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Asymmetric Framework Evolution of Named Data Networking and Use Cases in VANET

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***Abstract*—Named data networking (NDN) has been invented for a decade and has found lots of potential applications. It has also been extensively researched and regarded as one of the most promising architectures of the future Internet. However, at the same time, more and more work noticed its deficiency in time-sensitive applications or under complex scenarios such as vehicular ad-hoc networks (VANET), mainly due to its request-response communication model and binding of Interest and Data path. To address that, in this paper, an asymmetric framework, called *aNDN*, is proposed to evolve the architecture of NDN, which features decoupling the forwarding of Interest and Data packets as well as supporting both PULL and PUSH models. Furthermore, three basic use cases of aNDN in VANET were conducted, demonstrating its advantages in data transfer efficiency. More importantly, this work first calls for substantial evolution of NDN to fulfill much broader requirements from current and future emerging applications.**

***Index Terms*—Named Data Networking, asymmetric framework, PULL and PUSH, vehicular ad-hoc networks**

I. Introduction

No doubt, the Internet is one of the greatest inventions in history and has won unprecedented development and brilliant achievements changing our lives and the World greatly. However, current TCP/IP based Internet has also exposed weaknesses in security, mobility, and energy efficiency, especially in supporting various emerging applications such as large-scale content sharing, massive connections, delay tolerance, and deterministic networking [1], mainly due to its host-based addressing, connection-oriented transport and "best-effort" nature.

To address these concerns, two distinguished or even controversial approaches lay ahead: evolutionary versus clean-slate [2]. The former keeps patching the Internet with new protocols, making it more clumsy and suffering from such stubborn headaches as *network address translation* (NAT), *distributed denial of service* (DDoS) attacks; but thanks to the growth of computing power, service experiences seem still acceptable. In contrast, the latter wants to re-design the Internet from scratch, fulfilling current service better or future requirements; the main mission is to find a successor to the IP. Fortunately, it is not just the amusement of research communities anymore. Just recently, Huawei, the top vendor in the world, proposed a new standard for core network innovation, called "New IP", to the International Telecommunication Union (ITU), to enable emerging technologies like holograms and autonomous vehicles by a more *dynamic addressing system*.

Dated back to 2010s, many clean-slate designs [3] were mushrooming, funded by many huge projects from Governments all over the world, e.g., named data networking (NDN), MobilityFirst, NEBULA, and XIA from the Future Internet Architecture (FIA) projects by the United States, PRISP followed by PURSUIT, and NetInf from the EU FP7, identifier-based networks (IBN) and service customized networks (SCN) from China. With continuous evolution, the *information-centric networking* (ICN) gradually became a merged representative of some of them, which consists of a set of concerted common understanding and achievements on adopting "*named information*" (or content, or data) as the focal point of architecture, and is now going on the way to standardization in IRTF.

NDN, the most popular instance of ICN, takes *named data* as the new "narrow waist" [4], borrowing the request-response model from the application layer like HTTP to the network layer. In NDN, a consumer sends an *Interest* packet containing the name of requested content into the network; every router forwards the Interest based on its name until reaching the content producer or the node caching its duplicate; one *Data* packet will be sent back along the traversed path of Interest to the consumer. There are three main data structures in NDN routers: *pending Interest table* (PIT), *forwarding Interest base*

