Source Mobility in Vehicular Named-Data Networking: An Overview

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Abstract. This work investigates the problem of content source mobility in Vehicular Named Data Networking (VNDN). We evaluate through experiments the effects of source mobility on VNDN application performance, we analyze the main approaches already proposed in the literature to address its negative impacts and propose a new solution. Our proposed solution combines the concepts of Floating Content (FC) and Home Repository (HR). FC is an infrastructure-less mechanism that relies on in-network caching and content replication to support content sharing within a specific geographic region. An HR is a fixed node that can provide requested content objects on behalf of mobile content sources. Our main goal is to propose an efficient solution for source mobility in VNDN, able to provide high application performance and eliminate the weaknesses of existing approaches such as single points of failure and high overhead in the wireless communication medium.

Keywords: Source mobility · Vehicular Ad-hoc Networks
Named-Data Networking · Vehicular Named-Data Networking

1 Introduction

Named-Data Networking (NDN) [1] is currently seen as a viable alternative to overcome some of the main challenges associated with the traditional TCP/IP protocol suite. The TCP/IP model was conceived with the focus on static network topologies, formed by a small number of powerful and reliable computers, where resource sharing was the fundamental mission of the network. Nowadays, as opposite to resource sharing, content distribution has become the core use of computer networks [2]. The global Internet content traffic is expected to reach 1.4 zettabytes per year during 2017 [3]. Besides, network nodes have evolved from fixed to mobile and more recently to highly mobile, such as in the cases of Vehicular Ad-Hoc Networks (VANETs).

The performance of the IP point-to-point and host-based model is significantly affected by inherent VANET characteristics such as highly dynamic

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topologies, and short and intermittent connectivity among vehicles [4]. Furthermore, the Internet Protocol (IP) assigns network addresses (i.e. IDs) to hosts based on their topological network location. Consequently, as mobile hosts move to new physical locations, their IDs also change.

The current paradigm shift in computer networks and the high mobility of nodes bring a set of new and challenging tasks to overcome for the future Internet. At the data link layer, new wireless communication technologies such as the IEEE802.11p [5] have been developed, enabling vehicular communications. At the network and transport layers, new solutions are still being proposed as alternatives to problems that are not easy to solve under the assumptions of TCP/IP.

Considering the above stated, to efficiently support content distribution in the network layer, new network architectures have emerged. Named-Data Networking (NDN) [1], which evolved from Content-Centric Networking (CCN), is one of the most prominent among the recently proposed network architectures.

The NDN architecture presents the Interest/Data messages exchange model. Interest messages are used by content requesters to request content, and Data messages are used by content sources to deliver requested content objects. Besides, NDN maintains three types of data structures: (i) *Content Store* (CS), for caching incoming content; (ii) *Pending Interest Table* (PIT), to keep track of forwarded Interest messages; and (iii) *Forwarding Information Base* (FIB), to store outgoing interfaces to forward Interest messages.

NDN eliminates the use of node addresses and retrieves content through content names directly. NDN also does not require some of the specific TCP/IP requirements, such as maintaining neighbor lists, domain name services, network addresses, connection-oriented sessions, etc., which generate significant overhead in dynamic wireless scenarios, negatively impacting application performance.

In NDN, content objects are replicated and cached within the network, and content requesters can obtain the requested content from the closest available content source. The closest available content source can be either the original content producer or a node caching a valid copy of the requested content. Therefore, NDN reduces content delivery delay. In this way, also the number of content sources increase within the network, contributing to increasing content delivery probability and making the content available to requesters even after the original producer has disconnected from the network.

Despite its significant advantages, deploying NDN over VANETs (i.e. Vehicular Named-Data Networking (VNDN)) presents own challenges that shall be addressed to support content distribution efficiently. Among these challenges we can mention mobility factors such as source and receiver mobility, and low vehicle densities as well as wireless communication problems such as broadcast storms and message redundancy.

