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An Improved Push-based Protocol for Critical Data Dissemination in Vehicular Named Data Networks*

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Name Data Networking (NDN) is an instance of information centric network that is based on content-centric networking instead of the traditional host-centric networking. NDN provides a pull-based mechanism to acquire data from the producers. However for the critical data generated randomly in the network, the pull-based mechanism suffers high delays. In this paper, we present an analysis of push-based critical Vehicular NDN (Push-VNDN) and the challenges it faces. Additionally, an improved Push-VNDN scheme is proposed that overcomes the collision and flooding problems faced by the Push-VNDN scheme. Our results show that the iPush-VNDN scheme proves to effectively disseminate the critical data in the network while minimizing the number of data packets forwarded and interest satisfaction delay.

Keywords: named data networks (NDN), vehicular networks, critical data, pull-based data forwarding, push-based data forwarding

1. INTRODUCTION

Nowadays, the trend among on-road users is to use video streaming for safety (accident footage, traffic scenario, hazard alert, so on.) and non-safety (infotainment, news, advertisement, *etc*.) related services. In order to facilitate this flow of information, cooperative intelligent transport systems (C-ITS) provides means for vehicles to exchange messages wirelessly. Two main technologies that provide the means for such communication are IEEE 802.11p short range communication and cellular networks. The latter approach uses a centralized network topology where all the data traffic passes through the access point, *i.e*., the base station, whereas the former technology depends on direct communication among ITS stations (forming the Vehicular Network (VN)). The connected

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vehicles make use of vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-cloud (V2N) communications to form vehicular networks (VNs) that enables continuous sharing of information.

Recently, we have seen the future internet architectures been proposed to improve the fixed networks performance and reliability such as Information Centric Networks (ICNs). In ICN, the data is accessed on the basis of a particular content name instead of the traditional host-based (IP address). The application of ICN based approaches in the VNs offers opportunities for the researchers to develop novel applications for the consumers, manufactures and authorities. Recent studies provide the summary of the research focusing on the naming, mobility management and caching [1-3] techniques in a typical ICN environment designed for the mobility. Among the different flavors of ICN, Named data networks (NDN) [8] has been extensively used as the communication paradigm for VNs. NDN provides mobility and in-network caching support for improving the reliability, replication mechanism, and operation to decouple senders and receivers [4].

VNDN aim to provide geographically closest data access while supporting efficient data sharing by aggregating the resources, such as, storage, computation, bandwidth, of the network elements. The framework consists of a pull-based forwarding strategy, that describes the working principle of NDN and two packets formats, *i.e.*, an Interest and a Data packet. The Interest packet is sent by the consumer vehicle in order to obtain a data with a specific *name*. In reply, the Data packet corresponding to the specific *name* is forwarded by the Provider/Producer or intermediate vehicles. To enable this communication, each NDN enabled vehicle maintains three data structures, namely, a Content Store (CS) to cache the received or generated contents/Data, a Pending Interest Table (PIT) to keep track on the state of each forwarded Interests, *i.e.*, (name, incoming interface(s)), and a Forwarding information Base (FIB) that stores the outgoing interfaces and associated name prefixes [10].

In the VN scenarios that hold a high degree of decentralization and mobility, the need to support push-based communication is essential. Especially for the emergency event situations where the critical data should be forwarded urgently. In the pull-based forwarding model of NDN, the producer must wait for an Interest packet to arrive before it can send Data. Since the unsolicited data, which does not correspond to any PIT entry of a vehicle, is dropped by the vehicles, a proper Interest entry trail in the PIT of consumer/forwarders should be maintained [11]. For the critical data, this introduces extra overhead and delay in the network. In this context, push-based critical data forwarding protocol [12] (push-VNDN) was proposed which evaluated a push-based forwarding instead of the pull-based forwarding mechanism. The producers of the critical data pro-actively disseminate the critical data generated by the producers in the network. A special beacon message is sent to the 1-hop neighbors alerting them of the incoming critical data and its total chunks. Each neighbor upon reception of the beacon message creates synthetic PIT entries in their PIT and further forwards the beacon. As a result, the critical data broadcast is received and further forwarded by each 1-hop neighbor. Since the data packets contain the actual content, they are generally much larger than the Interest packers and are more likely to cause congestion. To summarize, compared to the pull-based VNDN, the Push-VNDN protocol is very effective in minimizing the data delivery delay and Interest overhead in disseminating the critical content, however, it critically relied on the flooding of beacon and content packets in the network. This introduces collisions and higher number of data packets being forwarded in the network [13].

