TRADING: TRaffic Aware Data offloadING for Big Data enabled Intelligent Transportation System

Tasneem S. J. Darwish, *Member, IEEE*, Kamalrulnizam Abu Bakar, Omprakash Kaiwartya, *Member, IEEE*, and Jaime Lloret, *Senior Member, IEEE*

***Abstract*—Todays' Intelligent Transportation System (ITS) applications majorly depended on either limited neighbouring traffic data or crowd sourced stale traffic data. Enabling big traffic data analytics in ITS environments is a step closer towards utilizing significant traffic patterns and trends for making more precise, and intelligent decision particularly in connected autonomous vehicular environments. Towards this end, this paper presents a Traffic Aware Data Offloading (TRADING) approach for big traffic data centric ITS applications in connected autonomous vehicular environments. Specifically, TRADING balances offloading data traffic among gateways focusing on vehicular traffic and network status in the vicinity of gateways. In addition, TRADING mitigates the effect of gateway advertisement overhead to avail the transmission channels for the traffic big data transmission. The performance of TRADING is comparatively evaluated in realistic simulation environment considering gateway access overhead, load distribution among gateways, data offloading delay, and data offloading success ratio. The comparative performance evaluation of results shows some significant developments towards enabling big traffic data centric ITS.**

***Index Terms*—Intelligent Transportation Systems,VANET, Vehicle-to-Internet, Gateway, Big Data**

I. INTRODUCTION

The evolution of big data analytics and the Internet of Things (IoT) technologies have played an important role in the realization of the intelligent transportation systems [1]. In ITS environments, huge data is produced by a variety of sources such as vehicles, sensors, loop detectors, microwave radar, CCTV camera, electronic toll tags, global position systems (GPS), cell phones and mobile applications. The ITS data can be described using the "5Vs of Big Data" including volume, variety, velocity, veracity and value. Therefore, big data analytics can be applied on the oceans of data produced in ITS environments to reveal meaningful information, trends, relationships, patterns, and insights for making traffic oriented decisions. It will improve the capability of many ITS applications to reduce congestion, improve roads safety, mitigate adverse environmental impacts, and optimize energy performance in transportation[2]. For example, traffic accidents can be reduced or prevented by analysing accidents factors and drivers behaviour. To perform big data analytics, such data need to be collected and delivered to cloud storage for processing by using vehicular networks [3].

As vehicular ad hoc networks (VANETs) can form a self-organized and large scale networks, it is considered an ideal networking environment for big data acquisition in ITS. More precisely, real-time microscopic transportation data can be collected through VANETs by relying on individual vehicles for traffic data offloading. In VANETs, vehicles are equipped with wireless communication devices along with processing capability to facilitate connectivity among vehicles through vehicle-to-vehicle (V2V) communications and between vehicles and fixed network infrastructures through vehicle-to-infrastructure (V2I) communications [4], [5]. V2I communications is enabled through accessing Wi-Fi access points, 3G/3.5G/4G/5G cellular network Base Stations (BSs), or IEEE 802.11p based Dedicated Short Range Communication (DSRC) enabled Road Side Units (RSUs) [6].

The conventional safety applications rely on limited traffic data exchanged between direct neighbouring vehicles and infrastructure. However, considering safety in advanced driver assistance systems and ultimately self-driving or automated vehicles applications, big data centric computing and communication approaches are needed to excel in the compute-intensive and latency-sensitive tasks [7]. For example, future safety applications might perform individual driver behaviour analysis which requires big data centric computation with fast response [8]. According to Intel, an autonomous car needs to analyze and fuse a massive amount of sensor data (approximately 1gb/s) in order to make safe decisions in on-road environment. In addition, it is expected that future safety applications will depend more on video streaming. It will be similar to multiplayer online gaming, and to augmented and virtual reality applications [9]. Basically, the reason for considering the traffic data processed in these applications as big data is the fast data generation rate and variety of data sources in ITS environments [2]. Any delays in collecting, processing or analysing the relevant data or delivering the analysed outcome may result in a catastrophe. To harness the power of big data analytics in ITS environments, traditional cloud-based store-and-process approaches may no longer be appropriate for many ITS applications. To enable real-time safety applications, data must be collected and processed in distributed manner at the network edge using fog computing [8]. Thus, vehicles need to intelligently communicate with roadside infrastructure in order to offload the traffic data to fog computing centres for further processing and analysis.

To effectively enable real-time big data oriented ITS appli-

T. S. J. Darwish and K. A. Bakar are with the Universiti Teknologi Malaysia (UTM), Malaysia (tasneem83darwish@gmail.com, knizam@utm.my).

O. Kaiwartya is with the Nottingham Trent University (NTU), UK (omprakash.kaiwartya@ntu.ac.uk).

J. Lloret is with the Integrated Management Coastal Research Institue, Universitat Politecnica de Valencia, Spain (jllorete@dcom.upv.es).

Manuscript received XXX, XX, 2019; revised XXX, XX, 2019.

cations, VANETs is capable of reliably and timely offloading the collected traffic data to fog nodes and to deliver the responses back to the end users. For example, autonomous vehicles need reliable and high-speed transmission for big traffic data enabled decision making in mobility centric real time environment [10], [11]. Therefore, in VANETs environment it is essential to provide fast and reliable communications between vehicles and infrastructure gateways, which can adapt to changes in vehicular network's traffic conditions [12]. The communications should be able to handle the ITS big data towards accurate data acquisition and timely responses. When a vehicle is not in any gateway's coverage area, it can utilize multi-hop communications to access the fog nodes [13]. The literature on gateway accessing in vehicular environments mostly relies on distance centric static information and lacks traffic dynamism consideration in the vicinity of gateways. Thereby, leading to low quality multi-hop communications with the chosen gateways. In addition, the network load on gateways is also neglected in gateway selection resulting in the degraded quality of V2I communications. Moreover, high network overhead while discovering an appropriate gateway is another concern in related literature due to the broadcast centred discovery approach.

In this context, this paper presents a TRaffic Aware Data offloadING (TRADING) approach for big data enabled ITS applications. The aim of TRADING is to provide reliable and low-delay communications for data offloading while mitigating network overhead of gateway discovery. TRADING discovers and selects a gateway to offload data, while considering gateways load as well as the traffic and network status in the vicinity of gateways. TRADING reduces network overhead of gateway discovery by adapting the gateway advertisement area and frequency based on vehicular traffic and network status. The contributions of this work are summarized in the following points:

1) Firstly, a traffic aware data offloading approach is presented for big data enabled ITS applications focusing on gateways discovery and gateway selection.
2) Secondly, an adaptive gateway advertisement algorithm is developed by dynamically managing the frequency and area of advertisement based on the network and traffic status in the vicinity of gateways.
3) Thirdly, the performance of the proposed traffic data offloading approach is evaluated in realistic environments. The comparative performance evaluation considers gateway access overhead, load distribution among gateways, data offloading delay, and data offloading success ratio as major metrics.

The rest of this paper is organised as follows: Section II describes the motivations and related work. Section III elaborates the design and components of TRADING. Section IV-B discusses and analyses the sensitivity of the metrics weights, which are used while evaluating gateways. In Section IV, the performance of TRADING is evaluated and compared to existing schemes in terms of packet delivery ratio, end-to-end delay, gateway access overhead and load distribution. Finally, Section V summarises the conclusions.

II. Related work

A. Traffic Data Offloading-Direct gateway Access vs. Multi-hop Based gateway Access

Based on the capacity-cost tradeoffs analysis that was carried out in [14], cellular networks can be more cost effective to offer low-speed communications to vehicles. However, when high-speed V2I communication is required, exploiting communication with RSUs connected to WLAN is more effective. As deploying a large number of RSUs is considered impractical, routing data packets through multi-hop communications can be utilized. After the study of a modelled vehicular content downloading system in [15], it was found that 80% of the data was chosen to be downloaded through relay vehicles. This is due to preferring the high-rate multi-hop paths towards RSUs to low-rate single-hop direct V2I communications with cellular networks. In fact, accessing RSUs through multi-hop communications extends their coverage range, reduces the frequency of handover, and provides longer communication sessions for data offloading. Therefore, RSUs connected to WLAN can be utilized as gateways to offload safety-related data. In VANETs, selecting the optimal gateway has a great impact on the quality of established connections for data offloading. In addition, with the unique and critical characteristics of VANETs (e.g. frequent link disruptions and highly dynamic topology), it is challenging to provide reliable direct and multi-hop V2V and V2I communications to offload the collected big data to enable real-time ITS applications. Recently, several studies were carried out on data offloading and accessing gateways through direct communication [6], [16]. Unfortunately, the schemes of direct access cannot be used for multi-hop access, as they have no consideration for the effects of multi-hop communications on gateway access performance. The process of accessing gateways over multi-hop communications consists of four main components: gateway discovery, gateway selection, gateway advertisement and communicating using intermediate vehicles. Gateway discovery is the process through which requester vehicles obtain information about gateways and probably the routes towards them. Afterwards, utilizing the received information a requester vehicle can make a decision to choose a gateway based on the preferred gateway evaluation metrics. On the other hand, gateways need to advertise themselves to the largest number of vehicles while minimizing the advertisement process network overhead. After making the gateway selection decision, the requester vehicle can communicate with the selected gateway utilizing a multi-hop communication scheme or routing protocol. A comprehensive review of VANETs routing protocols is provided in [4]. Based on the gateway discovery mode, gateway access over multi-hop communications schemes are classified into three categories, which are proactive, reactive, and hybrid [17].

