clear that, after forwarding the packets according to the relay node’s energy, the relay node will die. Therefore, a live-an-let-live strategy has been merged to fulfil the hybrid dynamic-static cooperative strategy by selecting the nodes with a selective drop percentage ≤ of 50% and isolating the uncooperative nodes.

4.2 Selection of Best Fit

The procedure of the selection of best fit was employed so as to improve the moderate quality of the population. The selection process provides the greatest chances of survival to the best chromosome. There are two types of selection: ordinal-based and proportionate. This work is based on the proportionate selection, which identifies the most effective nodes depending on their fitness values relative to the fitness of other nodes in the network.

Proportionate selection consists of roulette wheel selection, rank selection, tournament selection, steady-state selection, and elitism selection.

We opted for roulette wheel selection for our research. The values that offer the best fit provide a higher percentage of the wheel’s area, meaning that values that provide a better fit have a higher probability of producing offspring. In this paper, the node with a high fitness probability was used as a relay node. The roulette wheel selection was thus employed as a search algorithm to select the most suitable relay node.

4.3 Crossover Operator

Crossover generates new individuals in the population by combining parts of existing individuals. In this paper, the crossover on the node string was accomplished using the single-point crossover. Single point crossover is used when a sleep node becomes active and another active node falls asleep.

Extra characteristics incorporation are produced in the offspring using the crossover.

4.4 Mutation Operator

The mutation is a common operation used to maintain the population's diversity through finding new points in the search space for evaluation. When a chromosome is chosen for the mutation process, random change is made to some of its location values. The mutation is performed on the node string using a single point mutation used when the lifetime power of the parent node drops or rises.

5 Proposed Cooperation Modelling

Let us assume a finite population with N nodes distributed inside the network. Let n_i be the number of nodes in the population, where $i = 1, 2, \ldots, N$.

All nodes in the population are related with an energy constraint defined by E_i, and a lifetime expectation defined by L_i. Based on these necessities, we can contend that nodes have the average power constraint of $P_i = E_i / L_i$.

According to the assumption of the system model, this research is based on the following parameter:

N stands for the number of nodes in the population where each node represents a chromosome. $K = 3$, three genes inside each chromosome, where

$N_i = [E_i; L_i; Selective\_Drop_i]$.

Each chromosome is then entered to the GA optimisation with three genes: power constraints, lifetime, and selective drop percentage. Roulette wheel selection, single-point crossover, and single point mutation are then performed so as to optimise the population's relay nodes where the population represents the ad-hoc network.

A node in a wireless ad-hoc network exerts energy in conveying, receiving, and processing traffic. For the purposes of this research, this paper considered only the energy spent in traffic transmission. This consideration allowed us to disregard the destination node in the proposed model.

The consumption energy of the nodes in conveying traffic depends on several factors. These include channel conditions, modulation scheme, and the size of the file. Here, it is assumed that the energy necessary for relaying a session has been given to the GA where it is predefined for each session.

This paper is modelled based on the assumption that every session continues for one slot of time. The model can straightforwardly be extended to cases with more numerous sessions/ad-hoc networks in a solitary slot.

Our model involved a closed population consisting of individuals carrying wireless devices. Where these individuals travelled between locations in their completion of everyday tasks, they formed dissimilar ad-hoc networks. The proposed model seeks to reflect these dynamics. A source node requests the relay nodes to direct their traffic to the destination node. A relay node has the choice to either accept or refuse this request.

Let us presume that a relay node communicates its decision to the source according to a table based on the selective drop strategy, and the source node keeps its connection with the cooperative nodes (live-and-let-live strategy). The GA is applied on the table of the new hybrid dynamic-static cooperation strategy in order to optimise the decision made to transmit the traffic which enhances cooperation among nodes. This optimisation involves ensuring that every node has a connecting link with a generous node – defined as one which always accepts the request to forward packets for other nodes.

We assumed a finite population of *N* users. Moreover, for the sake of simplicity, we further assumed that time is slotted and each session persists for one slot. For every session, relays were arbitrarily selected from the *N* nodes based on the assumption that every existing node within the research was a relay so as to study their behaviour within the new strategy.

Each node has a drop percentage which is listed in a selective drop table. This table is then shared with other nodes. The relay node is chosen based on an evaluation of this table after finding the destination and the route. Fig. 1 displays the general flowchart of the proposed system and Fig. 2 shows GA for proposed system block diagram.

