PERFORMANCE EVALUATION OF CACHING TECHNIQUES FOR VIDEO ON DEMAND WORKLOAD IN NAMED DATA NETWORK

SADAQ JEBUR TAHER

**MASTER OF SCIENCE (INFORMATION TECHNOLOGY)
UNIVERSITI UTARA MALAYSIA
2016**

Perakuan Kerja Tesis/Disertasi

(To be substituted with signed document for this page)

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to:

Dean of Awang Had Salleh Graduate School of Arts and Sciences
UUM College of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok

Abstrak

Penggunaan Internet dalam konteks kontemporari berkembang pesat terutamanya untuk tujuan paparan maklumat. Ini disebabkan oleh kemunculan 'Information-Centric Networking' (ICN) dalam domain yang lebih luas iaitu akademik dan industri. 'Named Data Network (NDN)' adalah hasil daripada ICN. Di samping itu, NDN diutamakan sebagai seni bina untuk trafik video yang lancar diantara permintaan dan penerima video dalam talian. Penyelidikan ringkas ini mengenal pasti isu semasa yang menyebabkan kesesakan di beban kerja 'Video on Demand' (VoD) yang berpunca daripada penyimpanan kerap objek kandungan dalam repositori tempatan, yang membawa kepada masalah penampanan dan kehilangan paket data. Kajian itu akan menilai teknik cache NDN untuk memilih teknik penggantian cache yang lebih sesuai untuk menangani isu-isu kesesakan, dan menilai prestasinya. Untuk demikian, kajian semasa menggunakan proses penyelidikan berdasarkan 'Design Research Methodology' (DRM) dan pendekatan VoD untuk menerangkan aktiviti-aktiviti utama yang menghasilkan peningkatan dalam hasil akhir penyelidikan. Kumpulan data, serta topologi rangkaian Internet2 dan statistik tontonan video telah dikumpulkan dari platform PPTV. Sebanyak 221 pelayan disambungkan kepada rangkaian dari pusat akses yang sama seperti dalam penggunaan sebenar PPTV. Di samping itu, NS3 menganalisa prestasi metrik teknik penggantian caching (LRU, LFU dan FIFO) untuk VoD dalam 'Named Data Network' (NDN) dari segi nisbah hit cache, pemprosesan, dan keputusan beban pelayan dalam hasil yang munasabah yang muncul berkhidmat sebagai pengganti yang berpotensi dengan pelaksanaan topologi semasa Internet2, di mana nod diedarkan secara rawak. Berdasarkan keputusan, teknik LFU memberikan hasil yang lebih baik untuk kesesakan di antara teknik-teknik lain yang dibentangkan. Akhir sekali, kajian ini mendapati bahawa prestasi metric nisbah cache, kendalian, dan beban pelayan untuk LFU menghasilkan kadar kesesakan yang paling rendah dan mencukupi. Justeru, penyelidik membuat kesimpulan bahawa kecekapan teknik penggantian yang berbeza perlu juga disiasat untuk memberikan pandangan serta idea untuk melaksanakan teknik-teknik ini dalam konteks tertentu. Walau bagaimanapun, keputusan ini memenuhi pemahaman semasa untuk teknik penggantian saiz cache yang berbeza. Setelah teknik penggantian yang berbeza diaplikasikan dan diperiksa, ciri-ciri prestasi dan prestasi jangkaan juga didapati merangsang model cache untuk berjalan cepat merentasi pelbagai aplikasi terbenam.

