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# Content Caching in V-NDN: Schemes and their Performance Analysis

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**ABSTRACT:** Named Data Networking is a newly proposed Internet architecture that is currently being researched under the Future Internet Architecture Program by the U.S. National Science Foundation. NDN is based on an earlier project named Content Centric Networking (CCN) which was presented in 2006. NDN explores the evolution from the current host-centric network architecture, that is, IP, to data-centric network architecture (NDN). Vehicular ad-hoc environment presents a vision where vehicles can communicate with infrastructure as well as each other over all physical communication channels. A single framework known as Vehicular- NDN (V-NDN) has been developed to realize this vision.

Specifically, the built-in caching capability has proven to be essential for effective data delivery when the connectivity is short-lived and intermittent, as in the case of vehicular networks. The handling and caching of transient data is focused on by introducing freshness period in NDN. This paper gives a summary of the research results that have been achieved up till date, in the V- NDN domain to provide a safe, reliable and infotainment rich driving experience. This paper talks about the implementation of NDN to networking vehicles on the run till date. The various methods and their outputs have been discussed along with the performance assessment.

**KEYWORDS:** Named Data Networking, Content Centric Network, Host-Centric Network, Data- Centric Network, Vehicular-NDN.

## I. INTRODUCTION

Vehicular networks research has a number of separate branches. In the experimental setup, vehicles are connected via cellular networks. Roadside infrastructure, known as roadside units (RSU) are further connected to centralized servers. Vehicular Networking (VN) also extends to utilize ad hoc networking because vehicles often disconnect from each other and they can physically transport data from one location to another. Vehicles need to communicate not only with the infrastructure but also with each other over all physical communication channels. This is why NDN [1] is taken as the starting point and a single framework is developed, enabling vehicles to utilize any available channel for communication to upload and retrieve data. A prototype for the same has also been built [2].

One of the important changes that NDN brings about is the caching of content as it passes through various nodes. However, this can result in the wastage of network resources and reduce the cache efficiency. For content that is valid for only a limited amount of time, it is not an efficient strategy. This is usually the case in V-NDN. Such data is called transient data and it can be requested by vehicular applications in terms of parking lot availability, road congestion, maps of surrounding areas etc. The content lifetime should be properly conveyed because stale content will affect the behavior of the applications that use this content. This issue is almost unexplored by NDN in case of VANETs. [3] attempts to fill this gap by providing their contribution in this research. The benefits of tracking content lifetime are showcased. A simple and effective NDN- compliant strategy is devised that takes content lifetime into consideration. The ndnSIM simulator is used to study the impact of content lifetime in caching decision, in case of urban and highway vehicular scenarios. The traffic load and content popularity is varying. The effects of caching transient contents in V-NDN are studied and a freshness period based caching decision strategy is presented that can be implemented by vehicles autonomously. After studying the performance of the schemes in ndnSIM, it is concluded that FreshnessPeriod is an important parameter that needs to be considered as it impacts the cache hit ratio and as a result, the data dissemination performance.



The various challenges are faced by VANET due to dynamic topologies, host-centric model and ephemeral nature of vehicular communication. These challenges directly impact data dissemination, content delivery and user experiences. A detailed and systematic review of NDN- driven VANET, along with investigating the role and feasibility of NDN in VANET is given by [4]. NDN-based naming, routing, forwarding, caching, mobility and security mechanisms for VANET are covered in detail. The existing standards, solutions and simulation tools used in NDN-based VANET are discussed.

## II. NDN BASICS

The receiver in NDN initiates the communication. The receiver is known as data consumer. Consumer sends an Interest packet carrying the name of the data that is needed. A router will note the interface from where the Interest packet was received and forward the packet by looking up its name in the Forwarding Information Base (FIB). FIB is managed by following a name- based routing protocol. The Interest reaches the node that has the requested data and a Data packet is sent back to the consumer. The Data packet contains the name and content of data along with the signature by the producer's key. The Data packet follows the reverse of the path taken by Interest to reach the consumer. No IP addresses are used in the whole process. The routing of packets is based on names carried by the Interest packets. When a large number of Interests for the same data are received, the router sends the first Interest into the network and it is stored in the Pending Interest Table (PIT), where Interests for the same data are stored along with their respective interfaces. When Data packets are being sent, the router finds the matching PIT entry and forwards the data to the matching interface listed in the PIT. After satisfying the request, the entry is removed from PIT and the data is cached into the Content Store (CS), which is the router's buffer memory [1].

