IMPROVING SERVICE QUALITY IN VEHICULAR AD HOC NETWORK USING CUCKOO'S MULTI-OBJECTIVE OPTIMIZATION ALGORITHM

Abbas Karimi¹, Iraj Rezaei², Faraneh Zar Afshan³

¹Department of Computer Engineering, Faculty of Engineering, Arak Branch, Islamic Azad University, Arak, Iran
Corresponding Author: Abbas Karimi
Email: a.karimi@aftermail.ir

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Abstract

The vehicular ad hoc network (VANET), as a subset of the Mobile Case Network (MANET), provides the necessary platform for communication between vehicles and roadside equipment. One of the most important applications of the VANET network is to provide the necessary security for the passengers of vehicles and to improve the efficiency of resources in order to optimize the traffic flow. Therefore, providing quality of service (QoS) in this network will play an important role in the accuracy of intelligent transport system operation. In this paper, a new solution to improve the quality of service in VANET networks is presented. In the proposed method, the Cuckoo's search multi-objective optimization algorithm (MOCS) is used to optimize MAC layer parameters. In this method, the criteria of throughput, latency, and packet loss are considered as optimization objectives. The evaluation results of the proposed method show a 68% reduction in the time required to discover the optimal system parameters compared to the exhaustive search algorithm.

Keywords: Vehicular Ad Hoc Network, Service Quality, Multi-Objective Optimization, Cuckoo Search

I. Introduction

The vehicular ad hoc network improves the efficiency of the intelligent transportation system in fields such as: preventing accidents and optimum use of passages and resources (such as time and fuel) [I]. Given the importance of the data being exchanged on this network, providing a reliable communication platform for data exchange on this network will be essential. Given the dynamic nature of the network (mobility of nodes) and the high interference of radio waves in urban areas, several models have been proposed to be used in VANET networks to satisfy reliability in this platform [II]. Communication infrastructures adopted by vehicular
ad hoc communication systems increasingly need strategies to optimize the use of physical layer resources applied in communication infrastructures. Studying new strategies for optimizing the network resources available at VANET can address two important challenges to accelerate the adoption of vehicle networks in large urban centers: Improve the quality of service (QoS) provided by these networks and reduce the cost of network deployment [III]. Quality of service is described as a set of requirements that are required by the network to send data from source to destination [IV]. Providing a low latency, low packet loss and high throughput communication platform will improve VANET service quality. On the other hand, reducing latency and increasing throughput should occur while maximizing network resources. This will be possible by improving the coverage of RSUs in vehicle-to-infrastructure (V2I) communications or by utilizing the minimum possible throughput of OBUs in vehicle-to-vehicle (V2V) communications [V]. Architecture defined by the IEEE1609.4 standard known as WAVE (Wireless Access in Vehicular Environments) is recognized as the most widely used standard of service quality improvement researches in VANET due to its flexibility and scalability [VI]. For this reason, this standard is also used in this article. After defining the VANET architecture, some similar architecture-based solutions have been studied in the second part of the paper with the aim of optimizing the QoS-related criteria. The most of these studies have attempted to improve service quality in vehicle-to-vehicle communications using basic heuristic techniques.

Given the shortcomings of previous researches, the proposed method in this paper extends the existing optimization problem to a multi-objective optimization problem and attempts to optimize key aspects of service quality such as latency, throughput, and packet loss rate on the network at the same time. In the third section, the system model and architecture used to simulate VANET are described in this research. In the following, it is indicated that the set of possible values for parameters related to channel access in this architecture is varied and will result in the formation of a large value of space for the problem of searching for the optimal values of these parameters. For this reason, in this study, the multi-objective cuckoo search optimization algorithm (MOCS) is used to determine the optimal values of these parameters.

