Rapid Traffic Information Dissemination Using Named Data

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ABSTRACT

This paper applies the Named Data Networking (NDN) concept to vehicle-to-vehicle (V2V) communications. Specifically, we develop a simple traffic information dissemination application based on the data naming design from our previous work and evaluate its performance through simulations. Our simulation results show that data names can greatly facilitate the forwarding process for Interest and data packets. With adequate vehicle density, data can propagate over long distances robustly at tens of kilometers per second, and a requester can retrieve the desired traffic information 10km away in a matter of seconds.

Categories and Subject Descriptors

C.2.1 [**Distributed networks**]: Wireless communication-Network communications

General Terms

Performance

Keywords

Inter-vehicle communications, Named Data Network

1. INTRODUCTION

Vehicular networking has made an important breakthrough with the deployment of Vehicle-to-Infrastructure (V2I) networks. The next step is to make Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside units (V2R) networking a reality. At the link layer, wireless technologies for V2V communications (such as Dedicated Short Range Communications, DSRC [1]) are becoming mature and are expected to be deployed by all the main players in the automotive ecosystem within the next a few years. At the higher layers, however, it is also becoming clear that deploying the existing TCP/IP protocol suite in ad hoc vehicular environment can be quite challenging. Indeed, IP's point-to-point, location based communication model does not fit the highly dynamic and short, intermittent connectivity that distinguishes the ad hoc vehicular networks from wired Internet.

Named Data Networking (NDN) [2,3]) is a newly proposed architecture for the future Internet, which points out a new direction to design vehicular ad hoc networks. NDN focuses on retrieving desired data rather than establishing a session between two end nodes. NDN also eliminates the use of node addresses and retrieves data by using application data names directly. Thus NDN's request/reply exchange model seems ideally suited for the need of V2V data exchanges.

Our previous work identified the advantages of using named data for V2V communications and sketched a simple data naming design [4]. This paper takes a first step to evaluate that design through simulation experiments. Since V2V ad hoc communications utilize wireless channels which are broadcast in nature, one major challenge is a simple and effective collision minimization solution in order to provide efficient data propagation. In Section 3, we propose a solution to that problem that takes advantage of our data name design. In Section 4 we evaluate the design for traffic information dissemination. Section 5 discusses the related work. Finally, Section 6 summarizes our findings as well as our future work.

Our contributions from this work can be summarized as follows. First, we propose a mechanism that can proactively propagate traffic information data out as well as the use geo-location information embedded in data names to forward Interest packets without a network routing protocol. Second, we develop a simple NDN broadcast protocol that uses data names to minimize collision. Third, we provide quantitative measurements on the performance of V2V traffic information dissemination. Our results show that traffic information can propagate at speeds above 10 km/sec through multi-hop forwarding of data packets along traveling vehicles.

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NoM'12, June 11, 2012, Hilton Head, South Carolina, USA.

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2. BACKGROUND

The research literature of vehicular network can be largely categorized into Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), and Vehicle-to-Roadside unit (V2R). When it comes to disseminating traffic information, V2I communication raises the following challenges: (a) 3G/LTE coverage is not always available; (b) most 3G/LTE network service is not free of charge for the public; (c) disseminating information through the Internet may potentially suffer from long delays. Therefore this paper focuses on using V2V for traffic information dissemination, and we believe our design incorporates V2R cases as well.

Our earlier work investigated the use of NDN as an alternative communication model for automotive systems at a conceptual level [4,5], and sketched out a strawman proposal for the data naming convention. In this paper we present a cross-layer protocol design that applies the NDN concept in V2V network, and evaluated our design through simulation.

3. RAPID TRAFFIC INFORMATION DISSEMINATION

3.1 Application scenario

Our focused application scenario is traffic information dissemination on highways by using V2V communication. We envision that all the cars are equipped with wireless communication devices and NDN modules. Further, we assume that all the cars are able to communicate over a commonly agreed wireless channel, given that the DSRC standard is expected to be released in the near future. We also assume that cars are able to gather data about surrounding environments, e.g., traffic jam, accidents, road closures, etc. Since our current work is mainly on the communication side, how the data is generated is beyond the scope of this paper.