## III.V-NDN DESIGN SKETCH

IP network uses addresses to facilitate communication between nodes. The nodes send each other IP packets, using destination addresses obtained from DNS queries that translate application level name to IP address. NDN allows users to directly request content through application data names. Data names in NDN are defined by applications and exist independently from connectivity, which eliminates the IP address configuration. Data can be exchanged as soon as physical connectivity is established.

Two scenarios are discussed [2]:

- V-NDN for Mobile and Ad-hoc Networking
  - V-NDN for Local Data Circulation
- 1) V-NDN for Mobile and Ad-hoc Networking:

The NDN design is mainly focused on wire-connected setup and this setup does not fully suit dynamic and ad-hoc mobile networks like vehicular networks. [2] A node is equipped with a variety of wireless interfaces like 3G/LTE, Wi-Fi infrastructure and 802.11p (DSRC/WAVE). The goal is to enable a car to utilize any interface to communicate with other vehicles and servers as required by the applications. In situations where more than one interface is available, one must be able to choose the best option or use multiple interfaces simultaneously. V-NDN can use any interface since names are independent of the interface. The figure 1 shows Case 1 where a car is connected to the infrastructure through 3G/LTE or Wi-Fi as the point of attachment changes due to the car's movement. Interest and Data packets are exchanged between the car and the NDN routers via the wired infrastructure. The NDN is installed on Wi-Fi routers in order to communicate with the cars.

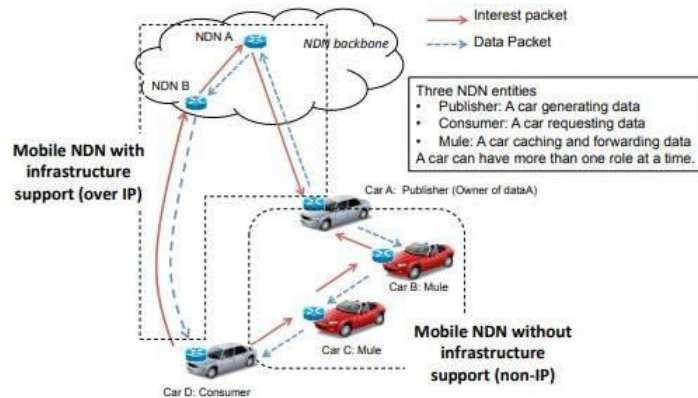


Fig 1. V-NDN supporting various networks

Case 2 is when a car exchanges NDN packets with neighboring cars locally through Wi-Fi ad-hoc mode, without the involvement of any infrastructure. For communication over cellular networks, a car will establish an IP tunnel a NDN router and send NDN packets over the IP tunnel. For communication through Wi-Fi ad-hoc mode or 802.11p (DSRC/WAVE), the car exchanges NDN packets with its neighbors and no infrastructure is involved. The Interest packet hops from one car to the next till it reaches the car with the requested data. NDN packets are carried over the link-layer protocol. A car is able to communicate through different interfaces and send or receive packets through any interface.

According to Jacobson et. al. [5], there are three main entities in a wire-connected NDN network, namely consumers, producers and routers. In a V-NDN network, four roles can be played simultaneously by the cars involved: consumer, producer, forwarder and mule. A mule is a car that physically carries data to other locations while not being connected to any other entity over NDN.

## 2) V-NDN for Local Data Circulation

Due to the need of wireless communication in case of vehicular networks, NDN must make necessary modifications. It is a good practice to take advantage of the adequate storage capacity and power supply available. In highly dynamic situations, one cannot assume that there is a stable chain of cars between the consumer and the producer. Therefore, along with using PIT for data forwarding, V-NDN uses wireless broadcasting and every node in the range will cache the received data. While designing V-NDN, we assume that every node and data names are linked to geolocation. This is because FIB for each data cannot be maintained because producer nodes are dynamic. Thus, data is fetched by using geolocation. The producer or publisher does not create FIB to advertise its data as in original NDN. This modification allows a lot of vehicular applications to fit in the V-NDN model. It is possible to embed geolocation in the name, but it is still naming the data and not the location. With this implementation, high levels of security measures are needed to protect the connected vehicles from digital attacks along with making the vehicles resilient in terms of accidents. NDN provides this security by making the producer digitally sign each packet.

