The Sharing at Roadside: Vehicular Content Distribution Using Parked Vehicles

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***Abstract*—In Vehicular Ad Hoc Networks (VANETs), content distribution directly relies on the fleeting and dynamic contacts between moving vehicles, which often leads to prolonged downloading delay and terrible user experience. Deploying Wifi-based Access Points (APs) could relieve this problem, but it often requires a large amount of investment, especially at the city scale. In this paper, we propose the idea of ParkCast, which doesn't need investment, but leverages roadside parking to distribute contents in urban VANETs. With wireless device and rechargable battery, parked vehicles can communicate with any vehicles driving through them. Owing to the extensive parking in cities, available resources and contact opportunities for sharing are largely increased. To each road, parked vehicles at roadside are grouped into a line cluster as far as possible, which is locally coordinated for node selection and data transmission. Such a collaborative design paradigm exploits the sequential contacts between moving vehicles and parked ones, implements sequential file transfer, reduces unnecessary messages and collisions, and then expedites content distribution greatly. We investigate ParkCast through theoretic analysis and realistic survey and simulation. The results prove that our scheme achieve high performance in distribution of contents with different sizes, especially in sparse traffic conditions.**

***Index Terms*—VANET, ParkCast, content distribution, line cluster.**

I. Introduction

In order to facilitate better road safety and comfort driving, information distribution is fast becoming a requisite to vehicle users. Typical information not only involves text messages, but also includes multimedia files like pictures, audio, and video. The primary requirement of content distribution is to efficiently deliver and share these multimedia-rich contents to the vehicles traversing the network.

VANETs have some unique characteristics as short radio range, low bandwidth, rapid-changing topology and high mobility of vehicle nodes. Vehicular content distribution becomes very challenging, for the communication directly relies on the fleeting and dynamic contacts between moving vehicles. Towards solving the problem, many existing works [1], [2], [3] have adopted Peer-to-Peer (P2P) file sharing and network coding techniques. P2P sharing enables vehicles to exchange small content chunks in transient contacts, while network coding reduces duplicate transmissions and simplifies the transmission scheduling. However, the performance is still very limited. For example, in CodeTorrent it takes 200 seconds to download a 1 MB file in an urban scenario [2]. In this case, a vehicle user has to wait 14 minutes, for receiving a music file of 4.2 MB. According to NHTS [4] from the U.S. Department of Transportation, ordinary people have 4 vehicle trips per day, totaling on 55 minutes of travel averagely. It means a typical vehicle trip only lasts 13 minutes and 45 seconds approximately. Unfortunately, it is probably impossible to play the music during the whole trip, even if the user requests it at the start time. Such prolonged downloading delay makes many valuable services useless, and brings terrible user experience inevitably.

As promising augmentation to inter-vehicle communication, Wifi-based APs have drawn much research efforts [5], [6], [7], [8], [9], for content distribution using them. Since APs provide high data access rate and abundant resources from the Internet, they are able to achieve fast distribution to nearby vehicles. But the AP-based approaches have their own problems. As static short-range units, APs are hardly adaptive to rapid-changing traffic. From the view of vehicle users, the downloading delay depends on opportunistically encountered public APs on their trips. The sparser the placement of APs is, the worse the performance is. At the same time, APs need costly installation of power and wired network connectivity - these costs can be as high as 5,000 US dollars per unit [10]. It makes the wide deployment very expensive, especially at the city scale.

In this paper, we propose the idea of ParkCast, which doesn't need investment, but leverages roadside parking to distribute contents in urban VANETs. With wireless device and rechargable battery, parked vehicles can communicate with any vehicles driving through them [11]. Owing to the extensive parking in cities, available resources and contact opportunities for sharing are largely increased. To each road, parked vehicles at roadside are grouped into a line cluster as far as possible, which is locally coordinated for node selection and data transmission. Such a collaborative design paradigm exploits the sequential contacts between moving vehicles and parked ones, implements sequential file transfer, reduces unnecessary messages and collisions, and then expedites content distribution greatly. We investigate ParkCast through theoretic analysis and realistic survey and simulation. The results prove that our scheme achieve high performance in distribution of contents with different sizes, especially in sparse traffic conditions.

The remainder of this paper is structured as follows. In Section II, we explain the design of ParkCast step by step, including assumptions, typical communication, contact analysis, and collaborative mechanism. Section III evaluates

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ParkCast through realistic survey and simulation, and Section IV summarizes the paper.