The remainder of this paper describes in Sect. 2 existing solutions for mobility support in VNDN. Section 3 describes the source mobility problem, which is in the main scope of this work, and analyzes the advantages and drawbacks of already proposed solutions. In Sect. 5 we sketch a possible solution to address the drawbacks of existing solutions and efficiently mitigate the effects of source mobility in VNDN. Section 6 concludes this work.

2 Mobility Support in Vehicular Named-Data Networking

Due to Receiver mobility often partitions in communication links between Data message forwarders (i.e. reverse path partitionings (RPPs)) occur, preventing content objects from being delivered to content requesters. This problem can be addressed applying the Auxiliary Forwarding Set (AFS) mechanism [6]. AFS takes various mobility factors as inputs, including average and limit road speeds, maximum expected content delivery delay, the maximum transmission range of vehicles and distances between consecutive Interest message forwarders, to determine RPP occurrence probability. When the probability of RPP is high AFS chooses a set of eligible vehicles to forward Data messages in addition to the original forwarders. AFS increases content delivery probability and significantly improves VNDN application performance.

The problems caused by low vehicle densities can be mitigated as shown in [7] by applying the concepts of NDN agent delegation and NDN store-carry-forward (NDN-SCF). The agent delegation approach takes advantage of existing Road Side Units (i.e. RSU agents) and allows content requesters to delegate content requests to close RSU agents. In this way, when the density of intermediate vehicles to forward Interest/Data messages between content requesters and content sources is not enough, which increases the number of unsatisfied content requests, RSU agents take the role of forwarding received messages. When infrastructure support is not available, VNDN-SCF can be applied. In VNDN-SCF whenever intermediate vehicles are not able to deliver messages to subsequent vehicles, messages are buffered and periodically re-forwarded until successful delivery is achieved.

The broadcast storm problem generates congestions in the wireless communication channel. The message redundancy problem cause erroneous stop of message propagation. Both problems lead to large decrease in content request satisfaction ratios and can be addressed in different ways. For instance, [6] presents a multi-hop, receiver/based, beacon-less, and distance-based VNDN routing protocol that mitigates both problems simultaneously.

Source mobility is another challenging problem that highly impacts VNDN application performance. Nevertheless, efficient solutions for the source mobility problem are still needed.

3 Source Mobility in Vehicular Named-Data Networking

In this section we describe the source mobility problem, we evaluate its effects on VNDN through simulations, we analyze the effectiveness of different solutions that have been proposed in the literature, and finally describe a new solution that intends to solve the weaknesses of existing approaches.

3.1 Source Mobility Overview

To understand the problem of source mobility in VNDN, let us consider the following example. A vehicle *A* advertises a content object *C1* as available in its current location. Vehicles *B, C*, and *D* receive the content advertisement and save this information. After a time interval *T1*, vehicle *B* decides to request the content object *C1*. To do so, vehicle *B* sends an Interest message towards the location, where vehicle *A* advertised *C1*. However, when the Interest message arrives at the destination, vehicle *A* might already have moved to a new location. Therefore, vehicle *A* is not able to receive the Interest message, and the content request is not satisfied.

The VNDN decentralized in-network caching property provides an alternative for the source mobility problem in cases of popular content objects. In such a case the content request might be satisfied by other neighbor vehicles that have a copy of the requested content object in their Content Stores (CSs). However, in the case of less popular content, which might be requested by a single vehicle, the probability of finding the requested content in the CSs of neighbor vehicles is low.

In the following Sub-section we analyze the effects of Source Mobility in VNDN application performance.

3.2 Impact of Source Mobility on the Performance of Vehicular Named-Data Networking

To evaluate the effects of the source mobility problem in VNDN applications we performed a set of simulations. For this, we evaluated the VNDN approach proposed in [6] in the Omnet++ simulator [8]. We used SUMO [9] and VEINS [10] for road traffic and inter-vehicular communications respectively. We applied the Erlagen SUMO traces [10] and simulate a flow of four hundred VNDN enabled vehicles driving along a 10 km portion of the E45 Route in the city of Erlangen, Germany. The E45 Route is a two-way highway with four lanes.