## IV. V-NDN IMPLEMENTATION

A vehicle can play four roles simultaneously in V-NDN architecture: data producer, consumer, forwarder and data mule. The architecture supports seamlessly forwarding packets across different communication mediums. The design needs storage to perform caching of data. [2] Researchers designed and developed a V-NDN prototype under Linux Ubuntu 12.04 version. There are no kernel dependencies which allow the software to run smoothly on any Linux distribution.

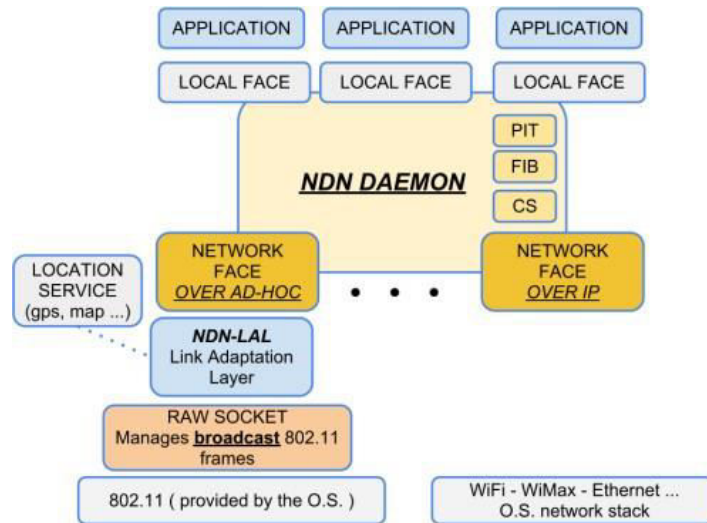


Fig 2: V-NDN logical structure as developed by [2].

The architecture has following components:

**NDN Daemon:** The core NDN capabilities are provided by NDN daemon. Key data structures like PIT, FIB and CS are managed here. The name prefix-matching and forwarding decisions are taken by the NDN daemon.

**NDN Local Face:** NDN Local Face is an interface between the applications and the NDN daemon. It is responsible for application name registration, Interest request by consumers and content delivery.

**NDN Network Face:** The NDN Network Face makes specific adaptation functions available along with technology used in the communication. In vehicular networks IEEE802.11 based wireless medium is used in ad-hoc mode for V2V communication. For vehicle to infrastructure (V2I), wireless technologies like Wi-Max, 3G and Wi-Fi based mesh networks.

**Link Adaptation Layer (LAL):** This is a conceptual 2.5 layer that enables NDN to efficiently implement certain technologies. LAL carries out a number of tasks in V2V scenario where there is no IEEE802.11 broadcast support. LAL sends all packets as L2 broadcast so as to minimize overhead. The NDN packet format is directly overlaid over the Wi-Fi framework so no other L3 protocol is needed to implement native NDN network layer.

**Location Services:** Location services, along with link adaptation layer, provide support to the applications. These services provide reverse geocoding capabilities, high level functions on distance and heading. LAL uses location services to scope the communication geographically.

**Cache:** All the nodes have a cache that stores contents that pass through each node. This implementation [2] does not assign expiration time to cache contents and they are virtually infinite.

## V. CACHING STRATEGIES IN V-NDN

In V-NDN, nodes can cache all data over the wireless channel due to lack of strict energy or memory constraints. This is known as the Cache Everything in the Air (CEA) strategy. Using CEA, vehicles can act as data mules between disconnected nodes and still be able to deliver data requested. However, practically, this strategy can lead to inefficient performance because of high cache redundancy and it is not feasible to use in areas with high number of vehicles. Due to this, other caching strategies needed to be developed [3].

### Cooperative and Autonomous Caching Strategy:

In case of wired networks, better performance, in terms of low cache redundancy and reduced retrieval latency, is achieved by using cooperative caching schemes. However, in vehicular networks, there are mobile nodes and unstable connectivity. It becomes difficult to consistently exchange information about the network status and take decisions efficiently. Therefore, traditional approaches for ad-hoc networks cannot be adopted with NDN. Due to the dynamic vehicular topology, mobility-aware caching strategies in the presence of full or partial road side units (RSU) are suggested. Popular content is prefetched at the RSUs so that those requests can be satisfied with lower latency. A scheme called Cooperative Caching based on Mobility Prediction (CCMP), where urban areas are divided into regions based on the mobility patterns of vehicles and a prediction model is applied to calculate the possibility of vehicles revisiting these regions. Nodes with higher probabilities of being in these regions for longer periods of time are selected



to cache contents. In situations where mobility prediction model is not available, cooperative caching schemes are not appropriate. Another caching strategy is Never Cache policy in which vehicles do not cache packets. This strategy shows results similar to Leave Copy Down (LCD). The general scenario is that vehicle mobility patterns are unknown in advance and communication is based on short-lived vehicle-to-vehicle (V2V) interactions. Autonomous caching schemes are better suited to vehicular networks. They are lightweight schemes that do not need additional knowledge about the network topology.