6 Simulation Details of the Proposed Cooperation Strategy

Our research was conducted under the assumption that the source, destination, and relay nodes were defined. This allowed a special target node to be defined so as to present the new hybrid static-dynamic cooperation strategy. The first step was to initialise the insert of the selective drop percentage for each node and create the selective drop table. We assumed and inserted them into the MATLAB function. We chose the relay nodes according to their selective drop percentage. 1,000 relay nodes were chosen to be tested with GA, and we set the minimum percentage equal to 50 (i.e. the maximum rate of packet dropping must not exceed 50%, so a relay node should drop 50% of the packet and forward at least 50%). After finding the destination (which we supposed to be its location), the relay nodes send the packets with a fixed percentage, as explained above. The power needed to send one packet for the source was 0.8%.

Since the system operated in discrete-time, in every slot, there was the same probability that any of the population’s nodes could be chosen as a source where all other nodes were considered viable options for testing and analysis different circumstances. Each source required a number of relays to reach the destination (the maximum number being represented by M). For the sake of simplicity, 1,000 nodes were assumed with selective drop of < 50% in order to be considered as relay nodes in each session. As described above, relays have the option to either accept or refuse the source's request to forward traffic. The relay node sends its decision to the source by transmitting either a positive or negative acknowledgment. A negative acknowledgment blocks the traffic session. Positive and negative acknowledgments may be sent depending on power constraints. The average relay accepted by the node is evaluated where for a relay node (*n*), B_n the number of relay requests made to node *n*, and by A_n the number of relay requests accepted to node *n*. It is defined as:

$$\psi_n = A_n / B_n \,. \tag{3}$$

Observe that ψ_n is the ratio of *n*'s accepted relay requests, to the number of requests made by *n*; thus, ψ_n is an indication of *n*'s throughput.

In the proposed cooperation algorithm, each node would maintain a record of its experience using the variable ψ_n. Therefore, each node would only maintain information per session type rather than the individual records of its experience with all of the network's nodes. The decisions would always be taken by the relay node based only on its ψ_n value. Assuming that a relay node *n* receives a relay request, let τ_n be the possible probability of its acceptance and ς_n the selective drop percentage of the neighbour node. The proposed hybrid cooperation strategy algorithm (2) is as follows:

If $\psi_n < \tau_n$ or $\varsigma_n > \psi_n - \tau_n$ $\rightarrow$ Reject

Else $\rightarrow$ Accept

Network throughput (ϑ) is measured as the ratio of the number of forwarded packets to the total requested packets per time slot.

Our research thus seeks to raise awareness on the relationship between power consumption and ad-hoc network performance. For this, we simulated an ad-hoc network based on nodes' power, and we used a GA to optimise a new hybrid cooperation strategy (that highlights the trade-off between power and network performance) in order to gain more cooperative nodes in order to increase the number of relay nodes, thereby enhancing network throughput. As power consumption becomes a key issue, awareness about power issues in network planning and operation is vital.

