Mitigate Traffic Congestion with Virtual Data Sink based Information Dissemination in Intelligent Transportation System

Li-Der Chou, David Chunhu Li and Hung-Wen Chao
Department of Computer Science and Information Engineering
National Central University
Jhongli, Taoyuan, Taiwan, R.O.C.
cld@csie.ncu.edu.tw

Abstract—Traffic congestion has been an inevitable problem in urban areas. The traffic congestion not only causes economic loss and environment pollution, but also hurts peoples’ health. Intelligent Transportation System (ITS) is developed to improve traffic management and among others. To amend existing traffic congestion control mechanism, in this research, we proposed a virtual data sink based information dissemination mechanism in vehicular ad hoc networks. A concept of virtual TTI (Traffic and Travel Information) sink is introduced to collect information of traffic volume and disseminated via cooperative inter-vehicle communications. With the help of our mechanism, the traffic congestion situation is predicted and travelling time is estimated. We took into account factors including traffic and travel information, road scale and topology in our mechanism. Our proposal is examined by extensive simulation. The simulation results show that average travelling time is significantly reduced with little network bandwidth consumption. The problem of overwhelming broadcast message is also effectively controlled.

Keywords—VANETs, ITS, Traffic Congestion, Inter-Vehicle Communications, Dissemination.

I. INTRODUCTION

According to research report of the United States 2009 [1], traffic congestion has become a severe problem in American 439 urban areas, and this problem is becoming worse in all regions with continuous increase of vehicles on the road. In 2009, the American spent extra 4.2 billion hours on travel and purchased additional 2.8 billion gallons of fuel because of traffic congestion, which is a significant increase of more than 50% over the past decade. In recent years, Intelligent Transportation System (ITS) is advocated to improve the service by including information and communication technology, transportation infrastructure and vehicles. As one of most important technology of ITS, Vehicular Ad Hoc Networks (VANETs) provides numbers of promising network applications, such as vehicle collision warning, road conditions report and route guidance systems, etc [2] [3]. The VANET is a special type of mobile ad hoc network, in which the vehicles equipped with various wireless communication devices can communicate with each other on the road. The VANET architecture can be divided into two types, namely the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) [4]. The V2V network is made up of vehicles, while the V2I network consists of vehicles and roadside units [5].

VANETs are expected to implement various wireless communication technologies such Dedicated Short Range Communication (DSRC), Wi-Fi, Cellular network, Satellite and WiMax, etc. There are a number of research projects on the ITS conducted by governments, industry and academia, such as MIT Portugal ITS research [6] and iTETRIS [7]. Traffic management is one of the most important applications in the Intelligent Transportation System. A centralized traffic management system is common system broadly applied in the world. Representative centralized traffic management systems are found in [8] [9], in which various traffic detection components including induction loop detectors, infrared and wireless access point are utilized to collect real-time traffic information. The collected data is then fed back to the traffic control center (TIC) via wired or wireless networks. The TIC will process data and broadcast traffic information to vehicles radio, CMS (Changeable Message Sign), web services, and UMTS (Universal Mobile Telecommunication System), etc. However, expensive cost of infrastructure installation in centralized traffic management system is major demerit [10]. In addition, it is difficult to maintain those components.

On the other hand, data transmission between components and traffic control center required large numbers of processing time since traffic information is required to compile, process and release to users. Therefore, the aforementioned demerits could results in the end users receive traffic information with a certain delay time. The TIC traffic information is not real time and cannot timely mitigate traffic jam in some situations [11]. To complement centralized traffic management system, a number of distributed information systems [12] [13] [14] applied to utilize global positioning system (GPS) device and wireless network communications on-board unit (IEEE802.11-like) implemented on vehicles. Each vehicle is viewed as a mobile detector which can automatically collect traffic information, share and exchange the messages through inter-
vehicle communication. Thus, rapid real-time traffic accidents or other events are rapidly reported and the vehicles in VANETs are able to choose an optimal travel route for saving travelling time.