**Dynamic Cooperative Caching Strategy:**

Dynamic Cooperative Cache Management Scheme (DCCMS) is based on frequently requested popular data [6]. This scheme improves cache efficiency and can be implemented in a dynamic environment. A two level dynamic caching approach is used in which a node is chosen to communicate with other nodes frequently. This node is also responsible for keeping the copy of most popular content and distributes it when requested. DCCMS is observed to improve cache performance in terms of reducing latency, server load, cache hit ratio, average hop count, cache utilization and diversity. A simulation supporting these results is also shown [6].

**Autonomous Strategy for Non-Transient Contents:**

Cache Everything Everywhere (CEE) and Cache Everything on Air (CEA) are two simplest autonomous caching schemes. They have intrinsic cache redundancy effects due to which random schemes with a static caching probability are devised. Here, the nodes cache Data packets that have a pre-defined probability  $p$ . If  $p=0$ , the node does not cache packets and if  $p=1$ , the node caches packets like CEE. In case of NDN, the most commonly used value of  $p$  is 0.5. This limits the cache redundancy without under utilizing the available storage space. [3]

**VI. PERFORMANCE ANALYSIS OF V-NDN**

[2] Grassi et, al. performed experiments on various types of connections in vehicular networks. The categories studied are:

- 1) V2V experiments: The vehicles had one Wi-Fi interface in ad-hoc mode. V-NDN LAL managed the link layer retransmissions and acknowledgements. The implemented model tried to limit the rebroadcasting of packets. The application is allowed to choose the degree of spatial acknowledgement, which is handled by V-NDN LAL. In case no acknowledgement is received, the LAL will retransmit the packet up to 7 times as set in this experiment. The factors studied in this experiment are (i) number of retransmissions needed to forward a packet by one hop, (ii) response time at application level, (iii) usage of cache vs. interest forwarding.

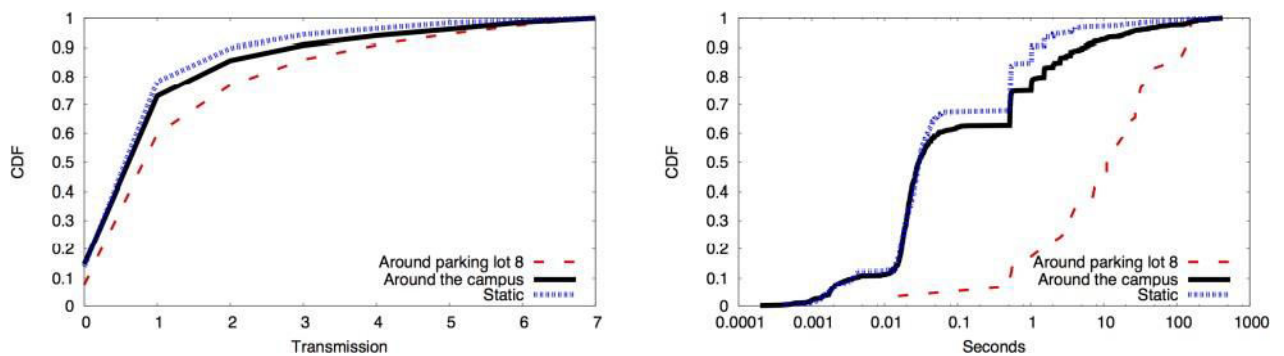


Fig 3. (a) V-NDN Info-Traffic application CDF number of Link Adaptation Layer retransmission  
(b) V-NDN Info-Traffic application: CDF Response time - from the first Interest to the corresponding data

- 2) Role of Infrastructure and V2X communication: On one occasion, two nodes were equipped with both Wi-Fi and Wi-Max interfaces, while another two nodes had Wi-Max interfaces and one node had an extra Wi-fi interface in infrastructure mode over the V2V interface. The performance results are qualitative and serve as the proof of concept.
- 3) Data survives the producer: After content is stored by various nodes in the network, it outlives the producer responsible for its creation. Once the information goes out, its lifeline becomes independent of the life of the producer. This decoupling of information and producer allows every node to use and pass on the content to any node requesting the data.
- 4)



Results:

Packet forwarding strategies for V-NDN are still in the early stages of development and they are bound to improve in the future. The preliminary simulation results [2] help to better understand V-NDN feasibility. The figure shown below depicts the number of interests sent on the networks each time the consumer issues an interest.

