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The Characterizes of Communication Contacts Between Vehicles and Intersections for Software-Defined Vehicular Networks

XueFeng Xiao · Xiaoyan Kui

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Abstract In software-defined vehicular networks, a centralized controller in the network through the road-side unit will greatly promote the efficiency of the network efficiency by temporarily storing the packets, improving the delivery ratio and providing highly reliable transmission. The inter-contact time between moving vehicles and intersections, and the duration of each contact are two key metrics in the designing and evaluating of this kind of software-defined vehicular networks, because they decide the frequency of contacts between vehicles and the intersections and how much data can be sent during the contact. In this paper, we analyze traces of thousands of operational taxies in Shanghai. By studying the inter-contact time and the duration of each contact between taxi-intersection pairs, we find that the distribution of inter-contact time follows a power-law up to a small value and decays exponentially afterwards. We find that a power-law with exponential decay model can approximate the distribution of inter-contact time better than exponential model, power law model and piecewise exponential decay model. The duration of contacts, on the other hand, mainly exhibits an exponential decay. Our findings make way for the future study of and the deployment of software-defined vehicular networks.

Keywords Software-defined networks · Vehicular networks · Communication contact · Performance modelling

X. Xiao (✉) · X. Kui
School of Information Science and Engineering,
Central South University, Changsha 410083, China
e-mail: kuixiaoyan@gmail.com

1 Introduction

Recently, with the development of software-defined networking (SDN) in Internet and data center networks [6, 11], wireless SDN also becomes an emerging interested topics for the area of wireless communication and networking [1, 5, 14, 15]. In wireless SDN, the control plan is decoupled from the data plane, and the network is controlled by an logically centralized controller, which dramatically simplifies network control and enables innovation and evolution. Specially, in the wireless communication and networking, control functions like wireless resource optimizing, packet routing and forwarding, and efficient mobility management, would greatly benefit the centralized control [5]. On the other hand, since different kinds of wireless networks, i.e., wireless vehicular networks, mobile sensor network, etc., have apparently different network properties, key architecture and the corresponding technologies for wireless SDN are still need to be investigated [14].

On the other hand, in recent years, Delay tolerant networks (DTNs) [3, 7, 8], have been studied under various circumstances, such as space communication, mobile ad hoc networks in sparse populated areas and vehicular ad hoc networks. The key problems in DTN is that the delay and disruptions are common in most networks, making the key issues, such as routing, safety, security problems, etc., vastly different from those in other mobile ad hoc networks. Among these problems, how to effectively forwarding the packets is the most essential one. Vehicular ad hoc network (VANETs), as a specific case of DTNs, has been attracting more and more interest from the researchers [2, 9, 10, 12, 13], since it can improve traffic efficiency, the communication among cars and data transfer between cars and the Internet. Thus, VANETs become as an important and hot topics for the research communities of wireless networks.

There are basically two kinds of communication, that is, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) [13]. Roadside Units (RSUs) are fixed infrastructure in VANETs, and it has been shown that infrastructure in VANETs can greatly enhance wireless networks in the delivery ratio [12]. Privacy and security can also been performed using those infrastructures. However, routing and forwarding is very difficult to obtain high efficiency since the network is very random using the distributed network control mechanism. Thus, applying the idea of SDN into VANETs, which introduce a centralized controller in the network through the RSUs or other wireless infrastructure like cellular network, will greatly promote the efficiency of VANETs.

In the software-defined vehicular networks, applications based on VANET with RSUs and the control decision of the SDN controller will strongly depend on the metrics like the inter-contact time and the duration of contacts. The inter-contact time depicts the frequency of contact by telling us how long does it takes for the RSUs at intersections to receive / forward packets to the passing-by vehicles. The duration of contacts, on the other hand, decides how much data can be transferred during the contact [4]. Thus, these two important metrics is significant to the SDN VANETs design. The characteristics of the inter-contact time have been exposed to many studies, many of which focused on theoretical models [16]. As there are more data to study in recent years, some studies try to use real traces to study the characteristics and reveals that real traces showed that vehicles exhibits different characteristics from human mobility, many of them then prove that similar characteristics can be observed from simple mobility models [16].

