A Geographical Aware Routing Protocol Using Directional Antennas for NDN-VANETs

Eirini Kalogeiton, Domenico Iapello and Torsten Braun
Institute of Computer Science, University of Bern, Switzerland
{eirini.kalogeiton, torsten.braun}@inf.unibe.ch, domenico.iapello@students.unibe.ch

source: https://doi.org/10.7892/boris.130425 | downloaded: 3.4.2024

***Abstract*—In Named Data Networking (NDN) content is retrieved based on names instead of locations of hosts. Therefore, NDN is a suitable candidate for content retrieval in Vehicular adhoc Networks (VANETs), which are characterized by path breaks due to intermittent connectivity. In an NDN-VANET to avoid path breaks broadcasting every message is considered the most reliable way for content retrieval. In this work, we unicast messages to reduce the usage of network resources, when it is possible. Our work limits the dissemination area of messages by installing directional antennas in vehicles. We develop an algorithm to choose the appropriate directional antenna to unicast a message, allowing vehicles outside of the spreading area of the message to perform other tasks. Moreover, each vehicle performs route discovery to nodes that store content, when the content is not retrieved after a specific time period. Therefore, when necessary, paths are reconfigured to include new vehicles.**

***Index Terms*—NDN-VANETs, Routing, Directional Antennas**

I. Introduction

Vehicular communications and, in particular, Vehicular Ad-Hoc Networks (VANETs), have been studied extensively over the last years, due to their challenging nature. In vehicular communications, the end to end path between vehicles breaks unexpectedly and, therefore, the current TPC/IP protocol fails. To this end, Named Data Networking (NDN) is a new architecture that deals with path breaks, by addressing content by its name and not on the location of the hosts. Thus, many studies propose the utilization of NDN in VANETs [1]–[4] to support content retrieval in a dynamic environment. Furthermore, recent works use the 5G cellular infrastructure to support vehicular communications [5]–[7].

However, all the aforementioned studies consider a centralized infrastructure, where Vehicle-to-Vehicle (V2V) communication is only performed for vehicles to obtain information about their environment, e.g. number of connected vehicles etc. In this study we assume that a vehicle is autonomous and should perform the necessary actions for meeting its application requirements without infrastructure assistance, when this is possible. A vehicle should be able to communicate with its surrounding environment, i.e., with other vehicles in its neighborhood, so as to collect all the necessary information (Fig. 1). Therefore, in a content retrieval process a vehicle should decide *where*, *how*, and *when* to forward a message.

In this work, we propose an enhanced Geographical aware Routing Protocol (eGaRP) to support multihop V2V communication in vehicles for content retrieval. Specifically, we assume that each vehicle has a navigation device installed on

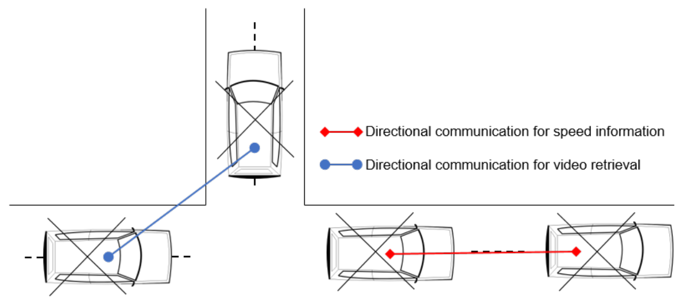

Fig. 1: V2V directional communication using directional antennas.

its On-Board Unit (OBU), which allows the vehicle to know its location at any given time, by using GPS. In addition, we install directional antennas in vehicles to target nodes in a specific direction. The geographical coordinates of a vehicle are included in the messages and assist in the selection of the appropriate interface, and thus, directional antenna, to send a message. In this work, each vehicle unicasts requests for a particular content through an interface, after a path from the requester to the content source has been established. To support vehicle mobility and path breaks, we use and develop a contention-based forwarding (CBF) mechanism. CBF assist us to identify unsatisfied requests with the help of separate timers in each vehicle. When a timer expires, the vehicle retransmits its request through another path. Fig. 1 presents our idea, where in an intersection vehicles retrieve different content from different paths. Each path is created only by vehicles that need to participate in a content exchange mechanism, leaving other vehicles unoccupied to perform other tasks.