With these assumptions, the starting use case of our application is an accident and traffic jam information dissemination system. Briefly summarized, a driver on a road would like to know if there is any accident or traffic jam on his/her planned route and make decisions about which alternative route to choose. Note that, in our scenario, the accident information is not going to be used for safety purpose like anti-collision systems but more for comfort purpose such as trip time and route re-calculation, etc.

We identified three roles that every car may play in the system: data requester, producer, and data mule. The first two are self-explanatory. As the data mule, each car would cache data packets that it overhears over the wireless channel, even though it may not need the data for itself.

3.2 Our design

The link-layer of 802.11-family protocols including DSRC [1] provide little protection against interference and collisions. In particular, due to the nature of wireless media, it is impossible to detect collision when a node is in active transmission. The only technique available is carrier sensing, meaning that before starting the transmission, a node checks if media is free and postpones transmission if media is busy. The commonly used RTS/CTS technique to provide link-layer retransmissions and limited data delivery guarantees is not designed and does not work for multi-party communications, such as V2V.[1] This limitations motivated us to design an NDN-layer broadcast that is trying to compensate these limitations by minimizing chances for collisions using a set of timers that are guided by the semantics of names: *collision-avoidance timer*, *pushing timer*, *NDN-layer retransmission*, and *application retransmission timer*.

[1]There are several attempts to bring RTS/CTS functionality to 802.11 broadcast [6], but this approach suffers from significant delays.

Unlike plain identifiers (e.g., IP addresses or simple geo-coordinates), names bring a new level of semantical meaning to the network layer, making it intelligent in forwarding decisions. Knowing where request is destined (or where data packet has been originated), NDN-layer broadcast is able to propagate interests and data packets to intended area(s) efficiently. Note that names allow expressing "where" not only in simple geo-coordinates, but also on a higher semantical level, defining the propagation objective. For example, names can express interests to gather accident or average speed information along particular freeway, along range of freeways, or even along a particular path.

Collision-avoidance timer (T_{ca}).

Dissemination of traffic jams, accidents, road closures does not require a large amount of data. Thus, it is possible to space-out transmissions by period that is significantly greater than the actual transmission time. In our simulations, every time packet needs to be broadcast, node sets a collision-avoidance timer T_{ca} for this packet to be a uniform random value from range ($0 \ldots 2$ ms). This way, even when two neighboring cars receive an interest at the same time, they will likely to schedule transmissions of the data packets at different times.

Pushing timer (T_{gap}).

In our use case study, locally generated data has more value further away from the point it was originated. For example, information about a traffic accident is valuable not near the accident, but for the drivers traveling towards this place. Thus, it is necessary to push all such data away from the producer in the direction of potential user. Semantics that can be encoded in names gives an opportunity to perform such pushing.

For our example, packet name will encode position of where the accident happens, as well as direction and number of closed lanes. When a node receives such a packet, it can decide whether and when to schedule re-broadcasting of this data packet. The need for additional wait is necessary because V2V networks are usually dense (especially in traffic situations) and there are usually multiple cars that can overhear every transmission. Because our objective is to disseminate packet farther away from the origin efficiently and with smaller overhead, it is desirable to make a transmitter's neighbor that is farther away to re-broadcast a packet (similar mechanism was proposed by Kaul et al. [7]). At the same time, we do not want to eliminate possibility of a nearby car to re-broadcast and to make at least some progress in data pushing. We do this by making a farther car from the previous transmitter wait shorter than a nearby car.

The following formula shows calculation of pushing timeout T_{gap} which is used in additional to T_{ca} timer:

$$T_{gap} = T_{dist} \cdot \frac{D_{max} - \min(D_{max}, D_{transmitter})}{D_{max}}$$

T_{dist} is a minimum delay for a node that is next to the previous hop, D_{max} is a maximum range for wireless transmission, $D_{transmitter}$ is a distance to the previous hop. In our simulations, we have used the following parameters: $T_{dist} = 5$ ms and $D_{max} = 150$ meters.