B. Traffic Data Offloading-Proactive Gateway Access

The proactive gateway access approach was adopted by several studies [18], [19], [20]. In the proactive mode, gateways broadcast gateway advertisements (GAs) periodically in the network or specific area. Based on the received GAs information, the vehicle chooses the best gateway for V2I communications. A gateway access scheme based on geographic routing (GeoNetwork) was introduced in [20], [19], where the geographical area between gateways is divided equally and each gateway manages one geographical area. Gateways periodically geobroadcast GA messages within their managed geographical areas. Gateway selection is done based on vehicles positions, as vehicles can exclusively access the gateway that manages the geographical area where the vehicle is located. However, the periodic advertisement of GAs may cause network congestions, especially in high vehicular density scenarios. In addition, the gateway selection has no consideration of gateways' load, and it is made based on the vehicle's position as vehicles in a certain gateway service area cannot access other gateways unless they move to their service areas. As a result, imbalanced network load among gateways may occur.

C. Traffic Data Offloading-Reactive Gateway Access

In reactive mode, a requester vehicle tries to discover and select a gateway by sending request messages. Upon receiving the reply messages from gateways, the requester vehicle can choose the best gateway based on the received information. Some studies proposed gateway access schemes based on the reactive approach [21] [22]. Although this approach has less network overhead compared to proactive mode, high delays might be experienced while discovering gateways. In addition, network overhead increases with the increment in the number of requester vehicles. Moreover, neglecting network load on gateways may lead to imbalanced load distribution.

D. Traffic Data Offloading-Hybrid Gateway Access

To reduce the network overhead of proactive mode and decrease the delay of reactive gateway discovery, the hybrid approach is introduced. What makes the hybrid approach more suitable for VANETs environment is that gateways advertise themselves in predetermined areas or number of hops, and requester vehicles located outside the gateway advertisement zone can send request messages.

A Quality of Service Location-Aided Gateway Advertisement and Discovery protocol (QoSLAGAD) introduced in [23], which balances load among gateways. QoSLAGAD utilizes contention based forwarding to propagate GAs, Request, and Reply messages between vehicles and gateways. To advertise a gateway, its GAs are sent to vehicles in its transmission range then periodically it advertises itself by broadcasting GAs within its advertisement zone. The advertisement zone of a gateway covers the road sections of the expected zone of the source vehicle as well as the road sections between the gateway and the expected zone. Based on the received Request messages, the gateway computes the expected zone of the requester vehicle. Each GA contains information about the gateway quality of service attributes and network load as well as the route that leads towards the gateway. Every vehicle receives a GA further propagates it if the vehicle is located inside the gateway advertisement zone. Using the collected information through GAs and Reply messages, the requester vehicle chooses the less loaded gateway that satisfies the specified QoS requirements. To enhance QoSLAGAD, [24] introduced a QoS and load balancing gateway discovery (E-QoSLAGAD), which connects requesters to the least loaded and nearest gateways that satisfy their QoS requirements while not congesting the routes towards a certain gateway. To increase the fault tolerance of E-QoSLAGAD, a Fault-tolerant Location-Aided Gateway Advertisement and Discovery (FLAGAD) protocol was proposed by [25]. FLAGAD adopts the gateway discovery and selection of E-QoSLAGAD. The contention based mechanism for packet forwarding introduced in QoSLAGAD is exploited by FLAGAD as well. When a gateway failure is detected by a vehicle, it broadcasts a FaultyG message and the gateway is flagged as faulty. Meanwhile, if a vehicle that has information about a faulty or overloaded gateway received a request message, it suggests an alternative gateway to the source vehicle.

In the hybrid approach, the network congestion effect of proactive approach can be reduced and the request/reply messages exchange delays can be limited as well. However, calculating the optimum broadcast area is a critical issue. In fact, increasing the broadcast area increases the proactive mode effect, while decreasing the area leads to more reactive gateways accesses. In addition, increasing the broadcasting frequency increases the network load, and decreasing the frequency provides less updated gateway advertisement with lower network load. However the schemes introduced in [23], [24], [25] generate high network overhead. This is the result of extending the broadcast area based on requester vehicles positions and not considering network and traffic conditions. In addition, while making the gateway selection decision, the schemes have no consideration for the gateways nearby roads' traffic and network conditions. As a result, gateways with unreliable accessing routes might be selected. With the large amount of generated ITS data, it is highly likely to experience network congestion on certain routes and imbalanced network load on gateways.

E. TRADING distinct features in comparison to existing work

This study introduces TRADING approach for ITS big data offloading, which accesses gateways in a hybrid mode using multi-hop communications, balances load among gateways and considers gateway's nearby roads status while selecting a gateway. In addition, GA packets broadcasting is adjusted dynamically based on network and traffic conditions, thereby reducing the unnecessary generation of gateway access overhead and freeing the channels for big data transmission. The following points highlight the distinct features of TRADING in comparison to existing proactive, reactive and hybrid data offloading schemes:

- In the proactive approach GAs are broadcasted periodically in a fixed broadcast area, and gateway selection is made based on vehicles position where each vehicle can only access the gateway serving its geographical area. In TRADING, the GAs broadcast area and frequency are adjusted dynamically based on traffic and network status in each gateway vicinity. In addition, vehicles' decision to access a gateway is not only made based on geographical position but also with the consideration of the gateway's load and its nearby roads' network and traffic status.

- While discovering gateways reactively, high delays might be experienced, increments in requester vehicles increase network overhead dramatically, and loads among gateways are not balanced. On the other hand, TRADING, reduces the effect of reactive gateway access through increasing the gateway broadcast area and decreasing the advertisement frequency in high vehicular density, which reduces the number of vehicle accessing gateways reactively. In addition, TRADING considers gateways' load while choosing a gateway to offload data.
- Existing hybrid gateway access schemes generate high network overhead. This is due to extending the broadcast area based on requester vehicles positions and without considering network and traffic conditions. In addition, the existing schemes do not consider load distribution among gateways, and neglect the gateways nearby roads' traffic and network conditions, which affects the reliability of data offloading. To overcome the limitations of existing hybrid data offloading schemes, TRADING considers both the gateway's load and the network and traffic status of the its nearby roads to select a gateway for data offloading. Thereby, increasing the reliability of data offloading and balancing loads among gateways. In addition, TRADING adjusts the GAs broadcast area and frequency based on the traffic and network status changes in the gateways vicinity, which reduces the unnecessary gateway advertisement/ discovery overhead.

III. Traffic Aware data offloading for big data enabled ITS

A. TRADING System Model

The work-flow of TRADING is depicted in Figure 1. In particular, TRADING consists of four main components including gateway discovery, gateway selection, gateway advertisement, and the multi-hop communications. Basically, to offload traffic data to a distant gateway for data offloading, the requester vehicle needs to go through three steps. First, the requester vehicle discovers the available gateways by collecting their information which includes the gateway load and the network and traffic status of the roads in the vicinity of the gateway. In this study, a road is defined as the street that connects two consecutive intersections (i.e. junctions) in the considered city area which vehicles can use. Second, based on the received gateways information, the gateways are evaluated and a score is calculated for each gateway. The gateway with the highest score is selected to offload the traffic data. Third, the multi-hop communication is established with the selected gateway, where data packets are routed based on the routing protocol introduced in [26], [27]. On the other hand, gateways adapt their GAs broadcast based on network and traffic conditions in their vicinity. In addition, gateways reply for the discovery requests received from vehicles.

