

Street Parked Vehicles Based Vehicular Fog Computing: TCP Throughput Evaluation and Future Research Direction

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Abstract—With the rapid technological advancement, the On-board Units (OBUs) in vehicles are becoming powerful. Besides supporting infotainment and managing vehicle safety, researchers are envisioning that the OBUs of vehicles would be able to offering a utility model of computing (i.e. processing power and storage as a service) to the end users residing in access network segment. Such an ambitious approach seems to be very realistic. The vehicles together with dedicated Fog-computing facility will leverage the computational and storage ability significantly. Some studies impart that 95% time of throughout a day vehicles are remained parked. In some recent research efforts, parked vehicles have been considered as a part of Fog-computing infrastructure—they have been referred as Vehicular Fog Computing (VFC) facility. In this paper, we aim at evaluating TCP throughput performance in a VFC facility. We consider AODV, DSR and AOMDV in our performance evaluation conducted using NS-2 simulator. For the mobility model as an input in the simulator, we consider SUMO generated traffic mobility traces. Findings based on simulation demonstrate that AODV offers the highest throughput among the compared protocols. Aside from this, in this paper, we provide insightful discussion that would open up new research avenues in order to improve performance of TCP in a VFC.

Index Terms—Vehicular fog computing, MANET, Fog-computing, DSR, AODV, AOMDV.

I. INTRODUCTION

Recent trending computer paradigm is pushing computation and storage resources to the edge of network which motivates the promising future of fog computing as a result of prevalence of connected smart devices that relies on cloud services. Data and computation will be in close proximity to end users at the edge layer, thereby providing newer applications and services with low latency, high bandwidth, and geo-locatable. Facilities that provides these services are called fog nodes. Two kinds of fog nodes available at fog layer: (1) resourceful servers and (2) resource-poor infrastructures such as vehicles, gateways, smart TV and other end devices [1].

We have witnessed major technological advancement in vehicles over the last decades. Nowadays almost all the vehicles are equipped with several sensors and on board

computing capability. The vehicles with advanced capabilities such as auto pilot and self-parking require significant amount of computing capacity. This technological advancement allows us to reap the immense opportunity that future vehicles could offer in fostering capacity of edge computing. Along with facilitating inter-vehicle and vehicle to Road Side Unit (RSU) communication (forming Vehicular ad-hoc networks), the On-board Unit (OBU) of future vehicle would serve as mobile servers providing opportunity to process and store information.

The number of vehicles annually are indefinitely increasing and on average, vehicles remain parked up to 95% of the time [2]. Parked vehicles are characterized by their static, localised and immobile nature for such prolonged time where newer vehicle models are equipped with newer technological devices and sensors that have computing power which would be wasted if this energy and resourceful source is not tapped for both economic and networking opportunities. To leverage the potential benefits of parked vehicles in Vehicular Ad-Hoc Network (VANET), the OBUs in newer vehicles can be exploited to make parked vehicles both as a Wi-Fi AP and computational hub. This provides Internet access to nearby moving vehicles or people equipped with mobile devices. And allow them enjoy services such as video streaming, web browsing, location sharing services, multimedia files rendering, and file transfer.

Several features that have increased the niche of having parked vehicles to provide similar or better benefits in comparison with mobile vehicles in the areas of communication and computation [3]. Figure 1 shows parked vehicles in on-street parking setting where each individual vehicle is configured as a Vehicular Fog Computing (VFC) infrastructure. One of the benefits of using parked vehicles with OBUs is integration of parked vehicles as RSUs to support urban vehicular networks for routing data traffic such as safety messages broadcast to nearby vehicles of congested road due to dense vehicle density [4]. This may potentially avoid the expense of deploying newer infrastructure based RSU as parked vehicles may also work in

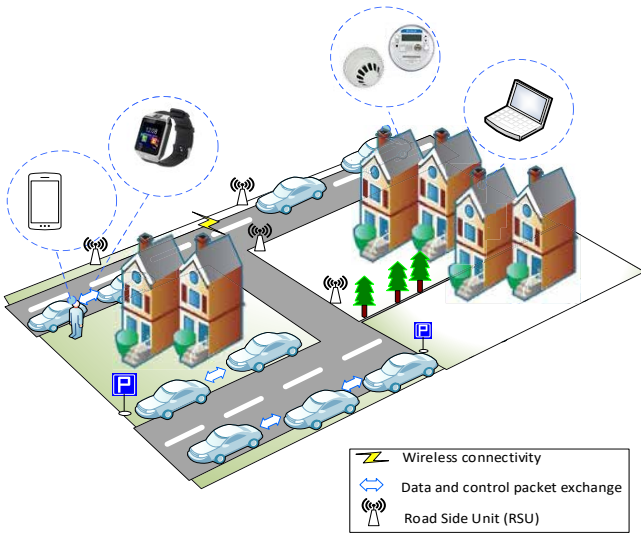


Fig. 1. Vehicular Fog Computing (VFC) facility supporting numerous applications in customer premises.

conjunction with existing RSUs.

