Review of random early detection optimization for congestion control in vehicular ad hoc networks

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ABSTRACT

The research area of "optimization of random early detection for congestion control in vehicular ad hoc networks (VANETS)" is emerging as a prominent area of research in internet, mobile and communication networks. The paper would draw the attention of development of VANETS in a wider context of internet and communications. It touches upon the problem of congestion that needs to be controlled or avoided for smooth performance of the network. It studies further to come up with methods of control or optimize. An update on these methods will be included. The concept of random early detection (RED) is included and studied in such a way the parameters are identified for defining the optimization problem for congestion control problem (CCP) in VANETS. Current trends of optimization of RED in CCP of VANETS will be reviewed, hence an outlook is created for the problem to be investigated with a final conclusion on the potential way forward for the research work.

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1. INTRODUCTION

With the extent of technology development, people lifestyles changing the increase in usage of mobiles and vehicles is exponential. This is causing performance issues and thus unsatisfied customers raising the need for improving the quality. To understand the problem clearly and figure out the potential solutions the following aspects are reviewed in the paper: What are vehicular ad hoc networks (VANETS) associated problems of congestion? How is this congestion handled and what are the trends for the same? The concept of random early detection (RED) has been developed to improve the quality of performance of the network. Different parameters may be identified which are used in defining the optimization of RED for potential congestion control or avoidance. In addition, variations of RED which are used in optimization are explored leading to way forward of the future research work of RED Optimization in congestion control problem (CCP) in VANETS.

2. METHOD

In early 2000's the mobile ad hoc networks (MANETS) have evolved into VANETS in a dynamically moving environment. Abidin *et al*. [1] has given variety of advantages like safety, information sharing and associated issues of congestion, resource utilization. This is expanding into new application such as disaster recovery [2] and intelligent transportation systems [3]. The connected car market is growing to 270% in 2022 to 125 million car drivers [4]. It explains the need for more research on VANETS. The following schematic in Figure 1 [1] shows generic architecture of VANET. It consists of internet components such as server, trusted authority (TA), road side unit (RSU) and vehicular components of onboard unit (OBU). Among these elements the dynamics of VANETS emerge. This is the context in which the issues of VANETS to be researched and solutions to be found out. This operates in two aspects i) vehicle to vehicle (V2V) and ii) vehicle to infrastructure (V2I). V2V is among the OBUs, vehicles for sharing information and V2I between, OBU, RSU and TA. RSU sends and receives information between TA and OBU.

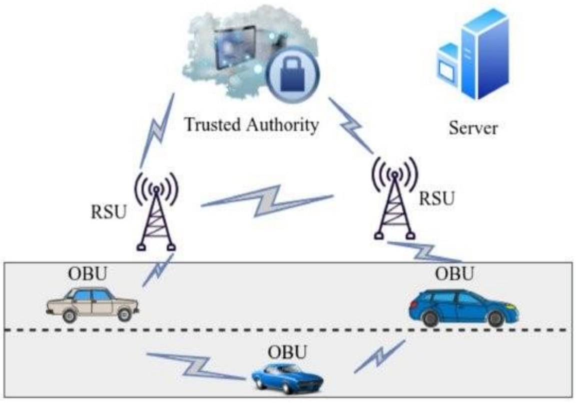

Figure 1. Schematic of VANET architecture

VANETS have interesting characteristics to study for the performance of the whole system. Abidin *et al*. [1] include primarily i) mobility as the vehicles move in and out of configurations causing intrinsically communication issues; ii) capabilities for information interchange is dependent on the users connected at any point of time in the system. These are both computing as well as storage requirements; iii) VANETS applications and components are time sensitive to respond to network events. Hence, need real time information inputs; vi) as the VANETS nodes connect and disconnect to various network configurations, thus it is more of dynamic network rather than a fixed one and associated performance challenges; This further linked with disconnections too often due speedy vehicles and weather conditions leading to frequent drop outs; v) both VANETS and MANETS use the same communication medium, wireless, causing security issues which need proper addressing; iv) In city areas, dedicated short range communication (DSRC), radio transmission has quite a range of performance challenges.