Initially, TRADING partitions the geographical area between gateways to virtual coverage (VC) areas by considering the gateways positions, which are obtained from the digital map. The boarders of each VC area equally divide the distance between each two gateways. Figure 2 shows an example of the partitioning which appears in blue doted lines. However, the gateway broadcasts its GAs in the broadcast area, which is calculated based on Algorithm 2 and it is a sub-area of the VC area. Afterwards, based on the requester vehicle position, TRADING discovers the available gateways by employing the developed Algorithm 1.

B. Gateway Discovery

Vehicles need to access infrastructure networks gateways and offload the collected data constantly. This process starts by discovering the available gateways (i.e. RSUs). Similar to a previous study [28], it is assumed that vehicles can obtain the positions of the available gateways from the digital map. The discovery process focuses on collecting the gateways information (i.e. IP address and network load) and the status of the roads in the vicinity of the gateway, which are used in selecting the best gateway to offload traffic data. The required information is obtained through GAs and REQUEST/REPLY packets. Each REPLY/REQUEST packet has the passed road evaluation (PRE) field. The vehicle that forwards the REQUEST/REPLY packet updates the PRE field by adding the IDs and lightweight road evaluation (LRE) (explained in section III-E) of adjacent roads. Thus, upon reaching the destination, the REQUEST/REPLY packet provides the status of passed roads and their adjacent roads. Once a GA or a REPLY packet is created, the load of the source gateway is included in the gateway load ratio (GLR) field, which is calculated based on Equation 1. The input buffering queue is used as an indication of the network load that a gateway is handling.

$$GLR = \frac{Number\ of\ packets\ in\ input\ buffering\ queue}{Capacity\ of\ input\ bufferring\ queue} \tag{1}$$

To discover a gateway, TRADING introduces three cases based on the requester vehicle situation.

(a) *Case 1:* The requester vehicle is located within a gateway transmission range. In this case, the vehicle can communicate directly with the gateway (line 10-16, Algorithm 1).

(b) *Case 2:* The requester vehicle is located within a gateway VC area and its broadcast area, thus it receives GA packets from at least one gateway. In such a case, the vehicle sends REQUEST packets to the available gateways that it has not received their GA packets. Afterwards, the vehicle needs to wait until it receives the REPLY packets from the gateways. The waiting time ($T_{case\ 2}$) is set to equal twice the maximum time that the received GAs consumed to reach the vehicle, as formulated in Equation 2. Upon receiving a new GA or REPLY packet, the vehicle updates its gateways table by recording the gateway IP address, PRE field values and gateway GLR (line 17-33, Algorithm 1).

$$T_{case\ 2} = 2 * max\left\{Received\ GAs_{travelling\ time}\right\} \tag{2}$$

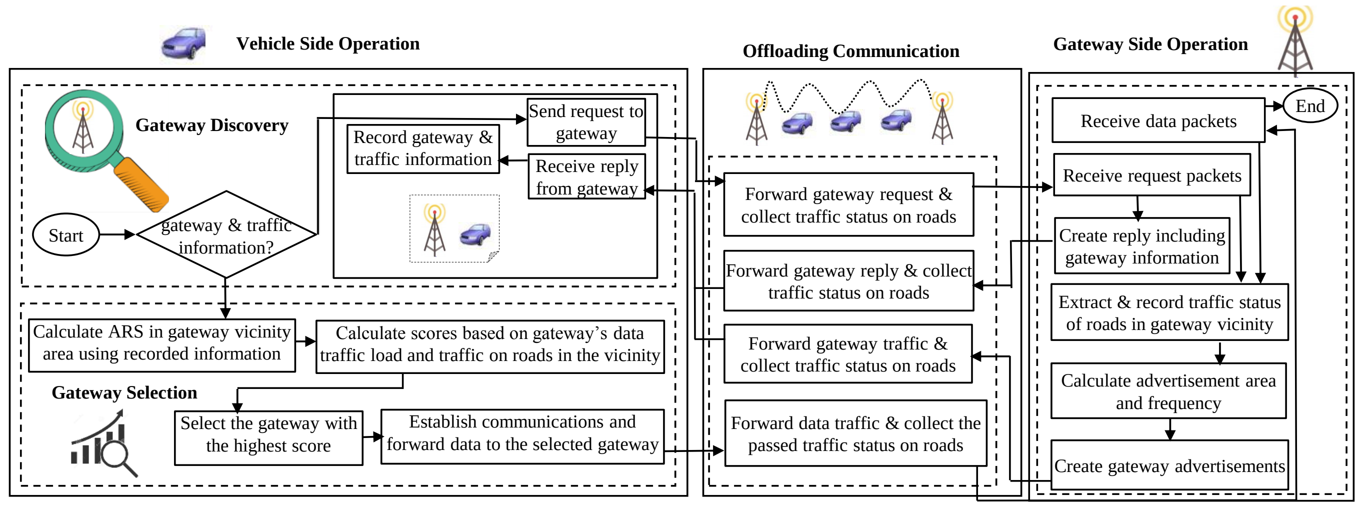

Fig. 1. TRADING work-flow

(c) *Case 3:* The requester vehicle is located in a gateway VC area and has not received any GA packet from any gateway as it is not in any broadcast area. Thus, the vehicle sends REQUEST packets to all available gateways. After, the vehicle receives the first REPLY, it will wait for a time equals the delivery time that the first REPLY packet consumed to reach the source vehicle. Thus, after sending REQUEST packets, the total waiting time ($T_{case\ 3}$) equals the delivery time of the first REQUEST and REPLY packets plus the delivery time of the first REPLY, which can be calculated using Equation 3. Consequently, the vehicle's gateway table is updated with the newly received gateway information (Line 34-46, Algorithm 1).

$$T_{case\ 3} = First\_REQUEST/REPLY_{exchange\ time} + First\_REPLY_{travelling\ time} \quad (3)$$

C. Gateway Selection

Upon receiving a REPLY or a GA packet from a gateway, the values of the fields GLR, Gateway Address and PRE are recorded in the vehicle's gateways table. Afterwards, the requester vehicle evaluates the available gateways information in its gateway table to make the selection decision (Algorithm 1, lines 47-57). Each gateway evaluation is based on two metrics: the GLR and the average road status (ARS) of roads leading to each gateway. The ARS value is calculated based on Equation 4, where RL is the road length, LRE is the road evaluation values obtained from the PRE field of received GA or REPLY packet, and k is the number of roads in a specific gateway vicinity that the vehicle received their IDs and LRE values in the PRE field of a REPLY or a GA packet. Basically, Equation 4 uses the road length and its LRE value to calculate an average road score (i.e. ARS) for all the roads in a specific gateway vicinity which the REPLY or GA packet passed through. Thus, ARS gives an indication of the status of the roads that lead to the evaluated Gateway. The ARS gives the roads status in terms of roads vehicular density and network connectivity. ARS values are in the range [0-1], and the higher the value the better the network and traffic conditions are in the gateway vicinity. Subsequently, using the GLR and ARS values, the gateway score is calculated based on Equation 5, where γ_1 and γ_2 are weighting factors for ARS and GLR, respectively. Section IV-B analyses the sensitivity of γ_1 and γ_2 values. To give priority for the gateways with the lowest load the value of $1 - GLR$ is utilized instead of GLR. Eventually, the gateway with the highest score is chosen for data offloading as it has the lowest load and the best nearby road status.

$$ARS = \frac{\sum_{n=1}^{K}(RL_n * LRE_n)}{\sum_{n=1}^{K} RL_n} \quad (4)$$

$$GatewayScore = \gamma_1 * ARS + \gamma_2 * (1 - GLR) \quad (5)$$

D. Adaptive gateway advertisement

In hybrid gateway discovery, calculating the GA packets broadcast area is a critical issue. More precisely, broadcasting within a large area leads to the proactive gateway discovery side effects and increases the network overhead. On the other hand, selecting a small broadcast area results in more reactive accessing for gateways. In addition, high advertising frequency may cause network congestions, while low advertising frequency reduces the freshness of gateway information and may result in generating more REQUEST packets. However, the main purpose of gateway advertising is to deliver the most updated gateways information to the largest number of vehicles, while minimising the generated communication overhead. To enhance the gateway advertisement, TRADING adjusts the GA packets broadcast area and the generation frequency dynamically based on the network and traffic status of the roads in the vicinity of the gateway. Therefore, TRADING introduces the Adaptive Gateway Advertisement (Algorithm 2), which reduces network congestion as it copes with the variant network and traffic status of the roads in the gateway