According to [6] and [7], fog computing is a highly virtualised platform that aims at bringing computational and storage capacity at the edge and access segment of a network in order to serve the applications that have stringent latency requirement. There are growing efforts both in research and development domains where the use of parked vehicles in fog computing provides impactful benefits to the future of distributed networking. The most important ambitions of the Tactile Internet is to transmit touch within perceived real-time in order to ensure haptics equipment provides desired performance [5]. In realizing Tactile Internet service, fog computing may play significantly important role as it pushes computational power close to the end users' devices.

The subsequent part of this paper is organized as follows: Section II presents the related works in this field and Section III elaborates on the simulation setup of the study. The results and discussions are explained in Section IV and finally the conclusions are presented in Section V.

II. RELATED WORK

During the last decade, VANET has brought significant attention from the researchers of industries and academia. Consequently, a good number of research works have been conducted to evaluate the performance of network traffic under different conditions (e.g. [8], [9]).

Authors in [8] studied UDP performance when AODV, AOMDV and DSR routing protocols are used in V2V for city scenario using NS-2. Based on SUMO generated trace, three performance metrics are analysed: Throughput, Normalized Routing Load and Packet Loss under increasing node density. Result shows that DSR has the better performance compared to AODV and AOMDV as node density increases in city scenario.

Authors in [9] investigated the performance of AODV, AOMDV, DSR, and DSVD routing protocols using 802.11p in VANET. The authors utilized NS-2 simulator to examine the Packet Delivery Ratio (PDR), average end-to-end delay, normalized routing load, and packet loss under variable vehicle speed and vehicle density per square meter. Among the routing protocols, AODV and AOMDV showed best performance in terms of PDR, whereas, DSDV showed lowest average end-to-end delay. In contrast, DSR routing protocol exhibited average performance for both PDR and average end-to-end delay.

In [10], authors studied the QoS of AODV, AOMDV, DSR, and DSVD routing protocols in terms of PDR, average end-to-end delay, and average throughput using NS-2 simulator. The simulation was carried out under SUMO generated scenario of Navi-Mumbai city using UDP by considering node density. Simulation results showed best QoS when DSR routing protocol came into action.

In [8], authors investigated the UDP performance of AODV, AOMDV, and DSR in V2V under city scenario using NS-2 simulator. Three performance metrics such as throughput, normalized routing load, and packet loss were measured for SUMO generated scenario under different node density. Like the results of [10], the simulation results showed best results for DSR routing protocol when node density had increased under city scenario.

Authors in [11] examined the performance of AODV and DSR in VANET under a parking lot scenario to route UDP traffic. The simulation was conducted in NS-2 simulator using Random Waypoint Mobility model to investigate the performance of throughput, average end-to-end delay, PDR, and packet drop by varying the node speed. Compared to other routing protocols, AODV showed better performance in a parking lot scenario.

III. SIMULATION SETUP

In this section, the simulation setup is explained along with the modelling of the urban street parking and mobility of vehicles in our simulation. To emulate real world scenario urban street scenario, the simulation needs to consider a real-world context that is bounded by buildings along the roads. For that reason, the Old Airport, Berakas, Brunei Darussalam is used as the area for simulating the VANET scenario as most government agencies in Brunei is situated in this area. The simulation work flow is depicted in Fig. 2.

In our research, we used Open Street Map (OSM) which is an open source map editor that allows extraction of real world location into OSM or osm.xml file. Either types of files are then imported into SUMO for mobility traces generation of Old Airport, Berakas environment. The simulation consists of the following steps: (i) extracting road maps using Open Street Map explains the underlying work for simulation based on a real map context, (ii) importing road map into SUMO and (iii) using mobility trace in NS-2 for performance evaluation.