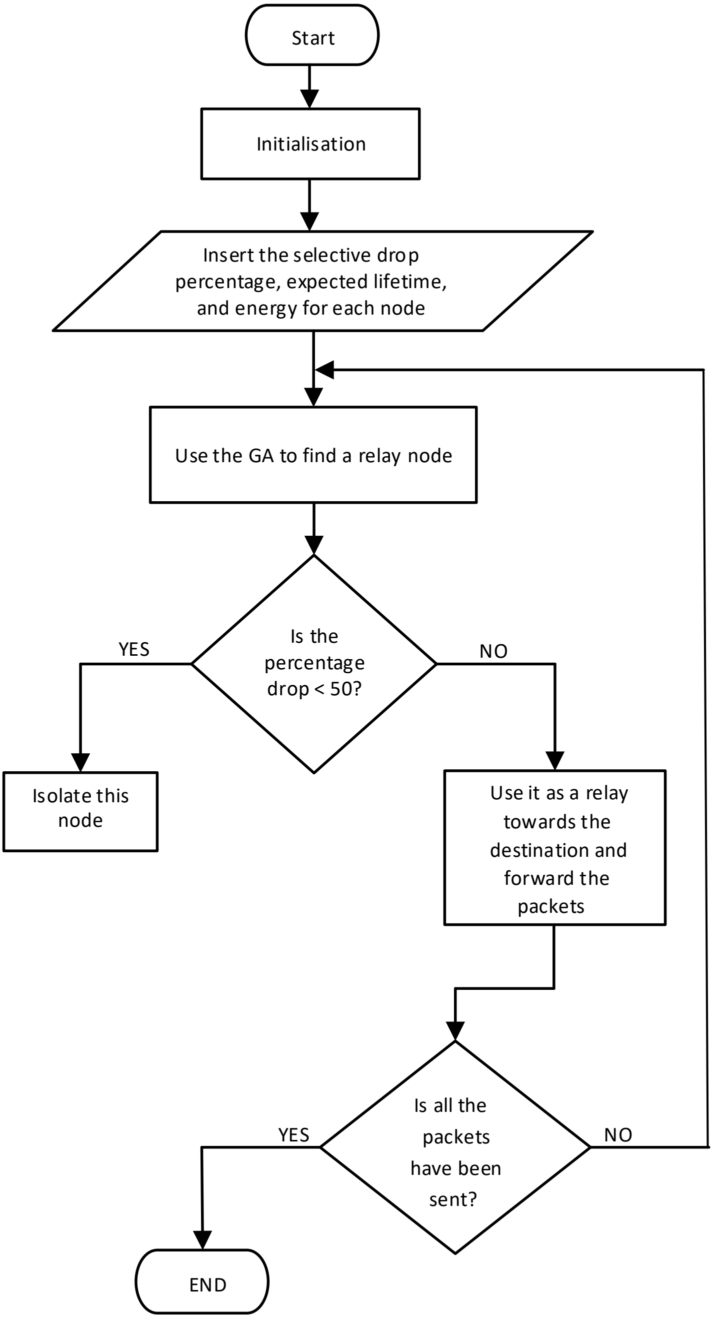

Fig. 1 – *New modelled cooperation strategy flowchart.*

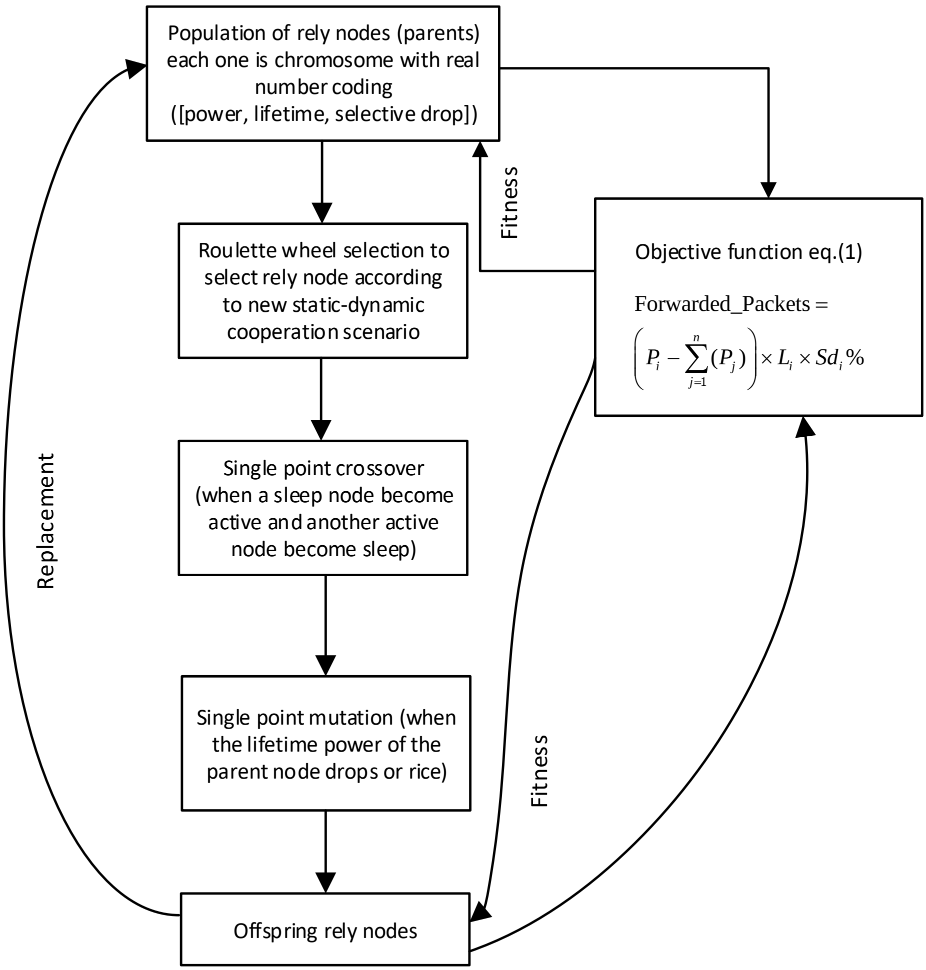

Fig. 2 – *GA for proposed system block diagram.*

7 Simulation Results

We implemented the algorithms using a MATLAB simulator, and ran them using Intel(R) Core(TM) i7-8550U CPU @ 1.80 GHz 1.99 GHz and 8GB of a computer's RAM. We used a GA to optimise a new hybrid dynamic-static cooperation strategy and solve the selfishness problem through the use of a different number of generations (iterations) and randomly selected chromosome genes (E, L, and Selective Drop).

We combined selective drop and live-and-let-live cooperation strategies. We applied the resulting combination to a network with 1,000 nodes. Thus, the population size was 1,000; the crossover rate was 0.65, and the mutation rate was 0.2. Fitness values and the number of cooperation nodes were tested by the algorithm for a different number of generations.

The strategy that we propose in this paper can be used to increase the cooperation relay nodes, and thus increase the throughput of ad-hoc networks. For example, let us use the energy (E), lifetime (L), and selective drop table, and implement the suggested new hybrid dynamic-static cooperation strategy both with and without GA procedures. The numerical equivalence of nodes' chromosomes is based on real number coding.

The chromosome of a node is E, L, and selective drop. For example, for node i, the chromosome will be 87 J, 3.83 h, and 45%, which means that this node has 87 J of energy, a lifetime of 3.83 h, and a selective drop percentage of 45. Note that this node could be a computer, tablet, mobile phone, or any other smart electronic device. Furthermore, this node drops 45 packets out of every 100 (i.e., it forwards 65 packets of every 100) and, according to the new hybrid dynamic-static cooperation strategy, it could be classed as a cooperative relay node since the condition of cooperation according to selective drop strategy is selective-drop node.

The power of each node can be obtained using (2).