Algorithm 1 TRADING Gateway Discovery and Selection

```
Require: The vehicle's gateway information table & available gateways positions
Ensure: The selected gateway based on gateways' load and nearby roads status
    Set Source = Current Vehicle
    Set Gateways = vectorofavailablegatewaysposition
    Set GatewayTable = Source.GatewayInformationTable
    Set StartGatewayDiscovery = true
    Set T_case2 = 0, T_case3 = 0
    Set REQUEST1 = first REQUEST sent to gateway
    Set REPLY1 = first REPLY received from a gateway
    Set HighestGatewayScore = 0
    Set SelectedGateway = null
for i = 1; i ≤ Gateways.size; i++ do
    if (hasDirectCommunication(Gateways[i], Source) == 1) then   /*Case1*/
        StartGatewayDiscovery = false
        startDirectV2ICommunications(Source, Gateways[i])
        break
    Endif
Endfor
if StartGatewayDiscovery then
    if GatewayTable.size > 0 then   /*Case2*/
        for i = 1; i ≤ Gateways.size; i++ do
            if Gateways[i] ∈ GatewayTable then
                GatewayAdv = GatewayTable.getRcvdAdv(Gateways[i])
                if GatewayAdv_travellingTime > T_case2 then
                    T_case2 = GatewayAdv_travellingTime
                Endif
            else
                sendREQUEST(Gateways[i])
            Endif
        Endfor
        waitAndReceiveREPLYs(2 * T_case2)
        update(GatewayTable)   /*using REPLYs information*/
        CallselectGateway
        Start multihop communications
    else   //Case3
        for i = 1; i ≤ Gateways.size; i++ do
            sendREQUEST(Gateways[i])
        Endfor
        waitForFirstREPLY( )
        T_case3 = REPLY1_arrivalTime − REQUEST1_generationTime
                  + REPLY1_travellingTime
        waitAndReceiveREPLYs(T_case3)
        update(GatewayTable)   /*using REPLYs information*/
        CallselectGateway
        Start multihop communications
    Endif
Endif
Function selectGateway
for i = 1; i ≤ GatewayTable.size; i++ do
    GLR = claculate GLR forGatewayTable[i]
    ARS = claculate ARS forGatewayTable[i]
    GatewayScore = γ1 * ARS + γ2 * (1 − GLR)
    if GatewayScore > HighestGatewayScore then
        HighestGatewayScore = GatewayScore
        SelectedGateway = GatewayTable[i]
    Endif
Endfor
ReturnSelectedGateway
```

neighbourhood. Algorithm 2 is explained in the following steps:

Step 1: The GA packets are broadcasted within the gateway transmission range. Then, vehicles that are not located in any gateway transmission range send REQUEST packets to the available gateways (line 5-7, Algorithm 2).

Step 2: Upon receiving a REQUEST packet, the gateway responds by sending back a REPLY packet, which carries the gateway IP address and its current load (i.e. gateway's GLR). In addition, the gateway records the LRE values, obtained from the PRE field of the received REQUEST or data packets, in its roads table to be used in calculating the ARS of the gateway VC area (line 8-15, Algorithm 2). ARS gives an indication of the gateway's nearby road status in terms of roads vehicular density and network connectivity. The higher the ARS value the better the network and traffic conditions are in the gateway vicinity.

Step 3: Based on the roads status values collected during the current advertisement interval, each gateway calculates the ARS of the recorded road evaluations in its VC area utilizing Equation 4. The calculation is done at the end of each gateway advertisement interval (line 17-18, Algorithm 2).

Step 4: By exploiting the calculated ARS value, the new broadcast area can be calculated based on Equation 6, where VC_{area} is the gateway's virtual coverage area. As a result, the higher the average road score the larger the broadcast area. In fact, high average roads score is an indication for high vehicular density with low network load on the considered roads. Therefore, extending the broadcast area in a proportional way to the average roads score ensures that a larger number of vehicles receive the GA packets. The broadcast area calculation is repeated after each advertisement cycle to adapt to changes in network conditions. In case the gateway's nearby roads have low vehicular densities or overloaded network, the GA broadcast area is reduced dynamically. Accordingly, the maximum broadcast area is equal to VC area, while the minimum broadcast area is set to the gateway transmission coverage.

$$Broadcast_{area} = VC_{area} * ARS \tag{6}$$

Step 5: The next advertisement interval time (i.e. advertisement frequency) is calculated using Equation 7 based on the road scores proportionally. The value of $Broadcast_{interval\ initial}$ is assigned based on the simulation parameter values listed in Section IV. Thus, the higher the average scores of gateway's nearby roads, the longer the broadcast interval. As a matter of fact, the higher the ARS value the higher the vehicular density on gateway's nearby roads, which has low density variation rate as well. In addition, large ARS value leads to advertising over a large broadcast area. Thereby, increasing the broadcast interval in a proportional way to ARS values reduces the effect of broadcast storms, especially with a large broadcast area and high vehicular density. Moreover, as large ARS value indicates lower vehicular density variation rates, short broadcast intervals are not required in such a case. The advertisement interval calculation is repeated after each advertisement cycle based on the updated road status information collected from received REQUEST and data packets.

$$Broadcast_{interval} = Broadcast_{interval\ initial} * ARS \tag{7}$$

E. Multi-hop Data Offloading

The multi-hop communication is provided based on the RTAR protocol introduced in [26], [27], which is exploited for sending REQUEST, REPLY and data packets between gateways and vehicles when direct communication is not possible. RTAR provides reliable and lightweight packet forwarding that adapts to traffic conditions. For instance, to send a REQUEST to targeted gateway, intermediate vehicles forward the packet which are chosen on hop-by-hop base while applying the routing algorithm of RTAR. Once the packet

Algorithm 2 TRADING- Adaptive gateway Advertising

Require: DigitalMap (DM), VC area of gateway, received LRE information through REQUEST or data packets

Ensure: Advertise gateway in calculated broadcast area and interval

Set $Broadcast_{interval} = GatewayAdvertisement_{interval}$ $/*The\ default\ value = 3seconds*/$

Set $LRE = 0,\ RL = 0$

Set $Broadcast_{area} = Gateway_{transmission\ range}$

1: $Include\ Broadcast_{area}\ in\ new\ GA$
2: $Update\ thenew\ GA\ with\ gateway\ information$
3: $Broadcast\ GA\ packets$
4: **while** $Broadcast_{interval}$ not over **do**
5: $\quad Received_{PRE} += REQUEST_{PRE}$
6: $\quad Received_{PRE} += DATA_{PRE}$
7: **Endwhile**
8: **for** $i = 1; i \leq Received_{PRE}.size; i++$ **do**
9: $\quad LRE += Received_{PRE}[i].LRE$
10: $\quad RL += DM.getRoadsLength(Received_{PRE}[i].RoadIDs)$
11: **Endfor**
12: $\quad /*CalculatestheAverageRoadsScoreforpassedroads----*/$
13: $k = RL.size$
14: $ARS = \frac{\sum_{n=1}^{K} RL_n * LRE_n}{\sum_{n=1}^{K} RL_n}$
15: $Broadcast_{interval} = Broadcast_{interval\ initial} * ARS$
16: $Broadcast_{area} = VC_{area} * ARS$
17: **Go To line:5**

reaches a vehicle which has direct communication with the targeted gateway, it is sent directly to the gateway interface. On the other hand, to send a REPLY packet, the gateway selects one of its neighbour vehicles as the first intermediate node for handling the packet forwarding. Afterwards, the selected neighbour vehicle performs V2V multi-hop routing based on RTAR protocol to deliver the packet to the destination vehicle.

RTAR is used to perform the V2V multi-hop communication for four reasons. First, RTAR provides reliable and lightweight packet forwarding that adapts to traffic conditions. Basically, it selects the next-hop based on roads structure, neighbours predicted positions and their received signal strength, and the recentness of the mobility information received from neighbours. Second, as an intersection-based routing, it makes its routing decision when the packet reaches an intersection area to choose the best next road for forwarding based on the intersection's adjacent roads' LRE values. Therefore, it is more suitable for city environment than full path routing [4]. Third, by using RTAR to forward a REQUEST, a REPLY or a data packet, whenever the packet passes an intersection RTAR records the LRE values of the intersection's adjacent roads in the PRE field. Thus, the values in PRE are used to know the road and network status of not only specific routes but also the roads adjacent to the packet route. As mentioned in section III-C, the LRE values saved in PRE field are used to calculate the ARS using Equation 4. Fourth, since vehicles availability affects routing [29], RTAR protocol evaluates roads status by utilizing the Real-time Traffic and Network Status Measurement (RTNSM) process introduced in our previous work [26]. At intersections, the RTNSM provides the LRE values that represent the real-time traffic and network status of an intersection's adjacent roads. The LRE values are used by RTAR to calculate a score for each road and the scores are used to make routing decisions.