Although many studies have been made on improve traffic management in intelligent transportation system, the traffic congestion is still an obstinate problem. To enhance traffic congestion management service, in this research, we propose a new virtual data sink based traffic congestion mitigation mechanism. Our contribution is summarized with three folds. Firstly, a collaborative approach between vehicles (V2V) is utilized to collect traffic information. The intersection is referred to the traffic confluence of the road network. We make good use of vehicles to play the role of data sink as a virtual data aggregation point. Secondly, we develop a distributed traffic information mechanism and propose algorithms that estimate the various travel time of different road segments to predict congestion situation of road segments. With the help of our algorithm, the vehicles can find less congested routes to reach the destination. Finally, the proposed mechanism can assist the vehicles to find a suitable congested routes to reach the destination. With the help of our algorithm, the vehicles can find less congested routes to reach the destination.

The rest of this paper is organized as follows. Section II presents related work on traffic information dissemination in VANETs. Our virtual data sink based traffic congestion mitigation mechanism is described in section III. Section IV describes simulation setup and results discussion. We conclude our work in section V.

II. RELATED WORK

There have been some studies on improving dissemination of traffic congestion information. Shibata, et al [15] split city map into blocks of fixed size in their traffic management approach. Each vehicle has a table of entry which records information that it entering the road, leaving the road and the spent time of passing through the block. To transfer traffic information, the vehicles broadcast traffic information message to all vehicles in the road network after passing through the block. With receiving the traffic information from neighbor vehicles, the destination vehicle can learn overall traffic information and avoid necessary traffic congestion. However, as all vehicles periodically broadcast sensed traffic information to their neighbors, the excessive exchange of message may cause severe data traffic congestion.

To overcome problem of broadcast storm in flooding traffic information, Inoue, et al [16] applied an event-driven approach that the vehicle congestion is treated as a particular event. Road segments in vehicular ad hoc networks were classified and a threshold number was defined to represent vehicle density on the road segment. When a vehicle passes through the road segment, the vehicle can receive real time traffic density of the road segment. If the traffic density exceeds the value of threshold, the vehicles will broadcast a traffic congestion warning message to all vehicles in the network. Zhong, et al proposed an algorithm called TrafficInfo to disseminate traffic information in vehicular ad hoc network [17]. In the TrafficInfo, each vehicle will broadcast its traffic time information for a road segment after the vehicle passing across it. Once a vehicle receives the message, it will calculate the priority of message in order to efficiently and timely exchange message. Factors including message survive time and position information were considered to enable the vehicle receive meaningful traffic information and guide the vehicle with short distance traveling path. However, the TrafficInfo lacks explanation about the efficiency of data dissemination.

III. VIRTUAL DATA SINK BASED TRAFFIC CONGESTION MITIGATION MECHANISM

As traffic congestion has been an obstinate problem to solve, we are motivated to mitigate it and propose a VTS (Virtual Traffic and travel information Sink) based traffic congestion mitigation mechanism. Our proposed distributed vehicular traffic information management mechanism consists of four modules. They are Virtual TTI (Traffic and Travel Information) Sink (VTS), Global Broadcast TTI (GBT), Estimation of Travel Time on Road Segment and Detour Decision Method.

To facilitate readers, we abbreviated our mechanism with the name of “VGED” algorithm which combines the first character of four modules name. Figure 1 illustrates the structure of our VGED mechanism. In general, the vehicular network is classified into two networks: data network and road network. Our design concept is based upon treating the vehicles as mobile traffic detectors and data collection sinks. The vehicle travelling among the road segments can collect and aggregate traffic information to form a “Virtual TTI (Traffic and Travel Information) Sink”. After aggregating specific amount of the TTI data, the vehicle will broadcast the TTI message to all vehicles in the road network.

To improve existing message broadcast methods and serve vehicle travel in road network, we take into consideration of factors including priority of messages, meaning of messages and message relay selection to design a new global broadcast

![Figure 1. Architecture of VGED mechanism](image)
TTI (GBT) method. When the vehicles in the road network receive the GBT message, they will estimate expected travelling time of road segments and update their traffic database. Accordingly, the least congested travelling route is recommended to the vehicles. We further describe each module in details in the following sections.