In this work, we propose an improved push-based forwarding scheme (ipush-VNDN) as a solution to minimize the above mentioned problem faced by push-VNDN. In iPush-

VNDN, the nodes observe specific data holding time based on their location in the network while forwarding the beacon and data packets. After receiving the special beacon message, the vehicle creates synthetic PIT entries in its PIT. Each vehicle observes a holding time before further forwarding the beacon. The vehicle which is furthest from the forwarding/source vehicle has the shortest holding time, and thus forwards the beacon message. The remaining vehicles cancel their broadcast when they receive the broadcast. Similar procedure is applied while forwarding the data packets. This greatly reduces the number of beacon/data packet copies in the network.

The rest of this paper is organized as follows. In Section 2, we present the recently made research efforts to extend push-based support in VNDN. In the nest Section 3, we discuss our evaluation about the preliminary simulation results for push-VNDN. Section 4 provides the details of our proposed ipush-VNDN scheme. The performance evaluation and simulation results of ipush-VNDN are summarized in Section 5. Finally, we conclude this paper in Section 6.

2. RELATED WORKS

Currently, several research works have targeted the challenges faced while NDN applicability in vehicular networks. The recent works by the research community in this regard can be separated into two categories: pull-based and push-based communication models.

In the pull-based communication model an interest packet is generated and forwarded for each segment of the data. A detailed summary of the initial works on multimedia streaming paradigm over different information centric networks is presented in [14]. In [15] the focus of the researchers is two video streaming applications: NDNtube and NDNlive. The former provides streaming of prerecorded video segments and the latter provides streaming of live video capability. Both the approaches have different application requirements and can be used as a general pull-based model. The NDN based real-time video conferencing library (NDN-RTC) proposed in [16], provides the platform for research on real-time low-latency and multimedia communication over NDN. Building on NDN-RTC, researchers recently proposed [17] a real-time data retrieval scheme to obtain the latest data with minimum delay. The goal is to provide most recent data to consumers and overcome the challenges posed by real-time applications such as, audio and video conferences.

The push-based communication models are a necessity for safety related applications in the vehicular environment. Push-based communication can provide retrieval of time-critical data to consumers without any Interest generation. Additionally, the push-based communication model can reduce the data retrieval delay by half compared to the pull-based communication. Currently, the NDN communication model does not support forwarding of data using a push-based model, furthermore, some results have been achieved by researchers [18]. The main concern of researchers in the push-based communication model is in the data retrieval and IoT environments, where the information from multiple sensors is gathered by sending a single Interest [19, 20]. Another approach [21] that utilizes pull-based mechanism of NDN to retrieve the push or pull traffic required by the consumer in IoT. However, the various challenges faced in vehicular networks due to the dynamic topologies, host-centric model, and ephemeral nature of vehicular communication are not covered in these proposals.

3. PUSH-BASED CRITICAL DATA DISSEMINATION IN VNDN: SIMULATION AND ANALYSIS

In this section, we present the behavior of push-VNDN scheme [12] while forwarding the Interest and Data packets. The push-VNDN scheme has been evaluated in a 10km long bi-directional highway using Network Simulator in vehicular network scenario. The vehicles operate using the NFD of the NDN using the IEEE 802.11p protocol stack to communicate with each other. The evaluation is performed under varying network conditions, such as, transmission range ($300m \sim 800m$), network sizes ($50 \sim 150$) and average speeds ($60km/hr \sim 110km/hr$). Two Road Side Units (RSUs) are located 5km apart on the highway. In the Push-VNDN critical content is forwarded towards the RSUs to avoid unlimited flooding. To evaluate the performance of the schemes, multiple critical events ($\lambda = 1, 3, 5$) are generated randomly in the network. Here, we consider 1000KB critical content size, with a total of 10 chunks and the size of each chunk is 100KB. The simulation run-time is 500s and the results are averaged over 10 runs.