II. Related Problems

As mentioned, reliability in message delivery for VANETs where the nodes in the network are highly dynamic, is a major challenge. Various studies have attempted to address this issue and have used a variety of approaches, such as clustering, data routing protocols, or optimizing media access. This research focuses on the overall optimization of nodes’ performance in the VANET network through adjustment of the wireless access parameters. In this study, a traffic scenario is considered in which messages are exchanged only between vehicles and the message exchange between vehicles and VANET infrastructure equipment is ignored. The purpose of this hypothesis is to investigate the performance of the proposed optimization algorithm under conditions where the nodes of the VANET network experience the greatest possible pressure.
In 2011, Rawat et al. (VII) proposed a new solution to adjust the CW (contention window) transmission power and size to improve VANET performance. This algorithm considers the congestion of vehicles on the highway to regulate the transmission power and considers only the collision rate to adjust the CW value. In 2015, Lim et al. (VIII) proposed a method called HaFL that uses fuzzy logic to optimize CW size based on three parameters: collision rate, SINR and queue overflow. These parameters represent the packet loss at different stages of data exchange. Experiments performed to evaluate the performance of this method show that the HaFL algorithm can increase network throughput with the default IEEE 802.11p and its predecessors in addition to reduce end-to-end latency. This approach is still problematic with the expanse of search space and the need for an optimal model to reduce computational cost.

One of the best ways to deal with this problem is to use optimization algorithms. Since several criteria are related to the quality of service in VANET, applying multi-objective optimization algorithms would be a better choice to solve this problem. The multi-objective cuckoo search algorithm is one of the newest optimization techniques introduced by Yang and Deb in 2013 [IX]. Experiments performed to evaluate the performance of MOCS show that this algorithm performs better than its predecessor optimization techniques in solving multi-objective problems. Another advantage of this optimization algorithm is no need to adjust multiple parameters. In this paper, the MOCS algorithm is used to determine the optimal values for the parameters involved in improving the quality of service of VANET networks. The purpose of this algorithm is to determine the optimal values for four parameters (CWmin, CWmax, time slot length and transmission power) to achieve the best possible values for the criteria of throughput, latency and packet loss. In the following, the system model used in the proposed scheme will first be discussed and then the details of the proposed solution will be presented.

III. System Model

In modeling VANET networks, two basic components must be considered: node mobility and network. Proper modeling of these components and their proper configuration will lead to a realistic model of the network. It should be considered that the motor vehicle model is dependent on traffic conditions, passageways and like these, and therefore it is implemented as a fully independent component. In the default system model in this research, the mobility and network components are defined as two independent sub-programs and run in parallel in the simulation environment. The task of the mobility component is to simulate the mobility of network nodes based on road traffic conditions, while the network component is responsible for simulating the performance of the application, MAC and physical layers. In this component, WSM is used to propagate the message between vehicles. 10 Hz frequency was used to send these messages for meeting the security requirements [II]. No routing protocol is used for these exchanges either, therefore the V2V communication method is used to disseminate information over the network. In this article, all the adjustments needed to improve the quality of service provided by VANET, are in the MAC layer. Figure 1 shows the platform used to perform the
simulation experiments and the proposed method. In this model, using the data generated by the mobility component and based on the input parameters of the proposed method (which will be discussed in Section 4), the network component simulates the communication performance of the network nodes (at a specific time interval) and calculates the criteria of throughput, latency and packet loss. After calculating the mean of these criteria, the responses generated by the optimization algorithm will be evaluated and parameter adjustment will be performed again if needed. In the next section we will describe this process.

**Fig. 1:** Platform used to improve the quality of service in VANET using the proposed method

**IV. Suggested Method**

In this section we will outline the proposed solution aimed at improving QoS in the MANET network by optimizing MAC layer parameters. To this end, we first study the IEEE 1609.4 protocol (used in this study) and its configuration space, and then provide an overview of the EDCA mechanism and its role in the VANET network. In the next step, after describing the optimization parameters search space in this model, we will describe the mechanism of optimization of the target parameters by the proposed method.