Once the road map is extracted from OSM, the map is imported into SUMO version 0.31 using an in-built command line application called NETCONVERT. It imports digital road

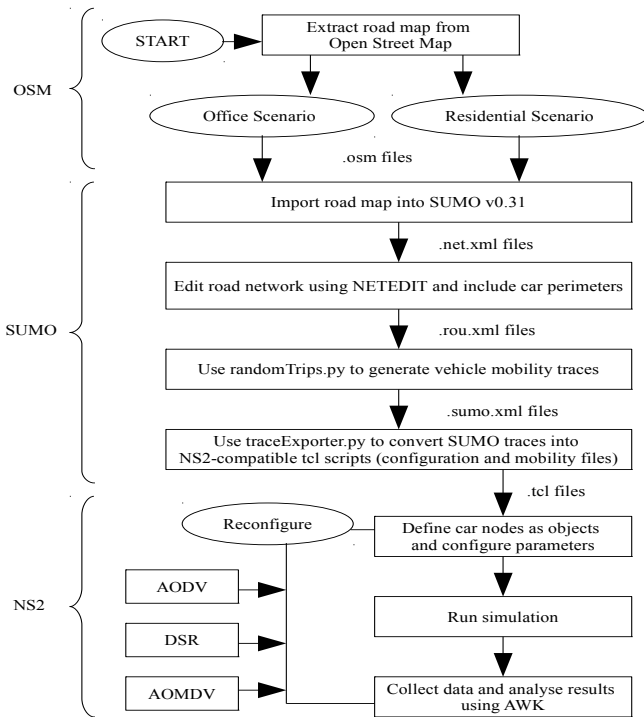


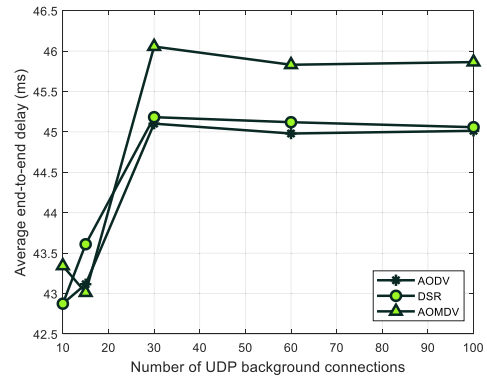
Fig. 2. Simulation work-flow (the use of OSM, SUMO and NS-2 in our simulation).

networks from different map sources including OSM and generates road networks that can be used in SUMO. The resulting road networks is output in the form of .net.xml file. SUMO road network consists of roads, lanes and buildings that can be modified to suit the objectives of the simulation. This is done using NETEDIT which is an in-built GUI network editor. In NETEDIT, both roads and lanes, called 'edges', allow user to include parameters that may influence the vehicles mobility. Buildings are called 'polygons' or 'place of interest' that does not play a part in the simulation, but serve as a means to improve the simulation appearance so to ease user's debugging. For the purpose of simulation, buildings are not animated in NS-2.

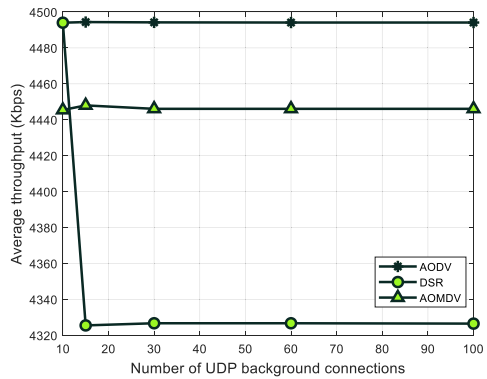
To evaluate influence of UDP background connections on TCP flows, a total of five different values of UDP background connections are used: 10, 15, 30, 60 and 100. Other performance parameters: 50 vehicles, 30 minutes parking duration and vehicle speed of 50 Km/h are kept constant for all simulation runs.

IV. RESULTS AND DISCUSSIONS

Here we present TCP throughput and delay results for two scenarios with varying background UDP connection: 30 TCP and 50 TCP flows. Figure 3 (a) shows the average end-to-end delay of 30 TCP flows having varying UDP background connections. The figure shows that the average end-to-end delay increases but gradually decreases at higher UDP background connections for all routing protocols. Initially, all



(a) Average delay performance comparison.



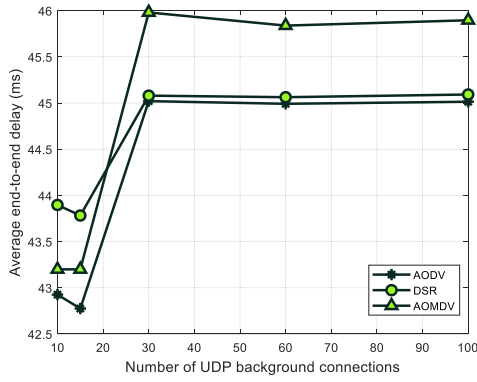
(b) Average throughput performance comparison.