If during any of the waiting periods a nearby node transmits an interest or data for the same name, this packet can be overheard and may be used to cancel previously scheduled transmission. Figure 1 shows more details on packet processing. In particular, every time a packet is received on wireless interface, the receiver checks packet type and determines if packet for the same name is scheduled for broadcasting. If so, it is necessary to check if the overheard packet is from somebody farther away from the origin (i.e., is there a push progress?). Also note that when a data packet is overheard, if an interest packet for the same name has been scheduled for broadcasting, this interest should be canceled, while the received data packet should be forwarded up to the application.

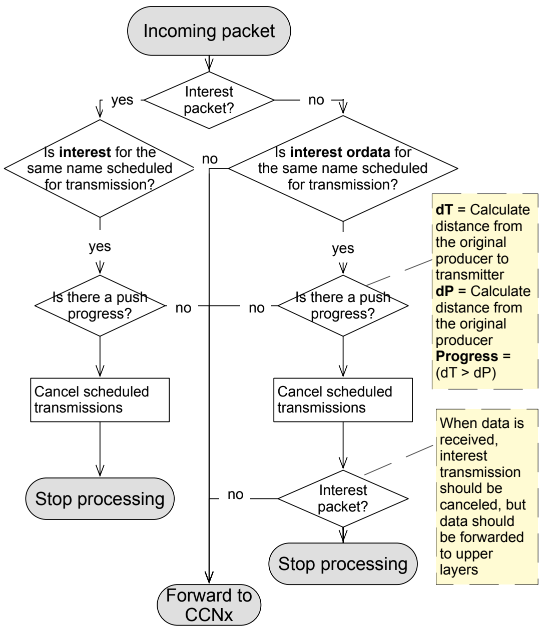

Figure 1: Packet processing on NDN broadcast face

NDN-layer retransmission timer (T_{retx}).

Of course, in a vehicular communication environment, there are many obstacles for wireless communication, as well as the V2V network itself is highly dynamic and tend to be partitioned frequently. As a result, there is a need to provide at least limited protection for link-level delivery of interest and data packets. Unfortunately, it cannot be accomplished using DSRC MAC layer: when a packet is broadcast, there is nobody to confirm reception of the packet.

To solve this problem, we make every node to broadcast every packet several times (up to eight times in our simulations) with a pre-configured retransmission timeout T_{retx}. When the node hears that the packet has been successfully re-broadcast farther (i.e., retransmission from somebody ahead is treated as an acknowledgment), it will cancel subsequent retransmissions.

In our simulations we decided to use $T_{retx} = 50$ ms, which is the main reason why the propagation speed decreases rapidly with decrease of car density (see Section 4). However, even with this parameter, pushing has very good performance. Taking into account the fact that cars are moving, the bigger the NDN-layer retransmission is, the more likely that there will be somebody new in the range that will decide transmit further.

Application retransmission timer (T_{app}).

Besides recovering from short-term packet collisions and network partitions, it is responsibility of the application to re-express interests if link layer fails.

Figure 2 shows transmission progress in the case with bad wireless reception and frequent partitioning. Even with multiple retransmissions on data link layer, the first request could not fetch data back to the requester. If the application is persistent with re-expressing interest, it will eventually pull the data. Note that due to intrinsic caching property of NDN, the retransmitted request propagate only to the closest node that happens to cache the data during the previous request.

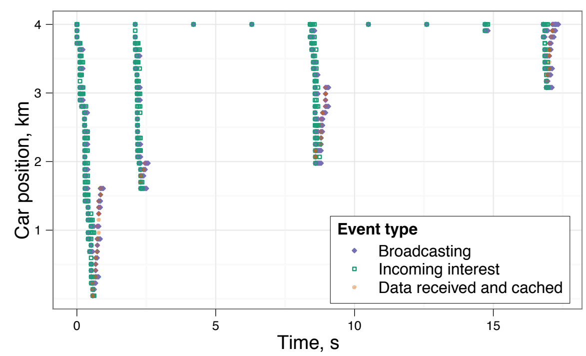

Figure 2: Re-expressing interests and caching effect on data pulling

4. SIMULATION RESULTS

In this section, we present our simulation results. Sepcifically for data *pushing*, we evaluated the following metrics: data propagation distance and speed in 4.2 since data expires quickly in vehicular environment; retransmissions of data packets in 4.3 for efficient use of the wireless channel; long distance throughput limit we can get from vehicle to vehicle communications in 4.4. And for *retrieving* data using interets, we measured the round trip delay in 4.5.