In this paper, we investigate the characterizes of communication contacts between vehicles and intersections for software-defined vehicular networks. Instead of studying the inter-contacts between vehicles, we focus on the characteristics of contacts between intersections and vehicles, including inter-contact time and duration. The inter-contact time between a specific vehicle and one certain intersection mainly follows an exponential decay. However, simply using the exponential model can result in big differences since the CCDF of inter-contact time can be better approximated as a power-law. Although this part is short, it contains more than 20 % of all inter-contact time data. Thus we propose to use the power-law with exponential decay model to approximate the inter-contact time. As to the duration of contact, we use the traces and the information of the taxi speed to estimate the duration. The result shows that the CCDF of duration is exponential. Based on these results, which should provide very fundamental and basic model for the software-defined vehicular network to design efficient centralized routing and forwarding control strategies.

The rest of the paper is organized as follows. After intruding the empirical data and computation model in Section 2, we present and analyze the results and proposed models for the inter-contact time and contact durations in Section 4 and Section 3, respectively. Finally, we conclude the paper in Section 5.

2 Empirical data analysis and computation

In this part, we would first introduce the data set we use in our study and the definitions/metrics we use. We will then present you how we compute the metrics.

2.1 Dataset

We use the data collected from the SG project in Shanghai [16], in which the information about taxies are recorded and collected from thousands of taxies in Shanghai in February, 2007. The information includes the taxi's ID, the longitude and latitude GPS coordinates of the current location, speed, angle, date time (timestamp) and status of the taxies [16]. The data is recorded on every one minute if the taxi is occupied and on every 15 seconds when it's vacant. With the speed information and short trace intervals, we are able to estimate the contact time between each taxi and selected intersections and the duration of each contact, considering that a device in the intersection can have a transmission range of 200m. In the following of this paper, we use the term of 'intersection' as the means of communication devices placed in the intersections.

2.2 Definition

Here we use the following definitions. An inter-contact time between a taxi and an intersection is defined as the length of the time interval over which the taxi is away from the transmission range of the potential intersections deployed at the intersection. We call CCDF of inter-contact time between one taxi and one intersection, the CCDF obtained for the inter-contact time gathered from one specific taxi-intersection pair. We further get the aggregate CCDF of all inter-contact time over all taxi-intersection pairs. We also have CCDF of inter-contact time between all contacts of one intersection with all taxies. This metric defines how frequently an intersection will have a chance to have a new contact with taxies. CCDF of duration is the CCDF of estimated durations of all contacts between taxies and intersections.

2.3 Computation

Roadside Units is different from vehicles, each intersection is stationary but has huge storage and has a relatively larger transmission range.

2.3.1 Selection of intersections

We get the rough city map through drawing the taxi traces, as shown in the figure below. By comparing the real-world map and the map we get from traces, we choose more than 33 intersections where traces are concentrated and the traffics from the roads connecting to them are equally busy. As shown in Fig. 1, the blue points indicate the taxi traces and we mark the intersections with red circles. Also, the area within the circles roughly represents the coverage of communication devices deployed at the intersections.

2.3.2 Defining coverage of intersections

Considering that the majority of intersections roughly consist of north-southern road and west-eastern roads, we use the sum of distances in both directions to measure whether a car is within the contact range of a intersection. Another reason is that signals are better along the roads and the metric we choose can reflect such fact: simply using the distances between intersections and taxies would ignore the fact that buildings the roads will block the signals to some extent.