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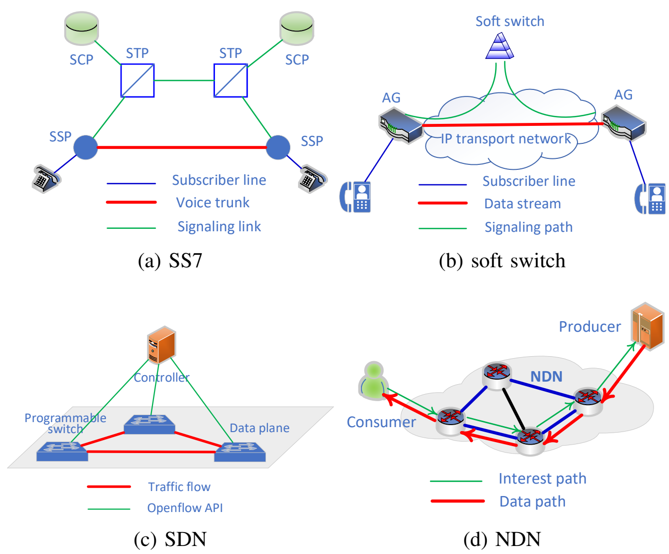


(a) SS7 (b) soft switch (c) SDN (d) NDN

Fig. 1. Relationship of control and data plane in historical architectures.

(FIB), and *content store* (CS). PIT records and aggregates unsatisfied Interests; FIB contains forwarding policy and routing information, like routing table in traditional routers; CS caches content duplicates, playing the role of in-network caches. In summary, NDN features a PULL-based communication model, name-based routing, stateful forwarding with symmetric paths, and in-network caching.

These attractive features enable NDN to find potential applications in many scenarios such as content distribution, Internet of things (IoT), vehicular ad-hoc networks (VANET). Using ubiquitous in-network caches, consumers can easily fetch contents from their nearest neighbors; multi-path nature makes NDN very fit for content sharing with a large number of connections. Massive research work has been done to polish the NDN design in many aspects, e.g., naming, routing, caching, and security [5], [6].

Nevertheless, the weaknesses of current NDN design have been revealed in some dynamic environments, e.g., VANET. However, little attention was paid to questioning its symmetric path feature when addressing the inefficiency of data transfer in VANET. The symmetric nature was originally designed to reuse the traversed path of Interest packets for Data packets without re-routing, but this design is defective or even invalid especially in wireless or high mobility environment. The optimal path for Interests is probably not suitable for Data packets, even does not exist when Data packets arrive in a rapidly time-variable topology.

From a historical point of view, the design of symmetric paths was relatively rare. First, take a look at several milestones of network architecture in Fig. 1. In telephone networks (Fig. 1a), SS7, a out-of-band signaling system, beat other in-band ones and still works in today's mobile networks although the underlying transport technologies have evolved several generations. Another example is soft switching (Fig. 1b). The session control protocol like SIP [7] configures data plane endpoints, and then allows transport networks to deliver the traffic independently, functioning still in 4G/5G core networks. The latest example is software defined networking (SDN) in Fig. 1c, which separates control and forwarding by opening the northbound interface to make forwarding programmable [8]. In all aforementioned paradigms, the control plane and data plane are separate. In contrast, NDN binds Data and Interest paths together (Fig. 1d), hindering it from being flexible enough to accommodate complex and rapidly changing environments. By decoupling the forwarding of Data and Interest packets, asymmetric paths will enable different underlying technologies to be leveraged, e.g., setting a name label switching path [9] for a long-term Data flow.

Another remarkable feature of NDN is the PULL-based communication model. NDN borrowed the `GET` method from HTTP but gave up the `POST`, mainly for content distribution applications. Nevertheless, PUSH has been found required in many cases, such as event-triggered sensing and notification, large scale uploading, content publishing, ubiquitous remote procedure calls, social media interaction, and posting. As an infrastructure of the future Internet, NDN ought to take a full and comprehensive consideration to support all of them flexibly [10].

Motivated by this, we regard NDN needs to evolve but is still a good start point. A new version is proposed in this paper, called *asymmetric NDN* or *aNDN*, named after the feature of *asymmetric* transfer of Data and Interest. It will keep core features like name-based addressing and in-network caching, and simultaneously be enhanced with at least two remarkable features: decoupling the forwarding of Interest and Data, and a PUSH method appended.

Our contributions can be summarized as follows.