There are several applications of VANET that are real time data sensitive. The volumes and densities of vehicles in VANET environment is tremendous hence, the problem of congestion control is of paramount importance. VANET transforms every participating car into a wireless router or node and this enables cars that are about 100 to 300 meters apart to connect and also create a network. This makes it not only autonomous but also a self-organizing wireless communication network, where nodes in VANET involve themselves both as servers and also as clients for information sharing and exchange [1].

3. RESULTS AND DISCUSSION

3.1. Congestion control problem in VANETS

Although VANET is well known with its additional features such as high mobility and high topology rate, yet it raised issues in data routing, data volume, data dissemination, security, and quality of service (QoS) [5]. This condition is known as congestion in the network and needs to be controlled so that the real time data needs of the applications are met. If the VANET is large with intermediate nodes, the problem is complicated with queuing of packets as well as dropping of packets at intermediate nodes causing the network performance challenges.

Initially, there is no congestion control policy except advertising the reduced window size [5] and buffering capacity beyond which the packets are dropped. This makes the gateway to slow down. Thus, it rises to situation of data transmission to a halt as the data flow is slow, buffers are full and packets are dropped. It results into network timeout, reflecting congestion, when all connections are forcefully closed. This needs to be addressed such that network performs well. Queue management techniques are the mechanisms for congestion control and avoidance. The initial methods are tail drop and random drop. However, these methods are not for congestion control and avoidance [5].

3.2. Congestion control techniques

These are mainly for allocating the resources in the network so that the performance is up to the expectations. Resources that are considered are band widths, buffer space (memory) and processing capacity at the intermediate nodes of the network [6]. For the purpose of control solution, the congestion is defined as the total sum of demands exceeding the available capacity on any resource mentioned above. Based on this definition, the control schemes or solutions are designed. This depends on how we look at the resource either single dumb resource or single intelligent resource or as a distributed resource where the link capacities are considered which is shown in Figure 2. Al Mallah *et al*. [7] further discusses the classification in an urban context. The solution designs are around increasing the available capacities of the resource(s) or decreasing the demand on the resource.

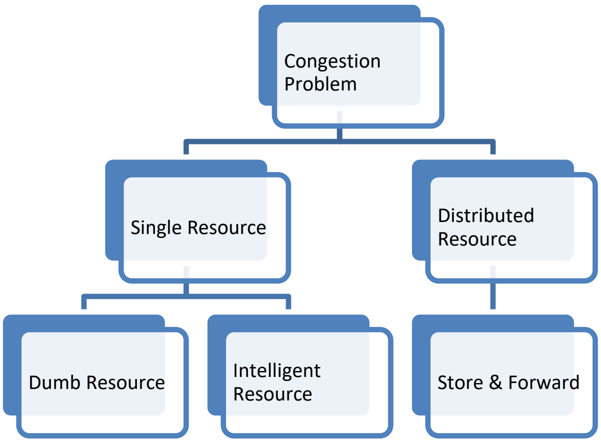

Figure 2. Congestion problem classification

Demand reduction methods are on the lines of i) service denial methods; ii) service degradation methods; and iii) scheduling methods. Application of these methods depend on the type of network [8]. This further depends on the total load on the network which works as feedback and control aspects of the congestion control problem. The control points are essentially the resources including the intermediate nodes of the network. The feedback mechanisms are in terms of messages such as i) feedback messages; ii) feedback in routing messages; iii) rejecting further traffic; vi) probe packets; and v) feedback fields in packets.

Some of the latest control techniques suggested are i) timeout based control where the network load is reduced on timeout and increased if the packet loss is controlled; [9] ii) bit based congestion avoidance technique based on throughput and network load performance; [10] and iii) three-part congestion avoidance is used for heterogeneous networks [11]. Further work can be done for formulation of optimization by path selection or splitting. Further the control schemes are categorized as reactive and proactive methods [12]. Reactive methods work based on the current network state. Whereas proactive methods work on predicting the congestion based on the historical data, thus preventing the congestion. Other techniques work on reducing the messages, [13] event driven messages, some are based on local and centralized mechanisms, [14] and others are heuristic based approaches [15].