We evaluated three different cases according to the maximum vehicle speeds. In the first case, vehicles drive with speeds between 0 and 20 km/h. In the second and third cases, we increase the maximum vehicle speeds to 50 km/h and 100 km/h respectively. In each case, we also vary the density of vehicles. We analyze the results regarding Interest Satisfaction Ratio (i.e. percentage of content objects received with respect to content objects requested) and Content Delivery Delay. The results are shown in Figs. 1 and 2.

In Fig. 1, we can observe that for the case of low mobility (20 km/h), high Interest Satisfaction Ratio (ISR) is achieved and that ISR decreases as the mobility increases. To understand why this happens, let us consider the case of two different vehicles *VA* and *VB*, advertising two different content objects, *CA* and *CB*, from the same place, at the center of a region *R*. For simplicity, let us assume that the region *R* has a circular shape and a radius $r = 200$ m. Both vehicles are following the same trajectory. However, *VA* is driving at 20 km/h (i.e. 5.6 m/s) whereas *VB* is driving at 100 km/h (27.8 m/s). Due to higher speed, *VB* only stays within the region *R* around 7.2 s after advertising the content object while

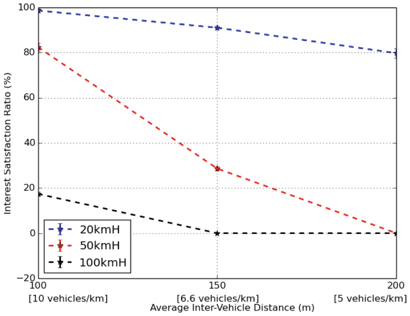

Fig. 1. Interest satisfaction ratio

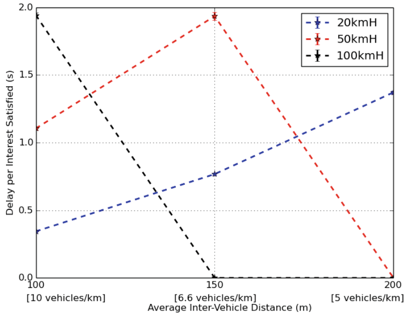

Fig. 2. Content delivery delay

VA stays within the region *R* around 35.7 s. Considering this, it is obvious that Interest messages sent by other vehicles towards the region *R* reach with higher probability *VA* than *VB*. Therefore, the Interest Satisfaction Ratio for content objects requested from *VA* is higher compared to *VB*. Furthermore, the effects of source mobility are exacerbated by the decrease in the density of vehicles.

In Fig. 2, we can observe that the Content Delivery Delay also increases as the mobility increases. We can also observe in Fig. 2 that in the case of vehicles driving with maximum speeds of 100 km/h and 50 km/h, Content Delivery Delay drops to zero when average inter-vehicle distances reach 150 m and 200 m, respectively. This happens due to complete disruptions on the communication links between vehicles that prevent content objects from being delivered to requester vehicles, as shown in Fig. 1.

Considering the above stated, solutions to efficiently address the source mobility problem in VNDN are required.

4 Existing Solutions for Source Mobility in Vehicular Named-Data Networking

In this Section we survey various approaches that have been proposed in the literature as solutions for the source mobility problem. For each solution we analyze its feasibility for VNDN scenarios.

In [11], the authors propose a proxy-based mobility support approach for mobile NDNs (PMNDN). They divide the entire network into multiple autonomous systems (ASs) and for each AS they deploy two new static functional entities. These new functional entities are called NDN access router (NAR) and proxy, respectively. NARs are used for tracking the mobility status of content sources and initiating mobility related signaling to the proxies. Proxies are used for maintaining reachability information about content sources. The authors also add two new types of data structures in NARs and proxies: the Source Location Table (SLT) and the Interest Packet Store (IPS). SLTs keep track of the content sources that are currently or previously resided in the management domain of the NAR (or the Proxy), while IPSs cache Interest messages that the NAR (or the Proxy) receives during the disconnection period of content sources.