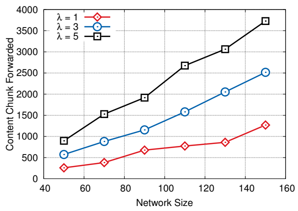

Fig. 1. 80km/hr average speed with Tr 500m.

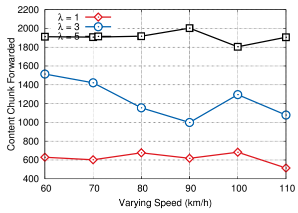

Fig. 2. 90 vehicles with Tr 500 m.

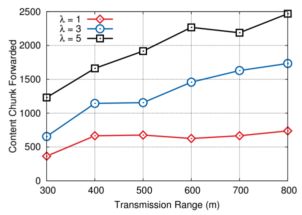

Fig. 3. 90 vehicles with 80km/hr average speed.

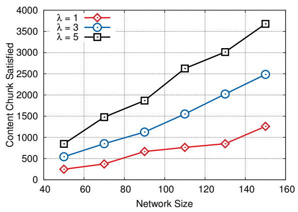

Fig. 4. 80km/hr average speed with Tr 500m.

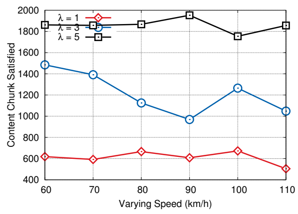

Fig. 5. 90 vehicles with Tr 500 m.

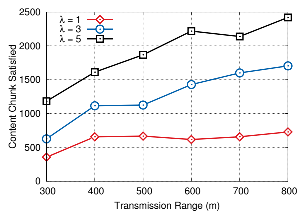

Fig. 6. 90 vehicles with 80km/hr average speed.

First we evaluate the performance of Push-VNDN in terms of data chunks forwarded. In the Fig. 1 the performance of Push-VNDN under varying network size is presented. The chunks forwarded by the Push-VNDN is analyzed for $Tr = 500m$, vehicle average speed 80km/hr and for multiple critical events ($\lambda = 1$, 3 and 5). Push-VNDN has large number of data chunks forwarded because it selects all the one-hop neighbors as forwarders. Push-VNDN concentrates on one-hop communication where a producer sends out a beacon message before broadcasting the content. The beacon message serves to alert the neighbor nodes of incoming critical data along with its meta-data that informs the neighbors of the incoming data and its number of chunks. Based on this information, the neighbors create PIT entries for each chunk in their PIT in order to receive the critical content. This beacon-data combination is forwarded by each vehicle until the RSU is located. In result it generates a flood of beacon and data chunk packets in the network.

Another important property of Push-VNDN was observed that increase in λ and the network size lead to an exponential increase; in the former case vehicles forward chunks of multiple critical events that increases the average CF and the latter case implies more data chunk forwarding vehicles in one-hop communication range.

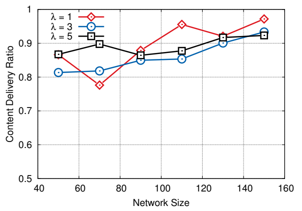

Fig. 7. 80km/hr average speed with Tr 500m.

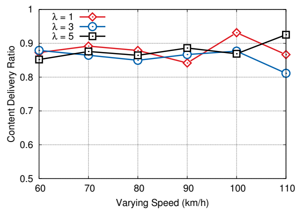

Fig. 8. 90 vehicles with Tr 500 m.

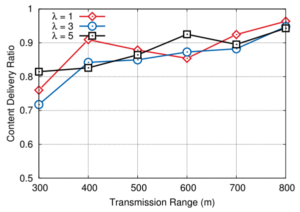

Fig. 9. 90 vehicles with 80km/hr average speed.

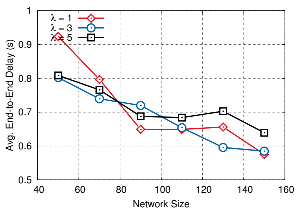

Fig. 10. 80km/hr average speed with Tr 500m.

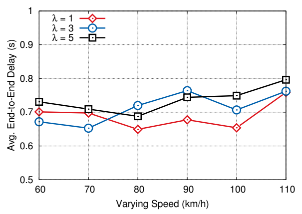

Fig. 11. 90 vehicles with Tr 500 m.