**Problem Modeling**

The IEEE 802.11e standard is used based on the IEEE 802.11p standard, due to its simplicity, flexibility, cost-effectiveness as well as scalability in VANET networks. The IEEE 802.11e standard uses a contention based channel access mechanism called EDCA to support a variety of applications and to guarantee network service quality. The EDCA mechanism will be designed for use in Ad-hoc
communications and when network infrastructure is unavailable. This mechanism is based on the CSMA / CA protocol and supports the MAC-level service quality and AC (access categories) with different CW and AIFS (arbitration inter frame space), in addition to the use of a slot-based binary access channel. Each AC belonging to each node, after finding out that the channel is free, independently launches a Backoff timer to the size of AIFS and competes with the other ACs for channel access and data transmission. In relation (1), how to calculate the AIFS variable is presented [X]:

\[
AIFS = (AIFS_n \times \text{Timeslot}) + SIFS
\]  

(1)

In the above relation, AIFS_n represents the number of DIFS (distributed inter frame space) in IEEE 802.11 standard and Timeslot indicates the latency that the transmitter has to wait after the backoff time is completed. Finally, SIFS (short inter frame space) represents a constant time gap between the two frames. In the EDCA mechanism, the initial value of the CW parameter is equal to CWmin, and if it fails to send, it will double and increases to CWmax value. The CW size will be reset to CWmin after reaching the CWmax value and this process will be repeated. It is clear that a smaller value of CWmin will lead to less latency in channel access and thus a greater chance of node in successful transmission. On the other hand, as Rawat et al. (XI) have indicated that nodes’ transmission capability is another important parameter that is effective in improving VANET network performance, because this parameter is directly related to the radio board of the VANET nodes. A higher value of transmission power in a node increases the radio board and thus increases the probability of interference between the nodes and the loss of packets. The relationship between the node's radio board and its transmission power is shown in Table 1.

### Table 1: Relationship between radio node board and transmission power

| Transmission Range [m] | Transmission Power (P_t) [dBm] | Transmission Power (P_t) [mW] |
|------------------------|-------------------------------|-------------------------------|
| 126-149                | 1                             | 1.26                          |
| 150-209                | 4                             | 2.51                          |
| 210-299                | 6                             | 3.98                          |
| 300-349                | 10                            | 10                            |
| 350-379                | 12                            | 15.85                         |
| 380-449                | 14                            | 25.12                         |
| 450-549                | 17                            | 50.12                         |
| 550-649                | 20                            | 100                           |
| 650-749                | 24                            | 251.19                        |
| 750-849                | 27                            | 501.19                        |
| 850-929                | 29                            | 794.33                        |
| 930-970                | 31                            | 1258.93                       |
| 971-1000               | 32                            | 1584.89                       |
According to above, the parameters: time slot length (used in AIFS calculation); CWmin, CWmax (used in CW) and transmission power are selected as optimization parameters in the proposed model. According to table 1, there are thirteen possible values for the transmission power parameter. Also, the number of possible values for the parameters of CWmin, CWmax and time slot length will be six, three and twenty respectively. These values will result in the formation of 4680 single-state space for permitted network configurations. Considering the extent of the problem space and the need to discover the optimal configuration in the shortest possible time, this paper uses the MOCS multi-objective optimization algorithm to find the response. In this model, each response vector of the optimization algorithm is defined as a vector with four lengths whose elements represent the selected values for the parameters of time slot length, CWmin, CWmax respectively, and the transmission power in current response. In order to construct the response vector in the optimization algorithm, each of the possible values in each of these four parameters is mapped to new numerical values; the result of which is presented in table 2.

