The impact of channel model on the performance of distance-based schemes in vehicular named data networks

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Article Info

Article history:

Received Feb 2, 2021
Revised Apr 19, 2022
Accepted May 12, 2022

Keywords:

Distance-based
Forwarding
Named data networking
Propagation model
VANET routing

ABSTRACT

Distance-based schemes present one of the methods to avoid the broadcast problem in vehicular named data networks. However, such schemes overlook the most factor in performance evaluation which is the variation in received signal strength caused by the propagation model choice. Thus, they are evaluated under one propagation model while neglecting the effect of the others. This paper evaluates the impact of the propagation variation model over three distance-based schemes, namely rapid named data networking (RNDN), enhanced vehicle on named data networking (EVNDN) and opportunistic interest forwarding protocol (OIFP). Simulation experiments are performed over three propagation models. Simulation results show that Nakagami significantly degrades network performance. However, it has a noticeable positive effect over higher distance resulting in a higher interest satisfaction ratio as compared to the other models. The RNDN exhibits a higher number of retransmissions across the Nakagami. In contrast, a higher number of retransmissions is exhibited by EVNDN when compared to the other schemes over the Friis and random. The OIFP show a higher interest satisfaction ratio when compared to EVNDN and RNDN under all models. OIFP shows robustness towards the adverse fading effects resulting from the Nakagami and exhibits lower end to end delays.

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1. INTRODUCTION

Research in vehicular named data networks (VNDN) has emerged rapidly over recent years, with a focus on the development of more robust networking protocols to guarantee stable communication [1]. In this kind of network, the basic method of forwarding packets is broadcasting. This approach will result in a collision and excessive redundancy leading to the well-known broadcast storm problem [2]–[5]. Distance-based schemes used in different applications in VNDN are proposed to attenuate the broadcast storm problem [6]. These schemes use the distance between the transmitter and receiver to make the forwarding decision. This decision is performed with the assistance of a predefined timer to propagate the packet further from the last sender. However, faster and successful reception pose strict demands on the design of forwarding schemes, especially in safety applications.

The vehicular network exhibits many factors that affect the reliability of forwarding [7]. One of the main factors is the method by which the wireless signal propagation environment is modeled, taking into account physical channel properties such as fading and path loss. The above-aforementioned channel properties present a critical influencing factor on the performance of distance-based schemes in VNDN. These properties impose a number of challenges in designing communication protocols in the same network, with the main challenge concerning the collision. The collision in network is exhibited in vehicular ad hoc networks (VANETs) due to the continuous nodes movement which easily allows vehicles to enter or exit the transmission range of each other. These movements also lead to the variation of signal strength which causes multiple copies that interfere with each other. The propagation model can predict the number of vehicles that may share a collision domain, which facilitates the evaluation of contention and interference in vehicular networks [8], [9]. Several distance-based schemes have been proposed in vehicular named data networking [10]–[15]. Nevertheless, all existing research work evaluates the performance of their schemes while taking into account only one propagation model, consequently neglecting the impact of changing the propagation model may bring to the performance. As a consequence, it makes the comprehension of the performance of a given scheme shown over different propagation models difficult. The scheme may exhibit superior performance over a certain propagation model, while the same scheme may show worse performance over another model. Indeed, evaluating performance over different propagation models may explain new performance trends for the proposed distance-based schemes in VNDN. To the best of our knowledge, the current literature lacks a thorough study regarding the performance impact of the variation of the propagation model in vehicular named data networks.

In fact, diverse comparative study of data dissemination has been carried out in vehicular named data networks [16]–[19], while neglecting the effect of the channel model along with the propagation model that can lead towards major performance variation of data dissemination. To fill this gap, this work aims to study the impact of the variation of the propagation model on the performance of extensively used category of data forwarding in vehicular named data networking, known as distance-based schemes. This work studies a new dimension of performance evaluation by using three models of propagation and analyzes the variations in the shown performance results. Such an issue is never addressed in vehicular named data networking literature as most research focuses on designing and developing new forwarding schemes along with their assessment over a single propagation model. To perform this investigation, the following tasks are executed:

- Adopt and compare three propagation models describing the main phenomena of a propagation process in a vehicular named data network simulation. We concern ourselves with two specific phenomena of the radio channels: path loss and fading. The first phenomenon represents the attenuation of the signal caused by the variation of the distance between transmitter and receiver, while the other phenomenon depicts the quick fluctuations of the signal amplitude over a short distance.
- Adopt and implement a distance-based scheme for studying the impact of the variation of propagation models on their performance.
- Evaluate the performance of the distance-based schemes over the investigated propagation models in terms of interest satisfaction ratio, number of retransmission and communication delay.