The main idea of RTNSM is based on creating and forwarding control packets between each two consecutive intersections to evaluate the road status in terms of both direction vehicular density, inter-vehicle communication link lifetime among neighbours, and the road's network load, which provides a comprehensive lightweight road evaluation (LRE). Afterwards, the LRE values of each intersection's adjacent roads are announced at the intersection area to be available for routing purposes. The RTNSM process evaluates roads when changes in roads status are expected to occur, resulting in detecting and reflecting the roads real-time status more accurately with minimised network overhead [26].

IV. Performance evaluation

TRADING approach performance in accessing gateways over multi-hop communications for data offloading is evaluated against FLAGAD and GeoNet gateway access schemes in terms of data offloading success ratio, gateway access overhead, data offloading delay and load distribution among gateways. The data offloading success ratio refers to the fraction of generated data packets that are successfully offloaded to the selected gateway. The gateway access overhead refers to the ratio between the number of transmitted bytes of REQUEST, REPLY and GA packets, and the accumulative number of bytes of delivered data, REQUEST, REPLY and GA packets. For instance, 20% gateway access overhead means that 20% of the transmitted bytes in the network are coming from the REQUEST, REPLY and GA packets. The data offloading delay refers to the average time that a data packet takes to traverse the network while being delivered from a source vehicle to a gateway. Load distribution among gateways measures the percentage of load that each gateway is handling in comparison to the summation of all gateways load. The following section explains the evaluation environment. Afterwards, the sensitivity analysis of the weighting factors is carried out followed by a discussion of TRADING performance with respect to each of the aforementioned evaluation metrics.

A. Evaluation environment

To evaluate TRADING performance, comparisons with the most relevant existing schemes is carried out using OMNET++ 4.6 as a network simulation environment along with SUMO for urban traffic mobility simulation. The two simulators are integrated to work simultaneously using the Veins framework.

The simulation scenarios are applied on part of Manhattan city map shown in Figure 2 (latitude: 39.1912 to 39.1839 and longitude: −96.5737 to −96.5629). The map data and structure is obtained from OpenStreetMap contributions (the blue doted lines represent the VC areas borders, the black semicircles around RSUs represent the RSU's transmission range, and the blurred texts are the streets names). The area of simulation map has 112 bidirectional roads and 64 intersections. The real traffic regulations (e.g. traffic lights, speed limits and traffic priorities), which are applied in that part of Manhattan city, are also considered in the vehicular traffic simulation. In the conducted simulations, it is assumed that all vehicles are equipped with communication devices. Table I demonstrates the simulation parameters utilized to evaluate TRADING scheme performance. The used data transmission rates (DTR) simulate a delay sensitive data transmission (e.g. VoIP), which has three transmission rates (20 ms, 40 ms, 60

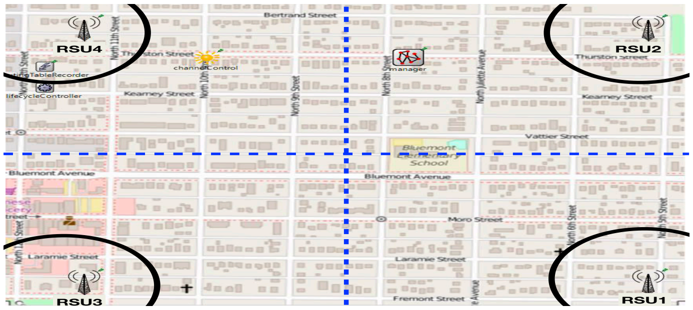

Fig. 2. Part of Manhattan city map considered for TRADING evaluation

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Simulation area	2000 m × 2000 m
Simulation time	400 seconds
Mobility model	Car following model
Vehicular Density	High density (40-50 vehicle/km/lane) Average density (13-16 vehicle/km/lane) Low density (6-8 vehicle/km/lane)
Maximum vehicle speed	60 km/sec
Beacon interval	1 second
Number of Gateways	4
Gateways $Broadcast_{interval\ initial}$	3 seconds
MAC layer protocol	IEEE 802.11p
Transport layer protocol	UDP
Network layer protocol	IPv6
Transmission range	300 m
Channel capacity	18 Mbps
Number of CBR connections	4-32

ms) with three different payload sizes (160 bytes, 320 bytes, 480 bytes). The parameters values in Table I are assigned based on the values used in [20], [25], [26]. The constant bit rate (CBR) encoding method is used as it provides faster data packets encoding while transmitting [30].

The relevant schemes to TRADING are FLAGAD [25] and GeoNetwork gateway access [20], which are used for comparison purposes. The reason behind choosing FLAGAD for benchmarking is that it exploits hybrid gateway discovery with dynamic gateway advertisement area, which makes it very relevant to TRADING. In addition, GeoNetwork gateway access is considered as a second benchmark as it broadcasts gateway advertisement within fixed geographical areas, where geographical routing is employed for V2I communications. In the following subsections, the labels (a), (b) and (c) of the sub-figures refer to the utilized DTRs in the simulations of each sub-figure.

Three scenarios are considered to evaluate the performance of TRADING in high, average and low vehicular densities environments. In fact, high vehicular density increases the proactive gateway access overhead due to the broadcast of GA packets among a large number of vehicles. On the other hand, high vehicular density means that a large number of vehicles need gateways information. However, high vehicular density reduces the speed of vehicles mobility resulting in lower vehicular traffic variation rate, which requires less frequent GA broadcasting. In contrast, low vehicular density allows vehicles to move faster, which requires more frequent GA broadcasting. In addition, less number of vehicles are requesting for gateway information in low vehicular density scenario. The following subsections discuss and analyse TRADING performance based on the considered evaluation metrics.

B. Sensitivity Analysis of Weighting Factors

The effect of using different weighting factor values while calculating gateways scores is analysed in this section. Equation 5 formulates the gateway score calculation, which combines the values of ARS and GLR of the evaluated gateway based on the weights γ_1 and γ_2. Basically, the weighting factors specify the percentage of the contribution that each component represents in the gateway score calculation. Therefore, the summation of the contribution percentages that γ_1 and γ_2 specify must equal to 100% (i.e. $\gamma_1 + \gamma_2 = 1$).

As there are no optimal ratios to be assigned to γ_1 and γ_2 which gives the best gateway access performance in all scenarios. Therefore, the sensitivity analysis for γ_1 and γ_2 ratios is conducted to study the effects of these weighting factors on the performance of TRADING. Three different weighting factor configurations are evaluated in this section. The first configuration is TRADING(0.2,0.8) which favours gateways load as a metric for selecting gateways by assigning $\gamma_1 = 0.2$ and $\gamma_2 = 0.8$. The second configuration is TRADING(0.5, 0.5), where gateways loads and the status of roads nearby them are treated equally while making the gateway selection decision ($\gamma_1 = \gamma_2 = 0.5$). The third configuration TRADING(0.8,0.2) studies the effect of favouring gateways' nearby roads status ($\gamma_1 = 0.8$ and $\gamma_2 = 0.2$). The three considered configurations are evaluated in terms of data offloading success ratio, data offloading delay and load distribution standard deviation in high and low vehicular density scenarios, as shown in Figure 3 and 4, and Table II.

The results of TRADING performance are obtained by carrying out experiments in the same simulation environment explained in section IV. It can be observed that TRADING(0.8,0.2) configuration provided the best performance in terms of data offloading success ratio and data offloading delay in both high and low vehicular density scenarios. The reason behind such performance is that TRADING(0.8,0.2) configuration gives preference to the gateways' nearby roads status while selecting a gateway, which results in significant improvements in the routing and packet delivery performance, especially in low vehicular density situations. Table II shows the standard deviation of load distribution among gateways, where TRADING(0.2,0.8) configuration achieved the lowest deviation due to the more balanced network load distribution that it imposes.