II. The Design of ParkCast

A. Assumptions

First, we assume that the wireless device on vehicles has a small rechargable battery, for supporting the communication in parking. It is widely deployed in current electronic equipments at very cheap price.

Second, we assume that vehicles are equipped with GPS and electric maps, which are also low-cost and available to most of the drivers nowadays. These devices can be used in the parking state with the support of the battery.

Finally, we assume that some vehicle users will share their devices and contents during parking. According to the running experience of P2P file systems [12], 30% users are found cooperative for collective welfare, and they are enough to support the whole systems. It proves that at least some users are willing to contribute resources, even if they cannot benefit from the sharing. Moreover, vehicle users can leave their wireless devices alive in parking, for downloading requested contents or continuing unfinished transmission. Thus, allowing ParkCast implies more downloading chances, and promotes vehicular services on one's own car, which is directly beneficial to each user.

B. Typical Communication

Parking on one or both sides of a road is commonly permitted in most cities, and brings extensive roadside parking. At the same time, driving is strictly constrained by traffic rules and street layout, so that it can be regarded as a series of path selecting at intersections and simple movement within single roads. Thus, when a vehicle is entering a road where parking is permitted, it will pass all parked vehicles at roadside in sequence. Comparing with the previous vehicle-vehicle or vehicle-AP contacts, such sequential vehicle-parking contacts make content distribution more predictable and more controllable. Fig. 1 describes the typical communication of ParkCast, in which a sequential file transfer is taken into account.

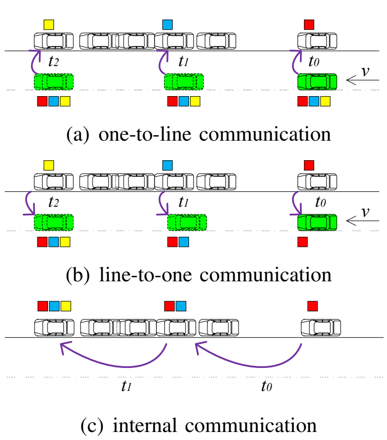


Fig. 1. Typical communication of ParkCast

One-to-line communication: When a vehicle drives through a road, the content chunks on it can be downloaded to the parked vehicles successively. In Fig. 1 (a), such communication is shown as the three delivering from right to left at the time of t_0, t_1, and t_2.

Line-to-one communication: When a vehicle drives through a road, the content chunks on the parked vehicles can be downloaded to it successively. In Fig. 1 (b), such communication is shown as the three delivering from right to left at the time of t_0, t_1, and t_2.

Internal communication: To the vehicles parked at one road, the content chunks on different vehicles can be downloaded to one vehicle for its request. In Fig. 1 (c), such communication is shown as the two delivering from right to left at the time of t_0 and t_1.

Generally, parked vehicles play a role of infrastructure for close proximity sharing at the street level. The challenge here is how to guarantee the effectiveness and the efficiency of the above communication, in which the key point lies in building upon enough coordination among row of parked vehicles and moving vehicles on the road. To solve this problem, we mainly focus on the following research efforts. First, the communication design needs in-depth analysis of vehicle movement and parking distribution, e.g. the describing and modeling of vehicle-parking contacts. Second, the clustering of parked vehicles should be adaptive to complex environments, easy to manage vehicle members, and convenient to exchange information. Finally, sequential file transfer requires proper node selection and transmission coordination, for keeping the balance between collision and efficiency. The rest of this study is meant as a step towards a deeper understanding of these fundamental issues.

C. Contact Analysis

As shown in Fig. 1, a vehicle-parking contact sequence happens when a moving vehicle is passing by a series of parked vehicles at roadside. Suppose the number of parked vehicles is n, we assume that $N(t), t \geq 0$ denotes the vehicle arriving at the position of the parked vehicle in the time of $(0, t]$. Furthermore, $N(t) - N(t_0) = N(t_0, t), 0 \leq t_0 < t$ denotes the number of overlap in the time of $(0, t]$ and the possibility of $N(t_0, t)$ is given by:

$$P_k(t_0, t) = P\{N(t_0, t) = k\} \qquad k = 0, 1, ... \tag{1}$$

Notice that the $N(t), t \geq 0$ satisfies the conditions of the Poisson process [13]. Therefore, $N(t), t \geq 0$ is a Poisson process with intensity λ where $P_k(t_0, t)$ can be proved as:

$$P_k(t_0, t) = \frac{\lambda(t - t_0)}{k!} e^{-\lambda(t - t_0)} \qquad t > t_0, k = 0, 1, ... \tag{2}$$