The core idea is that content sources only exchange signaling information with the proxies. Therefore, it avoids the overhead for tracking positions of content sources by other nodes. This intends to save the resources of the wireless communication medium as well as saving the amount of energy consumed by content sources. When a content source is not reachable due to mobility, the proxy caches Interest messages forwarded towards the old location of the content source, and when it reaches another AS and connects to a new proxy, the Interest messages are forwarded by the previous proxy to the new proxy and delivered to the content source. The content source then responds with the corresponding Data messages. Therefore, the information stored in the proxies, allows NDN nodes to recover communication links that are disrupted due to content source mobility.

The solution proposed in [11] targets NDN scenarios with low mobility. In VNDN scenarios with high mobility, both content sources and content requesters join and leave ASs frequently. In dense scenarios particularly, where large number of content sources might coexist in the same AS, this approach might generate significant overhead due to signaling between content sources and proxies simultaneously with content requests and delivery. Furthermore, [11] requires significant modifications to the plain NDN structure to include the proxy and the NAR entities as well as the new data structures. This raises compatibility concerns regarding the deployment in real world scenarios.

The work in [12] proposes the idea of Indirection Points (IP) to handle source mobility in NDN. An IP is a static node that is connected to a particular Internet Service Provider (ISP). This approach uses two different types of content names. A persistent name identifies a specific content object permanently, whereas a temporary name changes as the attachment points of the content source to the network also changes. Temporary names include a prefix under which the content source can temporarily receive Interest messages. Each IP maintains a new table, called Binding Table, that relates temporal content names with persistent content names. When an IP receives an Interest message with a specific persistent name, it first tries to satisfy it from its cache. If the content is not available in its cache, the IP performs longest-prefix matching on its Binding Table for the persistent name of the requested content object. If it finds a match, it encapsulates the Interest message with the current temporary name of the content source and forwards it. When a mobile content source receives the Interest message, it decapsulates the original Interest message and sends back the corresponding Data message. After receiving the Data message, the IP decapsulates the Data Message and sends it to the initial content requester. When a mobile content source connects to the NDN network the first time, it sends a binding request to the IP specifying the content objects that it can serve, as well as the prefix under which it currently can receive Interest messages. As mobile content sources move and change their attachment points, they request IPs to delete obsolete bindings. On their sides, IPs periodically check the reachability of temporary names. If a prefix is unreachable, it is removed from the Binding Table.

This approach generates less overhead compared to [11]. Apart from the content requests and content delivery, only one extra message is exchanged within each content source and the IP. However, content requests received by an IP for content objects served by a vehicle that has already disconnected from that IP are not satisfied. Furthermore, all content requests and delivery in a given region are performed through the IP, which might generate congestions in IPs in dense scenarios. This is critical as IPs represent single points of failure in this approach. Besides, only vehicle-to-infrastructure communication is used, ignoring the potentials of vehicle-to-vehicle communications.

In [13], the authors extend the idea proposed in [12]. This approach relies on a mobility agent called Home Repository (HR), which is similar to the IP presented in [12]. The HR is a static node that can receive Interest messages on behalf of the mobile nodes. When a mobile content source moves into a new domain, the corresponding HP assigns it a prefix related to its current location, which it can use to receive Interest messages. When a content requester sends an Interest message, the Interest message is routed towards the corresponding HR. In response, the HR sends a new Interest message that is identical to the received one, except that it specifies the prefix of the corresponding content source. The content source then responds with a Data message, which includes the requested content object as well as its location prefix. The Data message propagates back to the content requester via the HR. When the content requester receives the Data message, it extracts the location prefix of the content source. With this information, next content objects can be retrieved directly from the content source without using the HR.