A. Virtual TTI Sink (VTS)

Our concept of Virtual TTI Sink (VTS) is mainly motivated from Vehicle-to-Infrastructure (V2I) communication in VANETs, which assumes each intersection is installed with roadside units (RSUs) to collect traffic information, as shown in Figure 2. Different from existing studies, the VTS mechanism will play through the vehicles instead of roadside units. The vehicles play the role of mobile stations that collect traffic information and deliver the information to other vehicles. Accordingly, the drawback of communications that solely relying on roadside units and overwhelming messages on RSUs is overcome.

Figure 3 illustrates working flow chart of our VTS mechanism. When a vehicle passes through a road segment \((I_b, I_a)\), it will broadcast traffic information and its travelling information of road segment to other vehicles. The vehicles in VANETs within the communication range of other vehicles which enter into road intersection can overhear the broadcast content. Suppose a virtual data sink vehicle driving on a road segment \((I_b, I_a)\) and receiving the traffic information from the other vehicles. The traffic information is then temporarily cached in the vehicle. In addition, the virtual data sink vehicle can measure its travelling time and traffic volume of road segment \((I_b, I_a)\). The measured travelling time and traffic volume of road \((I_b, I_a)\) is calculated with (1) and (2).

\[
\begin{align*}
C_t(R_{S(I_b, I_a)}) &= C_t(R_{S(I_b, I_a)}) + \frac{C_t(R_{S(I_b, I_a)})}{C_t(R_{S(I_b, I_a)}) + 1} \\
+ T_t(R_{S(I_b, I_a)}) &= T_t(R_{S(I_b, I_a)}) \\
C_n(R_{S(I_b, I_a)}) &= C_n(R_{S(I_b, I_a)}) + 1
\end{align*}
\]

With the help of virtual TTI sink, the physical equipment of RSUs could be replaced and the problem of overwhelming message sent to the RSUs is conquered. To achieve timely report traffic volume information in the network, we set a time threshold of collecting cycle \((TH)\) to ensure the accumulated message can be transmitted before it become stale. In addition, a cumulative traffic volume threshold \((PH)\) is defined to prevent overwhelming message congested on vehicles. Once the travel and traffic volume information is accumulated with the threshold of \(TH\) or \(PH\) reached, the virtual TTI sink vehicle will immediately broadcast the accumulated TTI data to neighbor vehicles via global broadcast mechanism which is described in the following sections. The major advantage of our VTS mechanism is to aggregate many traffic and travel information of road segments into a single message. Our approach will reduce the number of broadcast traffic message in vehicular ad hoc networks.

B. Global Broadcast TTI (GBT)

Our Global Broadcast TTI (GBT) message mechanism
comprises three parts: calculate TTI priority, relay vehicle selection and broadcast domain determination. Each part is described in details in following sections.

1) Calculate TTI priority: As there are a large number of communication messages transferred in the vehicular ad hoc network, in particular, data traffic in some trunk lines of road network are becoming congested with the increase of crowded vehicles. In such a situation, how to timely and efficiently deliver the TTI message to the vehicle is important. It is necessary to prioritize different types of message in data network of vehicular networks. We observed the phenomena of traffic congestion and proposed methods to prioritize the TTI message. In general, the traffic congestion is becoming worse when the traffic accident is happened and the average velocity of vehicle that near the spot of accident is soon decreased. However, vehicle drivers often insist on their pre-decided and familiar travel route instead of instantly changing their routes. The significance of traffic congestion message is depending on average vehicles numbers on a road segment in a specific period. The \( Pr(m) \) priority of the traffic and travel information (TTI) message \( m \) is then deduced by (3). The \( Di \) is the average number of vehicles passing through the road segment \( i \) in the cycle of the VTS. The \( n \) is total numbers of road segments.

\[
Pr(m) = \frac{\sum_{i=1}^{n} Di}{n}
\]  

(3)

2) Relay Vehicle Selection: Many existing relay node selection in broadcast message schemes focus on reducing transmission delay and controlling broadcast storm. Few researches take the issues of data content and applications into account. As the purpose of our TTI message is for route planning in case of traffic congestion occurred. It is tolerant if the transmission of the TTI message with reasonable delays. However, the extent of message dissemination and penetration is important in order to make more vehicles receive the traffic congestion information.