Thus, we define W_n as a random variable and have the sequence of $W_0 = 0, ..., W_i = t_i, ...$, where t_i stands for the time from the beginning until the overlap at the number i

vehicle. The distribution function of W_n can be expressed as:

$$F_{W_n}(t) = \begin{cases} \sum_{k=n}^{\infty} e^{-\lambda t} \frac{(\lambda t)^t}{k!} & t \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Then we have the probability density function of W_n as:

$$f_{W_n}(t) = \begin{cases} \frac{\lambda(\lambda t)^{n-1}}{(n-1)!} e^{-\lambda t} & t > 0 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

It is obvious that W_n follows the Gamma distribution, and we notice that W_1 follows the Exponential distribution as $f_{W_1}(t) = \lambda e^{-\lambda t}, t > 0$.

Suppose the radio range is r and the vehicle speed is v, we can firstly calculate the period of time from the moment entering the first vehicle's range to the moment getting out of the last vehicle's range. T_{sum1} denotes this period of time, and the expectation is expressed as:

$$E(T_{sum1}) = (\frac{n}{\lambda} + \frac{r}{v}) - (\frac{1}{\lambda} - \frac{r}{v}) = \frac{n-1}{\lambda} + \frac{2r}{v} \quad (5)$$

To the time the moving vehicle is staying out of the range of parked vehicles, and we consider this period as T_{sum2}. The time of driving from the number $i-1$ vehicle to the number i vehicle denotes $T_i = W_i - W_{i-1}, i = 1, 2, ...$ Considering the vehicle is in uniform motion, T_i can represent the length between W_i and W_{i-1}. The probability density function of T_i has $f_{T_i}(t) = \lambda e^{-\lambda t}, t > 0$.

Therefore, the expectation of T_i is $E(T_i) = 1/\lambda$. We can get T_{sum2} by the comparing of T_i with $2r$. If $vE(T_i) \leq 2r$, we assume that T_{sum2} is too short to be take into account. If $vE(T_i) > 2r$, $T_{sum2} = (vE(T_i) - 2r)(n-1)/v$. Finally, the total contact time T is equivalent to:

$$T = T_{sum1} - T_{sum2} = \frac{2r}{v} + \frac{2r}{\lambda}(n-1) \quad (6)$$

That is to say, the vehicle-parking contact time shows a linear increment with the parked vehicles, and is little affected by driving speed if the parked vehicle number is large. To an urban vehicle trip, a long contact time is guaranteed by extensive roadside parking in urban areas.

D. Line Cluster

In ParkCast, we try to group all parked vehicles on one road into a line cluster, even if some of them are isolated. This is viable, for the moving vehicles will travel across the road, and help to maintain the whole line cluster. For the support of content distribution, the line cluster needs to handle the following three tasks: a) cluster management, including head election and membership management; b) resource management, mainly content and buffer management; c) content distribution, e.g. the three communication discussed in Fig. 1.

As shown in Fig. 2, a typical line cluster has two cluster heads, H_1 and H_2, and some cluster members as M_1, M_2, M_3, M_4, and M_5. The vehicles located at the two ends of a road are elected cluster heads, so that a moving vehicle entering the road will first encounter one of them. In a two-way road, the two cluster heads respectively provide services for the vehicles coming from the nearest intersection. The cluster members periodically reports their positions, contents, buffer status, and requests to the two cluster heads. Thus, the cluster heads are able to manage all parked vehicles and their resources, act as local service access points, and arrange one-to-line, line-to-one, and internal communication for content distribution. However, the line cluster will malfunction at once if the cluster head left surreptitiously. A example is H_1 in Fig. 2, which is isolated at the road end and may have no chance to inform others of its leaving. Thus, we introduce two quasi heads, as QH_1 and QH_2 in Fig. 2, to ensure fault-tolerance with respect to exception handling. A quasi head is the cluster member next to a cluster head, which always keeps a copy of recent cluster status from the cluster head. Thus, it becomes a special cluster member, working as a "warm backup" for the management of the line cluster.