- We propose an evolved framework of NDN, featuring decoupled forwarding of Interest and Data packets as well as supporting both PULL and PUSH models.
- Use case studies of the new framework in VANET were investigated. The flexibility and improvements of data transfer efficiency benefiting from the new design were demonstrated.
- More significantly, this work calls for substantial evolution of NDN architecture for the first time to adapt to the requirements of emerging applications.

The remainder of this paper is organized as follows. Section II describes the considerations and framework of the proposed approach in detail. Section III presents three typical use cases leveraging aNDN in VANET and assesses its advantages. Finally, Section IV concludes this paper with perspective.

II. Approach

A. System Model Overview

The system model of proposed aNDN is illustrated in Fig. 2, coarsely divided into wireline and ad-hoc scenarios. Compared to native NDN, aNDN has new features or improvements as follows.

- **Named everything**. Besides contents, every physical or virtual entity will be named and later addressed by its

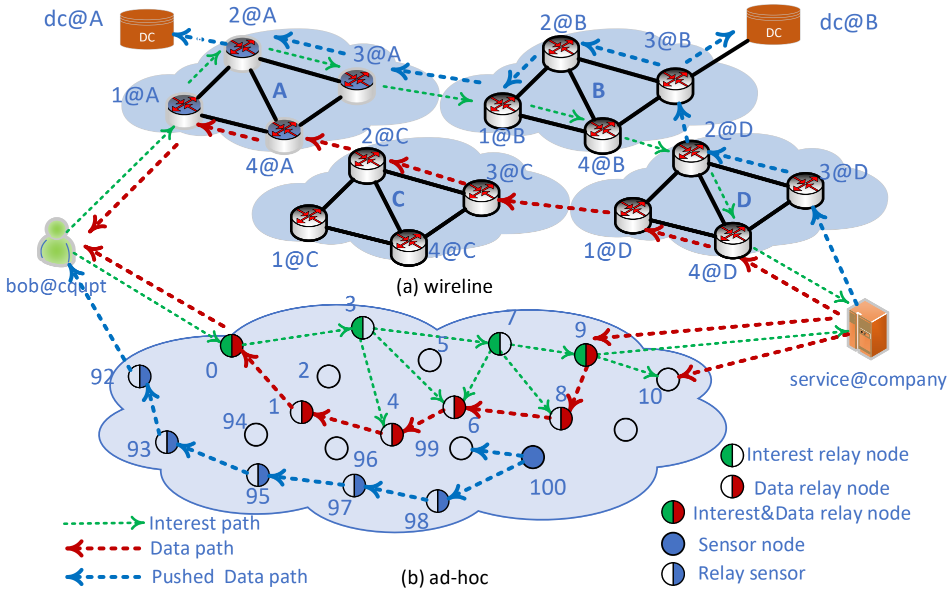


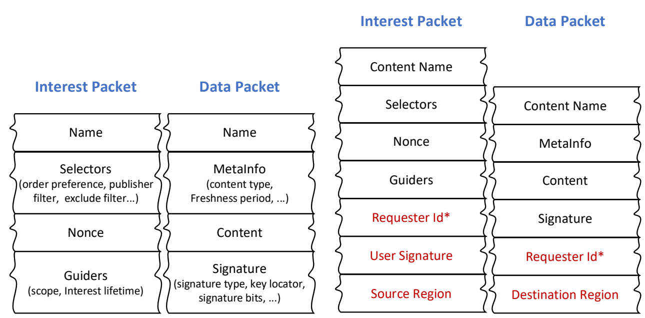
Fig. 2. The system model of asymmetric NDN.

name. For example, in Fig. 2a, *bob@cqupt* is the name of a consumer while *service@company* is the name of a producer; four regions are named *A*, *B*, *C*, *D*, while *4@A* is a router numbered by 4 in the region *A*.