Fig. 3. Average end-to-end delay and throughput performance for 30 TCP flows with varying UDP background connections.

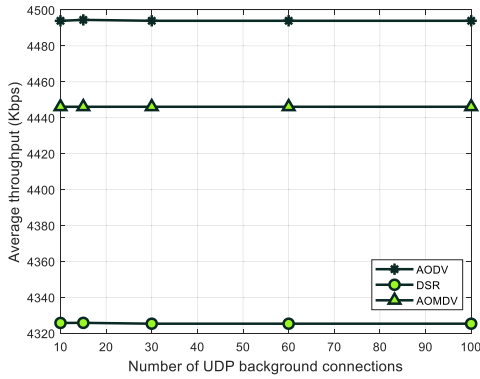
routing protocols have lower average end-to-end delay at lower UDP background connections with AODV having the lowest average end-to-end delay. However, the average end-to-end delay for all routing protocols increases gradually with increasing UDP background connections until 30 UDP background connections, whereby each routing protocol have shown to slightly decrease at higher UDP background connections. It can also be seen that at higher UDP background connections, the average end-to-end delay becomes linear at certain point. In summary, AODV has the lowest average end-to-end delay followed by DSR and AOMDV. The difference in delay under the maximum (100 UDP connections) and minimum (10 UDP connections) in each routing protocol is approximately 2 ms to 3 ms, as observed from Fig. 3 (a). This observation leads us to deduce that these number of background connections would not influence TCP significantly as the delay does not increase noticeably with the background connection increment¹.

As expected, we can observe from Fig. 3 (b), TCP throughput results of each routing protocols remain almost the same within the minimum and maximum number of UDP background connections in all three routing protocols. We can

¹earlier studies conclude that TCP throughput declines as the TCP packets experience delay [12]–[14].



(a) Average delay performance comparison.



(b) Average throughput performance comparison.

Fig. 4. Average end-to-end delay and throughput performance for 50 TCP flows with varying UDP background connections.

notice from this figure that the throughput performance at low background connection (i.e. 10 UDP connection), DSR and AOMDV show the same performance. However, with the background connection increment, throughput in DSR sharply drops and remain almost constant until 100 UDP background connection. Among all the three routing protocols DSR having the lowest average throughput. In summary, AODV achieves the highest average throughput followed by AOMDV and DSR. From the simulation traces, we noticed that average PDR when there are 30 TCP flows. We observed that, initially, all routing protocols shown to have a very high PDR at lower UDP background connections, but gradually decreases at higher UDP background connections. Based on our observation, AODV has a slightly higher PDR followed by AOMDV and DSR.

Figure 4 (a) demonstrates the average end-to-end delay of 50 TCP flows having varying UDP background connections. The figure shows that the average end-to-end delay increases but gradually decreases at higher UDP background connections for all routing protocols. Initially, all routing protocols have lower average end-to-end delay at lower UDP background connections with AODV having the lowest average end-to-end delay. But, gradually the average end-to-end delay for all routing protocols increases with increasing UDP background

connections until 30 UDP background connections, whereby each routing protocol shown to have slight decrease at higher UDP background connections. It can also be seen that at higher UDP background connections, the average end-to-end delay becomes linear at certain point. Here, AODV has the lowest average end-to-end delay followed by DSR and AOMDV.

Figure 4 (b) shows the average throughput of 50 TCP flows having varying UDP background connections. The figure shows that throughput in all routing protocols remains consistent from 10 UDP background connections onwards where AODV achieves the highest average throughput followed by AOMDV and DSR.

Nonetheless, there are several factors that can influence the throughput performance that should be considered such as security, the time (part of a day) and location of parked vehicles, parking duration, task management and inter vehicle communication approach as elaborated below:

- Security:** Although TCP employs handshaking and acknowledgement mechanisms to provide a reliable communication link, TCPs vulnerabilities have to be considered in preventing potential active or passive attacks as the disruptions in TCP operation may subsequently influence the throughput. For instance, upon establishing a TCP connection, both server and client will generate an initial sequence number from which the counting of the transmitted segments will start. Segments are accepted when the correct SEQ/ACK numbers are used. However, the structure of the TCP protocol allows the sequence number to be predicted and exploited as TCP sequence prediction attack [15]. The longer the connection time, the higher the chances of the attack going to be successful. As the parked vehicles are more static than the moving vehicles, end users using TCP applications such as web browsing, email and FTP could be affected under this attack. Apart from exploiting the TCP, other security threats may be present in multiple layers across various viewpoints between the provider (vehicle) and subscriber (end user) since either party can be malicious. Authentication, confidentiality, integrity and encryption factors have to be ensured to provide all-rounded security.
- Time and location:** The time of the day when vehicles are parked can affect the TCP throughput performance. While vehicles are likely to park in commercial areas during daytime, vehicles would also park in residential areas during nighttime. At any given time, the vehicle parking pattern would furthermore be affected by the seasonal occurrences such as weekend, weekday, peak hour or non-peak hour. It is logical to anticipate large number of end users if there are a large number of parked vehicles. Additionally, the location of parked vehicles would be able to determine the TCP throughput. Parked vehicles at a residential areas would have end users that are prone to perform leisure activities such as video streaming. In this scenario, the foreground traffic i.e. TCP traffic would be lower than the background traffic i.e. UDP traffic. In such case, due to high number of