This work in [13] solves some of the problems of [12]. Only the first segment of a content object is retrieved directly from the HR since after knowing the prefix of the content source, content requesters send subsequent Interest messages directly to the content source. With this, the single point of failure problem and congestion on the HR are avoided. However, the problem of retrieving content objects produced by vehicles that have already disconnected from the HR still occurs. In scenarios with high mobility, where content sources might disconnect from an HR and connect to another one frequently, this can lead to considerable degradation of application performance.

The work in [14] proposes a greedy routing protocol (MobiCCN), which works in parallel with the CCN routing protocol. The goal is to support source mobility in CCN. To distinguish between the two routing protocols (i.e. MobiCCN and CCN), two different prefixes are used. Whenever a node receives a message with the prefix *greedy* the MobiCCN protocol is used whereas when the message prefix is *ccnx*, the CCN routing protocol is used. MobiCCN differentiates routers from other nodes. Each router is assigned a virtual coordinate (VC), which is embedded into message content names, while the other nodes are identified by an ID. Each router maintains a table of neighbor VCs. To forward a message, a router first extracts the destination VC from the message, then it calculates the distance between the destination and each of its neighbors. The message is forwarded to the neighbor that is closer to the destination. The router then updates its FIB, so next messages to the same node are forwarded without having to calculate the distance again. In this approach, each node also has a dedicated router that is the one closest to it and acts as its host router in the network. The host router serves as a rendez-vous point and forwards traffic to the node. Whenever a content source moves to a new attachment point, it sends an update message to its host router. Each router that receives the update message updates the corresponding entries for that content source in its FIB. Then Interest messages towards the content source can be forwarded to the new domain. This work in [14] differentiates consumer nodes from routers. However, in VANETs any vehicle might perform either as a router when forwarding messages, or as a content requester/source. Furthermore, all communications in a given region are performed through the VC. The V2V communication approach is not considered. For instance, a vehicle requesting a content object that could be satisfied by another vehicle in its one-hop neighborhood has to request the content object from the VC instead of retrieving the content object from its neighbor. This increases the delay and also creates single points of failure in VCs.

In [15], the authors present the idea of Data Spots (DS). In a DS, every requested content object is associated with a geographical region and can be generated on demand by any vehicle currently in the region. For instance, in road traffic applications, a vehicle might send an Interest message requesting information about the road conditions at a given point ahead on its trajectory. The Interest message might be geographically routed towards the specified location and delivered to the vehicles currently at that location. These vehicles might then collect the requested information and send it back towards the content requester.

This approach targets the specific case where the requested content objects are produced when requested. However, for the cases where vehicles are requesting a content object that was previously advertised by a specific content source this approach is not useful. Furthermore, it assumes that there will always be vehicles in the region where content objects are requested to collect requested content objects. With the dynamics of vehicle movement in VANETs, especially when vehicle density is low, the case of no vehicle available in the region where the content object is requested when the Interest message arrives there, might often occur, leading to unsatisfied content requests.

5 Efficiently Addressing Source Mobility in Vehicular Named-Data Networking

In this Section, we describe a possible approach to addressing the problem of source mobility in VNDN. Our main goal is to simultaneously provide high application performance and avoid the weaknesses of the solutions presented in the previous Section. Particularly we aim to provide a general purpose mechanism for efficient content delivery in VNDN and at the same time avoid single points of failure and signaling overhead in the wireless communication medium. We propose a hybrid mechanism that combines the concepts of Floating Content [16]