Rest of the paper is organized as follows: section 2 introduces the distance-based scheme and discusses the three schemes considered for performance evaluation. Section 3 elaborates briefly the different propagation models adopted in this work. In section 4, the simulation environment is presented in detail. Section 5 describes and analyses the obtained results. Finally, section 6 provides a conclusion and suggests future research directions.

2. DISTANCE-BASED METHOD IN VEHICULAR NAMED DATA NETWORKS

In recent years, the named data network (NDN) is one of the most widely used information-centric networking (ICN) architectures through which vehicular communications are realized [20]. In this architecture, hierarchical names are used to identify content generated by vehicular applications instead of location-based internet protocol (IP) addresses. In addition, it offers important features such as caching, content naming, forwarding, security and mobility making it a promising solution for vehicular communication [21]–[23]. However, the integration of NDN in vehicular environments is not straightforward and faces several challenges. In fact, to retrieve the required content, vehicles use a simple muti-casting approach, in which the interest packet is broadcasted in all directions. The same packet is then rebroadcast by intermediate vehicles within their transmission range until reaching a potential provider. This situation leads to an explosive growth of traffic called the broadcast storm problem. Many research studies are devoted to suppress unnecessary broadcast transmission and finding the most suitable vehicle to rebroadcast the packet. The distance-based scheme is one of the most broadcasting protocol types used to reduce the redundant broadcast in vehicular named data network [24]. The distance method chooses nodes far from the last receiver to be the next-hop forwarder in order to cover the most additional physical area as possible. Each VNDN node in distance-based schemes maintains two data structures and they include: pending interest table (PIT) and content store (CS). Contrary to the fixed environment, the forwarding information base (FIB) is not used because of the publisher's movement. Furthermore, two types of packets are exchanged for communication: interest and data packets. Figure 1 shows the distance-based method in vehicular named data networks.

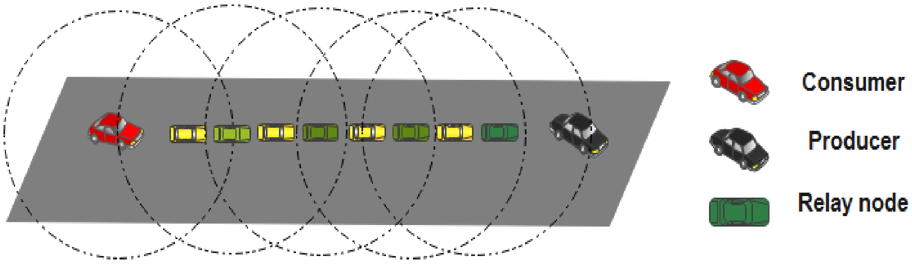


Figure 1. Relay node selection of distance-based schemes in vehicular named data networks

To determine whether or not to re-transmit a received broadcast, nodes in the distance method employ an assessment delay to self-elect the possible forwarder. The procedure is simple; the consumer node that requires a content object broadcasts an interest packet to all nodes within its transmission range. Intermediate nodes that receive the interest, check if the requested data exist in their content store, if it is the case, the node just broadcast the data packet. Otherwise, the node verifies in its pending interest table whether if there is already an entry with the same name of the requested content and if so, it discards the interest packet. If not, it records a new entry with the name of requested data in its pending interest table and calculates an assessment delay based on the distance that separates it from the last transmitter. During that time period, if the same packet is received by a node, the timer is ignored and transmission is canceled; otherwise, the node disseminates the packet. There are a plethora of distance-based protocols in vehicular named data networks [10]–[15]. Although they show their robustness to overcome the broadcast storms problem, some existing works [10], [12], [13] change the basic concepts of NDN architecture by adding additional fields in data/interest packets and/or new data structures. One of the major drawbacks of these changes is that they destroy the basic concepts of NDN and add more overhead to this architecture [24]. Consequently, we opted for three of them [11], [14], [15] that keep the basic NDN architecture to ensure better performance. These protocols are used jointly with the different propagation models in this investigation. The processes of relay selection and the timer calculation of these protocols are described in the following:

2.1. RNDN

Rapid named data networking (R-NDN) [14] is a distance-based routing protocol designed mainly to disseminate rapid traffic information. According to [25], this protocol is faster for vehicle-to-vehicle (V2V) communication compared to the conventional IP, as the NDN-based Interest forwarding and Data retrieval work well in this context. In R-NDN protocol, each node selects a node located at the edge of its transmission range to be the relying of that node. The other nodes that exist in the transmission range close to this node, receive the broadcasted packet but do not retransmit it. To do this, R-NDN protocol implements a pushing timer to control the time each node in the transmission range should wait before discard or retransmit the packet. The pushing timer is based on the relative distance that separates the receiver from the sender (T_p) and is defined as (1):

$$T_p = T_d \frac{R-D}{R} \quad (1)$$

where T_p is the pushing timer, R is the maximum transmission range, D represents the distance between the receiver and transmitter and $T_d$is a minimum waiting delay and equal to 5 ms.