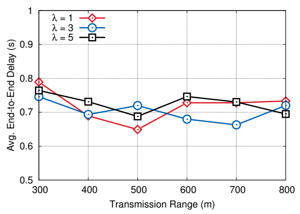

Fig. 12. 90 vehicles with 80km/hr average speed.

Similarly for the varying transmission range scenario, similar trend is observed (Fig. 3). Here we observed that increasing the transmission range of the vehicles improves the chances of higher number of 1-hop neighboring vehicles. This allows the producer/forwarder to disseminate the content further in the network. However, for the varying vehicle average speed the trend is almost straight line with slight decline (Fig. 2). This is due to the fact that an increase in average speed can reduce the connection time between the vehicles, which in turn reduces chunks forwarded, as a smaller number of vehicles participate in the forwarding.

Next, we evaluate the performance evaluation of Push-VNDN in terms of content chunks satisfied in the presence of multiple critical events. It was observed from the figures that the flooding of the content chunks in the network leads to higher content chunk satisfaction (Fig. 4). However, the chunks satisfied are almost similar to the number of chunks forwarded, due to the broadcast of beacon-data packets by Push-VNDN in the network leads to collisions and data redundancy where same chunk is forwarded/received by multiple sources at one-hop. Similar results were observed for the varying vehicle speed (Fig. 5) and transmission range (Fig. 6).

The Figs. 7, 8 and 9, present the content delivery ratio in terms of multiple λ for varying network size, average vehicle speed and transmission range. Content delivery ratio shows the ratio between the number of received chunks and the total content chunks averaged over the vehicles in the network. Here it is evident that the broadcast nature of Push-VNDN improves the content delivery ratio compared to other schemes. With the increase in network size, the number of forwarders in the 1-hop range increases, thus, there is a high chance to receive the content chunk. Similarly, the results improve with the increase in transmission range.

To further elaborate the effect of the flooding of beacon–content chunks the performance in terms of average total per chunk delay is presented in Figs. 10, 11 and 12. The data chunk delay is measured for each successfully delivered chunk in the network. The per-chunk delay calculation includes the time the content chunk was generated in the network and the time it is received at a vehicle in the network. In Push-VNDN, the flooding of beacon-content chunk implies that a single content chunk is forwarded multiple times in the network resulting in high Delay. Fig. 10 shows the average per-chunk delay for the varying network size. The increase in the network size is directly proportional to the number of 1-hop neighbors which reduces the average per-chunk delay. Similarly, with the increase in transmission range, the delay decreases. On the other hand, increase in speed implies short connection time among the vehicles, that requires the chunks to be forwarded in multi-hop manner.

4. PROPOSED IMPROVED PUSH-VNDN

The simulation analysis in the previous section highlighted the shortcomings faced by the push-VNDN scheme. Due to the wireless medium and broadcast nature of push-VNDN, there is a flooding of beacon and Data packets in the network. In our earlier works, we mitigated the flooding of Interest and Data packets in the pull-based VNDN. However, in the recent literature there is room for improvement in forwarding the critical data through push-based mechanism. Therefore, we proposed an improved push-VNDN (ipush-VNDN) mechanism that controls the flooding of beacons and data packets affecting the overall performance of VNDN.

4.1 iPush-VNDN

Consider a connected-vehicle scenario in which a producer would like to send critical content to its neighbors. In this framework, the vehicles can have one of three roles: Producer, Relay/Forwarder, or Consumer. Following the naïve pull-based VNDN approach as shown in Fig. 13 (a), the content is first advertised by the producers and the consumers generate an Interest packet to acquire the critical event content. Each relay vehicle creates a pending entry in its PIT before forwarding the Interest further. The content packet is only received and further forwarded by those vehicles who have a pending Interest entry in their PIT. For large-content such as a video, multiple chunks of the Content are created. The naïve approach entails individual chunks being requested through a separate Interest Packet. Each intermediate vehicle assists in forwarding the Interests towards the content producer and relays the chunk back towards the consumer.