Kata-kunci: Information-Centric Networking (ICN), Named Data Network (NDN), Video on Demand (VoD), Congestion, Caching Replacement Techniques

Abstract

The rapid growing use of the Internet in the contemporary context is mainly for content distribution. This is derived primarily due to the emergence of Information-Centric Networking (ICN) in the wider domains of academia and industry. Named Data Network (NDN) is one of ICN architectures. In addition, the NDN has been emphasized as the video traffic architecture that ensures smooth communication between the request and receiver of online video. The concise research problem of the current study is the issue of congestion in Video on Demand (VoD) workload caused by frequent storing of signed content object in the local repositories, which leads to buffering problems and data packet loss. The study will assess the NDN cache techniques to select the preferable cache replacement technique suitable for dealing with the congestion issues, and evaluate its performance. To do that, the current study adopts a research process based on the Design Research Methodology (DRM) and VoD approach in order to explain the main activities that produced an increase in the expected findings at the end of the activities or research. Datasets, as well as Internet2 network topology and the statistics of video views were gathered from the PPTV platform. Actually, a total of 221 servers is connected to the network from the same access points as in the real deployment of PPTV. In addition, an NS3 analysis the performance metrics of caching replacement technique (LRU, LFU, and FIFO) for VoD in Named Data Network (NDN) in terms of cache hit ratio, throughput, and server load results in reasonable outcomes that appears to serve as a potential replacement with the current implementation of the Internet2 topology, where nodes are distributed randomly. Based on the results, LFU technique gives the preferable result for congestion from among the presented techniques. Finally, the research finds that the performance metrics of cache hit ratio, throughput, and server load for the LFU that produces the lowest congestion rate which is sufficient. Therefore, the researcher concluded that the efficiency of the different replacement techniques needs to be well investigated in order to provide the insights necessary to implement these techniques in certain context. However, this result enriches the current understanding of replacement techniques in handling different cache sizes. After having addressed the different replacement techniques and examined their performances, the performance characteristics along with their expected performance were also found to stimulate a cache model for providing a relatively fast running time of across a broad range of embedded applications.

Keywords: Information-Centric Networking (ICN), Named Data Network (NDN), Video on Demand (VoD), Congestion, Caching Replacement Techniques

Acknowledgements

In the name of ALLAH, Most Gracious, Most Merciful:

"*Work; so Allah will see your work and (so will) His Messenger and the believers*;"

(The Holy Quran - AtTawbah 9:105)

Conducting this research marks the end of an interesting and eventful journey. The completion of this dissertation signifies the fulfillment of a long-awaited goal. It could not have been achieved without the professional academic and personal support of the following wonderful and talented people.

I will start by extending my deep and sincere gratitude to my supervisors Dr. Mohammed K.M. Madi and Professor Dr. Suhaidi Hassan (School of Computing, Universiti Utara Malaysia) for their tireless encouragement, wisdom and experience, who provided me with constant guidance and constructive criticism throughout all stages of my research. I must say a huge thank you to the current and past members of InterNetWorks Research Lab whom I enjoyed working with; especially, Dr. Massudi Mahmuddin, Dr. Nur Haryani Zakaria, Dr. Rohaida Romli, Dr. Ahmad Suki Che Mohamed Arif, Dr. Adib Habbal, Dr. Mohd. Hasbullah Omar, Dr. Norliza Katuk and others.

Finally, my heartiest gratitude goes to my family, to my father and mother lates , to my beloved wife (MSc. Rasha) for her understanding, support, and love, also deepest thanks to my sons (Jaafer and Osamah), and my daughter (Tabarak) for being so sweet and loving, to my wife's mother and my sister who always has faith in me and prays for my success,to my soul (Tareq) , to my brothers , to my wife's brothers, and to my friends who are willing to extend a helping hand.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ABR	-	Adaptive-Bit-Rate
ADSL	-	Asymmetric Digital Subscriber Line
CDN	-	Content Delivery Network
CS	-	Content Store
DoS	-	Denial-of-Service attack
FIB	-	Forwarding Information Base
FIFO	-	First-In-First-Out police
ID	-	IDentifier
IP	-	Internet Protocol
IPTV	-	Internet Protocol Television
ISP	-	Internet Service Provider
LFU	-	Least Frequently Used
LRU	-	Least Recently Used
NDN	-	Named Data Networking
NLR	-	National Lambda Rail
NS3	-	Network Simulation version 3
PC	-	Personal Computer
PIT	-	Pending Interest Table
PPTV	-	Platform Provider Television
P2P	-	Peer-to-Peer
TCP	-	Transmission Control Protocol
UCLA	-	University of California, Los Angeles
URL	-	Uniform Resource Locator
VoD	-	Video-on-Demand
TCP/IP	-	Transmission Control Protocol/Internet Protocol