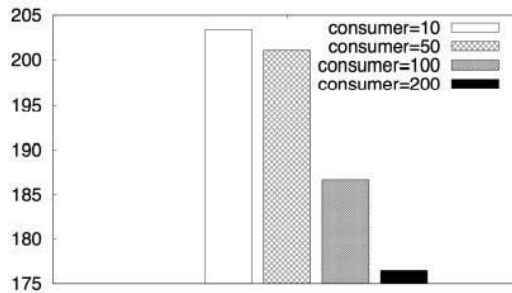
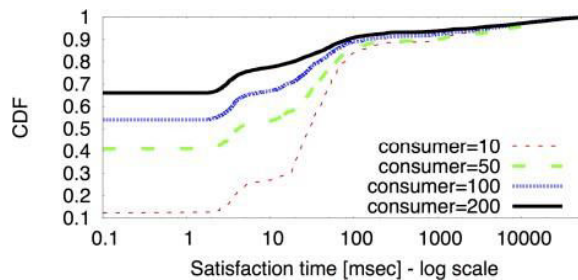


Fig. 4 V-NDN overhead

Fig. 5 V-NDN interest satisfaction time



The graph above shows the time taken for a consumer to get the requested content. Both the figures support the observation that when a large number of nodes are requesting the same data, the performance of the entire system in terms of satisfaction time and overhead improves significantly.

### VII. PERFORMANCE ANALYSIS OF CACHING TRANSIENT DATA IN V-NDN

A preliminary simulation using ndnSIM is conducted. There is urban and highway scenario, with the difference being the number of vehicles and the speeds of those vehicles. In Case 1, the nodes in the vehicular network implement CEE and LRU, without considering the freshness period of the data that is being cached. The freshness period (FP) is an application specific metric of content that is set by the original producer of the content. In Case 2, the Freshness Policy is being implemented and freshness period is considered. The simulation scenario is urban: Manhattan grid with 100 vehicles moving at speed between 20-40 km/h. In the middle of the topology, one road-side unit (RSU) is produced transient content. The vehicles and the RSU communicate via broadcasting Interest and Data packets. The freshness period for case 1 is 20 seconds and for case 2 FP is 10 seconds. Another parameter known as Zipf skewness parameter ( $\alpha$ ) is used to characterize the distribution of popular content. High value of  $\alpha$  means there is high number of requests for popular content. For the purpose of this simulation value of  $\alpha$  is 1 or 2. It is observed that cache hit ratio increases when  $\alpha$  goes from 1 to 2. Low FP results in high cache inconsistency. Hence, most of the cached data packets have expired by the time they are delivered. They have not been removed from the CS because they cannot be recognized and only LRU is being implemented. High value of  $\alpha$  indicates high cache inconsistency. In case 2, contents were cached according to their FP. Once the FP expires, the content was removed from the CS. Performance of three caching strategies: CEE, Random Caching (RC) and Freshness-Driven Caching (FDC) is compared in terms of cache hit ratio, content retrieval delay, hop count and number of data packets, is compared below with the help of graphs.

