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Differentiated Caching for Improved QoS in Vehicular Content-centric Networks

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Abstract— Vehicular networks facilitate safer and more comfortable travel, but pose several challenges due to high rates of mobility and poor link quality. Information Centric Networking (ICN) is a recently proposed network paradigm that improves performance of networks with content as the focus. In this paper, we propose a differentiated cache replacement scheme called D-cache for content centric vehicular networks. In D-cache, vehicular network traffic is divided into time-sensitive sensor data (S-data) and infotainment related data (I-data). Simulation results show that the proposed scheme improves both the cache hit ratio and the average content retrieval time even at high mobility rates for content centric vehicular networks.

***Keywords*—** Vehicular networks, content-centric networks, qualtiy of service, caching**.**

I. INTRODUCTION

Connecting vehicles for exchange of information has been an active area of research in the recent past. Communication in connected vehicles is typically from Vehicle to Infrastructure (V2I) or Vehicle to Vehicle (V2V) and is called V2X in general. While V2X communication is very useful for obstacle or pothole detection, cruise control, infotainment for passengers in the vehicle etc., it poses several challenges such as poor network links and high mobility of the vehicles. These challenges are handled poorly by traditional IP-based net-work architectures. One emerging network architecture that shows promise for improved V2X communication is Information-Centric Networking. In an Information-centric Network (ICN), data is routed not based on the IP address as in host-centric networks, but based on the name of the content. Content-centric Networking (CCNx) by PARC ([1]), Named Data Networking (NDN[2]) which is based on CCN, Publish-Subscribe Internet Routing Paradigm (PSIRP) ([3]) etc. are some popular architectures that follow the ICN paradigm. CCNx supports pull-based data transfer where consumers send interests for data and the content is sent in response. On the other hand, PSIRP is a publish-subscribe (Pub-Sub) architecture that allows content to be pushed to the consumers.

ICNs inherently support on-path or off-path caching of data, which pushes data to the edge of the network thus reducing both the content retrieval time and traffic in the network core considerably. However, the cache Decision policy which decides where and when data has to be cached depends on the application and can make a huge difference in the network performance. The other aspect of caching that can affect the performance of the network is the cache replacement policy, which decides which content from a cache needs to be evicted from it. Common ICN architectures follow simple policies such as cache everywhere for cache decision and Least Recently Used (LRU) for cache replacement. These may not be suitable for all kinds of applications. For example, entertainment applications such as audio/video stream-ing benefit better from Least Frequently Used (LFU) or other popularity-based cache replacement schemes, as has been proven in Web caching. Data produced and requested by vehicles can be of two types –

- Safety-related data which is generated or required by on-board sensors and control systems (On-Board Units or OBUs) for cruise control, obstacle or pot-hole detection etc. and
- Entertainment-related data generated or requested by users in the vehicle.

The in-network cache replacement policy decides whether a cached copy can be retrieved or the interest has to be sent to the producer of data. A bad choice of cache replacement strategy would result in poor Quality of Service (QoS) in terms of content retrieval time. The main contribution of this paper is a differentiated cache replacement policy (called D-cache) that performs cache replacement based on the nature of data- sensor data (road safety-related, abbreviated S-data) or Infotainment data (I-data). We present simulation results of this scheme for varying mobility rates.

The rest of this paper is organized as follows. In Section 2, we briefly discuss the working of content centric networks. In Section 3, we discuss the related work in the area of vehicular content-centric networks (VCCNs), followed by D-cache, our caching solution for different types of data in vehicular networks. In Section 5, we present the simulation results, where we compare the performance of D-cache with a unified cache policy that uses the same cache replacement algorithm for all types of data. In Section 6, we conclude the paper and discuss the scope for future work in this direction.

II. CONTENT CENTRIC NETWORKING – BASICS

Information Centric Networking (ICN) has attracted a lot of attention in recent times, in view of the increasingly data-oriented traffic in the Internet. In this section, we briefly describe the working of a popular ICN architecture, content centric networking or CCN, by PARC [1]. CCN has three major network elements - producers of data, consumers of data and routers to route data from the producers to consumers. A consumer of data requests for a data object in an interest packet. Routers maintain three data structures:

- **Forwarding Information Base (FIB)** which consists data object names and corresponding network faces,
- **Content Store (CS**) which is a cache for data Objects,
- **Pending Interest Table (PIT)** that holds the information of interests that are already forwarded.