CHAPTER ONE

INTRODUCTION

This chapter provides an overview of this study. It includes a brief introduction of Named Data Networking (NDN) technique and its application such as Video-on-Demand. Besides, the chapter contains the research problem and the research questions which are in line with the research objectives. The scope and significance of this research is also explained in this chapter.

1.1 Background of the Study

Named Data Networking (NDN) has been identified as the communication architecture used in an Internet video storage. It gives high priority to the data which include videos. The NDN architecture is basically comprised of communication units as shown in Figure 1.1 as interest packet and data packet [1].
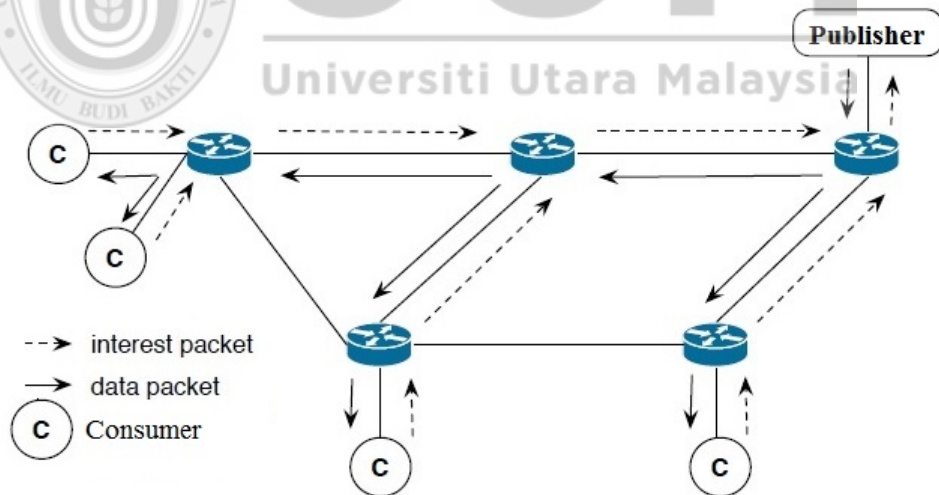

Figure 1.1: Data Flow in NDN Architecture [1]

The interest packet is one of the communication units in NDN sent upon the request of consumers of data or video steaming, while the data packet is protected by a cryptographic signature giving most integrity of the data video source from the cache.

The contents of the thesis is for internal user only

REFERENCES

[1]   L. Zhang, D. Estrin, J. Burke, V. Jacobson, J. D. Thornton, D. K. Smetters, B. Zhang, G. Tsudik, D. Massey, C. Papadopoulos, *et al.*, "Named data networking (ndn) project," *NDN-0001, Xerox Palo Alto Research Center-PARC*, 2010.

[2]   J. Burke, "Video streaming over named data networking," *E-LETTER*, vol. 8, no. 4, pp. 6–9, 2013.

[3]   C. Bian, Z. Zhu, A. Afanasyev, E. Uzun, and L. Zhang, "Deploying key management on ndn testbed," *UCLA, Peking University and PARC, Tech. Rep*, 2013.

[4]   V. Jacobson, D. K. Smetters, J. D. Thornton, M. F. Plass, N. H. Briggs, and R. L. Braynard, "Networking named content," in *Proceedings of the 5th international conference on Emerging networking experiments and technologies*, pp. 1–12, ACM, 2009.

[5]   C. Yi, A. Afanasyev, I. Moiseenko, L. Wang, B. Zhang, and L. Zhang, "A case for stateful forwarding plane," *Computer Communications*, vol. 36, no. 7, pp. 779–791, 2013.