The random nature of critical events in the network require a solution that does not rely on such a pull-based mechanism. The Push-VNDN scheme [12] avoids the pitfalls of the pull-based forwarding of NDN by utilizing beacon messages to inform the neighbors of incoming content. In Fig. 13 (b), the producer of the critical content sends a beacon message that contains the meta-data of the content to its neighbors, the neighbors upon reception of the beacon message generate synthetic interests in its PIT. This allows the vehicles to receive the subsequent content packets sent by the producer. The beacon and data packets are further broadcast by each vehicle resulting in flooding of both the packets. Furthermore, to limit unlimited flooding the authors propose that both the data packets and beacons are not further forwarded after reaching the nearest RSU. However, the Push-VNDN faces severe flooding since each vehicle forwards the beacon and data chunks to its 1-hop neighbors. Our proposed iPush-VNDN shown in Fig. 13 (c) avoids

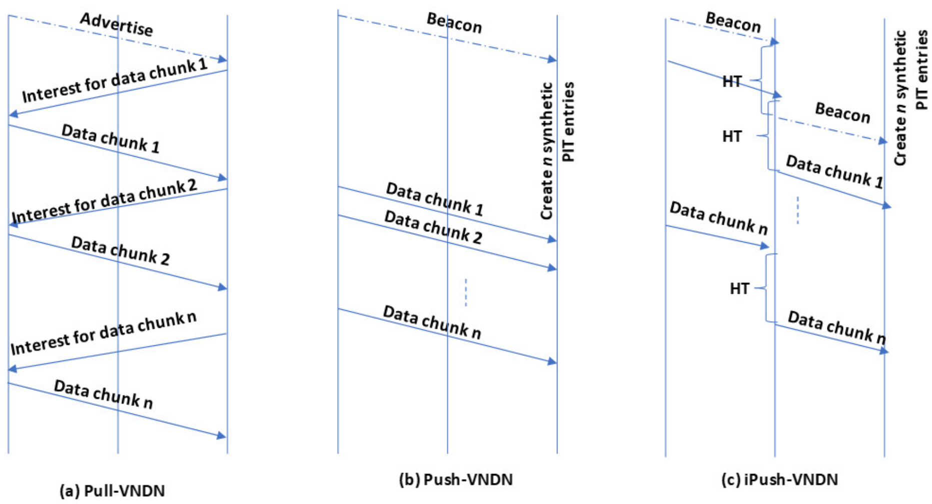

Fig. 13. Interest/data chunks forwarding.

this flooding by enabling each node to observe a holding time (HT) based on their distance from the broadcast source before forwarding the received beacons and data packets. This allows the vehicles which are furthest from the broadcast source to receive the messages and further forward their neighbors. The intermediate vehicles overhear the forwarding vehicles' broadcast and abort their own broadcast. This reduces the flooding of beacon and data chunks in the network and also increase the coverage of the messages. A comparison of the forwarding mechanism adopted by the three schemes, naïve pull-based VNDN, push-VNDN and iPush-VNDN is presented in Fig. 13.

4.2 Data Holding Time

In order to reduce collisions and flooding resulting due to the data broadcast by each vehicle per hop, a data holding time (T_{def}) is introduced. iPush-VNDN allows each vehicle to share its location information with its 1-hop neighbors. This information is shared through periodic beacon messages. It uses the basic channel access time, [22] to calculate the data holding time, such that the vehicles initiate the data transmission at variable time. T_{def} for the data chunks is calculated as follows,

$$T_{def} = AIFS_j + CT + DT, \tag{1}$$

where $AIFS_j$ is the arbitration inter-frame spacing for access category j. Different ACs are defined in [22] such that AC_0 has the highest priority, which is used here for critical data traffic communication. The $AIFS_0$ of the video data is calculated as,

$$AIFS_0 = AIFSN_0.aSlotDuration + \rho. \tag{2}$$

Here, $aSlotDuration = 13\mu$s is the IEEE 802.11p backoff timer unit for a 10MHZ channel spaces with $AIFSN_0 = 2$ and $\rho = 32\mu$s is the short inter-frame space.

The next term is CT (contention time) is computed as,

$$CT = \left(\frac{rand(0, CW(min)_0)}{HC}\right).aSlotDuration \tag{3}$$

where HC is the hop count from where the data packet was received and the value of $CW(min)_0 = \left(\frac{CW^{min}+1}{4}\right) - 1$ and $CW^{min} = 3$. The HC factor ensures that the data messages that are at higher hops from the producer is prioritized.