We are motivated by the concepts of position broadcast such as [18] [19] and design an application driven broadcast mechanism where the factor of traffic volume information of the road segment are included. As shown in Figure 4, we briefly color road segments to represent different traffic volume of each segment. The traffic volume in each road segment from high to low is respectively in red, yellow, dark green, light green and grey color. In the original position-based broadcast mechanism, the farthest vehicle \( n_2 \) to source node will be chose as the next relay node. In our application driven broadcast mechanism, the relay node is selected with taking account of factors including message penetration and handling heavy traffic flow road segments. As a consequence, the vehicle \( n_1 \) in the most congested road segment is selected as the first relay node and the vehicle \( n_2 \) is picked as the second relay node. To avoid possible broadcast storm in the data network of vehicular ad hoc network, as shown in Figure 5, each relay vehicle is assigned a different broadcast waiting time to re-broadcast the TTI message. Different message are broadcasted in different time slots. The vehicle’s broadcast waiting time is calculated by (4) and (5). The parameter \( i \) is the number of relay vehicle. The \( EWT_{ni} \) is expected value of relay vehicle’s broadcast waiting time. The \( Dist \) is the distance between the source vehicle and relay vehicle. The \( R \) is transmission range of the vehicles.

\[
WaitingTime_{(ni)} = (i-1) \times TimeSlot + EWT_{(ni)}
\]  

(4)

\[
EWT_{(ni)} = TimeSlot \times (R - Dist_{(ni)})
\]

(5)

However, it is inevitable that the transportation light bring significant impact on traffic congestion. The vehicle frequently crowds and jams round the intersection, on the other hand, there may have communication gaps happened on sparse traffic density road segments. Therefore, we take advantage of concepts of message ferry to assist the message delivery in such a communication gap situation. In the message ferry approach, the vehicle will temporarily cache and carry the data message if there is no any available neighbor vehicle to communicate. The data carrying vehicle will forward the message to the relay vehicle until there is vehicle in its communication range.
To prevent influence of long time message ferry happened, we assigned a parameter of $MF$ (Message Ferry) to limit how many road segments that the vehicle can temporarily cache and carry the data. When the $MF$ is equal to 1, the vehicle in current road segment is allowed to carry the data and move toward next road segment to forward the data. When the $MF$ is equal to 0, the vehicle is restricted to only carry the data of the road segment where it is moving.

3) Broadcast domain determination: In order to reduce wasted network bandwidth caused by excessively broadcast traffic information, we define the broadcast domain according to traffic congestion extent. In the urban area, once the traffic jam is occurred, it will take longer time to eliminate the congested situation than the time become traffic jam. Therefore, when traffic congestion happens, the traffic jam information should be transmitted as soon as possible to the distant vehicles so that they can have enough time to decide and alternate their routes in advance. Taking into account purpose of traffic information, we hope to limit broadcasted area of traffic information with space and time constraints. Accordingly, in our mechanism, a space parameter $r_c$ is utilized to limit the TTI message broadcast domain. We apply the parameter of time-to-live (TTL) with space factor $r_c$ on each broadcast TTI message as (6). The $L$ is the road length and the $V_{ave}$ is the average velocity of vehicles. The parameter of $\lambda$ is an experimental value decide by simulation test.

$$TTL = \lambda \times \frac{r_c \times L}{V_{ave}}$$  \hspace{1cm} (6)