When a router receives a request for a data object, it checks if it is already cached in the CS and if so, returns it on the reverse path to the consumer. If not, it makes an entry in the PIT and forwards the interest using longest prefix matching. Duplicate interest requests are suppressed using PIT lookup. When a router receives a data object for an interest forwarded by it, it makes an entry of that face in the FIB so that future interests are forwarded via this face. It may also cache the data object so that future requests can be satisfied from the router itself. This on-path caching is an important feature of CCN that reduces both network traffic and delay. However, caching all data at all routers along the path from the producer to the consumer is neither practical nor result in good network performance. This is because of two reasons - the CS is finite, making it impossible to store all data objects and more importantly, multiple copies of the data object at different routers result in the cache coherence problem. Routers choose a cache replacement policy such as the least recently used (LRU), least frequently used (LFU) etc.

III. RELATED WORK

ICN has been widely explored in recent times as an alternative to traditional host-based network architectures. Popular ICN architectures include Content Centric Networking (CCN, [1] by PARC, Named Data Networking, PSIRP (a FP7 EU project)etc. ICN for vehicular networks has been explored in principle by some researchers.

CROWN ([4]) is a content-centric framework for vehicular ad hoc networks. It is implemented on top of the 802.11p physical and MAC layers and is compliant with WAVE. Three different packet types are defined in CROWN - C-Objs (content objects), B-Ints (basic interests) and A-Ints (acknowledgement interests). Using these, and some additional data structures, the authors propose a scheme for seamless handoff. They evaluate it with ns2 simulations to establish that it shows better performance than legacy TCP networks. In [5], the authors propose and evaluate (using simulation) ICN for multimedia streaming from vehicle-to-cloud. In [6], the authors explore social cooperation and caching to improve performance in information-centric multimedia streaming in highway VANETs. Named Data Networking for rapid traffic information dissemination is proposed in [7]. Simulation of this push-based ICN architecture shows good network performance. All these establish that ICN is an attractive option for vehicular networks. However, because of the highly dynamic topology of vehicular networks, vehicular content centric networks face many challenges. Some of these are ([8]):

FIB and PIT management: CCN supports consumer mobility innately, as it has a pull-based data acquisition architecture. On the other hand, movement of producers is difficult to support, as the FIB and PIT entries may need to be updated when the producer moves. These changes may need to be done not only at the edge routers (i.e., routers which connect the consumers/producers to the network. Typically these are the RSUs in vehicular networks.), but also at the upstream routers in the core network. Several anchor-based and anchor-less schemes have been proposed for managing producer mobility ([9]), but the efficacy of these schemes for highly mobile topologies remains a challenge.

Cache management: Caching in host-based architectures is generally done optionally, generally using simple cache replacement policies such as LRU, MFU etc. Of late, popularity-based caching schemes have been used resulting in good network performance for the Web ([10], [11]). However, these require complex algorithms that work offline on large sets of data. On the contrary, caching in ICN is needs to be operate at in line speed ([12]). Also, unlike host-based caching schemes where the topology of caches in the network is formed as a linear cascading structure or a tree-like structure, caching in ICN is done ubiquitously. In addition, in the Web, objects are cached whereas in ICN, packets are cached. All these factors necessitate exploration of different cache replacement policies for ICN.

Interesting design choices in ICN include the cache decision policy (what and where to cache), the cache size and the cache replacement policy. Authors of [13] model CCN caching trees as continuous time Markov chains and study the effect of varying cache sizes at different locations along the data path. They conclude that popular content tends to get cached at the leaf nodes and that sizing of CCN caches is a non-trivial task as it depends on the distribution of arrival rates and flow of requests from the upstream. However, cache management for VCCN is an interesting problem due to the high rates of mobility.

QoS provisioning: Nodes in vehicular networks consist of fixed infrastructure elements such the RSUs, upstream routers etc. and mobile elements, which are the vehicles. Both V2V and V2I communication is possible. Data can be safety-related data (generally gathered by on-board sensors) and infotainment related data. Ensuring good quality of service for both V2V and V2I communication of different types of data is an open issue.

Naming and Name resolution: Naming of resources can be flat, hierarchical or hybrid. While most practical deployments based on CCN have hierarchical name spaces, the choice most suited for VCCN is yet to be established. Stand-alone content-centric networks do not require DNS-like name resolution as routing is done based on the name of the resource itself. However, when CCN is used as overlay architecture over the current host-based network architectures, resolution of names becomes an issue.