The last term DT (distance-based time) is set to prioritize the farthest vehicles in the transmission range for selection as Data forwarders.

$$DT = rand(CW(min)_0, CW(max)_0 * d_{fr}).aSlotDuration \tag{4}$$

Here, $CW(max)_0 = (\frac{CW^{min}+1}{2}) - 1$ and d_{fr} is the distance between vehicle 'f' and 'r' w.r.t the transmission range of 'f' calculated as, $d_{fr} = \frac{Tr_f - \sqrt{(x_r-x_f)^2+(y_r-y_f)^2+(z_r-z_f)^2}}{Tr_f}$

The vehicles near the edge of the transmission range will forward messages quickly, allowing the content to be shared promptly. The packets are terminated at the nearest RSU. A use case that highlights the effectiveness of iPush-VNDN compared with a close counterpart available in the literature is presented in the next section.

5. EVALUATION OF iPUSH-VNDN

As described earlier, we implemented a vehicular network use case, as depicted in Fig. 14, for evaluation of the iPush-VNDN with the recently proposed Push-VNDN scheme described in [12]. The proposed iPush-VNDN scheme and its counterpart the Push-VNDN scheme were developed for a 10km long highway in a vehicular network scenario. The vehicles operate using the NFD of the NDN using the IEEE 802.11p standard to communicate with each other. The transmission range of the vehicles is set to 250m, with varying network sizes and average speeds. Two RSUs are located 5km apart on the highway, as shown in Fig. 14. In the Push-VNDN and iPush-VNDN, data is forwarded towards the RSUs to avoid unlimited flooding. To evaluate the performance of the schemes, multiple critical events ($\lambda = 1, 3, 5$) are generated randomly in the network. The critical content shared in the network is same as in [12], *i.e.*, 10MB critical content object size, with a total of 384 chunks, and the size of each chunk is approximately 27KB. A homogenous content size is not strong assumption due to equal sized chunks for large files by VNDN.The simulation run-time is 500s and the results are averaged over 20 runs. The parameters and their respective values used in our simulations are summarized in Table 1. Both the schemes employ on-path caching of the video stream. The evaluation metrics considered are:

Table 1. Simulation parameters.

Parameter	Value
Transmission Range	250m
Network Size	20, 30,...,80
Propagation Model	Two Ray Ground
Critical Events	1, 3, 5
Road Segment Length	10 Km
Simulation Duration	500s

5.1 Performance Metrics

The performance metrics used in the simulations are as below,

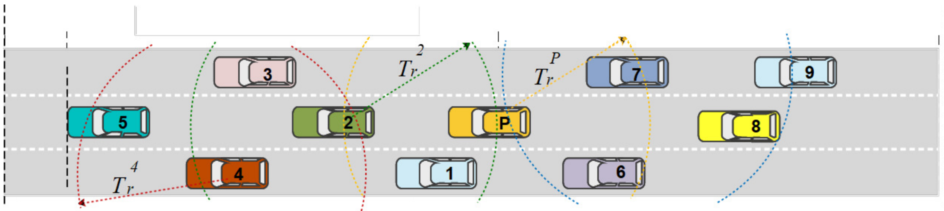

Fig. 14. Considered network.

- Chunks Forwarded (CF): This metric shows the average number of data chunks forwarded by the vehicles in the network.
- Chunks Satisfied (CS): This metric highlights the number of data chunks satisfied in the network. This metric shows the effectiveness of a scheme in dissemination of the critical content in the network.
- Average End-to-End Chunk Delay (CD): This metric represents the average per-chunk delay faced by the data chunks to be received by the vehicles in the network.
- Content Delivery Ratio (CDR): In our experiments, CDR is the ratio between the number of packets received averaged on all the vehicles and the total number of packets.

