CFT: A Cluster-based File Transfer Scheme for Highway VANETs

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Abstract-Effective file transfer between vehicles is fundamental to many emerging vehicular infotainment applications in the highway Vehicular Ad Hoc Networks (VANETs), such as content distribution and social networking. However, due to fast mobility, the connection between vehicles tends to be short-lived and lossy, which makes intact file transfer extremely challenging. To tackle this problem, we presents a novel Cluster-based File Transfer (CFT) scheme for highway VANETs in this paper. With CFT, when a vehicle requests a file, the transmission capacity between the resource vehicle and the destination vehicle is evaluated. If the requested file can be successfully transferred over the direct Vehicular-to-Vehicular (V2V) connection, the file transfer will be completed by the resource and the destination themselves. Otherwise, a cluster will be formed to help the file transfer. As a fully-distributed scheme that relies on the collaboration of cluster members, CFT does not require any assistance from roadside units or access points. Our experimental results indicate that CFT outperforms the existing file transfer schemes for highway VANETS.

I. INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) have attracted much attention in both academia and industry. Among the problems to be tackled in VANETs, effective vehicle-to-vehicle (V2V) file transfer is fundamental to many emerging infotainment applications, such as content distribution and file sharing. However, it remains to be a very challenging problem because inter-vehicle links tend to be short-lived and lossy thanks to fast node mobility. With short-lived and lossy links, it is very likely that only part of a file, which often turns to be useless in the end, can be transferred. This leads to a significant waste of network resources and hurts user experience seriously.

To enable efficient file transfer in VANETs, a variety of different schemes have been proposed. Deng *et al.* [1] proposed a Prior-Response-Incentive-Mechanism to stimulate vehicles to take part in cooperative downloading in VANETs-LTE heterogeneous networks. Huang *et al.* [2] proposed a cellbased clustering scheme and a strategy of inter-cluster Relay Selection to construct a peer-to-peer (P2P) network of scale-free property, which help to enhance the information spread. Ota *et al.* [3] proposed a cooperative downloading algorithm called Max-throughput and Min-delay Cooperative Downloading, in which the RoadSide Units (RSUs) intelligently select vehicles to serve towards the minimal average delivery delay of file transfer. Yang *et al.* [4] proposed a Cooperation-aided MaxRate First method, in which the roadside unit selects the node with the highest data rate as the receiver to serve. Liu *et al.* [5] proposed a cooperative downloading strategy that can provide mobile users with varied services to access the Internet using WiFi according to user-defined classes in highway scenarios. T. Wang *et al.* [6] proposed a cooperative approach based on coalition formation games, in which on-board units download pieces from RSUs and then exchange their possessed pieces by broadcasting to and receiving from their neighbors. S. He *et al.* [7] explored the joint pricing and allocation to incentivize mobile users to participate in mobile crowdsensing.

Most of the existing file transfer schemes focus on the QoS issues, such as packet delay and network throughput. Despite the importance of the QoS issues, we believe that file transfer integrity (i.e. whether a file can be completely transferred or not) plays a more important role because it has a direct impact on the quality of user experience. Normally, users can tolerate some extra delay. However, if file transfer attempts often lead to failures, users will be seriously upset. So far, only few studies on file transfer in VANETs have paid enough attention to the integrity aspect. Luan et al. [8] proposed an integrityoriented content transmission scheme, which focuses on the performance of the entire file transfer process and is optimized towards guaranteed integrity. However, with the scheme presented in [8], the file that is unlikely to be completely transferred during the transient connection time will simply be discarded, which is overly simple and leaves much room for improvement.

In this paper, we present a high-integrity Cluster-based File Transfer (CFT) scheme for highway VANETs. CFT adopts a cooperative approach and achieves high-integrity file transfer between vehicles without the assistance of roadside units or access points. With CFT, when the requested file cannot be successfully transferred from the source to the destination over a single direct V2V connection, a cluster is formed and the file is collaboratively transmitted over multiple hops. To facilitate the multi-hop file transfer, we developed a *Connection Time Prediction Model* and a *Content File Distribution Model* to evaluate the transmission capability of cluster members and optimally select the intermediate relay nodes.