Consequently, ad-hoc networks are arbitrary, the chromosomes of the population changes with each time slot, meaning that the results are measured by applying a GA on different networks. The results on **Table 1** demonstrate the fitness of the population node and the number of cooperation relay nodes for the traditional dynamic live-and-let-live strategy. **Table 2** displays the fitness of the population node and the number of cooperation relay nodes for the traditional static selective drop strategy. The enhancement in cooperation matter is demonstrated in **Table 3** through the use of the new hybrid dynamic-static cooperation strategy. This strategy enhances by increasing the number of cooperation nodes, which in turn increases the relay nodes, which then serves to strengthen the network's throughput. **Table 4** clearly demonstrates that using a GA optimises node cooperation and decreases the selfishness problem.

The number of cooperative nodes is this paper's primary concern as it impacts the performance parameters of an ad-hoc network. Ψ indicates the network's cooperation ratio, which also impacts its throughput. **Table 5** shows the minimum throughput of the networks described in **Tables 1 – 4**.

Table 1
Live-and-let-live cooperation strategy results.

No. of cooperative nodes from 1,000	Average Fitness	Generations	Ψ
142	206.96	10	0.142
146	186.96	25	0.146
141	212.09	40	0.141
136	186.87	55	0.136
136	198.68	85	0.136
159	200.24	90	0.159
134	219.45	100	0.134

Table 2
Selective drop cooperation strategy results.

No. of cooperative nodes from 1,000	Average Fitness	Generations	Ψ
149	255.46	10	0.149
145	208.43	25	0.145
147	276.56	40	0.147
157	280.30	55	0.157
149	238.03	85	0.149
147	271.53	90	0.147
150	246.23	100	0.15

Table 3
Hybrid dynamic-static cooperation strategy results without GA.

No. of cooperative nodes from 1000	Average Fitness	Generations	Ψ
402	335.0071	10	0.402
403	291.9628	25	0.403
439	279.2037	40	0.439
422	276.4007	55	0.422
399	316.2681	85	0.399
381	299.1012	90	0.381
391	304.5559	100	0.391

Table 4
Hybrid dynamic-static cooperation strategy results with GA.

No. of cooperative nodes from 1000	Average Fitness	Generation	Ψ
470	572.9330	10	0.47
461	511.3117	25	0.461
497	587.6798	40	0.497
488	564.0715	55	0.488
476	584.5283	85	0.476
455	527.9701	90	0.455
457	556.8484	100	0.457

Table 5
Minimum throughput of ad-hoc network.