II. Related work

Named Data Networking [8] is a future Internet architecture, where information is retrieved based on content names but not on location of hosts. In NDN messages -Interest and Data messages- are described by a unique name. Every NDN node contains three data structures: the Pending Interest Table (PIT) that stores forwarded Interests, the Forward Information Base table (FIB) acts as a routing table for Interest messages, and the Content Store (CS) acts as a content cache. When a node requests content, it sends an Interest message to the network. A node responds with requested content with a Data message.

NDN messages cannot be forwarded through incoming interfaces to avoid message loops. In wired networks using incoming interfaces to forward incoming messages will transmit the messages back to the sender. In Wi-Fi networks though, due to the broadcast nature of Wi-Fi, sending a message through its incoming interface does not guarantee that the message will be sent back to the sender node. Thus, to support multihop communication messages can be forwarded through their incoming interfaces in NDN-VANETs [9]. [10] discusses the core functionality of NDN followed by a new architecture proposed for Intelligent Transportation Systems (ITS) in smart cities. To reduce the dissemination area of messages, a location-based packet forwarding mechanism can be used. Interests are forwarded towards geographical regions, where Data can be found [11]. But in these schemes network resources are still wasted by message broadcasts. Our work relies on unicasting messages when possible and also uses directional antennas to reduce even further the dissemination area of these messages. In addition, we support path breaks by allowing each node to decide when the path to the content source is broken and then to use another path to reach the content source.

III. System model

Fig. 1 shows our envisioned idea, which allows vehicular directional communication. Each vehicle can be equipped with a number of directional antennas, and therefore send messages to a particular direction. This allows vehicles located outside of the coverage area of the directional antenna that transmits the messages, to experience less network traffic. In this work we install in every vehicle 4 directional antennas. In addition, we use unicast transmissions, when possible, to target particular vehicles, when messages can be retrieved by already established paths.

A. Directional Antennas

Our first proposal is to equip each vehicle with directional antennas, to support directivity of messages. We place each directional antenna to the vehicle in different locations, allowing us to differentiate each direction with a different directional antenna. The direction of each antenna is associated with the number of antennas that exist in a vehicle. Therefore, if a vehicle contains $N \in \mathbb{Z}^+$ antennas, each antenna $A_i, i \in \{1..N\}$ will have beam-width B:

$$B = \frac{360°}{N} \tag{1}$$

and the pointing P_{A_i} of an antenna A_i, i.e. where the antenna radiates and receives its greatest power, will be:

$$P_{A_i} = (i-1)B + B/2,\ \forall i \in \{1..N\} \tag{2}$$

The radiation pattern of each directional antenna is different. In general, such an antenna will radiate its greatest power towards one direction. If a vehicle is equipped with a large number of directional antennas, the effecting gains of each of its antennas will coincide with each other. In addition, the interference that a vehicle experience will be too high, leading to huge error rates and low Signal to Noise Ratio. Thus, it is possible that many messages will be corrupted and, therefore, dropped. On the other hand, a vehicle that is equipped with a low number of directional antennas is possible to have areas around it that are not covered with strong signal. Therefore, if a message arrives on a vehicle in an area around the vehicle with low signal strength, it is possible that the vehicle will not receive the message.

In this study, we use a low number of antennas to avoid the huge interference load around vehicles. To overcome the areas around the vehicle that are not covered with strong signal, we propose to rotate the antenna that is transmitting a message by a particular angle. The selection of an antenna and the angle calculation are described in Section III-B. This rotation allows us to improve the antenna gain and to allow a better connection to the vehicle that we want to send a message to. Finally, to guarantee that the vehicle will still have a $360°$ coverage area, even with some weak signal strength areas, we rotate all antennas of the vehicle by the same angle.