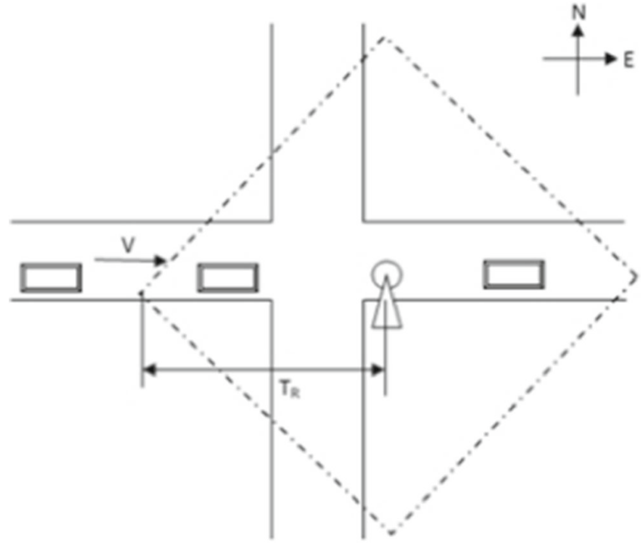
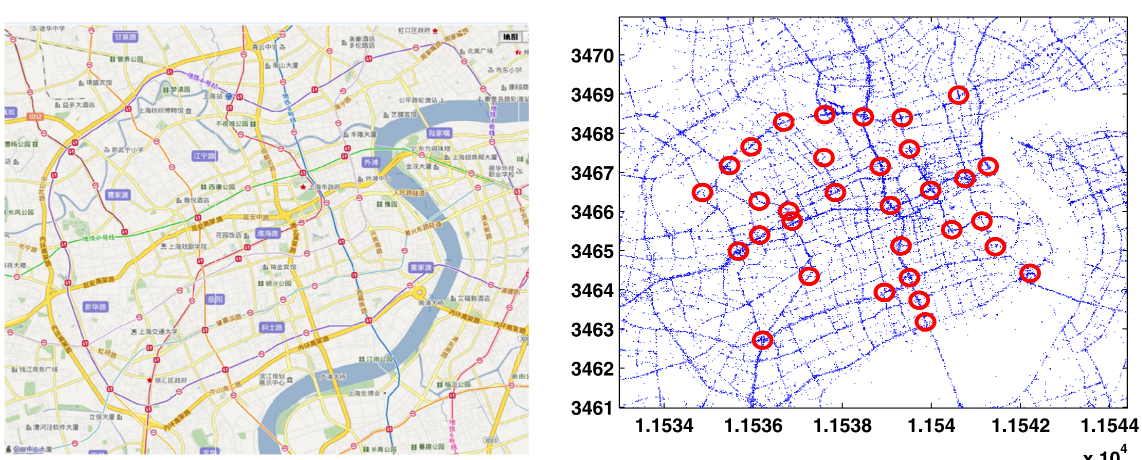


Fig. 2 Illustration of the computation model for inter-contact time and contact duration

Let T_R be the transmission range of a intersection, the coverage of one intersection is then a square as shown in the below figure. Notice that the terraces with edge represent the traces at different time instead of multiple taxies. Let d be the west-east distance, d' be the north-south distance and D, the total distance between a taxi and an intersection, be the sum of them. If $D < T_R$, then we assume that at that time point, the taxi meets the intersection. Simply finding out the traces when contacts happen is not enough since there might be a couple of successive traces recorded during a single contact, so we combine the traces from same contacts. The traces cover a month, and we are able to learn the inter-contact time of each taxi-intersection pair (Fig. 2).



(a) real-map (b) map generated by the traces

Fig. 1 Illustrations for the selected intersections on the real map and trace-generated-map

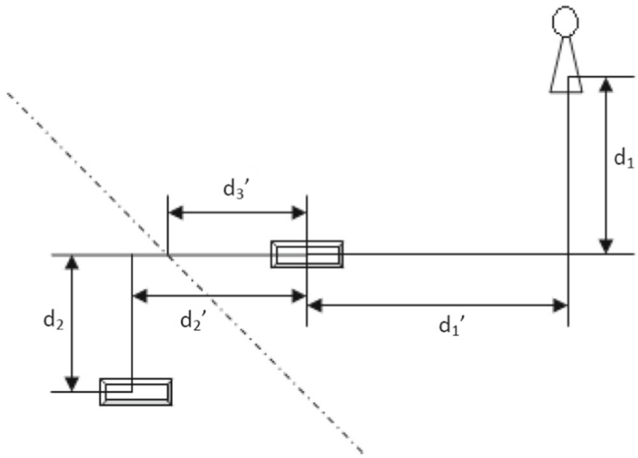


Fig. 3 Illustration of the computation model for estimation of vehicular arrival time and durations

2.3.3 Estimation of arrival time and duration

Let C be the set of traces of a contact between one taxi and one intersection, $C = C_1, C_2, ..., C_n$. The elements in C are in chronological order. Let $T_i (i = 1, 2, ..., n)$ be the timestamp of trace C_i, then the duration of contact can be roughly written as. This result should be revised because the time gap between each trace can be as long as 1 minute, which is comparable to the total length of duration and makes the estimation rough. We revise the duration using the adjacent traces and the speed information of C. Let $Duration_{pre}$ be the time gap between T_1 and the time taxi enters the coverage of the RSU, be the time gap between Tn and the time taxi leaves the coverage.