Besides the above schemes, in VANET, there are another set of congestion control schemes are available such as i) dynamic congestion control scheme [16] consisting of congestion detection phase and congestion control phase; ii) hybrid congestion control approach [17] having assignment of priority to messages and detecting and controlling congestion; iii) congestion control through beacon scheduling [18]; and vi) medium access control supported using multi priority [19] congestion problem and its control techniques address the problem after it's happened. The crux is whether it can be detected early and prevented such the performance is improved. Next section deals with this concept.

3.3. Random early detection

In VANET, congestion control is primarily queue management (QM) practice. In this the traditional ways are tail drop (TD) which causes the packets at the end, tail end, are dropped which is no control, but an indication of congestion already happening. TD has two main problems – full queue problem and lock out problem. Thus, TD causes system instability and unfair bandwidth sharing [20]. So, a method to find out the congestion beforehand is needed. Prior to this, let's understand another method, random drop (RD) which is primarily dropping the packets randomly from the sources according to their bandwidth flow. This helps congestion elevation; however, it is unfair with respect to the packets dropping at the nodes.

There is a need for a method to work on congestion control or avoidance in an active queue management (AQM). Thus, the technique random early detection (RED) that helps to drop the packets earlier to the congestion, proactively avoid buffer overflows. This improves link utilization, decreasing queuing delays, and packet loss.

3.4. Parameters for RED

The following are the parameters for RED to implement to ensure the performance of the network. To find out the packet drop probability 'p' and other parameters are:
Minth: minimum threshold packets
Maxth: maximum threshold packets
Avg: queue size or buffer size

$$〚Min〛\_th \leq avg \leq 〚Max〛\_th$$

will define the probability with which the packet will be lost.

There are different formulas to calculate the probability of certain packet loss. RED uses weighted average parameter to find out the average queue size. Average queue length is calculated with exponential weighted moving average

Steps of RED implementation are as: i) calculate the average queue size, ii) find out the status of the average queue with respect to min and max threshold values, iii) find out the probability of dropping the packet and iv) finally decide to enqueue the packet or drop the packet.

3.5. The solution space of optimization of RED

Considering the RED as potential approach to resolve the problem of finding the packet loss, packet delay (replace for packet loss in formulation) and the queue size, the problem needs to be defined accordingly. This has been formulated as optimization problem [20]. The decision parameters are: i) minimum queue length (qmin); ii) maximum queue length (qmax) and iii) packet loss probability (Ploss).

These are stated as:

$$Ploss = 0 \; if \; qi \leq qmin$$

$$Ploss = pi \; if \; qmin + 1 < qi < qmax$$

$$Ploss = 1 \; if \; qi \geq qmax$$

$$Pi = ((q - qmin))/((qmax - qmin)) \; pmax$$

The optimization objective is:

$$min \; Ploss \; subject \; to$$

$$0 \leq qmin < qmax$$

$$0 \leq pmax \leq 1$$

The solution steps are, i) find out the pmax value with assumption of qmin and qmax and ii) find out qmin and qmax for given probability value p. The decision variables are optimized for different nodes of end and intermediate levels. Different optimization techniques like integer programming, dynamic programming, etc. can be applied for generating time complex solutions.

3.6. Variations of RED for congestion control

RED variations are mainly due to changes in parameters for example Queue length, packet loss and packet delay. A comprehensive comparison has been done in [21] results presented in Table 1. These variations of RED are assessed on global synchronization, prediction of congestion in early stage, response to sudden congestion, unnecessary packet dropping, and delay. The indicators considered are average queue length, packet loss, arrival rate and queue length. The results show varied performance of the methods.