According to the pushing timer, the node having the greater value of D wait shorter than nearby vehicles and has the priority to retransmit the packet. When the other nodes overhear that the packet has been successfully retransmitted, they cancel scheduled retransmissions. R-NDN also has a collision avoidance timer used in addition to the pushing timer to reschedule data broadcasting at different times for vehicles that simultaneously receive an interest.

2.2. E-VNDN

The enhanced vehicle on NDN (E-VNDN) [11] is a revised version of the previous architecture R-NDN [14]. The EVNDN considers that the signal in the edge of the transmission range is very low. Therefore, the protocol selects the node located in the middle and the range’s extremity as relay instead of selecting the farthest node. With the aim of doing that, the E-VNDN uses 80% of the transmission range in the calculation of the defer timer. The defer timer formula of E-VNDN becomes:

$$Timer = T_1 \frac{\frac{4}{5} \times R - D}{\frac{4}{5} \times R} \tag{2}$$

where T_1 represents the maximum value of timeout, R is the transmission range and D is the distance between sender and receiver. E-VNDN protocol also includes a random collision avoidance timer similar to that of the R-NDN protocol to avoid collision between nodes with the same distance as the transmitter.

2.3. OIFP

The opportunistic interest forwarding protocol (OIFP) [15] is another distance-based protocol to tackle the broadcast storm issue in vehicular named data networks. The OIFP protocol uses the distance between nodes to prioritize the interest transmission among neighbor nodes. Similar to R-NDN, in the OIFP protocol, the prioritization is accomplished using the defer timer to elect the node closer to the boundary of the communication range as a relay node. In addition to the distance between transmitter and receiver, the OIFP protocol includes the signal propagation speed in the calculation of the timer to propagate the packet farther from the sender. The formula of the timer in the OIFP protocol is given as (3):

$$Timer = \frac{2}{c}(R - D) + \alpha \tag{3}$$

where c represents the speed of light and equal to 3×10^8, R is the transmission range, D is the distance between sender and receiver and α represents the collision avoidance delay and is defined as the ratio of NDN Interest packet length and the transmission rate.

3. DESCRIPTION OF CHANNEL AND PROPAGATION MODELS

3.1. The channel model in ndnSIM

In the recent past, technological developments in the field of wireless networks have given much attention and effort to vehicular named data networks. Currently, all major research efforts have been made to develop and optimize the communication schemes for improving road safety and traffic management. As a consequence, a suite of routing, transmission control and congestion control protocols have been proposed, such as [11], [14], [15], [25]–[35]. Typically, such protocols focus on the NDN strategy layer. However, factors of the physical layer have been neglected. Conversely, these factors have noticeable adverse effects on routing and congestion control protocols performance that we cannot overlook. So far, the named data networking simulator (ndnSIM) [36] is the most simulator used to evaluate the performance of these different protocols [24]. As can be seen in Figure 2, the ndnSim includes several primary simulation objects: mobility, application, NDN protocol stack, NDN forwarding daemon (NFD), and NS-3 NetDevice and channel. The NDN application initiates the process of data production when receiving an interest packet.