Minimum Throughput (1)	Minimum Throughput (2)	Minimum Throughput (3)	Minimum Throughput (4)
14.2 %	14.9 %	40.2 %	47 %
14.6 %	14.5 %	40.3 %	46.1 %
14.1 %	14.7 %	43.9 %	49.7 %
13.6 %	15.7 %	42.2 %	48.8 %
13.6 %	14.9 %	39.9 %	47.6 %
15.9 %	14.7 %	38.1 %	45.5 %
13.4 %	15 %	39.1 %	45.7 %

Minimum throughput is obtained when each cooperation node forwards one packet, as well as:

– Minimum Throughput (1): Throughput of an ad-hoc network based on the live-and-let-live strategy.
– Minimum Throughput (2): Throughput of an ad-hoc network based on the selective drop strategy.
– Minimum Throughput (3): Throughput of an ad-hoc network based on the hybrid dynamic-static cooperation strategy results without the GA (its readings performs the readings of [3]).
– Minimum Throughput (4): Throughput of an ad-hoc network based on the hybrid dynamic-static cooperation strategy results with the GA. The enhanced readings were taken by comparing them with the throughput readings of [3].

To achieve ϑ=100%, more than one packet should be forwarded (as illustrated in **Table 6**), where:

– N (1): the minimum number a cooperative node should forward based on the live-and-let-live strategy to achieve 100% throughput;
– N (2): the minimum number a cooperative node should forward based on the selective drop strategy to achieve 100% throughput;
– N (3): the minimum number a cooperative node should forward based on the hybrid strategy without the GA to achieve 100% throughput; and
– N (4): the minimum number a cooperative node should forward based on the hybrid strategy with the GA to achieve 100% throughput.

Table 6
*Number of forwarded packets/node to achieve throughput=*100%.

N (1)	N (2)	N (3)	N (4)
8	7	3	3
7	7	3	3
8	7	3	3
8	7	3	3
8	7	3	3
7	7	3	3
8	7	3	3

Fig. 3 shows the comparisons between the live-and-let-live, selective drop, and new hybrid static cooperation strategies. Figs. 4 and 5 illustrate the enhancements resulting from the new strategy both without and with the GA (where Fig. 4 shows the fitness value of the nodes population and Fig. 5 shows the number of cooperative nodes. Fig. 6 displays the throughput of the ad-hoc network as listed in **Table 5**.

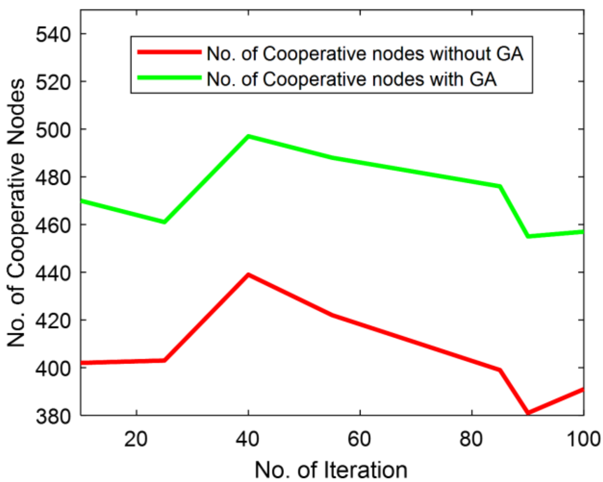

Fig. 3 – *Comparison results of cooperation strategies.*

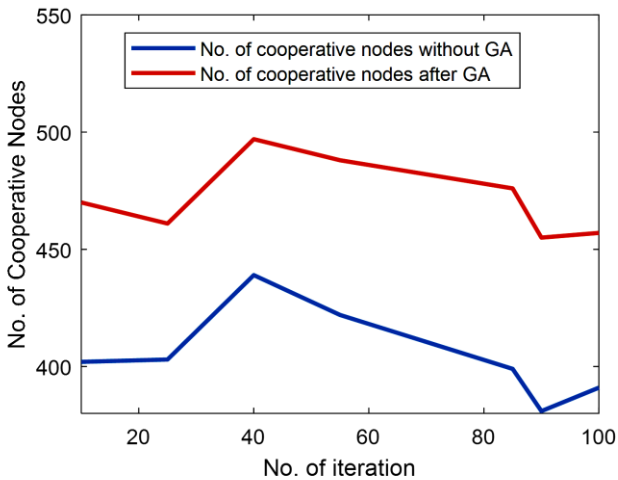

Fig. 4 – *New hybrid dynamic-static cooperation strategy fitness values without and with the GA.*

From Fig. 6 – which plots the results of **Table 5** – it is clear that the GA enhanced the network's throughput since 'Minimum Throughput (4)' (i.e., this paper's chief concern) is the highest.