4.1 Simulation set up

We use an NS-3 based NDN simulator [8] to evaluate the performance of our design. Our simulation has the following configurations:

- **Mac layer**: We use the Ad-hoc Wifi (802.11a) as an emulation of DSRC (not available in NS3). We believe this choice does not change the nature of the problem we are trying to evaluate.

- **Physical layer simulations**: We use a transmission power of 5 *dbm* (3.16 mW) and antenna gain of 1 for transmission. For receivers, the minimal energy that it can detect is set to -96.0 *dbm* (default in NS3). We use Nakagami propagation process to simulate signal losses on freeway. With these settings, packet delivery ratio can be more than 90% for receivers 50 meters away from a transmitter.

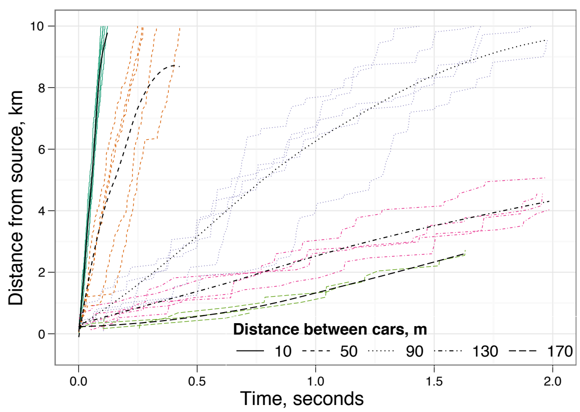

Figure 3: Data propagation over time (dashed lines represent runs with different random number generators, and highlighted lines are smoothed from the multiple runs)

- **Mobility model**: We use a simplified mobility model where cars move along a straight highway in the same direction at a constant speed of 60 mph. The distance between adjacent vehicles is the same for all, and we adjust this distance to adjust vehicle density. The simulation results in the next section are obtained from placing a sequence of cars that spans a total length of 10km. The number of cars is determined by the distance between neighboring cars, e.g. there will be 200 cars if neighboring distance is 50 meters.
- **Data publisher and requester placement**: A data publisher is placed at the head of the vehicle sequence in travelling direction. In proactive data *pushing*, data packets are injected at the publisher and then disseminated. For data *retrieval* evaluation, a requester is placed at the tail of the car sequence and generates Interests to get the data from the publisher.

4.2 Data propagation progress

When one piece of data is injected at the publisher, figure 3 shows how fast and how far the data travels depending on car density. For the case that neighboring distance is 170 meters, data propagation does not reach the 10 km distance because of packet loss. We can also tell from the figure that when the distance between cars is shorter (higher density), data tends to propagate faster. Figure 4 confirms the observation, and shows how data propagation speed changes under different distances between cars. Our interpretation is that in high density settings, there are more neighbors around each car who can potentially be the next forwarder. Therefore the expected waiting time of the first forwarder is shorter compared with the lower density settings. Even though the first neighbor who decides to forward may not be the furthest neighbor that has received the data, the resultant shorter waiting time overweighs and helps data propagate faster.

4.3 Retransmissions of data packet

As explained in 3.2, a receiver of data packet will actively broadcast the data multiple times if it doesn't hear other cars' forwarding as suppression. The retransmission