**Table 2: Search space for VANET service quality parameters based on IEEE 1609.4**

| Parameter       | Original Values                                                                 | Converted Value in MOCS                                      |
|-----------------|---------------------------------------------------------------------------------|--------------------------------------------------------------|
| Time slot Length| \{5,10,15,20,25,30,35,40,45,50,55,60, 65,70,75,80,85,90,95,100\}           | \{1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20\}          |
| CW\(_{\text{min}}\) | \{16,32,34,128,256,512\}                                         | \{1,2,3,4,5,6\}                                               |
| CW\(_{\text{max}}\) | \{1024,2048,4096\}                                                        | \{1,2,3\}                                                     |
| Transmission Power | \{1.26,2.51,3.98,10,15,85,25,12,50,12,100, 251,19,501,19,794,33,1258.93,1584.89\} | \{1,2,3,4,5,6,7,8,9,10,11,12,13\}                           |

According to table 2, the first layer of each response vector in the optimization algorithm can have a value between 1 and 20 indicating the time gap length between 5 and 100 milliseconds. Also, the second element of the response can be set with the allowed values between 1 and 6. The third element accepts a value between 1 and 3, representing the value 1024 to 4096 for the CW\(_{\text{max}}\) parameter. Finally, the last element of the response vector that represents the specified transmission power, can be set to any of the values 1 to 13. For example, if the optimization algorithm produces a vector as \(<3,1,2,4>\), the values set for the parameters of time slot length, CW\(_{\text{min}}\), CW\(_{\text{max}}\), and transmission power will be 15, 16, 2048 and 10, respectively. Therefore, based on the configuration defined by the response vectors, the network component simulates the communication performance of the nodes (within a specific time interval) and calculates the criteria of throughput, latency, and packet loss. After calculating the mean of these criteria, the responses generated by the optimization algorithm will be evaluated and parameter adjustment will be performed again if needed. In the following, the optimization steps in the proposed method is described.
Improve the Quality of Service based on Multi-Objective Cuckoo Search Algorithm

The proposed algorithm for multi-objective optimization of MAC layer parameters in the VANET network is as follows:

Algorithm 1: Multi-Objective Cuckoo Search (MOCS)

```plaintext
function MOCS(N,P_a)
Initialize Objective functions: \( f_1(x), ... , f_K(x) \) \( x = (x_1, ... , x_d) \)
Generate an initial population of n host nests \( x_i \) and each with K eggs;
While (t<MaxGeneration) or (stop criterion)
    Get a cuckoo randomly (say, i) by Lévy flights;
    Evaluate and check its Pareto optimal;
    Choose a nest among n (say, j) randomly;
    if new solutions of nest j dominate those of nest i,
        Replace i by the new solution set of nest j;
    end if
    A fraction \( (P_a) \) of the worse nests are abandoned and new ones are built;
    Keep the best solutions/nests;
    Sort and find the current Pareto optimal solutions;
end while
end function
```

In the cuckoo search algorithm, any cuckoo that is placed in nest, represents a solution. In this algorithm, since more than one egg is laid per nest, each nest represents a set of solutions. In other words, the solution and the egg both refer to one concept. Therefore, in the proposed method, each solution (the egg within the nest) is described as a set of value for four parameters of time slot length, \( CW_{\text{min}} \), \( CW_{\text{max}} \), and transmission power.

According to the pseudo-code above, the search algorithm starts with generating a set of random solutions for the nests. In the proposed method, the initial values of each solution are selected randomly from the values in table 2. Then, based on an iterative cycle, a cuckoo like i is first randomly selected and its optimum beam is calculated. In order to evaluate the beam optimality in each solution, the network component (Fig. 1) is configured and implemented based on four optimization parameters in the solution. Finally, the throughput, latency, and packet loss criteria are considered as output of the simulation. The purpose of this optimization algorithm is to reduce the criteria of latency and packet loss and the throughput increase. Therefore, in order to
integrate the objectives of optimization algorithm, we will describe the third goal (throughput increase) as the reduction of reverse throughput (1 / throughput). In the next step, a second random nest (solution set) such as j is selected and its beam optimality is compared with nest i. If nest j is predominant over nest i, the set of j nest solutions is designated as the best response set over nest i and the solution set j is replaced by i. In the next step of this algorithm, the P̃_nest ratio is fitted with worse fitting and a new set of solutions are generated randomly. At the end of each cycle, the best set of maintenance solutions are retained. These steps are repeated until the number of iterations of algorithm reaches the predefined maxGeneration value. In each iteration step of this algorithm, the best responses are retained, and in the last iteration of algorithm, the best N responses are considered as the final optimal responses.