In this method the indicators such as queue size or length, threshold values as well as dropping probability are used to control congestion. Variations of these indicators give different methods for congestion control. Average queue-based methods use the queue length indicator that uses the buffer state to calculate the dropping probability [21]. Packet loss is used as an indicator for congestion control in BLUE [21] method for calculating dropping probability. GRED and ERED [20] methods use queue and average queue size as indicators to detection congestion through dropping probability. Despite having several variations of RED algorithm, there is no definitive advantage of one over other. They all provide high link utilization. The response to different traffic flows is varied among the algorithms. There is a computational overhead for each incoming packet in all the algorithms.

Table 1. RED algorithm

Techniques	Indicator	Avoid global synchronization	Predict congestion in early stage	Response to sudden congestion	Avoid unnecessary packet dropping	No delay	Avoid parameterization
RED	Avg	Yes	Yes	No	Yes	No	No
FRED	Avg	Yes	Yes	No	Yes	No	No
RRED	Avg and q	Yes	Yes	No	Yes	No	No
WRED	Avg and q	Yes	Yes	No	Yes	No	No
GRED	Avg and q	Yes	Yes	No	Yes	No	No
CHOKe	Avg	Yes	Yes	Yes	No	No	Yes
ERED	Avg and q	Yes	Yes	Yes	Yes	No	Yes
BLUE	PL	Yes	No	No	Yes	Yes	No
SFP	PL	Yes	No	No	Yes	Yes	No
AVQ	Arrival rate	Yes	Yes	Yes	No	Yes	No
FDPS	Q	Yes	Yes	Yes	No	No	No
AFRED	Avg	Avg	Yes	Yes	No	Yes	Yes

3.7. Complexity of congestion and options for solutions

In VANETS, the network environment is dynamic due to mobility of vehicles, thus causing configuration changes. Thus, has challenges of routing that leads to usual congestion due to source nodes routing algorithms on intermediate as well as end nodes. This congestion is handled through different techniques mentioned above in section 4.0 congestion control techniques. This is reactive approach that applies various feedback messages to the sources ensuring the demand is reduced on the resources.

For a proactive and preventive approach, it needs to detect early the potential congestion based on the resources available at the intermediate and end nodes primarily the queue length, min, max thresholds and dropping probability. This is formulated into an optimization problem potentially a multi=objective optimization problem. However, the congestion problem should be addressed in an integrated way. In this, the proactive steps should be leading to enable message-based techniques to work on the demand from the sources. This is depicted in Figure 3. It can be enriched with all the relevant parameters mentioned.

The solution should emerge with the combination of routing optimization algorithms, feedback mechanisms and proactive optimization techniques adapting multi-objective optimization problem. Otherwise, the solution will be fragmented. This may have the challenges of adaptation of different parts of solution for smooth handling of the congestion and performance. In the current scenario of research, it is split into three which are routing optimization, congestion control and optimization of early detection.

It would need integration of all to get better performance, quality of service (QoS) results. Some of the examples of work done partially in this direction are routing optimization and congestion [22], decreasing traffic congestion with ant colony optimization algorithm [23], congestion control in VANETS [24] and dynamic congestion detection and control routing in ad hoc networks [25], [26]. Thus, it is pertinent to consider the integrated approach rather than partial approach.

The integrated approach works with single motto of improving the quality of service instead of sub tasks. So, the potential research on optimization of RED to have congestion control can consider the integrated approach with double optimization scope with a feedback mechanism. Routing optimization addresses the demand side from the sources and optimization on RED to work for resources at the intermediate and end nodes. These two parts are linked with the feedback mechanism. So, the research should formulate the comprehensive problem for solution of network performance quality.