The rest of the paper is organized as follows. Section II presents the models adopted in CFT and Section III describes

the details of the proposed cluster-based file transfer scheme. Section IV includes our experimental results and Section V concludes the paper with closing remarks.

II. SYSTEM MODEL

In this paper, we focus on the scenario in which vehicles travel on a bi-directional highway. We assume that all vehicles are equipped with the Global Positioning System (GPS) and are aware of their geographical locations.

In our research, we adopted three models to study the file transfer problem in VANETs: vehicle mobility model, connection time prediction model, and vehicle-to-vehicle communication model [9]. The details of these models are presented as follows.

A. Vehicle Mobility Model

Considering the mobility features on practical highways, we apply the free mobility model to represent the mobility of vehicles on highways [10].

The mobility features of vehicles are summarized as follows:

- The speed range is specified by a maximal speed and a minimal speed.
- A Safety Distance (SD) is defined. Namely, two adjacent vehicles on the same lane should maintain the SD for safety purposes. When the distance between two adjacent vehicles is less than SD, the rear vehicle should slow down until the distance between them meets at the SD requirement.
- A vehicle only travels along one lane of the highway.

In the mobility model adopted in our research, both the speed of all vehicles and the distance between two adjacent vehicles are specified. Fig. 1 illustrates the specifications for two adjacent vehicles.



Let Φ denote the set of vehicles. According to the mobility features mentioned previously, we can use the following velocity equations to represent the movement of two vehicles and the relationship between the speed of two vehicles:

$$\begin{cases} \left| \vec{V}_{i}\left(t + \Delta t\right) \right| = \left| \vec{V}_{i}\left(t\right) \right| + \gamma_{i}\left(t\right) * \left| \vec{a}_{i}\left(t\right) \right| * \Delta t, \\ V_{\min} \leq \left| \vec{V}_{i}\left(t\right) \right| \leq V_{\max}, \\ \left| \vec{V}_{j}\left(t\right) \right| \leq \left| \vec{V}_{i}\left(t\right) \right|, d_{ij}\left(t\right) \leq SD. \end{cases}$$

$$(1)$$

where $\vec{V}_i(t)$ represents the velocity vector of vehicle $i \in \Phi$ at time $t, \gamma_i(t)$ is a random number, $\vec{a}_i(t)$ is the acceleration

vector of vehicle *i* at time *t*, Δt is the time interval, $d_{ij}(t)$ is the distance between vehicle *i* and vehicle $j \in \Phi$ at time *t*, SD denotes the safety distance between two vehicles.

With these velocity equations, we can arrive at a highway mobility model in terms of both time and space. In our research, we assume that the initial distance between any two vehicles is $d_{ij}(t_0)$, and the initial speed of vehicles is set to $|\vec{V}(t_0)|$, and γ_1 and γ_2 are random numbers between 0 and 1. Then we have the following equations:

$$\begin{cases} d_{ij}(t_0) = (1+\gamma_1) * SD, \\ |\vec{V}(t_0)| = V_{\min} + \gamma_2 * (V_{\max} - V_{\min}). \end{cases}$$
(2)

B. Connection Time Prediction Model

We assume that the communication range of each node is R. The position, the velocity and the moving direction of vehicle $i \in \Phi$ at time t are $(x_i(t), y_i(t))$, $\vec{V}_i(t)$ and $\theta_i(t)$ respectively. Similarly, the position, the velocity and the moving direction of vehicle $j \in \Phi$ at time t are $(x_j(t), y_j(t))$, $\vec{V}_j(t)$ and $\theta_j(t)$ respectively. Fig. 2 illustrates how the connection time is predicted in our research.