As shown in Fig. 3, let C_0 be the trace just before entering the coverage, D_1 be the distance between the intersection and the taxi position at C_1, D_2 be the distance between C_0 and C_1, D_3 be distance the taxi travels in the coverage before recording C_1. If $V_1 \neq 0$, then . Otherwise, we assume that the taxi travels at constant speed from C_0 to C_1, then

$$Duration_{pre} = (D_3/D_2) * (T_1 - T_0).$$

We can get $Duration_{app}$ in a similar way. After revision, Duration can be written as,

$$Duration = Duration_{pre} + Duration + Duration_{app}.$$

Also, we can get the revised Estimated Arrival Time (EAT) of each contact as

$$Duration = Duration_{pre} + Duration + Duration_{app}.$$

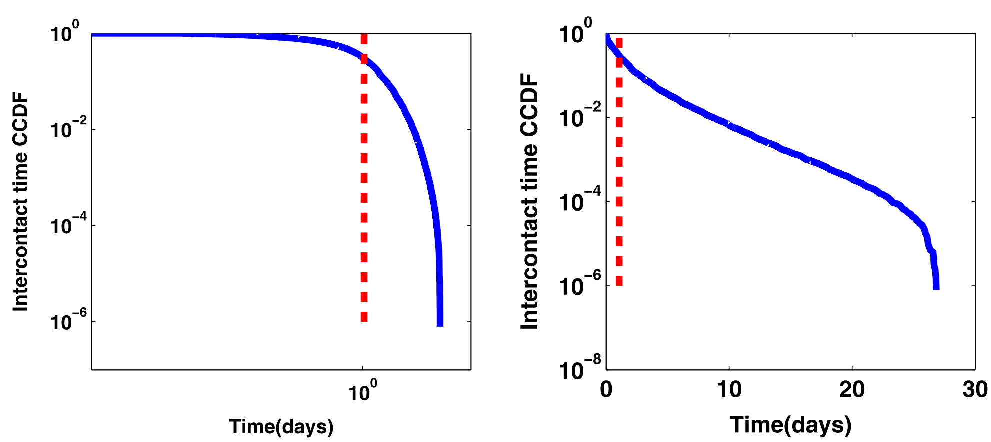
The inter-contact time can be calculated by differentiating the EAT series of each taxi-intersection pair and we can further get the aggregate inter-contact time by gathering these results.

3 Characteristics of inter-contact time

We plot the CCDF of aggregate inter-contact time in logarithmic coordinates in Fig. 4a, and find that the CCDF displays the characteristics of power law when time is short and an obvious exponential decay and cutoff in the rest part. To better illustrate the trend, we plot the CCDF in lin-log scale in Fig. 4b. The CCDF can be closely approximated by a straight line, showing that the CCDF has a clear exponential decay. The dichotomy of inter-contact times has been studied in 'Power law and exponential decay of inter contact times between mobile devices'. Here we introduce a concept, that is, the characteristic time. The decay is expected to be abruptly faster after that time point.

We use four models to the CCDF function and analyze the effect of each. The three models are, exponential decay, power-law, piecewise exponential decay and power-law with exponential cutoff. We use the least square method