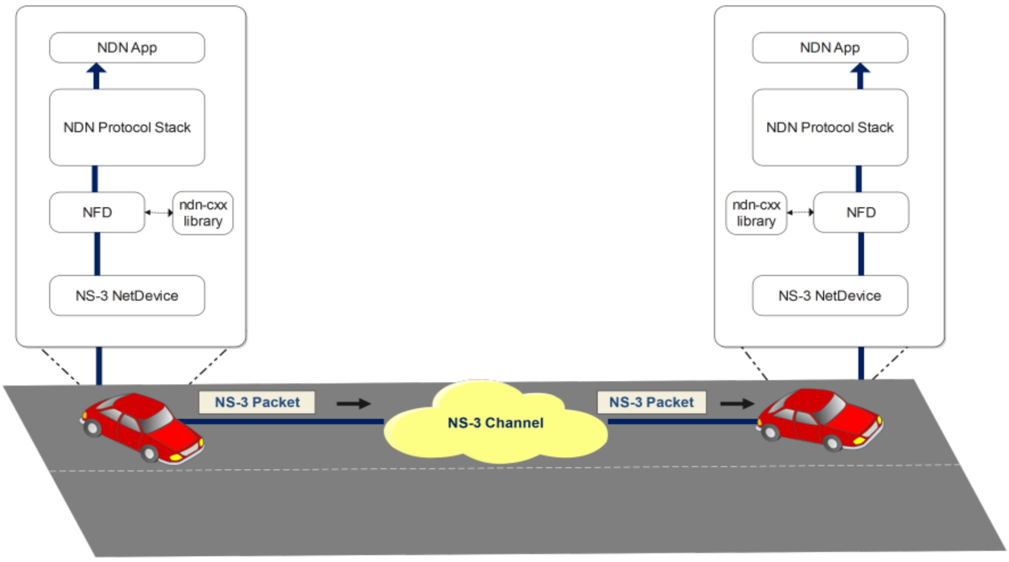


Figure 2. ndnSim basic components for vehicular ad hoc network

Data produced are signed and verified using ndn-cxx library and then injected into NFD instance using ndn-cxx face. Subsequently, NFD determines how to process the data packet based on the strategies modules that help to make the forwarding decision. The data packet allowed to be sent is encoded into NS3's Packet and transmitted further down in the network over NS3's NetDevice/Channel. When the other simulated node receives the data packet, NS3's NetDevice injects the packet in the installed NFD for further processing. The NS-3 NetDevice is closely coupled to the attached channel and form the physical layer for the ndnSim. The NS-3 NetDevice and channel represent the physical model and channel model respectively. The channel module includes three blocks to simulates the main phenomena described in the following:

- Path loss: This block is represented in the simulator by the chosen propagation model. This model is responsible for computing the signal power loss caused by the distance. Furthermore, it computes the received power *Pr* for every transmission between two nodes.
- Obstacles: Models objects that affect the propagation environment between the transmitter and receiver. This model is used to determine the relatively slow signal variation with respect to the value given by the first block to get a more realistic received power.
- Fading block: Represent the effect of reflection, diffraction, refraction, and scattering interaction on the average received power calculated by the previously described block.

3.2. Description of propagation models

In vehicular communication systems, wireless channels characterization is an important issue for system design, because the quality of wireless channels is a complex combination of effects due to fading and path loss [37], [38]. While traveling on established roadways, wireless signals suffer from obstruction due to attenuation, diffraction, reflection, and scattering from other vehicles [39], building and other human structure. At the receiver side, the signal will be received via a set of different paths leading to the so-called fading effect. Such effect can be grouped into two classes, i.e., large scale and small scale [40]. Large scale fading characterizes the radio signal variation over a larger distance and includes two-component: shadowing and path loss. The shadowing presents the power signal attenuation caused by obstacles, obstructed distance, or a combination of both in the propagation environment.

The path loss is the mean signal strength and depends mainly on the frequency and the distance between transmitter and receiver. It is calculated by averaging the received signal power *Pr* at a particular distance between two nodes, through the chosen propagation model for every transmission. At the receiver side, every packet that received power *Pr* is greater than the minimum power threshold *Rx* is correctly received. Furthermore, the packet is considered interfered, when *Pr* lower than the antenna sensitivity and greater than the minimum power threshold *Rx.* In case of two packets are received by a node, the higher Pr is processed while the other is considered interference. Both packets are discarded due to collision if neither of them meets the previous condition. For this study, two different propagation models are considered to simulate the path loss phenomena, which are Friis propagation loss model and random propagation loss model. The details of each of the chosen model will be explained in the following:

3.2.1. Friis propagation model

Friis propagation model is used to predict the signal strength in a free space environment. This model considers only one unobstructed line-of-sight (LOS) path between transmitter and receiver and neglects any reflections and/or diffraction that can alter the radiated wave. In the Friis model, the received power can be given by (4):

$$P_t = \frac{P_t G_t G_r K^2}{(4\pi d)^2 L} \tag{4}$$

where P_t is the transmitted power, (G_t, G_r) are the gain of the transmitter and receiver antenna respectively, K is the wavelength, L is an attenuation coefficient representing the system losses, and finally d is the distance between the transmitter and receiver. It is noteworthy that all parameters are constant except the distance. Therefore, the received power change with the distance between two nodes.

3.2.2. Random propagation model

In this model, loss follows a random distribution [41]. As a consequence, all packets experience a random propagation loss difficult to maintain. Furthermore, the loss is determined every time the model is invoked using a random variable. The default loss constant for this variable is 1 dB.