- **Asymmetric paths**. That means Data packets are allowed to go along a different path from that of corresponding Interest packets. As shown in Fig. 2a, an Interest path (green dashed line) through the network is *1@A* → *2@A* → *3@A* → *1@B* → *4@B* → *2@D* → *4@D* while the corresponding Data path (red dashed line) is *4@D* → *1@D* → *3@C* → *2@C* → *4@A* → *1@A*. As an example shown in the ad-hoc scenario in Fig. 2b, the Interest packets are relayed in sequence by node $\{0, 3, 7, 9\}$ while Data packets are returned by node $\{9, 8, 6, 4, 1, 0\}$.
- **Dual models of PULL and PUSH**. Using PULL, a consumer (e.g., *bob@cqupt*) can request contents by sending Interest packets to the network. Using PUSH, the content producer (*e.g., service@company*) can push contents to the consumer or its global data centers (e.g., *dc@A* and *dc@B*, blue dashed line in Fig. 2a); a sensor (e.g., node 100) can send an event-triggered notification to the consumer (blue dashed line in Fig. 2b).
- **Optional stateful forwarding**. Interest forwarding does not set the path for data plane anymore; PIT is not demanded unless a reliable mechanism is required in intermediate routers.

B. Packet Format

To enable forwarding Data and Interest packets independently, aNDN adds three new header fields `Requester Id`, `User Signature` and `Source Region` in Interest packet, and two header fields `Requester Id` and `Destination Region` in Data packet. The new packet format is illustrated in Fig. 3.



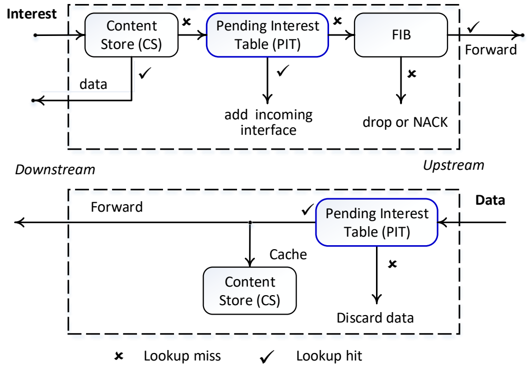
(a) native packet format [4] (b) new packet format

Fig. 3. New Packet format in aNDN.

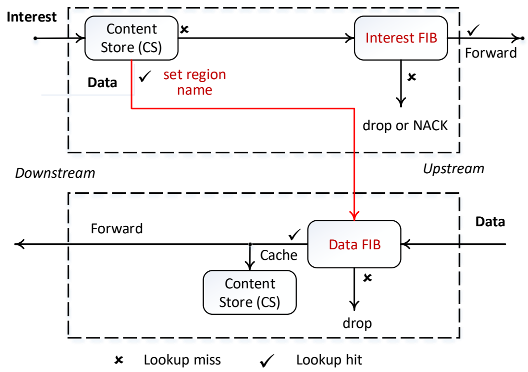
The combination of `Requester Id` and `User Signature` in the new Interest is for user authentication. At present, real-name verification has been demanded in major countries; but considering preserving user privacy meanwhile, a pseudonym authentication scheme can be leveraged with ciphered user identity [11]. `Requester Id` is also utilized to associate Data with Interest, along with the region name. The `Destination Region` of a Data packet is the same as the `Source Region` of the corresponding Interest packet.