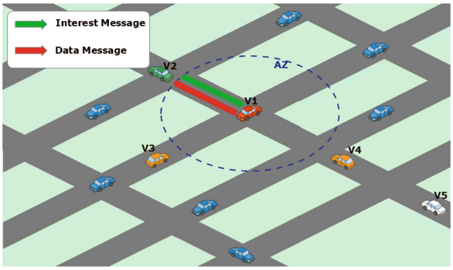

Fig. 3. Floating content

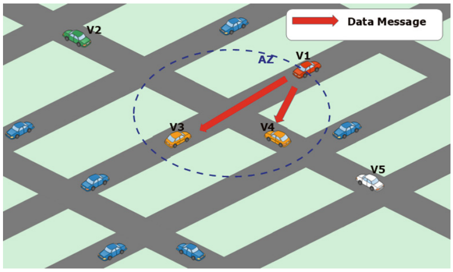

Fig. 4. Content replication 2

and the Home Repository [13] as discussed in the previous Section to provide seamless communication for VNDN content requests and delivery.

Floating Content (FC) [16] is a communication scheme for distributed content sharing within a certain geographic region (i.e. the Anchor Zone (AZ)), without the need for infrastructure support. In VNDN, FC might use decentralized in-network caching and content replication to make content available to vehicles within the AZ.

Whenever a vehicle possessing a content object leaves the AZ, it might replicate the content object to other vehicles currently within the AZ to maintain the content stored in the region where it was generated. In this way, after the vehicle that produced the content object disconnects from the network, the content can still be requested from the same region and provided by the other vehicles that received the content through replications from other vehicles that previously left the AZ.

As illustrated in Fig. 3, vehicle *V2* requests a content object *C1*. The Interest message is received by vehicle *V1* that possesses the content and sends the corresponding Data message. Later on, as shown in Fig. 4, when vehicle *V1* leaves the AZ, it replicates the content object to vehicles *V3* and *V4* that are within the AZ. When the same content object is requested by vehicle *V5*, as shown in Fig. 5, the content is provided by vehicle *V4*, which is the content source closer to vehicle *V5*.

In FC, a single vehicle caching a content object within the AZ might be enough to satisfy all content requests for that specific content object, from different vehicles. Therefore, to prevent extra overhead in the wireless communication channel, the number of vehicles that is required to replicate a specific content object can be tuned according to the density of vehicles within the AZ and the time interval between consecutive received content replicas.

In scenarios with extremely low vehicle densities, the case where no vehicle is available within the AZ at a given time, to receive content replicas from another vehicle leaving the AZ might happen. In such a case, the HR idea can be combined with FC to increase content availability probability within the AZ.

When applying HR (i.e. a fixed storage point), a vehicle leaving a sparse AZ might ask an existing HR in the AZ to also store the content object replicated.

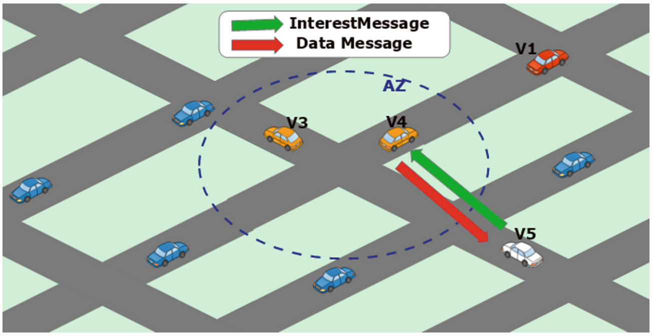

Fig. 5. Content delivery

In this way, the content object can be retrieved from the HR by other content requester vehicles. When applying this idea, content availability probability within AZ is not affected by the density of vehicles. The main reason for only storing content objects in HRs when the density of vehicles is low is to efficiently manage the storage capacity of HRs and avoid scalability issues.

6 Conclusions

In this work, we investigated the problem of content source mobility in Vehicular Named Data Networking (VNDN). We evaluated through experiments the effects of source mobility on VNDN application performance and proposed a new solution to increase content delivery probability based on the concepts of Floating Content and Home Repository. Our solution intends to eliminate the weaknesses presented by existing solutions and provide high VNDN application performance.

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