In this paper, we focus on caching for QoS provisioning and discuss below the state-of-art in these areas.
PeRCeIVE ([14]) is a proactive caching mechanism to improve network performance in ICN-based VANETs. PeRCeIVE considers three parameters of each vehicle - its velocity, interest frequency and position. In addition, it takes into account the number of chunks of each data object, RSU positions and ranges and suggests a frame-work to cache data before a consumer requests for it. LRU, LFU and FIFO are used as cache replacement strategies to evaluate the caching strategy. None of these schemes consider multiple traffic classes for provisioning of QoS.

The CONTACT project [15]) aims to provide mobility management and QoS support for CCN-based VANETs. The authors use geographic locations with geographic routing for managing mobility and resource reservation for QoS support. Resource reservation may not perform or scale well for highly dynamic topologies. Perhaps the closest to our work is [16], in which the authors propose a gap-based caching scheme for vehicular networks. Traffic is classified into safety or infotainment related traffic. Safety related data is cached based on its priority while infotainment-related data is cached based on its popularity. The popularity or priority values, together with the vehicular density values are mapped into a metric called gap. This metric determines where the data is cached in the network. Our scheme also classifies data into safety and infotainment related data, but uses a split cache mechanism and improves performance by using different cache replacement algorithms for each type of data. In [17], the authors propose a differentiated service scheme much like that in the Internet for NDN and show that a differentiated service model results in good performance for NDN networks.

IV. D-CACHE - A DIFFERENTIATED CACHE REPLACEMENT MECHANISM FOR VCCNS

In this section, we present D-Cache, a caching mechanism for improved QoS in VCCNs. We consider a VCCN where vehicles gather road safety information using on-board sensors and share it with the RSUs, which can then share it with other vehicles. This type of data is called S-data (sensor data) and is delay-sensitive but does not occupy much memory or bandwidth. In addition, vehicles may receive infotainment data or I-data, which occupies more memory and bandwidth, but is not as delay sensitive as S-data. Further, we consider the VCCN to have the following elements:
Producers: These are producers of data. For S-data, the producers are the sensors on-board **vehicles.**
For infotainment data, servers in the network are the producers.

Consumers: These are vehicles which request for S-data or I-data.

These are network elements that connect the producers and consumers.
Each of these elements have the necessary CCN data structures (FIB, PIT and CS). In addition, we consider the cache (content store) at all routers to be split into two parts - the first part for S-data and the second for I-data. Traditionally, cache split is done for CPUs to store data and instructions separately. D-cache, on the other hand, uses one physical cache with data tagged as S or I data. Within this cache, the space for S or I data is fixed, and different replacement policies are used for each type of data.

IV.I Caching S-data

As a vehicle moves within the range of a RSU, it sends an interest packet for S-data to the edge router (RSU). The edge router forwards interests as in a traditional CCN. When a vehicle receives an interest packet from its edge router, the vehicle sends the data gathered by the on-board sensors and transmits it to the edge router. Typically, along with the sensor readings, the vehicle location and a time stamp is also sent. This data is then relayed to the consumer vehicle by the edge router. An edge router caches the S-data it receives before relaying it. The cache replacement policy that we propose for S-data is First in First out (FIFO), as newer S-data is more valuable than old S-data.

IV.II Caching I-data

When a vehicle requests for some I-data by sending an interest, the edge-router checks if it is in its cache. If yes, the data is sent to the vehicle. Otherwise, the interest is forwarded as in a traditional CCN. Unlike interests for S-data (which has high local relevance), interests for I-data may travel many hops in the core network before the data object (or a cached copy) is found. Also, requests for I-data depend on content popularity. Popularity-based content caching uses replacement algorithms that range from simple Least Frequently Used (LFU) scheme and its variants to complex schemes such as that proposed in [18] that use collaboration to improve performance. In this paper, we consider LFU for illustrating the benefit of differentiated cache replacement.

V. SIMULATION RESULTS

To evaluate the performance of the D-cache mechanism, we ran simulations using ndnSIM [19], a popular simulator for ICNs. We considered 500 nodes in an area of 250 x 250m spread and moving randomly. Interests were generated for S and I-data. For S-data, they were generated .