C. Forwarding Process

Correspondingly, the forwarding process in routers is to be modified. As demonstrated in Fig. 4, PIT, the key role in native NDN linking those two paths, can be eliminated and FIB is divided into *Interest FIB* and *Data FIB*. Besides, if matching Data is found in the CS for the incoming Interest, one duplicate

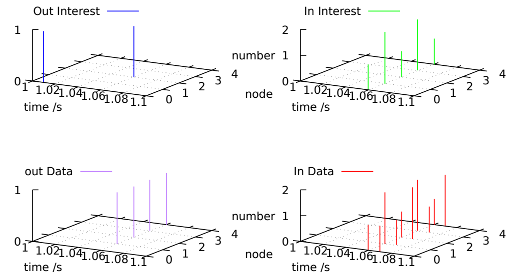


(a) native NDN forward [4]

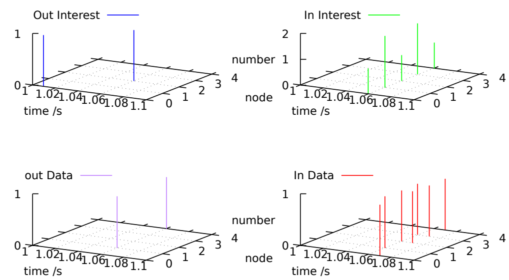


(b) aNDN forward

Fig. 4. Modifications of forwarding process.



(a) using native NDN.



(b) using aNDN.

Fig. 5. Comparison of packet traces using different frameworks.

will be created and sent to the Data path after its destination region name is set.

In the Data path, every receiving node just forwards the Data packet according to the strategy in Data FIB, populated by routing protocols, no matter whether it has received a corresponding Interest packet before. It means that aNDN accepts unsolicited Data packets that are not allowed and will be dropped by default in native NDN.

In the next section, we endeavor to apply aNDN for data transfer in VANET to explore its advantages.

III. Use Case Studies in VANET

VANET is a promising and competitive scenario for NDN, but the broadcast storm and emergency message transfer are still big challenges although massive work has been done for that [12]. In this section, three use cases of aNDN in VANET are investigated and the brought advantages are examined.

A. Differentiate Forwarding for Interest and Data

First, consider a simple scenario of five vehicles, $V_0, V_1, \ldots, V_4$, in a line with random inter-vehicle space. The tail V_0 sends one Interest to request a Data packet from the head V_4. Use native NDN and aNDN to complete this task respectively and examine their transfer effects.

In the native NDN scheme, to address the issue of Interest broadcast storm as well as demonstrate the relay process clearly, a new forwarding strategy called *random-wait* was designed, similar to the timer-based scheme in R-NDN [13]. In this strategy, a node receiving an Interest will initiate a random-wait timer; when the timer is expired, the Interest will be transmitted; if receiving another identical Interest before that, the scheduled transmission will be canceled. The Data packet is forwarded normally, according to Fig. 4a. The resulted packet traces are demonstrated in Fig. 5a, divided into Out/In Interest and Out/In Data process at each vehicle. It is observed that the Interest was sent from the consumer (V_0), relayed then by V_2, and received by all vehicles 7 times; a Data packet was released from V_4, retransmitted in turn by V_3, V_2, V_1, and received by all vehicles 14 times.

In the aNDN scheme, the Interest forwarding adopts the same strategy as in the native NDN. The difference is that aNDN can impose the *random-wait* strategy in the Data path, according to Fig. 4b. It means only the intermediate node won the shortest wait timer will be allowed to re-transmit the received Data packet. As a result in Fig. 5b, only V_1 was selected as the Data relay, and the Data packet was re-transmitted once and received 7 times, just half of using the native NDN, decreasing the redundant data transmission and receiving significantly, which means less energy consumption and less wireless interference.

As shown above, aNDN made it possible to optimize the Data transfer independently from the Interest, alleviating the Data packet storm in the VANET environment.

B. Send Interest and Data on Different Channels

In this section, advantages of aNDN in customizing Interest/Data transfer further into wireless channels are inves-

TABLE I.
SIMULATION PARAMETERS TABLE.