TABLE I: NDN Data structures. New fields are denoted in italic

(a)

PIT Table
Prefix
Face (MAC Address)
Expiration timer
Current geographical coordinates
Creation time

(b)

FIB Table
Prefix
Face (MAC Address)
Latency
Current geographical coordinates
Hop count

(c)

NDN messages additional info
Current geographical coordinates

B. Route Discovery and Forwarding

Our work relies only on V2V communication. We assume that each vehicle has a navigation device and, therefore, knows at any moment its geographical coordinates. As in the original NDN architecture, every vehicle contains the traditional NDN data structures, i.e. PIT, FIB, and CS. The new fields that are contained in these data structures are shown in Table Ia and Table Ib. In the PIT and FIB table we include the current geographical coordinates of a vehicle. In the PIT table we included also a new field, named creation time, that denotes the time that the PIT entry was created. In the FIB, we included the hop count field, indicating how many hops the content source is away from the node. This hop count increments every time a new node receives a Data message.

In this work, we use V2V communication, but without using beaconing. We rely on the native NDN messages, named Interest and Data messages to perform content retrieval, when the network conditions, e.g. message paths, network traffic etc., are unknown. Hence, we included in both messages an additional field, named current geographical coordinates, which indicates the geographical coordinates of the node according to its GPS device (Table Ic).

In a content retrieval process, the requester sends the first Interest message. The requester node will check its FIB table to identify possible next nodes to unicast the message [12]. When the first Interest is being sent, the FIB table of the

Algorithm 1: Interest forwarding

Data: $MAC\_$: MAC Address
$(x\_, y\_)$: geographical coordinates
i: Interest
n: Current node
f: Selected FIB entry
t_{Tol}: Tolerance
p_k: Pointing of antenna of interface k
1 **if** $PIT\ Entry \neq \emptyset$ **then**
2   Update PIT Entry($MAC_i, (x_i, y_i), t_{Tol}$)
3   Delete Interest
4 **else**
5   Create PIT Entry($MAC_i, (x_i, y_i), t_{Tol}$)
6   **if** *FIB Entry* $= \emptyset$ **then**
7   Update Interest($MAC_n, (x_n, y_n)$)
8   Broadcast Interest
9   **else if** *FIB Entry* $\neq \emptyset$ **then**
10   Select FIB with lowest hop count ($MAC_f, (x_f, y_f)$)
11   Calculate angle ϕ ($(x_n, y_n), (x_f, y_f)$)
12   Update Interest ($MAC_n, (x_n, y_n)$)
13         $k \leftarrow$Select interface (ϕ)
14   Rotate Antenna ($p_k \rightarrow \phi$)
15         $k \rightarrow$Unicast Interest ($MAC_n, MAC_f, (x_n, y_n)$)

requester node is empty. Thus, the Interest is broadcast and transmitted through the node's available interfaces (that are equipped with directional antennas). The requester includes in the Interest its own MAC address (as source MAC address), together with its current geographical coordinates as extracted from the navigation device. When this broadcast Interest arrives at an intermediate node, the node checks its PIT to identify if it has forwarded the Interest before. If it has, then the node will update the PIT and delete the Interest (Algorithm 1, lines 1-3). If it has not, the node will create a new PIT entry with the source MAC address and the geographical coordinates that exist on the Interest. The node will check its FIB, and since this is the first Interest the FIB will be empty. Therefore, the node will broadcast the Interest through all its interfaces. Before broadcasting, the node will update the Interest to include its own MAC address and geographical coordinates. The processing and forwarding of the first broadcast Interest is described in Algorithm 1, lines 6-8. This process continues until a node with the content (content source) receives the Interest.

The content source will respond with the Data message. The Data message follows the breadcrumbs on the PIT tables of vehicles. This Data message is unicast. Therefore, the node should select one interface to send the Data. The content source extracts the current geographical coordinates of the entry that exists in the PIT, i.e. the position of the node that the content source wants to send the Data message to. Then, the content source calculates the angle (by using simple trigonometric functions) between its own position (that is known from its own GPS device) to the node that should receive the Data message, by taking into account the other node positions as stored in the PIT. Afterwards, the content source updates the Data to include its own MAC address and