Based on the conducted sensitivity analysis, it can be deduced that TRADING performance with different configurations of γ_1 and γ_2 is not sensitive to changes in traffic status (vehicular density). The first configuration resulted in the highest load balancing among gateways with low offloading success ratio and high delays compared to the other configurations. The third configuration resulted in the poorest load balancing among gateways while providing the highest offloading success ratio and the lowest delays in

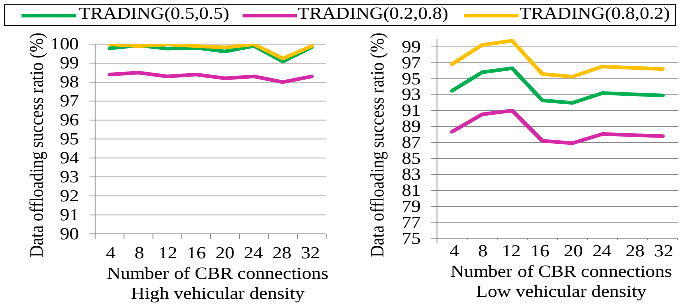

Fig. 3. Data offloading success ratio with various number of CBR connections under different TRADING configurations

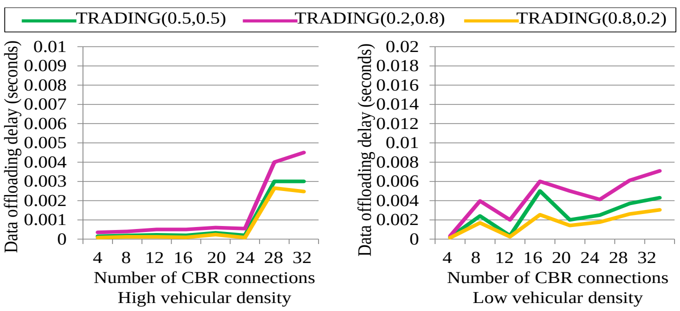

Fig. 4. Data offloading delay for various number of CBR connections under different TRADING configurations

comparison to the other configurations. To give equal consideration for gateways' load balancing and the performance of data offloading (i.e. offloading success ratio and delay) the second configuration, TRADING(0.5, 0.5), is considered in all subsequent simulations. However, in TRADING real-life implementation the weighting factors configuration can be adjusted based on the requirements that need to be considered in the data offloading process. For example, if offloading data successfully in a short time has higher priority than balancing loads among gateways, then the third configuration TRADING(0.8,0.2) should be used.

C. Gateway Access Overhead

The aim of this evaluation is to show how successfully TRADING mitigated the gateway access overhead by adapting to network conditions. Figures 5, 6 and 7 depict the percentage of generated gateway access overhead in high, average and low vehicular density scenarios respectively, where TRADING generates the lowest gateway access overhead in comparison to existing schemes. In particular, average reductions of 79.94%, 84.95% and 81.655% are achieved by TRADING as compared to existing schemes in high, average and low vehicular densities. Based on the analysis of obtained results, it can be concluded that the highest reduction is in the average vehicular density scenario.

TABLE II
TRADING CONFIGURATIONS STANDARD DEVIATION OF LOAD DISTRIBUTION

Configuration	Load distribution standard deviation	
	High density	Low density
TRADING(0.2,0.8)	0.71	0.71
TRADING(0.5,0.5)	1.0	1.0
TRADING(0.8,0.2)	1.58	1.42

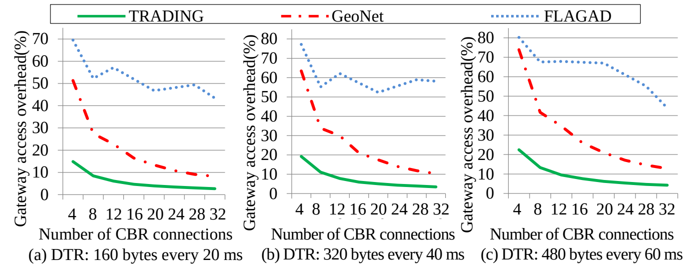

Fig. 5. Gateway access overhead in high vehicular density scenario

Unlike the existing schemes, the gateways adopting TRADING scheme collect information about the network and traffic status of their nearby roads, which is received through REQUEST and data packets. Afterwards, the collected information is utilized to adapt the GAs broadcast area and interval dynamically, in order to achieve the objective of delivering the GA packets to the largest number of vehicles with the lowest network overhead. For instance, in high vehicular density scenario, increasing the broadcast area and interval of gateway advertisements leads to delivering GAs packets to the largest number of vehicles, while generating low network overhead. When the vehicular density and network connectivity of the gateways' nearby roads is low, GAs are broadcasted in a small area with higher frequency as vehicles tend to leave that area rapidly. In addition, vehicles located outside the broadcast area, which are few in number, can access gateways through sending REQUEST packets. Consequently, unnecessary broadcast over a large area is avoided to free the short lifetime communication links between vehicles for data transmissions.

When the number of gateways increases, vehicles will attempt to discover more nearby gateways which may create extra network overhead. However, TRADING's adaptive gateway advertising algorithm does not increase the gateway advertisement with the increment in number of gateways. This is because the area between gateways is divided to non-overlapping VC areas which represent the maximum broadcast area for each gateway. Thus, the GAs broadcast area of each gateway decreases when there are more gateways. In addition, each gateway adjust its broadcast area based on the network and traffic status in its neighbourhood. However, the only overhead increment comes from the REQUEST/REPLY messages sent to the gateways that the vehicle cannot receive their GAs. On the other hand, FLAGAD is expected to experience high network overhead with the increment in number of gateways. This is due to using unrestricted GA broadcast area by each gateway in addition to the increase in REQUEST/REPLY messages. For GeoNet the overhead is independent of the number of gateways but this comes with the price of not allowing vehicles to access any gateway other than the one in their associated geographical area. Moreover, GeoNet does not adjust its broadcast area based on traffic and network status which results in high network overhead especially in high vehicular density situations.

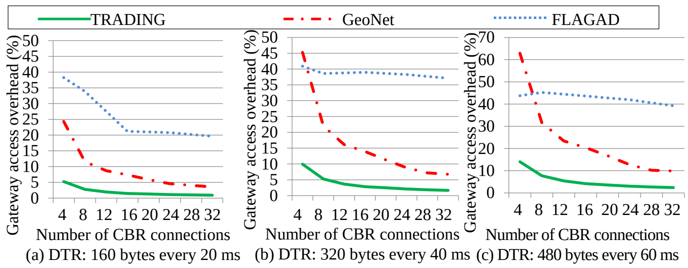

Fig. 6. Gateway access overhead in average vehicular density scenario

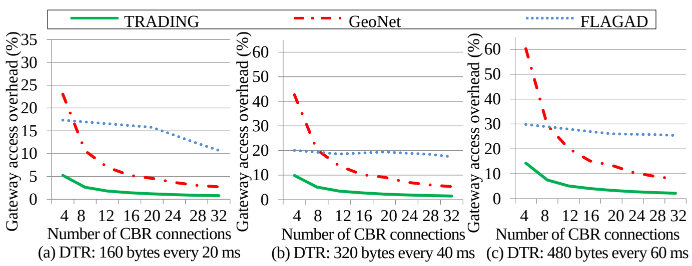

Fig. 7. Gateway access overhead in low vehicular density scenario

D. Load Distribution Among Gateways

This subsection discusses the performance of TRADING and FLAGAD in terms of load distribution among gateways, where three different vehicular density scenarios are considered. The GeoNet gateway access was not considered in this section because it does not apply any load balancing mechanism and depends solely on vehicles distribution. Figure 8, illustrates the load distribution among gateways for the three vehicular density scenarios i) High, ii) Average and iii) Low, while considering a randomly chosen 32 CBR connections. The red bars represent the percentage of requester vehicles in each VC area (i.e. geographical distribution of vehicles). In particular, in the high vehicular density scenario, the largest number of requester vehicles are located within *RSU1* VC area, while the lowest number of requesters are located within *RSU4* VC area. For the average vehicular density scenario, requester vehicles are distributed equally among gateways VC areas. However, in the low vehicular density scenario, the lowest number of requesters are located within *RSU2* VC area.

To evaluate the impact of load balancing among gateways, the standard deviation of load distribution is calculated for each scheme in the three different vehicular density scenarios, as shown in Table III. It is obvious that TRADING achieved higher load balancing among gateways in all scenarios in comparison with FLAGAD, as the standard deviation values of TRADING are smaller than FLAGAD. The reason behind such improvement is that TRADING considers the network load on the gateway's nearby roads, as highly loaded network in the gateway vicinity is another indication for the high number of requester vehicles in that area. However, TRADING does not consider network load on specific routes as measured in FLAGAD, instead, it considers the load in a wider area around the gateway. In addition, FLAGAD might avoid accessing some gateways just because of the high network load on the routes leading to them, which is mainly generated while discovering or advertising gateways. Unlike FLAGAD, TRADING reduced the gateway access network overhead, which reduces the chance of avoiding accessing certain gateways just because of the discovery network overhead generated in their vicinities.