In order to predict the connection time between two vehicles, we assume that once a vehicle is within the transmission range of resource vehicle, its speed will keep unchanged, then we use the following equations to calculate the connection time ΔT_{ij} [11]:

$$\begin{cases} \Delta v_x = |\vec{V}_i(t)| \cos\theta_i(t) - |\vec{V}_j(t)| \cos\theta_j(t), \\ \Delta v_y = |\vec{V}_i(t)| \sin\theta_i(t) - |\vec{V}_j(t)| \sin\theta_j(t), \\ \Delta d_x = x_i(t) - x_j(t), \\ \Delta d_y = y_i(t) - y_j(t), \\ (\Delta d_x + \Delta v_x * \Delta T_{ij})^2 + (\Delta d_y + \Delta v_y * \Delta T_{ij})^2 = R^2, \\ \begin{cases} A = \Delta v_x * \Delta d_x + \Delta v_y * \Delta d_y, \\ B = \Delta v_x^2 + \Delta v_y^2, \end{cases}$$
(4)

$$\Delta T_{ij} = \frac{-A + \sqrt{B * R^2 - (\Delta v_y * \Delta d_x - \Delta v_x * \Delta d_y)^2}}{B}.$$
 (5)

C. Vehicle-to-Vehicle Communication Model

In this section, we analyze the transmission capacity of the physical layer in vehicle-to-vehicle communication. Considering the characteristics of DSRC communication, the received signal power obeys Rice Distribution initially, but with the increase of the distance between two vehicles, the received signal power obeys Rayleigh Distribution. In order to better simulate the envelope of fading signal in highway vehicular networking environment, we apply the Nakagami-m distribution. The probability density function of the signal envelope $f(x; \mu, \Omega)$ is formulated as

$$f(x;\mu,\Omega) = \frac{2\mu^{\mu}}{\Gamma(\mu)\Omega^{\mu}} x^{2\mu-1} \exp(-\frac{\mu}{\Omega} x^2), \qquad (6)$$

$$\Gamma(\mu) = \int_0^\infty e^{-x} x^{\mu-1} dx, \tag{7}$$

where μ is the signal fading index related to the surroundings and the distance between two communication vehicles [12]. In our research, we adopt the following reference values: μ =0.74 when $d_{ij} \in [90.5, 230.7]$; μ =0.84 when $d_{ij} \in [230.7, 588]$. Ω is the average received power before envelope detection. It can be defined as

$$\Omega = P_t G_t G_r \frac{h_t^2 h_r^2}{d_{ij}^{\alpha} L},\tag{8}$$

where P_t is the transmission power, G_t and G_r are the transmission and reception antenna gain respectively, h_t and h_r are the transmission and reception antenna length respectively, L is the loss coefficient of the system, and α represents the path loss index [13]. Then we can calculate the cumulative density function of the signal to noise ratio (SNR) using the following equation:

$$P_r(\frac{\Omega}{N_r} \le x) = 1 - \frac{\Gamma(\mu, \frac{\mu}{\Omega} N_r x)}{\Gamma(\mu)}, \qquad (9)$$

where N_r is the thermal noise power, $\Gamma(\mu, \frac{\mu}{\Omega}N_r x)$ is formulated as

$$\Gamma(\mu, \frac{\mu}{\Omega} N_r x) = \int_{\frac{\mu}{\Omega} N_r x}^{\infty} e^{-x} x^{\mu-1} dx.$$
(10)

Here, we assume that the transmitter of each node in vehicular environment supports K modulation rates, c_k is the k^{th} modulation rate ($c_1 < c_2 < \cdots < c_k$, $1 \le k \le K$), and v_k is the pre-set threshold. When $v_k \le \frac{S}{N_r} \le v_{k+1}$, the module velocity is c_k . In addition, we set $v_{K+1} = \infty$. Consequently, according to the equations mentioned previously, the transmission rate c_k is selected with the probability

$$\Pr\{C = c_k\} = \begin{cases} \frac{1}{\Gamma(\mu)} (\Gamma_k - \Gamma_{k+1}), & 1 \le k \le K - 1\\ \frac{\Gamma_k}{\Gamma(\mu)}, & k = K, \end{cases}$$
(11)

$$\Pr\{C=0\} = 1 - \sum_{1}^{K} \Pr\{C=c_k\},$$
(12)

where Γ_k and Γ_{k+1} are defined as

$$\begin{cases} \Gamma_k = \int_{\underline{\omega}}^{\underline{\omega}} N_r v_k y^{\mu-1} e^{-y} dy, \\ \Gamma_{k+1} = \int_{\underline{\mu}}^{\underline{\omega}} N_r v_{k+1} y^{\mu-1} e^{-y} dy. \end{cases}$$
(13)