3.3. Fading model

Small scale fading characterizes rapid variation in the instantaneous signal power over a shorter distance and/or time durations. These variations result mainly from the mobility of the transmitter or receiver, and/or the movement of the objects in the propagation environment. There are several models for small scale fading known as Rayleigh, Ricean, Nakagami and Weibull. Overall, the Nakagami is the most commonly used for modeling wireless communication systems and is presented in the following:

3.3.1. Nakagami propagation model

Nakagami is a continuous probability distribution used to model the small-scale influence of signal transmission in various environments. This model follows the gamma distribution and tackles several fading occasions according to the different values of parameter m. The Nakagami formula can be given as (5).

$$P_z(Z) = \frac{2m^m}{\tau(m)(P_r)^m} z^{2m-1} e^{-\frac{m}{p_r}z^2} \tag{5}$$

In the formula, m is the Nakagami-m random variable, $\tau(m)$is a Gamma function, $P_r$is the expected average received power. The parameter m is the fading depth and describes the fading severity. The lower value of this parameter gives more severe fading.

4. SIMULATION SETTINGS

The simulation scenario consists of a multi-hop NDN-based VANET, where we analyze the impact of propagation models on the performance of NDN-based VANETs distance-based protocols. To do this, we carried out several simulations using the NS-3 based named data networking simulator (NdnSim) [36]. ndnSim is a simulator that offers a common, user-friendly, and open-source simulation platform based on the NS-3 [42]. We set up a highway scenario in which nodes move according to a straight line in the same direction at a constant velocity of ≈30 m/s. The distance between any two adjacent vehicles was the same. Therefore, the traffic pattern is considered to be an In-line car following model in which vehicle follows another along a highway length of 10 km.

We considered a high density of vehicles to prevent packet discarding. Therefore, data transmissions will be more prone to be interfered and can show the efficiency of the investigated protocols. In the scenario, we include one publisher and one consumer on each end of the highway. The consumer node initiates a continuous communication by generating Interests for the entirety of the simulation time to get intended data from the publisher node. This consumer node transmits 300 bytes data packets per second at a constant bit rate for the entire simulation time of 300 s. The results are obtained from ten simulations per distance value, using one of the investigated propagation models per simulation. Table 1 summarizes the main simulation settings.

Table 1. List of simulation settings

Parameter	Value
Simulator	ndnSim
Number of nodes	1000 vehicles
Average speed of vehicles	30 m/s
Map zone	10km highway
Path loss	Nakagmi, Friis and Random
Power transmission	5 dBm
Channel frequency	5900 MHz
Transmission range	250
Bandwidth	24 Mbps
Mac specification	IEEE 802.11a
Receiving sensitivity	-99 dBm
Simulation time	300 s
Packet size	300 bytes
Routing protocol	OIFP, RNDN and EVNDN

5. SIMULATION RESULTS

The goal of this paper is to evaluate the impact of propagation models on the performance of three distance-based schemes in NDN-based VANETs networks, namely RNDN, OIFP and EVNDN. Performance of all schemes is compared against each other to clearly portray the impact of varying the propagation model over communication. In order to thoroughly comprehend the underlying investigation, our evaluation considers extensively the following performance metrics:

- Interest satisfaction ratio (ISR): This indicates the percentage of satisfied interests to all requested ones.
- End-to-end delay: This represents the total time taken by a packet to be transmitted from the source to the destination including propagation and transfer through channel time, and waiting timer.

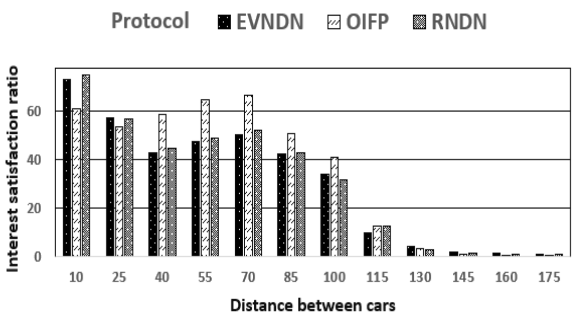
– Number of retransmissions: This illustrates the average number of retransmissions necessary for an interest to reach the destination.