Parameters	Value
Number of vehicles (N)	10
maximum initial X[a]-spacing (m)	60
minimum initial X-spacing (m)	10
maximum initial Y[b]-spacing (m)	5
minimum initial Y-spacing (m)	-5
initial spacing distribution	uniform
mobility model	ConstantVelocity
minimum velocity (m/s)	15
maximum velocity (m/s)	40
velocity distribution	uniform
session number of observed traffic	1
type of observed traffic	ConsumerCbr
Int. sending rate of observed traffic (Int./sec)	10
maximum sequence number of observed traffic	20
distribution of observed traffic	uniform
session number of background traffic	4
background traffic type	ConsumerCbr
Int. sending rate of background traffic (Int./sec)	$2, 4, 8$
distribution of background traffic	exponential
Interest random-wait timer	$0.5 \sim 3$ ms
Data random-wait timer	$1 \sim 10$ ms

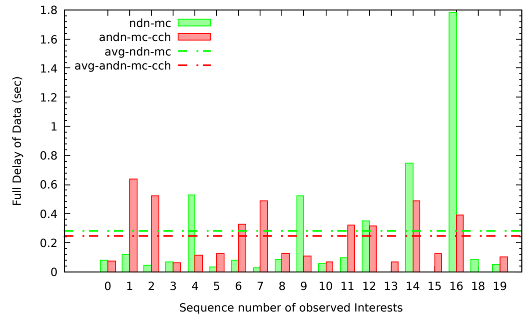
[a]parallel to the road.
[b]vertical to the road.

tigated. Specifically, given wireless access in vehicular environments (WAVE) [14] as the underlying technology, Interest packets in aNDN can be transmitted on WAVE control channels (CCHs) as signaling while Data packets are transferred on service channels (SCHs) as usual. It is expected to outperform native NDN, especially under heavy traffic load, in which both Interest and Data packets have to crowd on the SCHs.

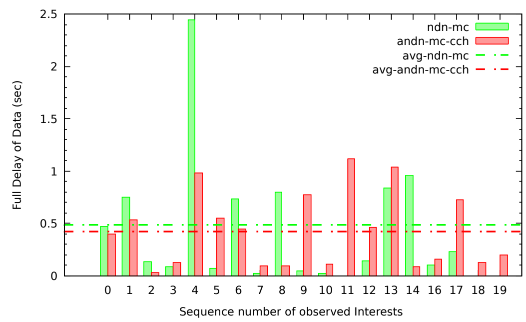
Given $N = 10$ vehicles positioned linearly with random initial spacings, the task is to let V_0 request 20 Data packets from V_{19} (the observed session) through competing traffic imposed by other vehicle pairs (background sessions). Main simulation parameters are given in Table I. The performance metric utilizes the *full delay* (FD), the elapsed time between each Data packet arrival and the initial sending of its corresponding Interest. FD can also indicate the missing Data packet.

Two schemes were compared, denoted by ndn-mc and andn-mc-cch. The former represents native NDN using `multicast` strategy; the latter represents aNDN using the same strategy but sending Interests on CCHs.

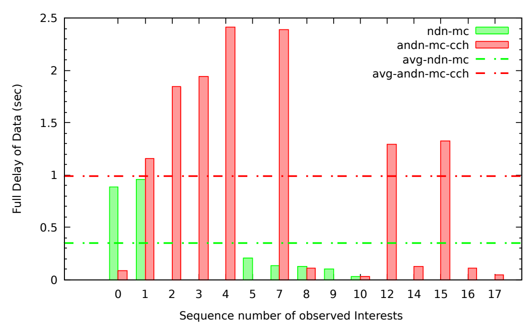
The simulation results are shown in Fig. 6, under different Interest sending frequency of every background session: 2, 4, 8 Interests per second. According to Fig. 6a, under light traffic load, two schemes pulled back respectively 19 and 18 Data packets, with average FDs about 248 ms and 279 ms. No obvious advantages are observed for sending Interests on CCHs. But as the background load increased, aNDN pulled back more Data packets (19 vs 16) than native NDN, and took less average FD (423 ms vs 489 ms), as shown in Fig. 6b. When the background load became more heavier, aNDN still could pull back more Data packets than NDN did, although the number decreased and the average FD became larger due



(a) background frequency: 2 interests/second.