5.2 Results & Discussion

The CF by the proposed scheme is analyzed for $Tr = 250m$ in the presence of multiple critical events ($\lambda = 1,3,5$). The evaluation is based on varying network size and speed of the vehicles in the network, refer Fig. 15 and Fig. 16. As explained earlier, the Push-VNDN protocol has large CF because it selects all the one-hop neighbors as forwarders. Push-VNDN concentrates on one-hop communication where a producer sends out a beacon message before broadcasting the content. The beacon message serves to alert the neighbor nodes of incoming critical data along with its metadata that informs the neighbors of the incoming data and its number of chunks. Based on this information, the neighbors create PIT entries for each chunk in their PIT in order to receive the critical content. This beacon-data combination is forwarded by each vehicle until the RSU is located. In result it generates a flood of beacon and data chunk packets in the network. Another important property of Push-VNDN was observed that increase in λ and the network size lead to an exponential increase; in the former case vehicles forward chunks of multiple critical events that increases the average CF and the latter case implies more data chunk forwarding vehicles in one-hop communication range.

In Comparison, iPush-VNDN reduces the beacon and chunk packet forwarding in the network as shown in Figs. 15 and 16. It utilizes the holding time (HT) that allows the furthest vehicle in the communication range to send the data chunk quickly. This results in less number of data chunks being forwarded in the network. This is due to the fact that connected-vehicle network is prone to unstable paths, topological changes due to high mobility and both the beacon/data packets observe the packet holding time which may result in vehicles leaving the one-hop communication range. More precisely, iPush-VNDN reduces the content chunk forwarding by 63% and 62% ($average(\lambda)$) for varying vehicles and speed, respectively.

The Figs. 17 and 18 present the performance evaluation of the two schemes in terms of CS in the presence of multiple critical events for varying network size and speed, respectively. It is obvious from the figure that the broadcast of beacon-data packets by

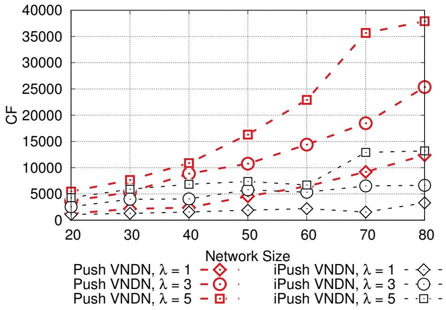

Fig. 15. 80km/hr average speed with Tr 250m.

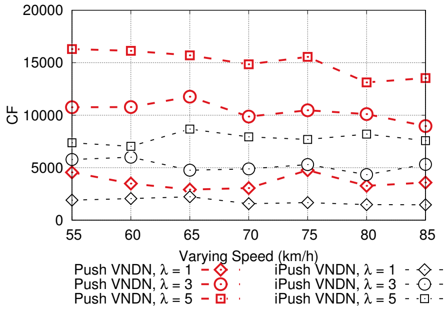

Fig. 16. 90 Vehicles with Tr 250m.

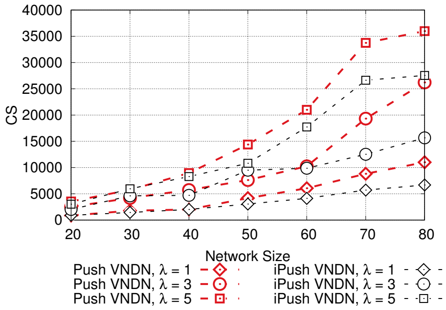

Fig. 17. 80km/hr average speed with Tr 250m.

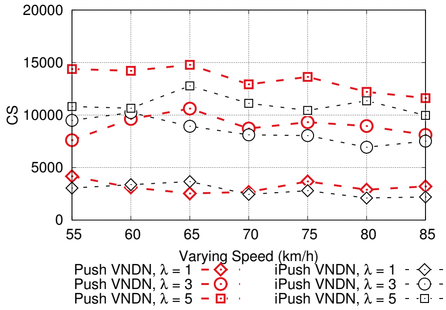

Fig. 18. 90 vehicles with Tr 250m.

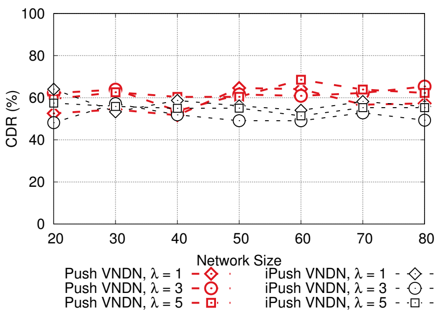

Fig. 19. 80km/hr average speed with Tr 250m.