Thus, the average transmission rate can be obtained through the following equation:

$$E(c) = 0 \cdot P_r(C = 0) + \sum_{i=1}^{K} c_i \cdot P_r(C = c_i)$$

= $\sum_{i=1}^{K} c_i \cdot P_r(C = c_i).$ (14)

III. CFT: A HIGH-INTEGRITY FILE TRANSFER SCHEME

In this section, we present the details of the proposed highintegrity file transfer scheme, CFT. Based on the established clusters, CFT leads to high file transfer integrity. An overview of CFT is presented as follows:

- When a vehicle needs a file, it will broadcast a resource request message to its neighboring vehicles. If a neighbor vehicle has the file, it will send a response message back. Thereafter, the request vehicle selects a neighboring vehicle as the downloading source according to the velocity, the direction of the vehicle and the communication capacity.
- If two vehicles can complete the file transfer within their

connection time, the request vehicle downloads the file directly without establishing a cluster.

• If two vehicles cannot complete the file transfer within their connection time, the request vehicle establishes a linear cluster. Then the request vehicle cooperates with the vehicles in the cluster to download the file.

To evaluate the communication capacity between two vehicles and establish a cluster when necessary, each vehicle requires the position, the velocity and the moving direction its neighbors. Therefore, we assume that all vehicles in the VANETs under investigation are equipped with GPS. In addition, each vehicle broadcasts Hello messages periodically in order to collect the position and velocity information of its neighboring vehicles. The details of CFT are presented as follows.

A. Transmission Capacity between Two Vehicles

In order to evaluate the transmission capacity between two vehicles [14], we developed the *Content File Distribution Model* in our research. This model can be illustrated using Fig. 3.



Fig. 3: Content File Distribution Model: S selects another vehicle (V_i) to transfer fragments once the predicted amount of fragments have been transferred to the current cooperative vehicle (V_i) .

If the request vehicle and resource vehicle cannot complete the file transfer within their connection time, cooperative vehicles are needed. The file content is equally divided into N fragments denoted by $\Gamma = \{\gamma_1, \gamma_2, ..., \gamma_N\}$ with the size of each fragment s. During the whole connection time $\Delta T_{i,S}$, vehicle $i \in \Phi$ can not exactly download n fragments since vehicle i is out of the communication range of the resource vehicle S so that the link L_i between i and S is disconnected when the n^{th} fragment is transferring. And according the predicted connection time $\Delta T_{i,S}$, we can obtain the number of fragments n_i by

$$n_i = \left\lfloor \frac{E(c) \cdot \Delta T_{i,S}}{s} \right\rfloor,\tag{15}$$

where $\lfloor \cdot \rfloor$ denote the floor function, $E_{(c)}$ is the average transmission rate which can be obtained by Eq. 14. Besides, in Fig. 3, Δt^0 is the time spending on downloading n_i fragments completely, $\Delta t'$ is the time $\Delta T_{i,S}$ minus Δt^0 and during which the n^{th} fragment can not be downloaded completely. Their relationship is formulated as

$$\begin{cases} \Delta t' + \Delta t^0 = \Delta T_{i,S}, \\ \Delta t^0 = \frac{n_i \cdot s}{E(c)}. \end{cases}$$
(16)

In our proposed scheme, upon transferring the n_i^{th} fragment, S selects another cooperative vehicle $j \in \Phi$ to transfer file fragments and establishes the link L_j . Through this method, such data loss D_{loss} will not occur and it is of great importance for transfer time saving. Consequently, the communication capacity $C_{i,S}^c$ between any vehicle i and resource vehicle S is calculated as

$$C_{i,S}^{c} = s \cdot \left\lfloor \frac{E(c) \cdot \Delta T_{i,S}}{s} \right\rfloor.$$
(17)

In the cooperative phase, if several vehicles are in the communication range of resource vehicle, as shown in Fig. 4, the resource vehicle S will transfer the file fragments to the vehicle with the shortest distance from S.



Fig. 4: Multiple Vehicles within Communication Range: the nearest vehicle is selected as the cluster member, thereafter S transfers fragments to it.