5.1. Interest satisfaction ratio

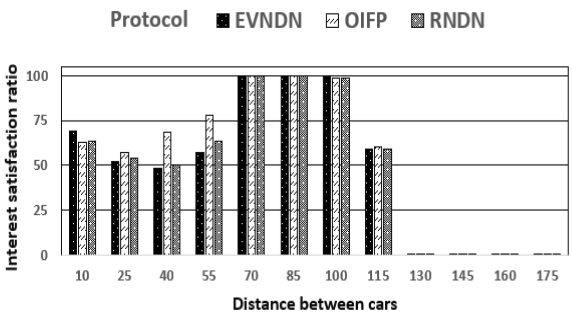
This section presents and discusses the results of the investigated schemes in terms of their interest satisfaction ratio. Figures 3(a) to 3(c) show the interest satisfaction ratio exhibited by OIFP and RNDN and EVNDN schemes under Nakagami, Friis and Random propagation models. Based on Figure 3(a), the multipath fading effect deteriorates the network performance significantly as compared to the others model. This deterioration can be justified by an increased variability of the received signal that results in instantaneous signal level drops which cause packets being lost. However, despite this random drop in signal strength, the results reveal that the variability of the signal can also provoke important increases in the received signal levels and can be a positive effect to guarantee the correct reception of broadcasted interest especially for higher distance between cars as noticed in Figure 3(a).

Figure 3(b) notice that Friis model provides a higher value of ISR than the Nakagami models. With reference to the formula (4) of Friis model, signal power loss increases as the distance between cars increase. However, Figure 3(b) noticed a general decrease in interest satisfaction ratio when the distance between vehicles equals 10 m and 25 m. This is due to the increase of potential interfering vehicles, and hence the probability of packet losses. As the distance between vehicles increases, the interest satisfaction increases until reaching the point at which the signal reduces due to the sparsity of the network.

Conversely, random model shows a high signal power for all distance and therefore show a high ISR for all protocols as shown in Figure 3(c). The results also indicate that OIFP scheme outperforms the RNDN and EVNDN scheme when the distance between cars becomes greater than 25 m overall propagation models. This can be justified by the fact that OIFP scheme tends to select nodes nearer to the source as the distance between cars increases. As a result, the OIFP scheme selects nodes as relays in the higher bound communication range with the previous sender. In contrast, EVNDN also shows greater ISR result when the distance between transmitter and receiver lower than 25 m.



(a)



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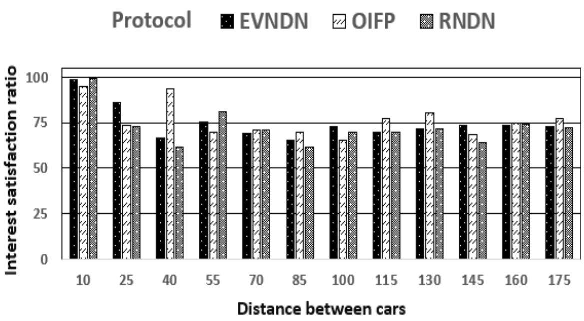


(c)

Figure 3. Impact of propagation models on interest satisfaction ratio of distance-based schemes in VNDN: (a) Nakagami, (b) Friis, and (c) random

5.2. Number of retransmissions

Figures 4(a) to 4(c) show the number of retransmissions as a function of distance between two nodes experienced to Nakagami, Friis and random propagation model respectively. Note that the number of retransmissions describes the quality of the waiting timer. It allows for illustrating the effectiveness of the protocol to reduce the collision and attenuate the broadcast storm problem.

In Figure 4(a), Nakagami model shows the largest number of retransmissions as compared to the others models. This is due to the high packet loss ratio. For all protocols, a sender node retransmits a packet when a packet reception cannot be confirmed in the predefined waiting timer. In a fading wireless channel, the shadowing effect decreases the transmission power. This incurs many packet losses occur frequently at the relay node, resulting in an increase in the number of retransmissions. Figure 4(a) also shows that RNDN has a higher number of retransmissions compared to EVNDN and OIFP routing protocols. Due to the use of a very low predefined waiting timer, RNDN cannot reduce the number of broadcasts entirely. As mentioned above, the ideal value of the timer is not straightforward to define and cannot be too low as this would lead to many unnecessary retransmissions. Conversely, OIFP shows a significant advantage over RNDN and EVNDN. The number of retransmissions increase as the distance between the two nodes increase. This means that, when the receiver and transmitter are closer to each other, there is only one wireless link between the two nodes. However, when the distance between transmitter and receiver increases others, wireless link is added between two nodes which increases the possibility of the packet error, drop, and hence the number of retransmissions.

Figures 4(b) and 4(c) show that the Friis and Random model overestimates the achievable communication range particularly for larger distances, and hence significantly under-estimates the number of retransmissions as compared to Nakagami model. Another notable finding there is that a higher number of retransmissions is exhibited by the EVNDN scheme as compared to that by OIFP and RNDN schemes. This actually depicts that selecting nodes between the middle and the range's extremity instead of nodes falling furthest in distance from the source, i.e. using the EVNDN scheme over Friis and Random propagation model, results in selecting a higher number of relay nodes, which in turn means a higher number of retransmission.