V. Simulation and Results

In this section, the results of the simulation of proposed method is presented. MATLAB 2015a software has been used to implement the network component and optimization algorithm in the proposed method. The mobility component (Figure 1) is also implemented in a form of service by C#.net programming language to simulate the mobility independence of vehicles and network traffic model with the least possible error. The service runs in parallel with the network simulator and provides node position reports to the network component. In order to model the mobility pattern of the vehicles, the traffic information of Valiasr Street in Tehran (capital of Iran) is used. The simulation process is run on a 64-bit Windows 7 desktop PC, running a 3.0 GHz Intel Core i7-4500U processor and 16 GB of main memory.

Determining two parameters of the number of optimization algorithm’ iterations and its population size is directly related to the execution time of algorithm. Since each solution has to be simulated to evaluate its optimality, if the parameter of the number of iterations in the optimization algorithm is G and the population size is N, then to find the optimal response, N × G will be required to run the simulation. On the other hand, these two parameters must be set to be N × G < 4680. For this reason, in this section, the experiments will be investigated for three N = 30, N = 40 and N = 50 modes. In all three cases, the number of iterations of optimization algorithm is 50.

Figures 2, 3 and 4 show the throughput, latency, and packet loss diagrams, respectively, for different population sizes and the number of 50 iterations for the optimization algorithm. These results show that with each of the modes N = 30, N = 40 and N = 50, similar optimal results can be obtained. It should be noted that given the value of 50 for population size, the configuration found in the final response will be slightly better than the other two modes. But given that the number of simulations needed to achieve this response is equal to 2500, this size of population cannot be considered optimal. On the other hand, given the value of 30 for the population, the optimization algorithm can achieve a similar response with only 1500 simulation times. Therefore, it can be concluded that the appropriate parameters for implementing
multi-objective optimization algorithm in the proposed method will be $N = 30$ and $G = 50$.

**Fig. 2:** The best (inverse) throughput detected during different iterations of the optimization algorithm

**Fig. 3:** The best latency detected during different iterations of the optimization algorithm by proposed method

**Fig. 4:** The best packet loss found during different iterations of the optimization algorithm by proposed method

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Table 3 shows the processing time of the proposed algorithm for optimal mode discovery compared to the exhaustive search algorithm (checking all possible modes). According to the results presented in Table 3, the proposed method can achieve optimal response by consuming less processing resources and also in shorter time. According to these results, the exhaustive search algorithm requires 24703 minutes of continuous processing to investigate all 4680 possible modes; however, the proposed algorithm uses the input parameters N = 30 and G = 50 to find the final optimal response in 7934 minutes, which will reduce the search time by 68% compared to the exhaustive search algorithm.

**Table 3: Search space for VANET service quality parameters based on IEEE 1609.4**

| Algorithm          | # of Simulations | Total Processing Time (min) |
|--------------------|------------------|-----------------------------|
| Exhaustive Search  | 4680             | 24703                       |
| MOCS (N=30,G=50)   | 1500             | 7934                        |
| MOCS (N=40,G=50)   | 2000             | 10637                       |
| MOCS (N=50,G=50)   | 2500             | 13196                       |

**VI. Conclusion**

In this paper, a new approach is proposed to determine the quality of service provided in the VANET network and to use the MOCS multi-objective optimization algorithm. In this method, the criteria of throughput, latency and packet loss are defined as three objective functions in the optimization algorithm. The proposed method attempts to improve the quality of service in VANET by optimizing these three objectives with configuring EDCA parameters along with the node transmitting parameter. According to the experiments, the proposed method can achieve similar results with the best exhaustive search algorithm by reducing the processing time by 68%.

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