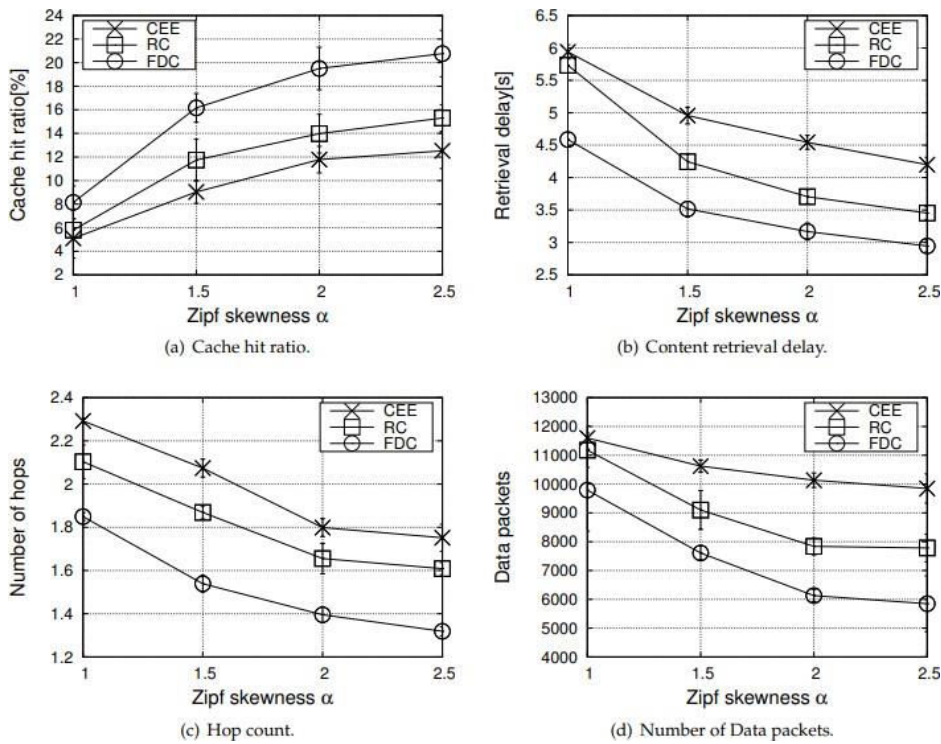


Fig. 6 Performance metrics in urban scenario with varying Zipf skewness

For highway scenario, [3] considered a 2 km-long highway road segment, where 100 vehicles move at a maximum speed of 90 km/h. The trends observed are very similar to the ones in the urban scenario.

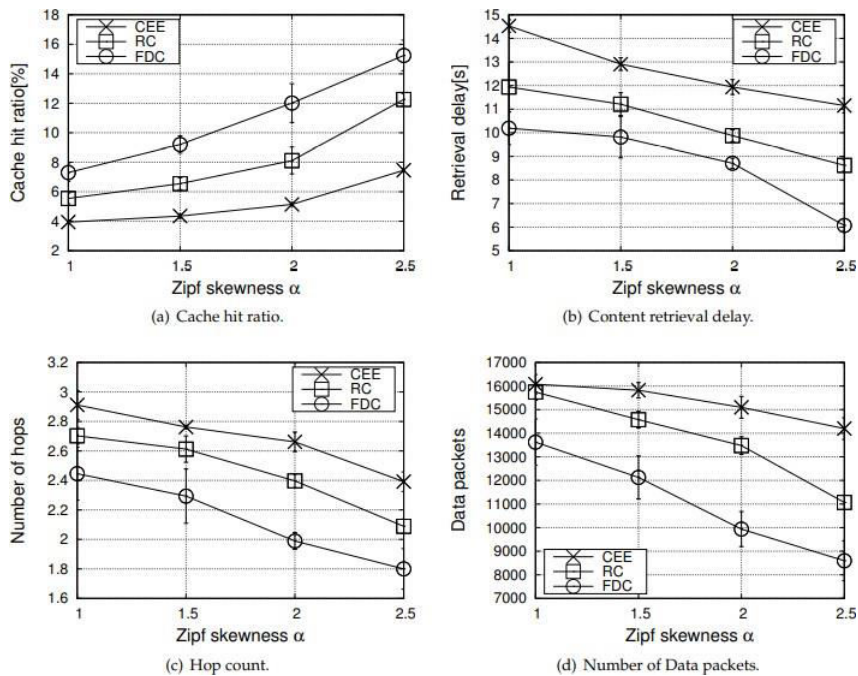


Fig. 7 Performance metrics in the highway scenario, with varying Zipf skewness

Results:

For urban scenario, CEE has the poorest performance out of all the three schemes and RC has slightly better performance. FDC, on the other hand, shows increased cache hit ratio, and decreased content retrieval delay. Due to the popular content already being available in the cache, the number of hops for content retrieval is





also considerably reduced. The overall performance improves as number of consumers goes from 20 to 40 at  $\alpha = 1.5$ .

In case of highway scenario, the same trend of performance was observed. FDC has the best performance metrics and as the value of  $\alpha$  increase, all schemes perform better than before.

## VIII. CONCLUSION

This paper summarizes the research done till date in the field of V-NDN. The V-NDN design is explained and specifically, efficient caching schemes are discussed and their performance in terms of various valuable metrics is evaluated and compared. Transient contents are focused upon due to the importance of content freshness period in order to efficiently make use of the storage available in the vehicular networks. The simulation results confirm that FDC is superior to traditional caching techniques used in vanilla NDN. It is possible to integrate FDC in traditional caching approaches to make them ideal for dealing with transient content.

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