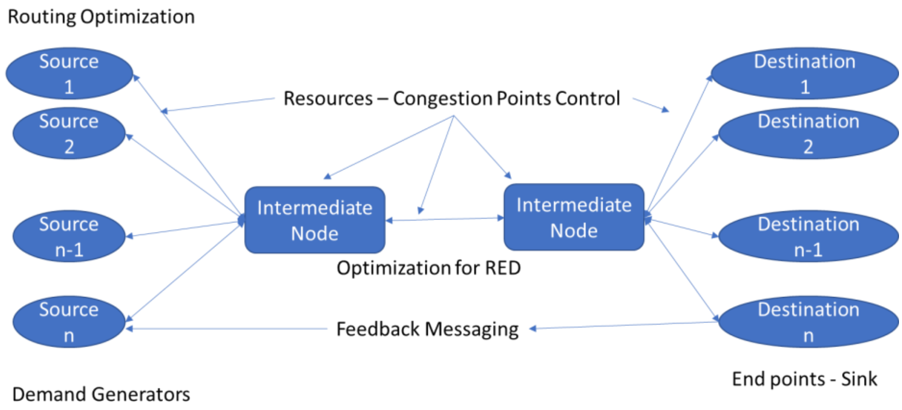

Figure 3. Integrated approach for congestion control and RED

4. POTENTIAL RESEARCH WORK

Three decades of research on random early detection has delivered various improvements but not any radical changes to view the congestion problem in a different way. The integrated approach mentioned above in 9.0 complexity of congestion and options for solutions gives potential avenues. Potential research in optimization of random early detection can take shape in three directions:

- Conventional optimization path where different optimization techniques [27] can be applied to find out the better results for minimized dropping probability and optimal queue length, thresholds as well as packet delays. Here the source nodes routing algorithms will operate normally. So there still lies the chance of instability. The dynamism that is inherent in VANET adds to the complexity, thus the problem remains challenging and addressed only partially. The optimization results may be improved by more research on the: i) using integer programming techniques, ii) using dynamic programming techniques, iii) path splitting, thus relaxing the resource constraints, iv) utilizing computational intelligence and or overhead at different nodes, v) integrating demand and supply of resources through routing and RED optimization, and vi) incorporating the feedback responses in the problem formulation.
- Understanding the congestion pattern, is it the resource constraint or demand pressure and then devise the strategy for improving the situation. This leads further to conventional route for optimization [28] of resource elevation and demand reduction in a better way. This, in turn applies to areas mentioned in the point (1) above. In this approach, details of the following will help better formulation of the problem in general and optimization in specific i) network type (complexity and size), ii) resource type (Hub, Router, Server and Bridge), iii) packet priority, and vi) source – destination complexity (numbers and connectivity).
- Integrated approach is for improving quality of service for reduced congestion, less delay and minimal loss of packets. In this, three legs of the problem are addressed – routing where demand is generated; feedback mechanisms to help balance the demand supply for resources and the early detection of congestion to prevent the losses. Tunga *et al.* [29] in this, the problem formulation, potentially multi-objective optimization problem, could be challenging, but still interesting to solve. These are addressed in terms of routing optimization, packet loss – congestion control – RED optimization and formulation with feedback responses.
- Depending on the context and the network environment, traffic conditions, the quality of service is improved through machine learning techniques. It may be explored how Integrated approach of routing [30] and RED optimization [31]–[33] can be implemented so as the historical data is utilized for performance improvement [27], [34]–[39].
- Thus, the optimization of random early detection approach has quite wide scope of future research [40]–[45]. However, caution should be exercised for problem formulation and solution in the integrated approach as well as RED optimization option [46]–[50].

5. CONCLUSIONS

In this paper, it is introduced briefly about the VANETS and its characteristics. Further touched upon the problem of congestion control and corresponding techniques which deal with actual congestion happening. However, the need is to detect the congestion early and minimize the loss and delay. This led to come to random early detection technique. Further helped to formulate an optimization problem that is solved iteratively to find the decision variables of queue length including thresholds and the dropping probability. From there it is discussed the complexity and solutions possible for congestion problem. Included are the areas of future research for improving the quality of service in an integrated approach including in three parts of optimization of routing, RED and feedback messaging. Further, latest techniques of artificial intelligence and machine learning can be used for better results.

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