B. Cluster Establishment

With CFT, if a vehicle cannot download the required file completely from the resource vehicle within the connection time between them, then the vehicle will establish a linear cluster and cooperate with other vehicles in the cluster to download the file. There are many methods to establish a cluster in VANETs. The key problem is how to find the vehicles that have similar characteristics as cluster members. In the proposed scheme, the following steps are used to establish a cluster.

Step 1: The request vehicle broadcasts a request packet for cooperative file transfer, then a neighboring vehicle which is within the communication range and willing to assist sends back an ACK. When the request vehicle receives the ACK, it will request the basic information, such as velocity and location, of the neighboring vehicle. Thereafter, the appropriate neighboring vehicle will be invited to join the cluster. Note that the neighboring vehicle is a cluster member while the request vehicle is the cluster-head.

Step 2: The neighboring vehicle that joins the cluster continues to broadcast the request packet for cooperative file transfer and invites its neighbors to join the cluster. Then the basic information about the newly-added cluster member is forwarded to the cluster-head vehicle. Step 2 is repeated until enough cluster members have jointed the cluster.

According to the V2V communication model mention previously, we are able to calculate the amount of data every cluster member can download. Assuming that the size of the file to be transferred is V_{file} , the size of all file fragments that vehicle *i* in the cluster can download is V_{data}^i and the number of the required vehicles (i.e. the size of the cluster) is N_c , then V_{data}^i and N_c are formulated as

$$\Gamma_{data}^{ri} = C_{i,S}^c, \tag{18}$$

$$N_{c} = \left\{ \min\left\{n\right\} \mid \sum_{i=1}^{n} V_{data}^{i} \ge V_{file}, n = 1, 2, \cdots \right\}.$$
 (19)

C. Cooperative Vehicles Transfer File Fragments to Request Vehicle

After cluster members complete the file fragment transfer, they forward their fragments to the resource vehicle. We adopt the IEEE 802.11b DCF mechanism as the MAC protocol of the network and employ the RTS/CTS mechanism to avoid the hidden terminal problem. Furthermore, we calculate the back-off time using a constant back-off window size so that we can calculate the average transmission probability of each vehicle as

$$\zeta = \frac{2}{W+1}.\tag{20}$$

In order to calculate the success probability of packet transmission, we assume that n nodes compete for one channel where n obeys Poisson Distribution and its probability mass function is formulated as

$$f_N(n) = \frac{(\rho R_{cs})^n}{n!} \exp(-\rho R_{cs}),$$
 (21)

where ρ is a traffic density parameter, R_{cs} is the diameter of carrier sense range of a vehicle. Then the probability that a node successfully sending packets in any slot can be calculated as

$$P_{suc} = \frac{n\zeta(1-\zeta)^{n-1}}{1-(1-\zeta)^n}.$$
(22)

Then the throughput of the MAC layer between two vehicles can be formulated as

$$R_{thr} = \frac{E[V_{payload}]}{E[length \ of \ a \ slot \ time]} = \frac{P_{suc}L_p}{T} [1 - (1 - \zeta)^n], \ (23)$$

where $V_{payload}$ is the payload information transmitted in a slot time, L_p is the average length of a packet, T is the average length of a slot which is formulated in [8].

Consequently, the amount of data that can be transferred between cooperative vehicle i and request vehicle R within their connection time can be calculated using the connection time $\Delta T_{i,R}$, which can be obtained using Eq. 5, and the throughput R_{thr} , which can be obtained using Eq. 14.

D. Detailed File Transfer Process

Fig. 5 includes a file transfer example. If R can download the file from S within the connection time, then R will not establish a cluster. Otherwise, R will establish a cluster for cooperative file transfer. We assume that three vehicles are needed to finish the file transfer in this example and each of them can finish the file fragment transfer within the connection time. After cluster members complete the file fragment transfer, they forward their fragments to the clusterhead R, which is illustrated in Fig. 6.



Fig. 6: Cluster Members Forward File Fragments to Cluster-Head

IV. EXPERIMENTAL RESULTS

In our research, we studied the performance of CFT via extensive theoretical analysis and Mablab-based simulations. Our detailed experimental results are presented in this section. Specifically, the performance of CFT was investigated in terms of average connection time, average throughput, average transmission capability, maximum file transfer volume, and cluster size. We also compared CFT to one of the state-of-the-art scheme, IOCT [8], to understand the advantages and disadvantages of CFT. Our detailed experimental results are presented in this section.