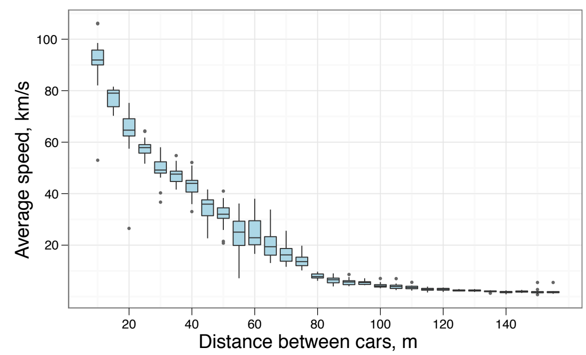

Figure 4: Data propagation speed vs distance between cars

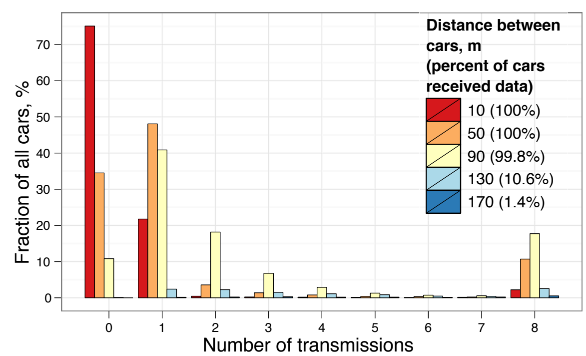

Figure 5: Count of data transmissions

increases reliability of data propagation. On the other hand, when no other car is in a packet receiver's broadcast range or cars in broadcast range have all already cached the data, the receiver will not hear any suppression. Retransmissions represent inefficient use of the wireless channel in these cases. Therefore it is important to evaluate the retransmission distribution under different car density settings, as shown in figure 5. We set the maximum retransmission limit to be 8. As we can see, under neighboring distance setting of 90 meters, majority of cars retransmit less than 4 times. As the neighboring distance increases, cars tend to retransmit more times. Also the legend tells us that the total percent of cars who finally received data decreases as neighboring distance gets larger.

4.4 Throughput

To evaluate the reliability of active data forwarding, we start with the same setting as above but with more data packets injected at the publisher side. Then we measure the throughput perceived by a car 10 km away from the publisher. Clearly the end-to-end throughput depends on the publisher side injection rate, and also the car density in between. We start with a slow injection rate of 25 packets per second, and gradually increase the rate to be 200 packets per second. For each injection rate, we measured the throughput under different car densities with distance between cars varying from 10 meters to 130 meters. Figure 6 shows the simulation result. Since the data packet size in our simulation is 300 bytes, we can derive the data injec-

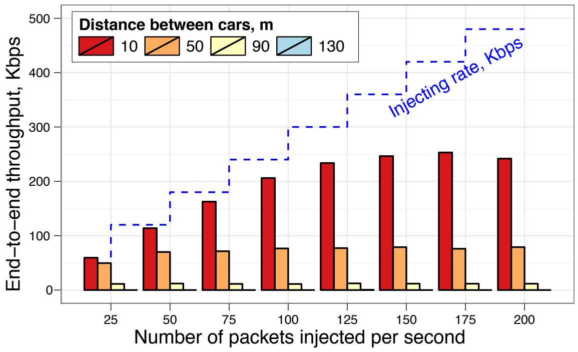

Figure 6: The end-to-end throughput increases with the injection rate in low rate cases, but eventually saturates.

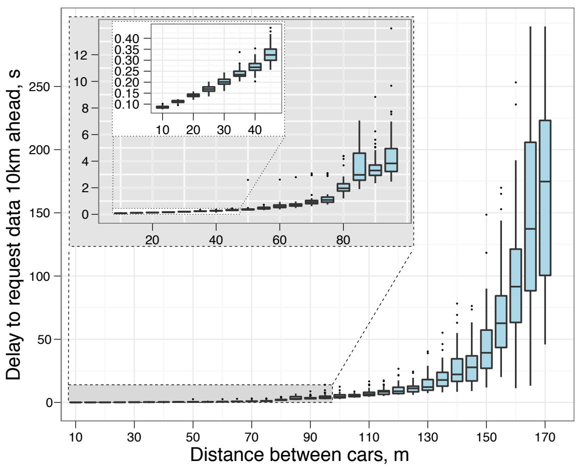

Figure 7: The delay to retrieve data 10km away under different car densities

tion rate in units of Kbps according to number of packets injected per second, which is shown as the dashed line in the figure. The dashed line provides an upper limit for the end-to-end throughput. As we can see, for low values of injection rate, the throughput increases with injection rate. But after the injection rate gets to certain point, the throughput saturates because the propagation channel through cars gets congested, e.g. for the 10 meter distance cases throughput saturates at 253.09 Kbps when injection rate gets to the 175 packets per second.