Fig. 1. Cache Hit Ratio for I-data as per uniform distribution.
For I-data, they were based on the Zipf distribution with a popularity exponent of 1.25 and content is produced by a few network nodes. Each router [20] had a content store of 100 chunks, with a chunk size of 10kB. We considered equal parts of the CS for S-data and I-data, but this can be varied. We varied the mobility rate of the nodes and measured the cache hit ratio and average content retrieval time.
The cache hit ratio (CHR) is an important parameter for evaluating cache replacement schemes. It is calculated as -

$$\text{CHR} = \frac{\textbf{No. Of.Cache hits}}{\textbf{No .Of. Items requested}}$$

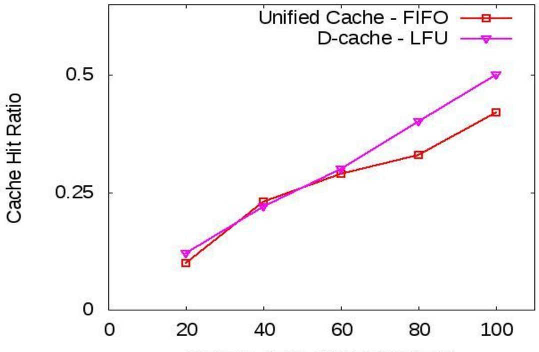

Fig. 1. Cache Hit Ratio for I-data as per uniform distribution

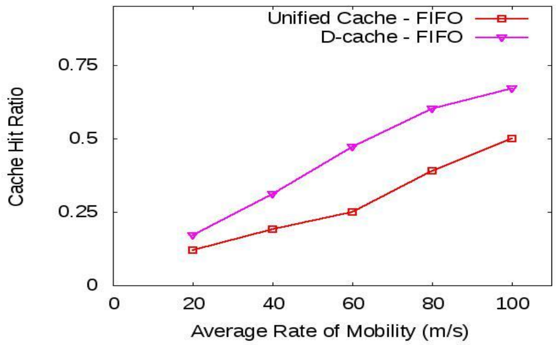

Fig. 2. Cache Hit Ratio for S-data

Figs. 1 and 2 show the variation in the cache hit ratio for I and S-data respectively, with varying mobility rates. We compared two schemes - a unified cache with a simple FIFO replacement policy and D-cache scheme with FIFO for S-data and LFU for I-data. It can be seen that for both types of data, the split cache scheme gives better results.
Similarly, Figs. 3 and 4 show the average retrieval time. This is the time taken from the transmission of an interest to the receipt of the data for I-data and S-data. Compared to a unified cache, the retrieval time is lesser when the cache is split. This is because when FIFO is used for S-data, the most recent data is available in the content stores. Since LFU is used for I-data, the most popular data is stored in the content stores.

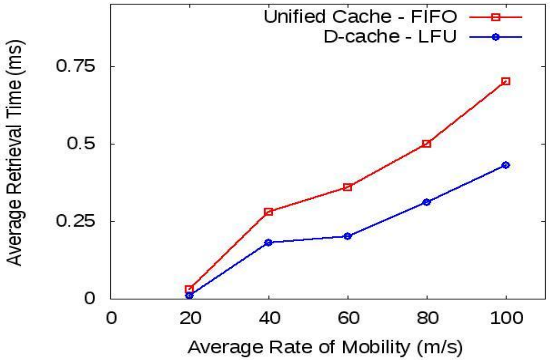

Fig. 3. Average Retrieval Time for I-data

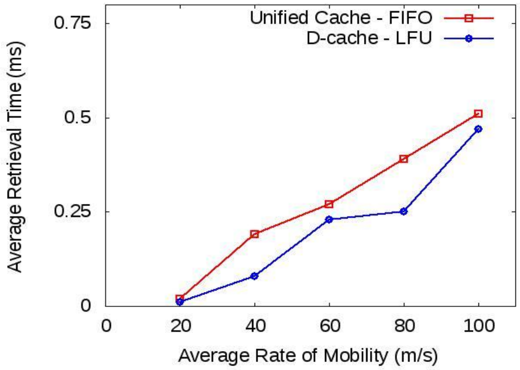

Fig. 4. Average Retrieval Time for S-data

In typical information centric networks, there is no differentiation of type of content and all the content is treated equally with some replacement policy such as FIFO. On the other hand in D-cache, the content is classified into I-data and S-data. The cache is organized with different replacement policies - FIFO for S-data and LFU for I-data. Because of cache split and application of different cache policies for specific content, better quality of service can be provided to vehicular network consumers.

VI. CONCLUSION

Vehicular networks have a huge potential to improve safety and quality of travel. As traffic in networks is increasingly becoming content-centric rather than host-centric, vehicular content centric networks have a great potential for improved network performance with features like in-network caching. However, traffic generated in vehicular networks may or may not be delay-sensitive. In this paper, we propose a differentiated cache replacement policy called D-cache for content stores in vehicular content centric networks. Simulations show that D-cache results in better cache hit ratio and also lowers the average content retrieval time for varying rates of mobility.