IV. SIMULATION AND DISCUSSIONS

We conducted extensive simulations to examine our proposed VGED traffic congestion mitigation mechanism. The simulator is NCTUns 6.0 [20]. Vehicles’ mobility model is car following model. Each Vehicle will keep safe distance with front vehicle and react to the traffic signal by accelerating or decelerating. The simulation performance metrics are number of broadcast, vehicles’ average travelling time and communication bandwidth consumption. The simulation area is 6000*5000 m. The simulation map is a Manhattan grid scenario. The number of intersections is 143. The MAC protocol of vehicles is IEEE802.11b. The transmission range of vehicle is 250 m. The number s of simulation vehicles are 500 - 1100. Vehicle’s maximum speed is 50 km/h. The acceleration speed of vehicle is 4 m/s². The transmission control protocol is UDP. The data traffic of vehicle communication is CBR. The data packet size is 512 bytes. The simulation time is 2700 seconds. We compared our VGED mechanism with the algorithm TrafficInfo [17].

As illustrated in Figure 6, the number of broadcast message per second in the vehicular ad hoc data network is significantly decreased with the aid of our Virtual TTI Sink approach. The $TH$ is the cycle of time period to accumulate the TTI message in second. The reason of significant decrease of broadcast message is that in the VTS scheme, the vehicles have RSUs-like behavior and collect traffic information for a cycle time. The vehicles then send aggregated the TTI message to the desired area and vehicles. This approach is different from general road side units based broadcast methods and introduces two advantages: First, the traffic information near an intersection can be aggregated into one message for a time period. The vehicle only broadcasts the representative message to other vehicles. Consequently, the number of broadcast message can be significantly reduced. Second, the dissemination of information in the data network of VANET is more stable because the chance of data message collision is reduced. Our VGED mechanism also reduces unnecessary re-broadcast messages. Figure 6 also shows that in the case of 1100 vehicles and the $TH$ is 80 and 120 seconds respectively, the VTS scheme can reduce 89.09% and 90.77% of the volume of broadcast traffic information. The VTS mechanism has the better performance of traffic information dissemination.

On the other hand, in Figure 7, it is found that the overall travel time of vehicle is reduced with the help of VTS mechanism when compared with the TrafficInfo algorithm. With the number of vehicles is increasing, in the VTS mechanism in two different $TH$ values (80s and 120s), the
network, simple flooding dissemination mechanism in networks. With the increase of number of vehicles in communication bandwidth because of its simple flooding mechanism. With the problem of late receiving of the travel and traffic information (TTI) and cannot timely avoid the congested road segment. Thus, an excessive TH extension may cause negative impact on performance of VTS mechanism. As to the performance of bandwidth consumption, Figure 8 shows that the Traffico info consumes more wireless communication bandwidth because of its simple flooding mechanism. With the increase of number of vehicles in the network, simple flooding dissemination mechanism in Traffico info is inclined to occupy large amount of bandwidth of VANET with the rapid rise of number of vehicles. The experiment result shows that the bandwidth consumption of our VTS based mechanism is significantly saved. When the collection cycle time is set to 80 seconds, the average consumed bandwidth is only 15.85% of Traffic info costs, which is the decrease of 84.15%. When the TH is 120 seconds, the consumed bandwidth in our VTS based traffic congestion mechanism fell to 11.39%. This mechanism not only introduces benefits of saving communication bandwidth, but also extends message dissemination coverage while reducing the number of broadcasts.

V. CONCLUSIONS

To sum up, we proposed a virtual TTI sink based traffic congestion mitigation mechanism in intelligent transportation system. In our VGED mechanism, the vehicles travelling among the road segments are utilized to collect and aggregate traffic and travel information and form the virtual data sink. We also designed new global broadcast message mechanism with taking account of message priority, space and time constraints, etc. We examined our mechanism with extensive simulation work. The evaluation results revealed that problem of overwhelming message broadcast in vehicular data networks can be significantly solved with our virtual data sink based traffic congestion mitigation mechanism. In addition, the overall average travel time of vehicles is reduced with less communication bandwidth consumption.

REFERENCE