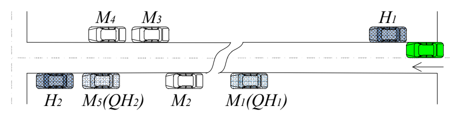


Fig. 2. A typical line cluster

We use the finite state machine, as shown in Fig. 3, to precisely describe the principle and operating process of our proposed clustering scheme. Each vehicle operates under one and only one of four states at any given time, under the control of seven state-transition conditions.

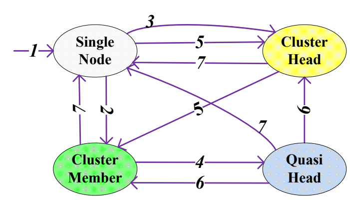


Fig. 3. The state transitions of parked vehicles

1. Parking(initiate): Once parked, a vehicle begins to periodically send its status toward the two ends of the road, e.g. the nearby intersection positions from electric maps.

2. Joining a cluster: A vehicle receives an echo from the cluster head, and then becomes a cluster member.

3. Electing cluster head: If there's no cluster head in one direction, single nodes need to elect the one closest to the intersection. Since each node sends its position toward the intersection and all intermediate nodes send back an echo for the message from the neighbor, the node never receiving an echo will be the cluster head.

4. Appointed by cluster head: Once a cluster head is elected, the node will appoint the nearest cluster member as a quasi head.

5. Reclustering: When a cluster head finds that a new single node has a shorter distance to the intersection, it resigns the duty and appoints the node a new cluster head.

6. Confirmed by moving vehicle: In order to detect the absence of cluster head, an extra bit in beacon is deployed to indicate whether a moving vehicle contacts with a cluster head of local road. If the quasi head meets a moving vehicle without encountering a cluster head, it will provide service for the vehicle. If the quasi head meets such vehicles successively, the quasi head confirms the absence of the old cluster head, and becomes new cluster head automatically.

7. Leaving/losing contact: When a parked vehicle drives away, it will sending a leaving message to the cluster heads and quit the cluster. Sometimes, a cluster member or a cluster head may lost contact with the cluster, for not receiving any echo or report from the cluster. In this case, it becomes a single node and has to support content distribution individually.

E. Sequential File Transfer

Small text messages can be shared at the cluster head directly, for being distributed as soon as possible. But the distribution of large contents involves sequential file transfer among different vehicle nodes, which requires a collaborative design paradigm, including message delivery, node selection, and transmission coordination.

Message delivery: We adopt an additional field in beacon frame of vehicles, for avoiding extra service messages. It has a structure as follow: one bit for clustering control, which is used to detect the absence of cluster head in the last subsection; two bit for service type, e.g. one-to-line, line-to-one, or internal communication; and some reserved bits for requested vehicle ID, content ID, and chunk ID.

When a moving vehicle meets a cluster head, it will reports its request and carrying contents. Then, the cluster head decides whether to provide service, and sends back the answer. In one-to-line communication, the cluster head selects some vehicle nodes to store the content, and informs the moving vehicle of its schedule. In later driving, the moving vehicle distributes the chunks to the corresponding nodes on the schedule. In line-to-one communication, the cluster head informs the moving vehicle of the IDs and locations of those nodes that have requested file chucks. In later driving, the moving vehicle broadcasts requested vehicle ID, content ID, and chunk ID in beacon frame. After receiving the beacon, the matched parked vehicle actively pushes file chunks to the moving vehicle. The process is repeated until the moving vehicle have all requested contents, not requesting chunks in its beacons. To a line cluster, the cluster heads only arrange the communication, while the cluster members carry out the actual transfer of file chunks.

To internal communication, the distribution is carried out in a different way. With periodic reports from cluster members, the cluster head checks local requests and contents. If some pairs are matched, it uses the echo messages to piggyback a file transfer order to the content holders, and initiates internal communication.