4.5 Data retrieval delay

Since in vehicular network connectivity is highly disruptive, active data propagation may stop after certain hops due to sparse car density. Later on when car density becomes high again, requesters should rely on expressing interests in order to retrieve data. Thus it is important to investigate the delay between a requester sending out an interest and the time it receives the data. Figure 7 shows the delay to retrieve data 10 km away from a requester under different density settings. As we can tell, in the neighboring distance setting of 90 meters, it takes less than 4 seconds to retrieve a data packet when car distance is less than 90 meters. The delay increases when neighboring distance gets larger as expected. Also due to packet loss the requester may need to express the interest multiple times as shown in figure 2, therefore the variance of delay increases dramatically as neighboring distance increases.

5. RELATED WORK

There are a number of existing researches that closely relates to our work. It is shown in [9] that distributed traffic management system with vehicular ad hoc networking can reduce road traffic congestion in realistic scenarios.

Kaul et al. [7] proposed a geo-backoff mechanism that uses spatial diversity (geographic distance to the destination) to select forwarding nodes that are most likely to succeed. Our use-case study in this paper does not assume a fixed destination nodes, but rather relies on naming design to implement a similar backoff mechanism to efficiently forward information in direction of a potential user.

Leontiadis and Mascolo [10] introduced an event dissemination protocol that uses opportunistic cache and relay mechanisms to deliver content to subscribers in a given geographical area. Wu et al. [11] proposed the mobility-centric data dissemination algorithm (MDDV) that uses vehicle mobility for opportunistic forwarding, trajectory-based forwarding, and geographical-based forwarding. Different from all above approaches that use destination location, our proposed approach uses naming design for choosing forwarding nodes in highly dynamic vehicular environments.

6. CONCLUSION

In this paper we conducted simulation evaluations of our NDN-based V2V traffic information dissemination design and learned the following.

First, we identified the need for simple and effective collision prevention solutions for wireless broadcast communications in V2V environment. Existing wireless standards provide solutions to prevent collisions for unicast communications only. We developed a solution at the NDN layer to minimize collisions, which uses a smart randomized scheduling based on the geo-location information carried in data names in order to minimize collision as well as speed up the data propagation by letting furthest node from the sender forward the data.

Second, we made a general observation that data gets generated at one location, but potential consumers for this data are most likely to be far away. To speed up the data propagation towards interested consumers, we proposed to proactively push data out through active data mules. The data mules take advantage of wireless broadcast channel to capture any data sent on the medium and further forward it. This represents a departure from the original pull-based data retrieval considered for wide area NDN networks.

Third, our simulation results confirm the validity and feasibility of the design sketched out in [4]. With adequate vehicle density, data can propagate over long distances robustly at higher than 10 km/sec speed. Our results also further confirm that named data is the right approach to vehicle communications: in our proposed application, both data source (the producer) and destination (the consumer) vehicles are unknown a priori. This makes IP's point-to-point delivery model an ill-fit as it relies on identifying endpoints by their IP addresses. The intermediate forwarders (data mules) are also unknown a priori; they automatically take on the role as they see the opportunity based on data names.

We have identified two important tasks for further investigations. Our immediate next step is to evaluate our design with disconnected segments of traffic. We would like to examine how effective and efficient the system could be in traffic information dissemination when vehicles travel with disconnected segments, and how fast and reliably data could be propagated when cluster of nodes experiences intermittent connectivity in between.

Second, we believe it remains an open question whether ad-hoc vehicular networks require a dynamic routing protocol. In wide area NDN networks, Interests are routed towards data producers. In our system, proactive data push performed by active mules helps move the data towards interested consumers, reducing the distance Interests have to travel. In addition, geo-aided Interest forwarding also diminishes the need to run a routing protocol between the vehicles. Further experimentations under different road distributions and traffic conditions would help shed light to this question.

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