REFERENCES

[1] V. Jacobson, D. K. Smetters, J. D. Thornton, M. F. Plass, N. H. Briggs, R. L. Braynard, Networking named content, in: Proceedings of the 5th International Conference on Emerging Networking Experiments and Technologies, CoNEXT ’09, 2009, pp. 1–12.

[2] Named Data Networking, https://named-data.net/project/, [Online; accessed 01-October-2018] (2010).

[3] PSIRP: Publish-Subscribe Internet Routing Paradigm, http://www.psirp.org/, [Online; accessed 09-October-2018].

[4] M. Amadeo, C. Campolo, A. Molinaro, Crown: Content-centric networking in vehicular ad hoc networks, IEEE Communications Letters 16 (9) (2012) 1380–1383.

[5] W. Quan, F. Song, C. Yu, M. Zhang, Icn based vehicle-to-cloud delivery for multimedia streaming in urban vehicular networks, China Communications 13 (9) (2016) 103–112.

[6] W. Quan, C. Xu, J. Guan, H. Zhang, L. A. Grieco, Social cooperation for information-centric multimedia streaming in highway vanets, in: World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014 IEEE 15th International Symposium on a, IEEE, 2014, pp. 1–6.

[7] L. Wang, A. Afanasyev, R. Kuntz, R. Vuyyuru, R. Wakikawa, L. Zhang, Rapid traffic information dissemination using named data, in: Proceedings of the 1st ACM workshop on emerg-ing name-oriented mobile networking design-architecture, algo-rithms, and applications, ACM, 2012, pp. 7–12.

[8] M. Amadeo, C. Campolo, A. Molinaro, Information-centric networking for connected vehicles: a survey and future perspectives, IEEE Communications Magazine 54 (2) (2016) 98–104.

[9] S. Chilukuri, K. Chakravarthy Chilukuri, S. Korla, Provider mobility in content centric networks - issues and challenges, International Journal of Mobile Network Design and Innovation 7 No. 3/4 (2017) 150 – 157.

[10] S. Podlipnig, L. Bosz¨ormenyi,¨ A survey of web cache replacement strategies, ACM Computing Surveys (CSUR) 35 (4) (2003) 374– 398.

[11] M. Rabinovich, O. Spatscheck, Web caching and replication, Vol. 67, Addison-Wesley Boston, USA, 2002.

[12] G. Zhang, Y. Li, T. Lin, Caching in information centric networking: A survey, Computer Networks 57 (16) (2013) 3128–3141.

[13] I. Psaras, R. G. Clegg, R. Landa, W. K. Chai, G. Pavlou, Modelling and evaluation of ccn-caching trees, in: International Conference on Research in Networking, Springer, 2011, pp. 78–91.

[14] D. Grewe, M. Wagner, H. Frey, Perceive: Proactive caching in icn- based vanets, in: Vehicular Networking Conference (VNC), 2016 IEEE, IEEE, 2016, pp. 1–8.

[15] G. Rizzo, M. R. Palattella, T. Braun, T. Engel, Content and context aware strategies for qos support in vanets, in: Advanced Information Networking and Applications (AINA), 2016 IEEE 30th International Conference on, IEEE, 2016, pp. 717–723.

[16] Y. Li, Y. Yang, R. Rahmani, T. Kanter, X. Su, J. Riekki, Gap-based caching for icn-based vehicular networks, in: 2016 IEEE 83rd Ve-hicular Technology Conference: VTC 2016-Spring, Nanjing, China, 15–18 May 2016, IEEE Computer Society, 2016.

[17] Y. Kim, Y. Kim, J. Bi, I. Yeom, Differentiated forwarding and caching in named-data networking, Journal of Network and Computer Applications 60 (2016) 155 – 169.

[18] K. Cho, M. Lee, K. Park, T. T. Kwon, Y. Choi, S. Pack, Wave: Popularity-based and collaborative in-network caching for content-oriented networks, in: Computer Communications Work-shops (INFOCOM WKSHPS), 2012 IEEE Conference on, IEEE, 2012, pp. 316–321.

[19] NS-3 based Named Data Networking (NDN) simulator, http://ndnsim.net/1.0/index.html, [Online; accessed 09-October-2018].

[20] R.Kumari, P. Nand, “Performance Analysis of existing Routing Protocols” International Journal of Scientific Research in Computer Science and Engineering (IJSRCSE), ISSN-2320-7639, Vol. 5 No. 5, October-2017.

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