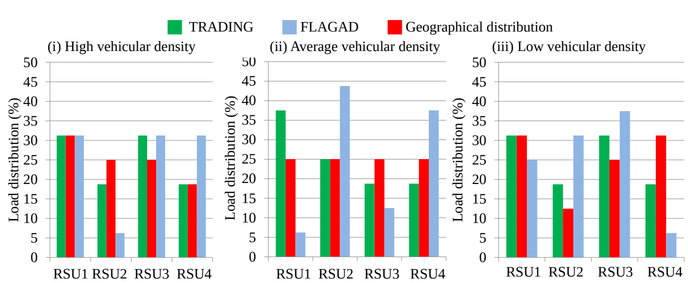

Fig. 8. Load distribution among gateways

TABLE III
THE STANDARD DEVIATION OF LOAD DISTRIBUTION AMONG GATEWAYS

Scheme	Load distribution standard deviation		
	High density	Average density	Low density
TRADING	1.0	1.23	1.0
FLAGAD	1.73	2.55	1.87

E. Data Offloading Success Ratio

Figure 9 depicts the behaviour of TRADING, GeoNet gateway access and FLAGAD in the scenario of high vehicular density, while considering different numbers of CBR connections. It is obvious that TRADING has achieved distinguished performance in comparison to the existing schemes in terms of data offloading success ratio. For the average vehicular density scenario, Figure 10 illustrates the performance of the three simulated schemes. It is clear that TRADING maintained a high performance in comparison to the existing schemes, especially with the data transmission rate (c). Figure 11 demonstrates the effect of low vehicular density on the performance of the three simulated schemes. Obviously, TRADING still has higher data offloading performance in comparison to existing schemes even in low vehicular density situations.

Based on the obtained results, the highest improvement was in the high and average vehicular density scenarios. This is because TRADING mitigated the effect of gateway discovery overhead, thereby network congestion and transmission contention are reduced. In contrast, existing schemes suffer the effects of the relatively high gateway access overhead and the low reliability in routing, which lead to poor data offloading performance. In the low vehicular density scenario, TRADING performance is still high. Due to TRADING's traffic awareness, it not only considers load balancing while selecting a gateway for V2I communications, but also takes the vehicular traffic density and network connectivity on gateways' nearby road into consideration. This performance clearly shows the effect of traffic awareness in selecting and accessing a gateway for data offloading. In addition, TRADING routes data packets utilizing RTAR protocol which increases V2V communication reliability, thereby resulting in higher data offloading success ratio.

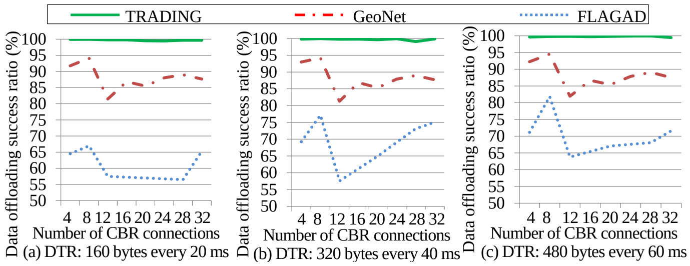

Fig. 9. Data offloading success ratio in high vehicular density scenario

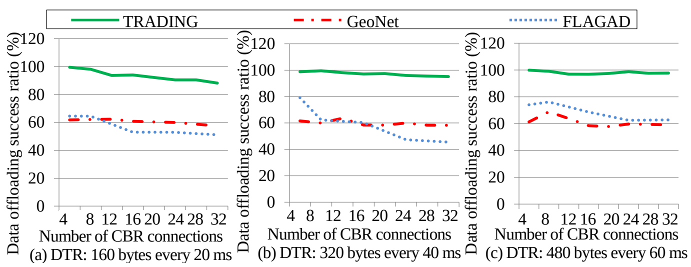

Fig. 10. Data offloading success ratio in average vehicular density scenario

There are several reasons behind the low data offloading success ratio of FLAGAD and GeoNet. First, FLAGAD and GeoNet produce high network overhead causing network congestions and high contention on communication channels, which affects the data offloading success. Second, FLAGAD and GeoNet do not consider the network and traffic status on the roads of the selected gateway's vicinity which may result in offloading data to a gateway that does not have good multi-hop communication towards it. Third, the routing protocols used by FLAGAD and GeoNet do not consider network and traffic conditions while forwarding packets which leads to low packet delivery ratio due to poor adaptation to the variable traffic and network conditions while forwarding packets.

F. Data Offloading Delay

This subsection investigates the end-to-end delay consumed by TRADING, GeoNet and FLAGAD to deliver data packets between vehicles and gateways, where different vehicular density scenarios are considered with the three traffic patterns (a), (b) and (c). The aim of this evaluation is to show the impact of TRADING on the data packet delivery time in comparison to the benchmark schemes.

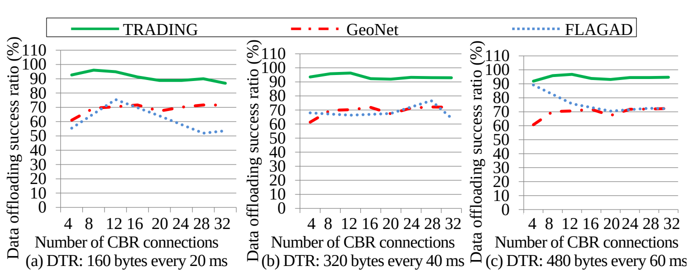

Fig. 11. Data offloading success ratio in low vehicular density scenario

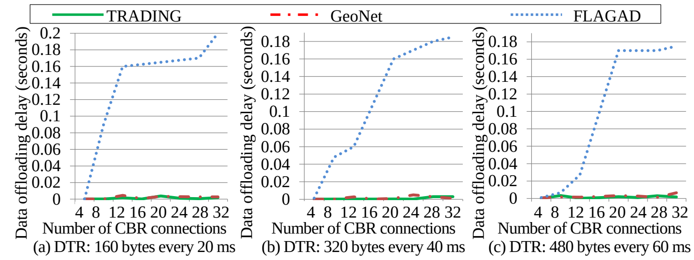

Fig. 12. Data offloading delay in high vehicular density scenario

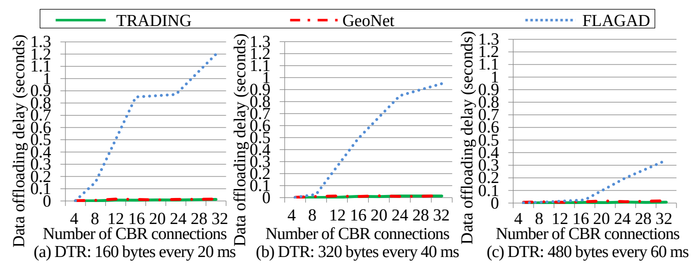

Fig. 13. Data offloading delay in average vehicular density scenario

Figure 12, 13, and 14 show the average end-to-end delay in high, average, and low vehicular density scenarios, respectively. In comparison to FLAGAD, TRADING achieved an average overall reduction of 98.39% in end-to-end delay, which is based on the results analysis of the different vehicular density scenarios in Figure 12, 13 and 14. However, the highest reduction is in the high vehicular density scenario. This is due to selecting a gateway based on its network load and its neighbourhood roads status. In addition, utilizing the forwarding protocol RTAR, which is based on unicast routing instead of the contention based forwarding utilized by FLAGAD reduces the end-to-end delay. In comparison to GeoNet, TRADING achieved a 2% average reduction in offloading delays even though in some situations TRADING and GeoNet have approximately equal end-to-end delay. However, TRADING provides a very high offloading success ratio as compared to GeoNet (as explained in section IV-E). In fact, GeoNet tends to forward data packets through the shortest paths, and TRADING might increase the number of hops by selecting the best status roads instead of the shortest. However, as TRADING chooses roads with the lowest load and best connectivity for forwarding, the end-to-end delay is not increasing even with longer routing distances. In addition, the high reductions in the gateway access overhead free the communication links to offload data more reliably. It is obvious that TRADING delivers data packets in a more reliable way and faster than the other schemes, which makes it more suitable to serve the real-time big data ITS applications.