A. Simulation Settings

In our simulations, we use a freeway model, where vehicles travel on a bi-directional highway with two lanes per direction [15]. The major parameters are included in Table I. We use the IEEE 802.11b DCF mechanism as the MAC protocol and V2V communication protocol as the wireless communication protocol [16]. In addition, the RTS/CTS mechanism is used to avoid the hidden terminal problem.

TADIE I. Simulation Deromata

Parameter	Value
Length of per lane (km)	11
Width of per lane (m)	5
Minimum speed (km/h)	60
Maximum speed (km/h)	120
Traffic density ρ (car/km)	$\{5, 6, \ldots, 10\}$
Communication range of vehicle $R(m)$	$\{250, 300, \ldots, 600\}$
Safety Distance $SD(m)$	$\{75, 100, 150\}$
Size of file fragment s (MB)	8
Size of back-off window W	32
Length of a Packet L_p (KB)	4.2
Length of a slot $T_{slot-time}$ (us)	13
Transmission time of RTS frame (us)	53
Transmission time of CTS frame (us)	37
Transmission time of DIFS frame (us)	32
Transmission time of SIFS frame (us)	53
Transmit power P_t (W)	0.2
Hot noise power N_r (dBm)	-96
Path loss index α	4
G_t, G_r, h_t, h_r, L	1

B. Simulation Results

1) Average Connection Time: Fig. 7 shows the average connection time under different traffic densities and communication ranges when SD = 150 m. Note that ρ denotes the number of vehicles per kilometer. Our analysis and simulation results indicate that the average connection time increases with the communication range. When the communication range is 250 m, the average connection time is 5.3 s. When the communication range is 600 m, the average connection time is about 12.7 s. The average connection time does not vary significantly with the densities under investigation.

2) Average Throughput: Fig. 8 shows the average throughput between two vehicles under different traffic densities, safety distances and communication ranges. Our experimental results indicate that when $\rho = 5$ and the communication range varies from 250 m to 600 m, the average throughput varies from 6.6 Mbps to 8.0 Mbps; when $\rho = 6$, the average throughput varies form 6.9 Mbps to 8.2 Mbps; when $\rho = 7$, the average throughput varies form 7.2 Mbps to 8.4 Mbps. In summary, the average throughput increases with the traffic density and communication range.

3) Average Transmission Capability: Fig. 9 shows the average transmission capability between two vehicles under different communication ranges and traffic densities when SD = 150 m. Our experimental results indicate that when $\rho = 5$ and the communication range varies from 250m to 600 m, the average transmission capability varies from 35.0 MB to 102.9MB; when $\rho = 6$, the average transmission capability varies from 37.1 MB to 104.8 MB; when $\rho = 7$, the average transmission capability varies from 38.1 MB to 107.9 MB Therefore, the average transmission capability increases with the traffic density and linearly increases with the communication range.

4) Maximum File Transfer Volume: Fig. 10 shows the maximum file transfer volume of CFT and IOCT under different traffic densities when R = 250m. Our experimental results indicate that when ρ varies from 5 to 10, the maximum file transfer volume of IOCT varies from 35 MB to 45 MB, the maximum file transfer volume of CFT varies from 295 MB to 415 MB. The reason why the maximum file transfer volume of CFT is much greater is that a file can be transferred through multiple cluster members. Whats more, we can see from Fig. 10 that the maximum file transfer volume of IOCT is not sensitive to traffic density, which is because IOCT only involves two vehicles.

5) Cluster Size: Fig. 11 shows the average cluster size under different file sizes. Our experimental results indicate that the average cluster size increases with the file size. When $\rho = 10$, the average cluster size varies from 1.7 to 13.2. Given the same file size, lower traffic density leads to a greater required cluster size.

V. CONCLUSION

In this paper, we present a high-integrity file transfer scheme for highway VANETs, CFT, which is based on the V2V communication model and connection time prediction model.