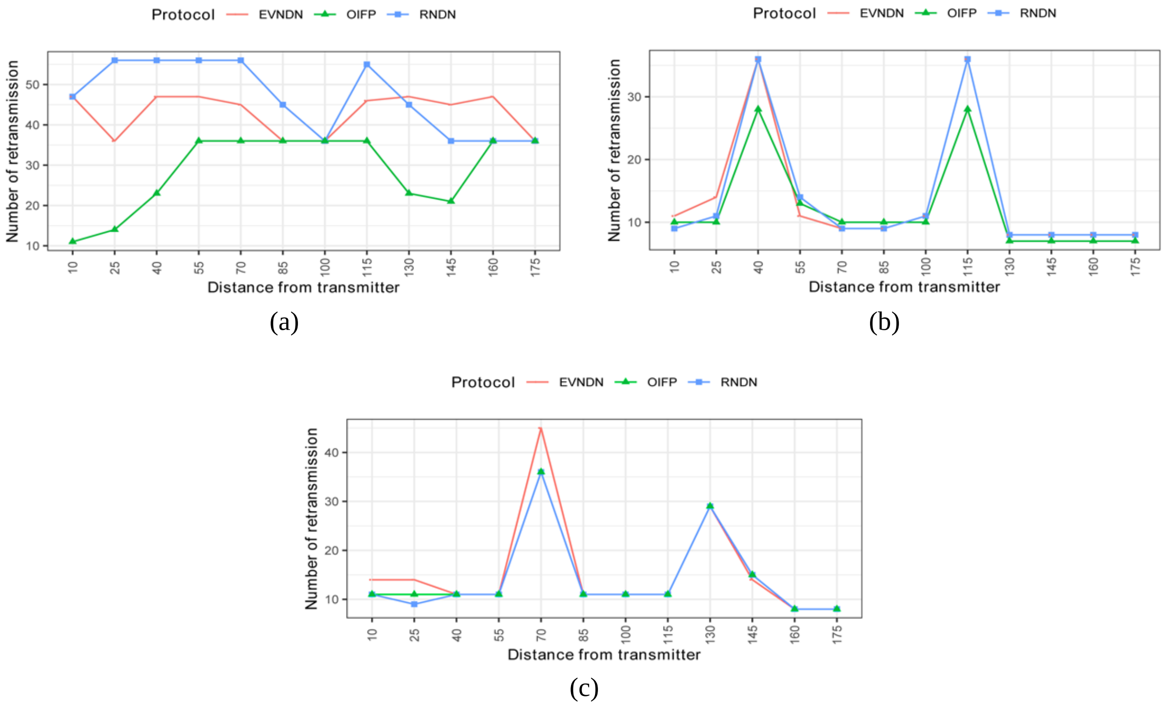


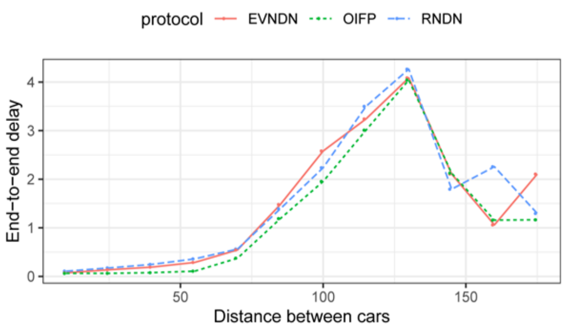
Figure 4. Impact of propagation models on number of retransmissions of distance-based schemes in VNDN. (a) Nakagami, (b) Friis, and (c) random

5.3. End-to-end delay

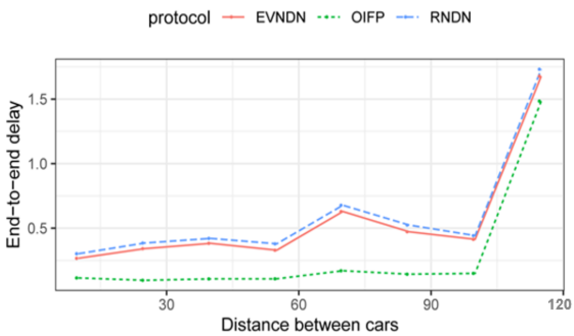
In Figures 5(a) to 5(c), the end-to-end delay of all protocols is presented for various distances between transmitter and receiver over Nakagami, Friss and random models respectively. In the considered schemes, a prominent difference in delay is observed over the investigated propagation models. This derived from the computations of the path loss coefficients at each receiver that differ from one model to another, as described previously in section 3. As a consequence, the random model can significantly reduce the end-to-end loss during transmission since the path loss is random and does not need any calculation. In contrast, due to the complex computation of the path loss in a fading wireless channel, the Nakagami model exhibits higher end-to-end delay compared to Friis and random.