Algorithm 2: Data forwarding

Data: $MAC\_$: MAC Address
$(x\_, y\_)$: geographical coordinates
d: Data
h: Hop count
n: Current node
p_k: Pointing of antenna of interface k
1 **if** $PIT\ Entry = \emptyset$ **then**
2   Delete Data
3 **else**
4   Create FIB Entry($MAC_d, (x_d, y_d), h$)
5   **foreach** $i \in$ *PIT Entry(d)* **do**
6   Get fields $MAC_i, (x_i, y_i)$
7   Calculate angle ϕ ($(x_n, y_n), (x_i, y_i)$)
8   Update Data ($MAC_n, (x_n, y_n), h + 1$)
9         $k \leftarrow$Select interface (ϕ)
10   Rotate Antenna ($p_k \rightarrow \phi$)
11         $k \rightarrow$Unicast Data ($MAC_n, MAC_i, (x_n, y_n)$)

geographical coordinates and selects the interface with the directional antenna that covers the angle that was calculated. Then, it rotates this antenna to point in the calculated angle and all other interfaces by the same angle and unicasts the Data message.

Intermediate nodes receiving the Data message follow the same procedure as the content source. In addition, they create a FIB entry including the MAC address, geographical coordinates and hop count that are included in the received Data, and increase the hop count by one before transmitting the Data message to other nodes. The Data processing is shown in Algorithm 2.

When the requester wants to send the second Interest message, and there exists an entry into the FIB table, then the Interest is unicast. In particular, the requester extracts from the FIB the MAC address and geographical coordinates, calculates the angle between its own position (that is known from its own GPS device) to the node that should receive the Interest, by taking into account the other node's position as stored in the FIB and, then, the node updates the Interest. Finally, the requester selects the appropriate interface with the directional antenna that points to this angle and unicasts the Interest through this. This process continues to all nodes receiving the Interest, until the Interest reaches by unicast the content source (Algorithm 1 lines 9-15).

C. *Contention-Based forwarding*

One of the most challenging problems in VANETs is the intermittent connectivity between nodes. Vehicles move, hence, the paths between them break unexpectedly. In NDN, as mentioned before, the Data follow the breadcrumbs of the PIT entries on vehicles. Therefore, when a path breaks, because one vehicle has moved to another (unknown) position, the Data will not be delivered to the requester node, resulting in unsatisfied content.

To deal with the aforementioned problem, in this work, we let the decision of detecting a path break and reestablishing a new path to the content source to each node that forwarded an Interest message. We use a contention-based forwarding algorithm, where each node decides individually when and where to forward a message to find a route that leads to the content source. In particular, every PIT entry contains an expiration timer, that indicates the time a node should wait for the requested Data. We define this expiration timer as the *tolerance* of an Interest in a vehicle t_{Tol} (for simplicity we just call it vehicle's tolerance and assume that it is about the same PIT entry). We also define $t_{Tol} = ht_{\alpha}$, where h is the hop count of the FIB entry that was selected for forwarding and t_{α} is a constant time, usually defined from the application. A high t_{α} means a more delay-tolerant application.

When the $tolerance$ of a node expires, the node checks to identify another unicast route to the content source. If there is no route, i.e. no entry into the FIB table, the node does not broadcast the Interest. Instead, the node enters a new $t'_{Tol} = t_{INTlif}$, where t_{INTlif} is the Interest lifetime, to the PIT entry, which is the maximum tolerance. This is because, we try to minimize broadcast transmissions to reduce network traffic. Hence, if a vehicle does not have a FIB entry to the content source, i.e. cannot unicast the Interest message, we let the decision of re-establishing a path to the content source to vehicles that the Interest has passed and their tolerance has expired. If in every vehicle in the initial path the tolerance expires and the FIB tables of all nodes are empty, the requester node is responsible for finding a route to the content source.

Moreover, nodes overhear Interest transmissions. When a node overheads an Interest transmission it checks its PIT to identify if it has forwarded the Interest before. If it has not, then it deletes the Interest. But if it has transmitted the Interest there will be a PIT entry. In that case, the node resets the PIT entry's $tolerance$ to start from the time the node overheard the Interest transmission.