Fig. 4 Results of the distribution for inter-contact time



(a) in log-log coordinate (b) in log-linear coordinate

Table 1 Fitting results

Model	CCDF	b	Confidential intervals	MSE
Exponential decay	$F_{\exp}(x) = b_1 e^{-b_2 x}$	0.8499	[0.8497, 0.8501]	0.0020
		1.0362	[1.0356, 1.0367]	
Power-law	$F_{power}(x) = b_1 x^{-b_2}$	0.3036	[0.3044, 0.3048]	0.0076
		0.3911	[0.3907, 0.3915]	
Power-law with exponential deca	$F_{power-\exp}(x) = b_1 x^{-b_2} e^{-b_3 x}$	0.6671	[0.6671, 0.6672]	$9.6e-5$
		0.0641	[0.0641, 0.0642]	
		0.7342	[0.7341, 0.7344]	
Piecewise exponential decay	$F_{piecewise}(x) = \begin{cases} b_1 e^{-b_2 x} & x \le 1 \\ b_3 e^{-b_4 x} & x > 1 \end{cases}$	0.8686	[0.8685, 0.8687]	3.8852e-004
		1.1936	[1.1930, 1.1942]	
		0.5715	[0.5703, 0.5726]	
		0.6392	[0.6379, 0.6405]	

to fit the CCDF of inter-contact time. The fitting result is as follows (Tables 1 and 2):

To have a better picture of the differences of the fitting results of those models, we show the fitting result of CCDF in lin-log scale where the inter-contact time is smaller than its average in Fig. 5. This part of data takes more than 70 % and clearly, the power-law with exponential cutoff fits the CCDF much better than exponential decay model. We should also notice that the exponent of the model is quite small, suggesting that the power-law part mainly affects the front part, the exponential decay dominates the middle part. However, simply using the exponential model would cause large error in the front part.

We further study the inter-contact time of contacts between one intersection and all selected taxies, and the results are shown in Fig. 6. The distribution shows exactly the same trend, that is, a power-law when the time is short and follows exponential decay beyond the mean inter-contact time.

4 Characteristics of contact duration

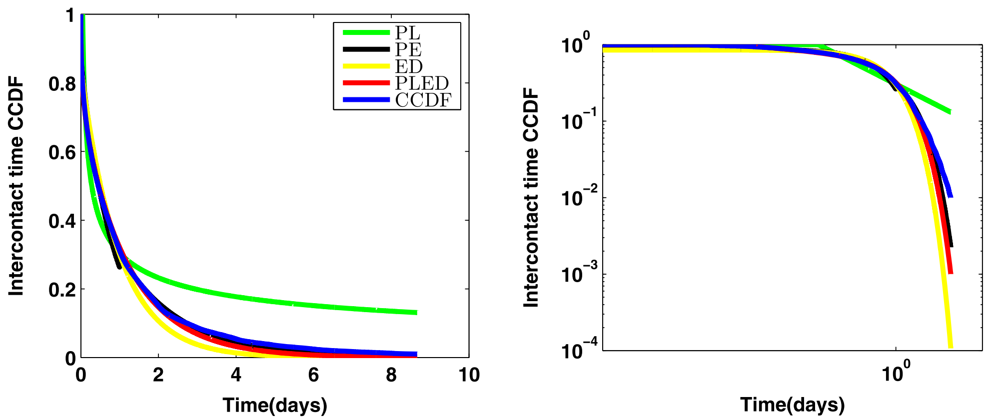
With the data we get from the data, we plot the CCDF of duration of contacts in Fig. 7a. Similar to aggregate CCDF, the duration CCDF here is the aggregate data from all taxi-intersection pairs. In the inter-contact time CCDF, the existence of particular large inter-contact time is logical since a taxi may revisit a same intersection after a long time if the taxi is active in other areas. However, a contact with a long duration suggests that the taxi is inactive during that period, and it is useless in VANET. Such contacts only consist of a tiny part of data, so we leave out the durations longer than 10 minutes (contacts whose duration longer than 10 minutes hold less than 0.6 From the CCDF in lin-log scale, we could observe that the CCDF could be closely upper bounded with a straight line, suggesting that exponential decay dominates the CCDF of duration.