With CFT, if the request vehicle can download a file completely within the connection time between the request vehicle and the resource vehicle, it will download the file directly. If not, the request vehicle will establish a linear cluster, where the cluster members cooperate with each other to download the file. Through extensive simulations, we studied the performance of CFT in terms of average connection time, average throughput, average transmission capability, maximum file transfer volume, and cluster size. Our simulation results indicate that CFT outperforms the state-of-the-art file transfer schemes for highway VANETs.

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REFERENCES

- G. Deng, F. Li, and L. Wang, "Cooperative downloading in vanets-lte heterogeneous network based on named data," in *Proc. IEEE INFOCOM WKSHPS*, pp. 233-238, Apr, 2016
- [2] W. Huang and L. Wang, "Ecds: Efficient collaborative downloading scheme for popular content distribution in urban vehicular networks, *Computer Networks*, vol. 101, pp. 90C103, Jun, 2016.
- [3] K. Ota, M. Dong, S. Chang, et al. "MMCD: cooperative downloading for highway VANETs," *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 1, pp. 34-43, 2015.
- [4] S. Yang, C. Yeo, and B. Lee. "MaxCD: Efficient multi-flow scheduling and cooperative downloading for improved highway drive-thru Internet systems," *Computer Networks*, vol. 57, no. 8, pp. 1805-1820, Jun, 2013.
- [5] J. Liu, Y. Ge, J. Bi, et al. "Cooperative downloading strategy on highway scenario," in Proc. of IEEE CIT, pp. 828-832, Oct. 2012.

- [6] T. Wang, L. Song, Z. Han, and B. Jiao, "Dynamic popular content distribution in vehicular networks using coalition formation games, *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 9, pp. 538C547, Jul, 2013.
- [7] S. He, D.-h. Shin, J. Zhang, J. Chen and P. Lin, "An exchange market approach to mobile crowdsensing: pricing, task allocation and walrasian equilibrium, *IEEE Journal on Selected Areas in Communications*, to appear.
- [8] T. H. Luan, X. Shen, F. Bai. "Integrity-oriented content transmission in highway vehicular ad hoc networks," in *Proc. of IEEE INFOCOM*, pp. 2562-2570, Apr. 2013.
- [9] H. Zhou, B. Liu, T. H. Luan, F. Hou, L. Gui, Y. Li, Q. Yu, and X. S. Shen, "Chaincluster: Engineering a cooperative content distribution framework for highway vehicular communications, *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 6, pp. 2644C2657, May, 2014.
- [10] Chen C, Pei Q and Li X. "A gts allocation scheme to improve multipleaccess performance in vehicular sensor networks," *IEEE Transactions* on Vehicular Technology, vol. 65, no. 3, pp. 1549-1563, Mar. 2016.
- [11] W. Su, S. J. Lee, M. Gerla. "Mobility prediction and routing in ad hoc wireless networks," *International Journal of Network Management*, vol. 11, no. 1, pp. 3-30, 2001.
- [12] X. Ta, G. Mao and Brian D. O. Anderson. "On the giant component of wireless multihop networks in the presence of shadowing," *IEEE Transactions on Intelligent Transportation Systems*, vol. 58, no. 9, pp. 5152-5163, Jun. 2009.
- [13] G. Mao, Brian D. O. Anderson and B. Fidan. "Wsn06-4: Online calibration of path loss exponent in wireless sensor networks," in *Proc.* of IEEE GLOBECOM, pp. 1-6, 27 Nov.-1 Dec. 2006.
- [14] X. Wang, W. Huang, S. Wang, J. Zhang and C. Hu. "Delay and Capacity Tradeoff Analysis for MotionCast," *IEEE/ACM Transactions* on *Networking*, vol. 19, no. 5, pp. 1354-1367, Oct. 2011.
- [15] G. Mao and Brian D. O. Anderson. "Graph theoretic models and tools for the analysis of dynamic wireless multihop networks," in *Proc. of IEEE Wireless Communications and Networking*, pp. 1-6, Apr. 2009.
- [16] Z. Miao, X. Cai, Q. Luo, and W. Dong, A FLRBF Scheme for Optimization of Forwarding Broadcast Packets in Vehicular Ad Hoc Networks, in *Proc. of IEEE PIMRC*, pp. 1-5, Sep. 2016.