IV. Results

Preliminary results of our algorithm show that we manage to deliver more Data messages in the requester node than other approaches. By attaching directional antennas to the interfaces of each node we manage to reduce also the average latency of the received Data messages. This means that we receive more content quicker than our previous approach [12]. In addition, because of our introduction of a contention based forwarding mechanism, we notice less retransmissions of Interest messages in the requester node, because intermediate nodes can also retransmit Interests, when the Interests expire.

V. Conclusions

This study presents a V2V communication system for VANETs. We present a new forwarding scheme, where vehicles are autonomous and not supported by any infrastructure. We propose the installation of directional antennas in vehicles, to support directional forwarding of messages. Therefore, vehicles can send messages to particular locations to restrict the geographical dissemination area of messages. Hence, we release network resources in vehicles, where no message exchange is necessary. Furthermore, we propose a contention-based forwarding strategy to support mobility of vehicles. Based on a timer based scheme, vehicles know when a message exchange has failed through a path. In that case, vehicles retransmit messages that are unsatisfied through another established path.

Acknowledgment

This work was undertaken in the CONTACT project, CORE/SWISS/15/IS/10487418, funded by the National Research Fund Luxembourg (FNR) and the Swiss National Science Foundation (SNSF).

References

[1] G. Grassi, D. Pesavento, G. Pau, R. Vuyyuru, R. Wakikawa, and L. Zhang, "Vanet via named data networking," in *2014 IEEE conference on computer communications workshops (INFOCOM WKSHPS)*. IEEE, 2014, pp. 410–415.

[2] C. Bian, T. Zhao, X. Li, and W. Yan, "Boosting named data networking for data dissemination in urban vanet scenarios," *Vehicular Communications*, vol. 2, no. 4, pp. 195–207, 2015.

[3] G. Deng, L. Wang, F. Li, and R. Li, "Distributed probabilistic caching strategy in vanets through named data networking," in *2016 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*. IEEE, 2016, pp. 314–319.

[4] C. Bian, T. Zhao, X. Li, and W. Yan, "Boosting named data networking for efficient packet forwarding in urban vanet scenarios," in *The 21st IEEE International Workshop on Local and Metropolitan Area Networks*. IEEE, 2015, pp. 1–6.

[5] A. Hussein, I. H. Elhajj, A. Chehab, and A. Kayssi, "Sdn vanets in 5g: An architecture for resilient security services," in *2017 Fourth International Conference on Software Defined Systems (SDS)*, May 2017, pp. 67–74.

[6] A. A. Khan, M. Abolhasan, and W. Ni, "5g next generation vanets using sdn and fog computing framework," in *2018 15th IEEE Annual Consumer Communications & Networking Conference (CCNC)*. IEEE, 2018, pp. 1–6.

[7] J. Liu, J. Wan, D. Jia, B. Zeng, D. Li, C. Hsu, and H. Chen, "High-efficiency urban traffic management in context-aware computing and 5g communication," *IEEE Communications Magazine*, vol. 55, no. 1, pp. 34–40, January 2017.

[8] L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, P. Crowley, C. Papadopoulos, L. Wang, B. Zhang *et al.*, "Named data networking," *ACM SIGCOMM Computer Communication Review*, vol. 44, no. 3, pp. 66–73, 2014.

[9] M. Amadeo, C. Campolo, and A. Molinaro, "Forwarding strategies in named data wireless ad hoc networks: Design and evaluation," *Journal of Network and Computer Applications*, vol. 50, pp. 148–158, 2015.

[10] S. H. Bouk, S. H. Ahmed, D. Kim, and H. Song, "Named-data-networking-based its for smart cities," *IEEE Communications Magazine*, vol. 55, no. 1, pp. 105–111, January 2017.

[11] G. Grassi, D. Pesavento, G. Pau, L. Zhang, and S. Fdida, "Navigo: Interest forwarding by geolocations in vehicular named data networking," in *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2015 IEEE 16th International Symposium on a*. IEEE, 2015, pp. 1–10.

[12] E. Kalogeiton, T. Kolonko, and T. Braun, "A topology-oblivious routing protocol for ndn-vanets," *Annals of telecommunications*, vol. 73, no. 9-10, pp. 577–587, 2018.