From Figures 5(a) and 5(b), we can also notice that the packet faces more end-to-end delay as the distance increases. As it was explained earlier, the waiting timer is added to the forwarding decision to make sure that the packet has been forwarded one hop further from the previous sender. During this period the node retries to send the packet if it does not ensure the packet is forwarded one hop further. As the distance between nodes increases, most of the packets will be sent after waiting for more than one retries. Another notable finding there, is that all schemes experienced to the Friss model can operate up to a distance of only 115 m. This conclusion can also be seen in Figure 3(b) The Friis model produces the lowest ISR when the distance becomes greater than 115 of the models analyzed.

According to Figure 5(c), the Random keeps the delay roughly the same as distance between nodes increases. This owing to the fact that the received power does not rely on distance, unlike the other models. Although there is not a great difference between all schemes in the Random model, the EVNDN scheme exhibits lower end to end (E2E) delays when compared to OIFP and RNDN schemes over the Random model. While the OIFP protocol exhibits a lower delay over Nakagami and Friis propagation models as shown in Figures 5(a) and 5(b).



(a)



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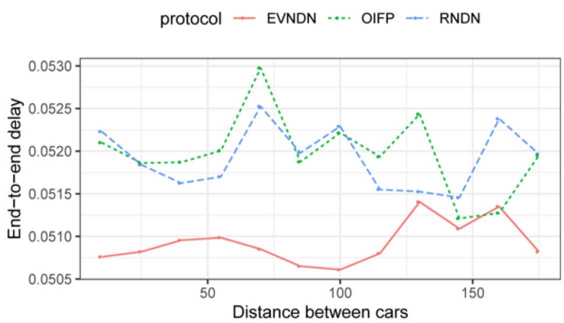

(c)

Figure 5. Impact of propagation models on delay of distance-based schemes in VNDN: (a) Nakagami, (b) Friis, and (c) random

6. CONCLUSION AND FUTURE WORK

This work investigates the performance impact of different propagation models in vehicular named data networks. For that, three propagation models are adopted where the first two propagation models simulate the path loss phenomena, while the last one is used to accurately predict the fading effect on the performance of vehicular communication. The study is conducted over three distance-based schemes, namely RNDN, EVNDN and OIFP schemes. Performance of the investigated schemes are evaluated in terms of ISR, number of retransmissions and E2E communication delays over varying distances between transmitter and receiver. The simulation-based evaluations demonstrate major performance shifts between all models in terms of number of retransmission requirements. The Nakagami model shows the highest number of retransmissions as compared to the other models. In addition, the RNDN has the poorest performance in terms of number of retransmissions when compared to OIFP and EVNDN under Nakagami model. In contrast, a turnaround is exhibited by the EVNDN scheme when evaluated over the Friis and Random model, where the number of retransmissions noticeably increases. On the other hand, interest satisfaction ratio is evaluated for all schemes over the three considered propagation models. In all models, the OIFP outperformed the RNDN and EVNDN schemes with performance, especially over sparse networks. Over high and medium distances, a decrease in interest satisfaction delay is observed by all schemes when Nakagami model is taken into account. However, an increase is observed by all schemes when this model is applied and over higher distance between cars. Over the Nakagami and Friis model, the delay of all schemes raises noticeably as the distance between node increase. Furthermore, the OIFP scheme tends to maintain lower delays when compared to that exhibited by the EVNDN and RNDN schemes. However, both of these schemes show more delay under the Random model as compared to EVNDN scheme. The above-described result gives an insight on the impact that a change on the propagation model can have over the performance of distance-based schemes in vehicular named data networks. In fact, a shift in the number of retransmissions by all schemes under the different propagation model is an alarming observation that needs to be considered when proposing new schemes to attenuate the broadcast storm problem. The variation of communication delay is another finding that needs to be considered when deploying a distance-based scheme in future connected vehicles that use NDN. In contrast, all schemes have revealed more promising performance in terms of interest satisfaction Finally, several researches can be built up over this investigation, where few significant suggestions include the evaluation of other types of vehicular named data network protocol over the considered propagation models. The evaluation of distance-based schemes can also be executed over urban road networks or road segments that have intersections. Moreover, different mobility speed scenarios can be adopted while evaluating the performance of these schemes under the different channel models.

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