Fig. 7 shows the general convergence curve of the population.

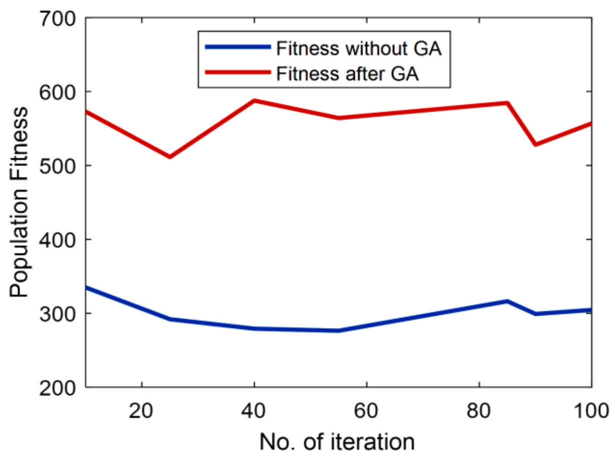

Fig. 5 – *New hybrid dynamic-static cooperation strategy fitness values without and with the GA.*

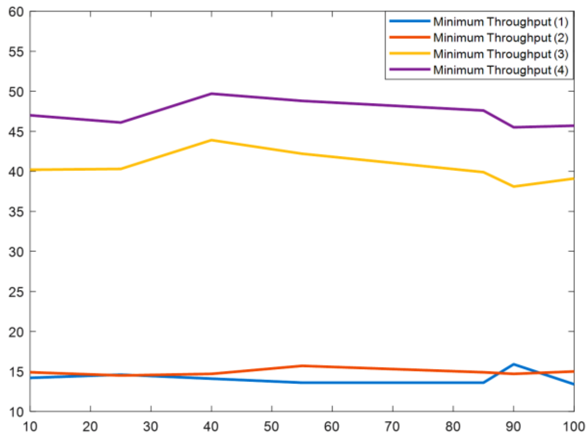

Fig. 6 – *Minimum throughputs of ad-hoc network.*

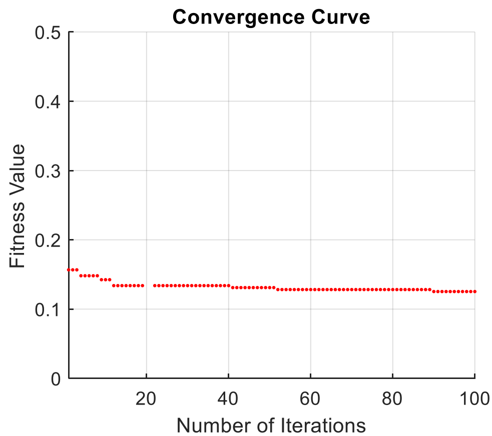

Fig. 7 – *General convergence curve.*

8 Conclusion

This study has used two strategies (static selective drop and dynamic live-and-let-live) to create a new hybrid strategy that combines the best functions of both. The new strategy is named the 'Hybrid dynamic-static cooperation strategy', and optimises nodular performance by increasing the number of cooperative nodes. This strategy relies on the live-and-let-live concept which transforms selfish nodes into cooperative ones by decreasing the percentage of selective drop when its energy level is increased. The simulation results compare the number of cooperative nodes, wherein the live-and-let-live strategy contained between 134 – 159 nodes, while the selective drop strategy contained between

145 – 157 nodes – both out of a possible 1,000. The integration of both strategies resulted in a new hybrid cooperation strategy which increase the cooperation of nodes, as well as their number (between 381 – 439).

We used a GA to optimise the Hybrid dynamic-static cooperation strategy and increase the number of cooperative nodes in the network. Equation 1 should be used to cover the parents' selection step of the GA and select the cooperative nodes to stably initiate the network. The crossover step should be used to maintain the network's stability by cautiously classifying the selfish nodes and cooperative networks based on energy level changes. This classification will help the GA's mutation process involve the cooperative nodes and eject the selfish ones. The simulation results of using the GA for optimisation revealed a drastic enhancement to between 455 – 497 cooperative nodes out of 1,000.

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