V. CONCLUSIONS

In this article, we present a traffic aware data offloading approach for big traffic data centric ITS applications, to enhance the gateway selection for data offloading and mitigate the gateway advertisement network overhead. Gateways are evaluated based on their network load and the roads status

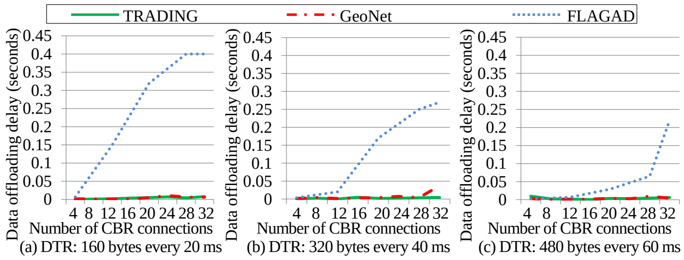

Fig. 14. Data offloading delay in low vehicular density scenario

in their vicinity, and the advertisement is adapted based on the vehicular density and network status on the gateway's nearby roads. Results show the advantage of TRADING in terms of reduced data offloading delays and network overhead, increased data offloading success ratio, and balanced load among gateways. Our next step is to evaluate TRADING using real big data sets obtained through vehicular networks to further investigate the reliability and efficiency of TRADING in data acquisition in ITS environments.

ACKNOWLEDGMENT

This work has been done under the Post-doctoral Fellowship Scheme of Universiti Teknologi Malaysia for the project: "Vehicular fog computing resource allocation scheme for real-time big data processing in intelligent transportation systems"

REFERENCES

[1] L. Farhan, R. Kharel, O. Kaiwartya, M. Quiroz-Castellanos, A. Alissa, M. Abdulsalam, A concise review on internet of things (iot)-problems, challenges and opportunities, in: 2018 11th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP), IEEE, 2018, pp. 1–6.
[2] M. Chowdhury, A. Apon, K. Dey, Data Analytics for Intelligent Transportation Systems, Elsevier, 2017.
[3] A. Aliyu, A. H. Abdullah, O. Kaiwartya, Y. Cao, M. J. Usman, S. Kumar, D. Lobiyal, R. S. Raw, Cloud computing in vanets: architecture, taxonomy, and challenges, IETE Technical Review 35 (5) (2018) 523–547.
[4] T. Darwish, K. Abu Bakar, Traffic aware routing in vehicular ad hoc networks: characteristics and challenges, Telecommunication Systems 61 (3) (2016) 489–513.
[5] F. Malandrino, C.-F. Chiasserini, S. Kirkpatrick, The impact of vehicular traffic demand on 5g caching architectures: A data-driven study, Vehicular Communications 8 (2017) 13–20.
[6] R. Lacuesta, J. Gallardo, J. Lloret, G. Palacios, Integration of data from vehicular ad hoc networks using model-driven collaborative tools, Mobile Information Systems 2016.
[7] M. A. Amin, S. Hadouej, T. S. J. Darwish, Big data role in improving intelligent transportation systems safety: A survey, in: Advances in Internet, Data and Web Technologies, Springer International Publishing, Cham, 2019, pp. 187–199.
[8] T. S. J. Darwish, K. A. Bakar, Fog based intelligent transportation big data analytics in the internet of vehicles environment: Motivations, architecture, challenges and critical issues, IEEE Access 6 (2018) 1–1.
[9] A. Aliyu, A. H. Abdullah, O. Kaiwartya, Y. Cao, J. Lloret, N. Aslam, U. M. Joda, Towards video streaming in iot environments: Vehicular communication perspective, Computer Communications 118 (2018) 93–119.
[10] N. Kumar, J. J. Rodrigues, J. Lloret, A. Dua, Replication-aware data dissemination for vehicular ad hoc networks using location determination, Mobile Networks and Applications 20 (2) (2015) 251–267.
[11] A. Daniel, K. Subburathinam, A. Paul, N. Rajkumar, S. Rho, Big autonomous vehicular data classifications: Towards procuring intelligence in its, Vehicular Communications.
[12] A. Aliyu, A. H. Abdullah, O. Kaiwartya, F. Ullah, U. M. Joda, A. N. Hassan, Multi-path video streaming in vehicular communication: Approaches and challenges, in: 2017 6th ICT International Student Project Conference (ICT-ISPC), IEEE, 2017, pp. 1–4.
[13] Y. Xiao, C. Zhu, Vehicular fog computing: Vision and challenges, in: Pervasive Computing and Communications Workshops (PerCom Workshops), 2017 IEEE International Conference on, IEEE, 2017, pp. 6–9.
[14] N. Lu, N. Zhang, N. Cheng, X. Shen, J. W. Mark, F. Bai, Vehicles meet infrastructure: Toward capacity-cost tradeoffs for vehicular access networks, IEEE Transactions on Intelligent Transportation Systems 14 (3) (2013) 1266–1277.
[15] F. Malandrino, C. Casetti, C. F. Chiasserini, M. Fiore, Optimal content downloading in vehicular networks, IEEE Transactions on Mobile Computing 12 (7) (2013) 1377–1391.
[16] G. S. Aujla, R. Chaudhary, N. Kumar, J. J. Rodrigues, A. Vinel, Data offloading in 5g-enabled software-defined vehicular networks: A stackelberg-game-based approach, IEEE Communications Magazine 55 (8) (2017) 100–108.
[17] K. Ju, L. Chen, H. Wei, K. Chen, An efficient gateway discovery algorithm with delay guarantee for vanet-3g heterogeneous networks, Wireless Personal Communications 77 (3) (2014) 2019–2036.
[18] C. T. Ngo, H. Oh, A gateway discovery approach using link persistence based connected dominating sets for vehicular ad hoc networks, in: Ad-hoc, Mobile, and Wireless Network, Springer, 2013, pp. 305–316.
[19] V. Sandonis, M. Calderon, I. Soto, C. J. Bernardos, Design and performance evaluation of a pmipv6 solution for geonetworking-based vanets, Ad Hoc Networks 11 (7) (2013) 2069–2082.
[20] V. Sandonis, I. Soto, M. Calderon, M. Urueña, Vehicle to internet communications using the etsi its geonetworking protocol, Transactions on Emerging Telecommunications Technologies 27 (3) (2016) 373–391.
[21] K. Shafiee, V. C. M. Leung, Connectivity-aware minimum-delay geographic routing with vehicle tracking in vanets, Ad Hoc Netw. 9 (2) (2011) 131–141.
[22] X. Zhu, J. Bi, M. Li, H. Liu, Adaptive video streaming uploading with moving prediction in vanets scenarios, in: IEEE International Conference on Networking, Architecture and Storage (NAS), 2015, pp. 39–44.
[23] N. Aljari, K. Abrougui, M. Almulla, A. Boukerche, A reliable and robust gateway discovery mechanism for vehicular ad hoc networks, in: Proceedings of the 10th ACM International Symposium on Mobility Management and Wireless Access, MobiWac '12, ACM, New York, NY, USA, 2012, pp. 121–124.
[24] N. Aljeri, K. Abrougui, M. Almulla, A. Boukerche, A performance evaluation of load balancing and qos-aware gateway discovery protocol for vanets, in: 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA), 2013, pp. 90–94.
[25] N. Aljeri, K. Abrougui, M. Almulla, A. Boukerche, A reliable quality of service aware fault tolerant gateway discovery protocol for vehicular networks, Wireless Communications and Mobile Computing 15 (10) (2015) 1485–1495.
[26] T. Darwish, K. A. Bakar, Lightweight intersection-based traffic aware routing in urban vehicular networks, Computer Communications 87 (2016) 60 – 75.
[27] T. S. J. Darwish, K. A. Bakar, K. Haseeb, Reliable intersection-based traffic aware routing protocol for urban areas vehicular ad hoc networks, IEEE Intelligent Transportation Systems Magazine 10 (1) (2018) 60–73.
[28] A. Fonseca, T. Vazão, Applicability of position-based routing for vanet in highways and urban environment, Journal of Network and Computer Applications 36 (3) (2013) 961–973.
[29] T. Darwish, K. A. Bakar, Traffic density estimation in vehicular ad hoc networks: A review, Ad Hoc Networks 24 (2015) 337 – 351.
[30] G. D. Kondylis, S. V. Krishnamurthy, S. K. Dao, G. J. Pottie, Multicasting sustained cbr and vbr traffic in wireless ad-hoc networks, in: 2000 IEEE International Conference on Communications. ICC 2000. Global Convergence Through Communications. Conference Record, Vol. 1, 2000, pp. 543–549 vol.1.