We used three models to approximate the CCDF of Duration, and the results are shown in Fig. 7b. The difference

Table 2 Fitting results

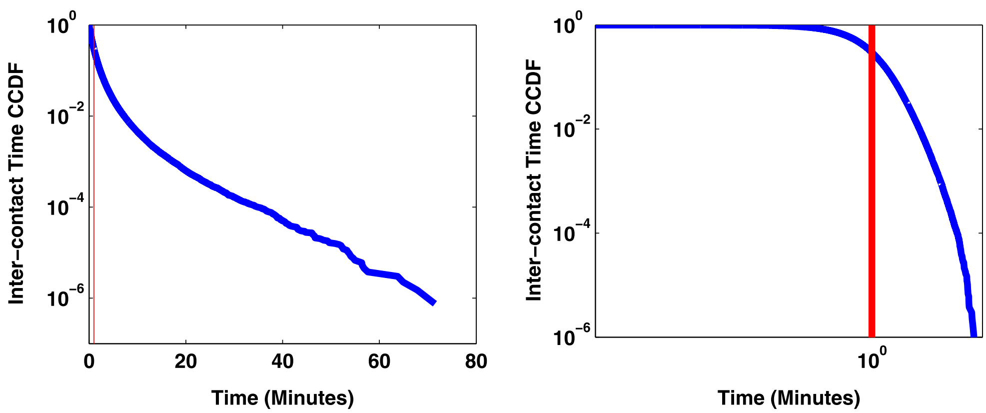
Model	CCDF	b	Confidential intervals	MSE
Exponential decay	$F_{\exp}(x) = b_1 e^{-b_2 x}$	1.4056	[1.4050, 1.4061]	0.0015
		0.7250	[0.7246, 0.7253]	
Power-law	$F_{power}(x) = b_1 x^{-b_2}$	0.6803	[0.6801, 0.5094]	0.0057
		1.0896	[1.0887, 1.0906]	
Power-law with exponential decay	$F_{power-\exp}(x) = b_1 x^{-b_2} e^{-b_3 x}$	1.4822	[1.4815, 1.4829]	0.0013
		−0.0597	[−0.0599, −0.05954]	
		0.7734	[0.7730, 0.7738]	

Fig. 5 Fitting results for inter-contact time



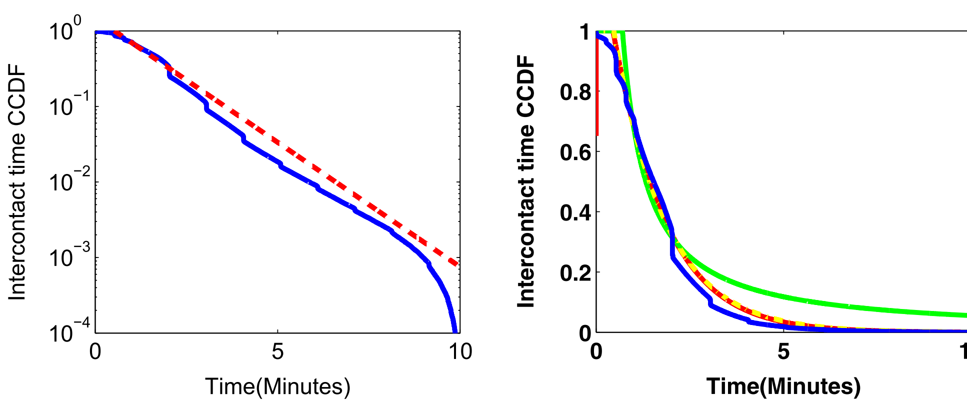
(a) in log-linear coordinate (b) in log-log coordinate

Fig. 6 Results of inter-contact time between one intersection and all selected taxies



(a) in log-linear coordinate (b) in log-log coordinate

Fig. 7 Distribution and fitting results of contact duration



(a) contact duration distribution (b) fitting results here is that, the relative error of estimate is much larger in the Duration, so the main purpose here is to reveal the exponential decay of CCDF of Duration.

5 Conclusion

In this paper, we use empirical traces to study the characteristics of the inter-contact time and duration of contacts of taxi-intersection pairs. We observed that both metrics follows an exponential decay but the CCDF of aggregate inter-contact time displays the characteristics of power-law when time is short. As a result, the model of power-law with exponential cutoff can better approximate the trace, producing much smaller MSE than other models, including exponential model, power-law and piecewise exponential model. The CCDF of duration mainly displays an exponential decay. These models for the inter-contact time and contact duration would benefit the development of software-defined vehicular networks by supporting centralized controlled network mechanism. Future work may study the deployment of intersections and the possible forwarding/routing algorithms used in software-defined vehicular networks.

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