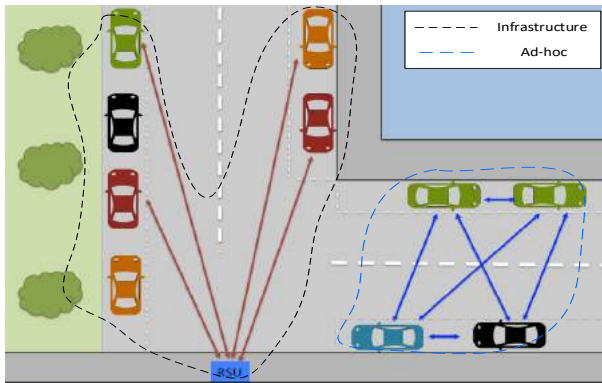


Fig. 5. Parked vehicles in infrastructure and ad-hoc approach for facilitating communication in a VFC.

background UDP connections foreground TCP traffic may end up experiencing lower throughput. Furthermore, these traffic behavior would change depending on the end users active period. The traffics would be lower after midnight than it was in the early evening. On the other hand, parked vehicles in a commercial area might have end users that are prone in using TCP-based applications such as web browsing and email. Hence, this scenario would have the opposite result from that in the first scenario.

- **Centralized management:** Having a centralized management would expedite the decision-making process in a vehicle based fog computing infrastructure, hence optimizing the utilization of resources. Deploying a machine learning algorithm into the centralized management would help in recognizing the vehicle parking duration and task processing patterns. The broker acting as the central manager would be able to decide the kind of application that should be served by which vehicles (tasks and vehicles mapping). As the end user request would vary, finding the right vehicle to process it would require some time—a small task would presumably need a shorter amount of time to complete as compared to a large task. Thus, identifying the patterns such as parking duration, parking time, and vehicle computational and processing capability, would increase the accuracy of prediction and in return would result in improved TCP performance and utilization of resources in a VFC.
- **Inter vehicle communication approach:** If the vehicles are arranged in clusters, the resources can be accumulated to form bigger resource pool. Nevertheless, the cluster size can influence the energy consumption as bigger clusters tend to consume more energy. A cluster can be classified into infrastructure or ad-hoc topology. When vehicles are clustered in an infrastructure manner, communication has to pass through the coordinator in order to communicate with another vehicle as illustrated in Fig. 5 where vehicle communications are denoted by the red lines. In case of ad-hoc manner communication, in a cluster, vehicles would communicate distributed

approach—each vehicle is in charge of forwarding traffic in this case (denoted by blue lines in Fig. 5). Both approaches have strengths and weaknesses. In case of ad-hoc approach, a packet might need to travel longer distance to reach the destination node when the cluster size is big. This would result in reducing TCP throughput and increase energy consumption of the nodes in a cluster. In contrast, in infrastructure approach, the coordinator node (e.g. RSU) could be point of bottleneck in presence of large number of vehicles, resulting in reducing TCP throughput and increasing packet delay. For a given number of vehicles it is important to understand the most appropriate communication approach between the two. In such, investigation, performance metrics such as throughput, delay, jitter, packet drop rate and energy consumption should be taken into account.

It is worth highlighting that using different kinds of TCP protocol would have an impact on energy consumption where it is shown that TCP protocols such as TCP Tahoe, TCP Reno, TCP New Reno and TCP SACK would result in different energy consumption rate [16].

V. CONCLUSION

VFC facility formed by parked vehicles has lots to offer in leveraging edge computing capacity. Besides, this will reduce both capital expenditure and operating expenses of fog computing service providers. Furthermore, this will open up a new business model. Based on simulation, our observation summarize that AODV offers the highest throughput among the compared protocols. The factors that might affect the TCP throughput performance in a VFC facility formed by parked vehicles are also discussed in this paper.

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