(b) background frequency: 4 interests/second.



(c) background frequency: 8 interests/second.

Fig. 6. Application delay of the observed session.

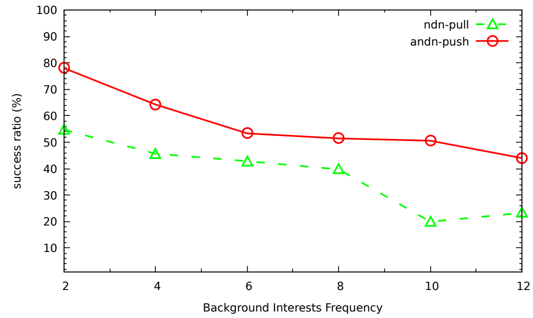
to high congestion, as shown in Fig. 6c.

It can be inferred that sending Interests on CCHs can alleviate the congestion in the Interest path, especially under heavy traffic, but better overall performance can be expected with Data forwarding strategy integrated, only allowed in aNDN.

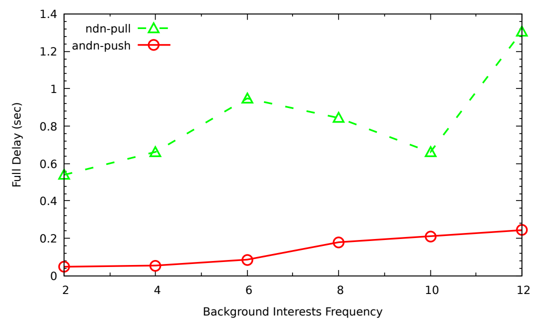
C. Push Messages

With the PUSH function provided by aNDN, messages can be dispatched actively by the producer such that emergency warning dissemination among all vehicles can be accelerated.

Compare two schemes: one is V_0 *pulls* contents from V_{19} in native NDN; the other is V_{19} *pushes* contents to V_0 in aNDN, with most parameters described in Section III-B. In both cases, `multicast` strategy is utilized. Success ratio (SR) of Data delivery and average full delays are investigated under different background traffic loads. SR for PULL is calculated by dividing the number of received Data packets



(a) success ratio of Data delivery.



(b) average full delay.

Fig. 7. Comparison of PUSH and PULL models.

by the total number of transmitted Interest packets, including re-transmitted ones, while SR for PUSH is calculated by dividing the number of received Data packets by the number of transmitted Data packets. The full delay for PUSH means the travel time of a Data packet from the producer (V_{19}) to the observed consumer (V_0). All FDs are averaged by the number of received Data packets.

Changing the background Interest frequency from 2 to 12, the performances of two schemes were evaluated. It is observed in Fig. 7 that the PUSH model outperformed the PULL one significantly in both terms. As shown in Fig. 7a, generally, SR kept decreasing as background traffic load increased, and PUSH displayed always better than PULL with a gain of about 20%. According to Fig. 7b, under most background traffic loads, average full delays of PULL were more than 3 times longer of those of PUSH. But thanks to in-network caches, it did not keep rising all the way. In a word, PUSH not just saves one way trip time but lower half the risk of congestion, thanks to no injecting any Interest into the network.

Note that all codes including the extension to ndnSIM and simulation scenarios will be found on GitHub [15].

IV. Conclusion

In this work, weaknesses of NDN architecture was discussed and an evolved framework, aNDN, was unveiled systematically, which features asymmetric and decoupled forwarding of Interest and Data packets, and supporting both PULL and PUSH models. Three use cases in the VANET environment gave a preliminary evaluation of the advantages of aNDN in data retrieval and broadcast efficiency.

This work just opens a door. Satellite Internet, massive connections IoT and future various emerging applications call for the evolution of NDN to adapt to their requirements and finally push the evolution of the current Internet.

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