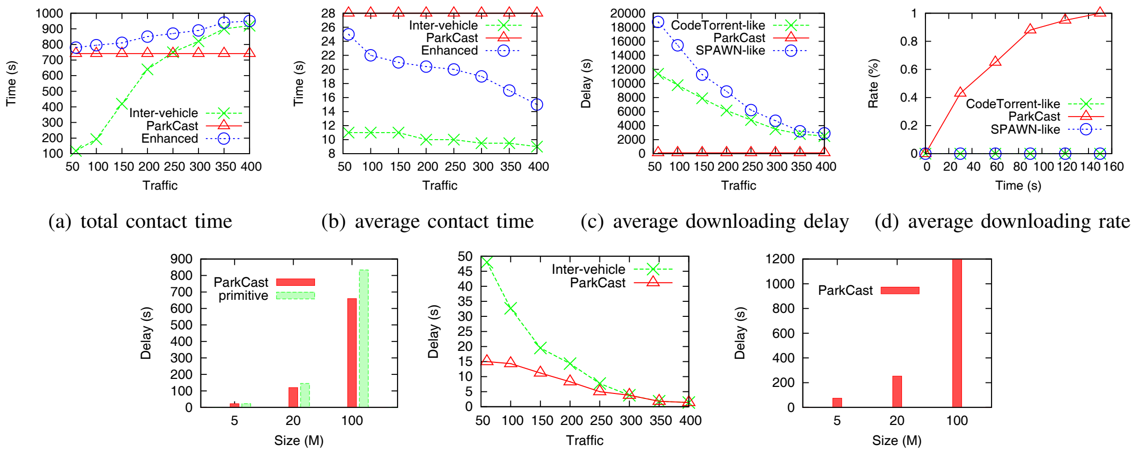
Node selection: In one-to-line communication, we propose a simple algorithm to efficiently select nodes for sequential file transfer. The principle is distributing chunks to those nodes have more available buffers. First, an appropriate chunk size is defined as downloading a chunk to a node during the time driving through the distribution range at local speed limit. (In content distribution, the distribution range is usually smaller than the radio rage, for reducing interference.) Second, the node with max buffer is selected and the nearby nodes within the distribution range are excluded. The process is repeated in the rest nodes until the number of chosen nodes equals the total chunk number. At last, we have a selection failure or a node set as the final sequence for one-to-line communication.

III. Performance Evaluation

We performed a six weeks' survey on an urban area of Chengdu, a city in China, for collecting realistic parking and traffic data [11]. It covers a real street map with the range of 1600m×1400m, which contains 10 intersections and 14 bidirectional roads totaled up to 7,860 meters. During the survey, we counted the passing vehicles and the parked ones at roadside, and calculated the traffic and parking profiles in this area. With collected data, we use NS-2.33 to generate the simulations. The radio range is set at 250m, while the distribution range of sequential file transfer is 50m. The MAC protocol is 2Mbps 802.11. In the simulation, parked vehicle nodes are located on random positions of each street. We assume that the line clusters are established at the beginning of simulation, and are maintained at a cycle of 60 seconds. The intersections in the map cover a 20m×20m segment without parking. Since not all parked vehicles are willing to join ParkCast, a participating ratio of 30% is deployed.

Contact time: We mainly discuss three distribution strategies: inter-vehicle content distribution, parking-based one, e.g. our ParkCast, and enhanced one using the both two mechanism. We evaluate the original contact time of the three ones, for giving some insights into system design. The maximum possibility to exchange data is indicated in Fig. 4 (a), while the average quality of each contact to transfer data is represented in Fig. 4 (b). Based on stable roadside parking, ParkCast has stable contact opportunities and high-quality contacts, without affecting by traffic changes. In sparse traffic conditions, it has great advantages. Inter-vehicle scheme shows more contact possibilities with the increase of traffic, but also involves quality penalty in dense traffic. Enhanced scheme has better possibilities and more short contacts in dense traffic, which requires wise selection among available contacts according to different applications.

Large content distribution: We use a 20M file to test the performance of ParkCast and that of two previous inter-vehicle approaches, a SPAWN-like scheme without network coding [1] and a CodeTorrent-like scheme with network coding [2]. In Fig. 4 (c), ParkCast reduces the average downloading delay almost 100 times in sparse traffic, and 20 times in dense traffic, although it doesn't adopt network coding. In Fig. 4 (d), ParkCast reaches 100% average downloading rate within 160 seconds in sparse traffic. Using the same time, the inter-vehicle schemes even cannot download one chunk.