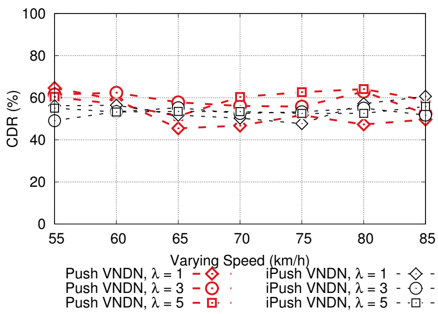

Fig. 20. 90 vehicles with Tr 250m.

Push-VNDN in the network leads to collisions and data redundancy where the same chunk is forwarded/received by multiple sources at one-hop. This is the reason that despite having large number of forwarded chunk, the CS of Push-VNDN is approximately similar to the iPush-VNDN. On the other hand, Push-VNDN performs less than both the other scheme due to the fact that the beacon and data chunk holding time of iPush-VNDN may allow some vehicles to move out of the transmission range of the forwarder vehicle. Similarly, Push-VNDN gain advantage over iPush-VNDN in terms of CS, 31% and 12% ($average(\lambda)$) for varying vehicles and speed, respectively.

Next the CDR is calculated to evaluate the performance of the two schemes. Fig. 19 and Fig. 20 show the CDR in terms of multiple λ for varying network size and vehicle

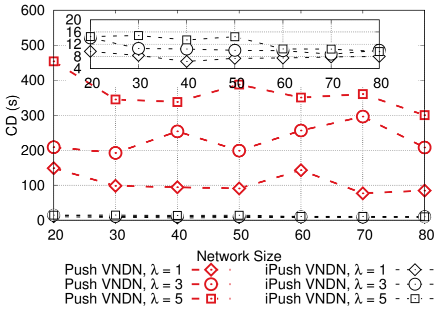

Fig. 21. 80km/hr average speed with Tr 250m.

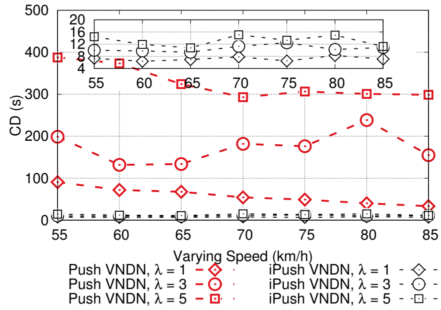

Fig. 22. 90 vehicles with Tr 250m.

speed, respectively. CDR shows the ratio between the number of received chunks and the total chunks of the content averaged over the vehicles in the network. The broadcast nature of Push-VNDN improves the content delivery ratio compared to other schemes. The drawback of holding time is more evident from these results where the neighboring vehicles move out of the transmission range of the forwarder vehicle while it is observing the chunk holding time. Precisely, iPush-VNDN performs 9% and 3% ($average(\lambda)$) less efficiently in terms of CDR for varying network size and speed, respectively.

The low CF and relatively similar CDR observed by vehicles in iPush-VNDN compared with Push-VNDN indicate optimal use of the channel resources by the proposed iPush-VNDN. To elaborate the performance in terms of CD is presented for the two solutions. Figs. 21 and 22 demonstrate the CD in terms of varying λ for varying network and vehicle speed, respectively. The CD is measured for each successfully delivered chunk in the network. The per-chunk delay calculation includes the time the content chunk was generated in the network and the time it is received at a vehicle in the network. In Push-VNDN, the flooding of beacon-content chunk implies that a single content chunk is forwarded multiple times in the network resulting in high DL. Push-VNDN performance degrades drastically for large number of content chunks, contrary to initial analysis in section 3 where only 10 chunks are broadcast. Whereas, in iPush-VNDN the beacon-content chunk forwarding observes holding time at each vehicle, resulting in considerable less per chunk delay compared to Push-VNDN.

6. CONCLUSION

In this paper, we have proposed an improved push-based forwarding (iPush-VNDN) mechanism to disseminate critical data generated in the vehicular named data networks. We provided a detailed analysis of Push-VNDN scheme, highlighting the challenges it faces. The proposed solution is able to minimize the number of contents forwarded in the network while reducing the overall interest satisfaction delay. Future directions of this work include comparison with other recent related works, data scheduling and caching mechanisms.

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