(a) total contact time (b) average contact time (c) average downloading delay (d) average downloading rate

(e) collaborative design (f) small message distribution (g) empty car downloading

Fig. 4. Contact and distribution performance of ParkCast and other schemes

Collaborative design: Although we adopt line cluster and sequential file transfer, a primitive PaskCast scheme as individual roadside units is still feasible. As shown in Fig. 4 (e), the collaborative scheme is no better than the primitive one in the distribution of a 5M file. As the downloading delays of 20M and 100M files, the lager the content is, the more important the collaborative design is.

Small message distribution: In ParkCast, cluster heads are designed to support the distribution of small messages. Fig. 4 (f) compares the average delays over traffic before a moving vehicle get the requested message, and proves that ParkCast speeds up the dissemination of message, especially in sparse traffic conditions.

Empty car downloading: In Fig. 4 (g), internal communication enables empty car downloading so that vehicle users can access immediate service in next driving. Even to a 100M file, the downloading in sparse traffic conditions only costs 20 minutes averagely, which is far less than a typical parking duration. Thus, it is attractive to ordinary vehicle users, for advocating them to join ParkCast and share their resources with others.

IV. Conclusion

Motivated by prolonged downloading delay of content distribution and substantial costs of constructing infrastructure, we propose ParkCast to make the best of roadside parking for vehicular content distribution.

In the paper, we define typical communication for roadside sharing, investigate the sequential contacts through theoretical analysis, group individual parked vehicles into per-street line cluster, and implement sequential file transfer along urban streets. The simulation results show that ParkCast makes substantial improvement over the past inter-vehicle schemes: the average downloading delay is reduced almost 100 times in sparse traffic conditions, and 20 times in dense traffic ones. Furthermore, it supports empty car downloading by totally eliminating the downloading delay.

Acknowledgment

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References

[1] A. Nandan, S. Das, G. Pau, M. Gerla, and M. Sanadidi, "Co-operative downloading in vehicular ad-hoc wireless networks," in *WONS 2005*. IEEE, 2005, pp. 32–41.

[2] U. Lee, J. Park, J. Yeh, G. Pau, and M. Gerla, "Code torrent: content distribution using network coding in vanet," in *Proceedings of the 1st international workshop on Decentralized resource sharing in mobile computing and networking*. ACM, 2006, pp. 1–5.

[3] S. Lee, U. Lee, K. Lee, and M. Gerla, "Content distribution in vanets using network coding: the effect of disk i/o and processing o/h," in *SECON 2008*. IEEE, 2008, pp. 117–125.

[4] "National household travel survey," 2001. [Online]. Available: http://www.bts.gov/programs/national_household_travel_survey

[5] J. Eriksson, H. Balakrishnan, and S. Madden, "Cabernet: vehicular content delivery using wifi," in *MOBICOM 2008*. ACM, 2008, pp. 199–210.

[6] Y. Zhang, J. Zhao, and G. Cao, "Service scheduling of vehicle-roadside data access," *Mobile Networks and Applications*, vol. 15, no. 1, pp. 83–96, 2010.

[7] B. Chen and M. Chan, "Mobtorrent: A framework for mobile internet access from vehicles," in *INFOCOM 2009*. IEEE, 2009, pp. 1404–1412.

[8] P. Deshpande, A. Kashyap, C. Sung, and S. Das, "Predictive methods for improved vehicular wifi access," in *Proceedings of the 7th international conference on Mobile systems, applications, and services*. ACM, 2009, pp. 263–276.

[9] M. Li, Z. Yang, and W. Lou, "Codeon: Cooperative popular content distribution for vehicular networks using symbol level network coding," *Selected Areas in Communications, IEEE Journal on*, vol. 29, no. 1, pp. 223–235, 2011.

[10] JUPITERRESEARCH, "Municipal Wireless: Partner to Spread Risks and Costs While Maximizing Benefit Opportunities," Jupitermedia Corporation, Tech. Rep., 2005.

[11] N. Liu, M. Liu, W. Lou, G. Chen, and J. Cao, "Pva in vanets: Stopped cars are not silent," in *INFOCOM 2010*. IEEE, 2010, pp. 431–435.

[12] S. Saroiu, P. Gummadi, S. Gribble *et al.*, "A measurement study of peer-to-peer file sharing systems," in *Proceedings of Multimedia Computing and Networking 2002 (MMCN02)*. Citeseer, 2002.

[13] W. Feller, *An introduction to probability theory and its applications*. Wiley, 2008, vol. 2.