[6]   Z. Zhu and A. Afanasyev, "Let's chronosync: Decentralized dataset state synchronization in named data networking.," in *ICNP*, pp. 1–10, 2013.

[7]   C. Huang, J. Li, and K. W. Ross, "Can internet video-on-demand be profitable?," *ACM SIGCOMM Computer Communication Review*, vol. 37, no. 4, pp. 133–144, 2007.

[8]   L. Gomes, "Will all of us get our 15 minutes on a youtube video?," *Wall Street Journal*, vol. 30, p. B1, 2006.

[9]   A. Ali-Eldin, M. Kihl, J. Tordsson, and E. Elmroth, "Analysis and characterization of a video-on-demand service workload," in *Proceedings of the 6th ACM Multimedia Systems Conference*, pp. 189–200, ACM, 2015.

[10] G. Xylomenos, C. N. Ververidis, V. A. Siris, N. Fotiou, C. Tsilopoulos, X. Vasilakos, K. V. Katsaros, and G. C. Polyzos, "A survey of information-centric networking research," *Communications Surveys & Tutorials, IEEE*, vol. 16, no. 2, pp. 1024–1049, 2014.

[11] A. Ghodsi, S. Shenker, T. Koponen, A. Singla, B. Raghavan, and J. Wilcox, "Information-centric networking: seeing the forest for the trees," in *Proceedings of the 10th ACM Workshop on Hot Topics in Networks*, p. 1, ACM, 2011.

[12] A. Smith, "The internets role in campaign 2008," *Pew Internet & American Life Project*, vol. 15, 2009.

[13] T.-Y. Huang, R. Johari, N. McKeown, M. Trunnell, and M. Watson, "A buffer-based approach to rate adaptation: Evidence from a large video streaming service," in *Proceedings of the 2014 ACM conference on SIGCOMM*, pp. 187–198, ACM, 2014.

[14] J. Liu, A. Panda, A. Singla, B. Godfrey, M. Schapira, and S. Shenker, "Ensuring connectivity via data plane mechanisms.," in *NSDI*, pp. 113–126, 2013.

[15] Y. Sun, S. K. Fayaz, Y. Guo, V. Sekar, Y. Jin, M. A. Kaafar, and S. Uhlig, "Trace-driven analysis of icn caching algorithms on video-on-demand workloads," in *Proceedings of the 10th ACM International on Conference on emerging Networking Experiments and Technologies*, pp. 363–376, ACM, 2014.

[16] Z. Ming, M. Xu, and D. Wang, "Age-based cooperative caching in information-centric networks," in *Computer Communications Workshops (INFOCOM WKSHPS), 2012 IEEE Conference on*, pp. 268–273, IEEE, 2012.

[17] S. Salsano, A. Detti, M. Cancellieri, M. Pomposini, and N. Blefari-Melazzi, "Transport-layer issues in information centric networks," in *Proceedings of the second edition of the ICN workshop on Information-centric networking*, pp. 19–24, ACM, 2012.

[18] A. Balachandran, V. Sekar, A. Akella, and S. Seshan, "Analyzing the potential benefits of cdn augmentation strategies for internet video workloads," in *Proceedings of the 2013 conference on Internet measurement conference*, pp. 43–56, ACM, 2013.

[19] L. Saino, I. Psaras, and G. Pavlou, "Icarus: a caching simulator for information centric networking (icn)," in *Proceedings of the 7th International ICST Conference on Simulation Tools and Techniques*, pp. 66–75, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2014.

[20] G. Bianchi, A. Detti, A. Caponi, and N. Blefari, "Check before storing: what is the performance price of content integrity verification in lru caching?," *ACM SIGCOMM Computer Communication Review*, vol. 43, no. 3, pp. 59–67, 2013.

[21] H. Jun, "Icnrg j. hong internet draft etri intended status: Informational w. chun expires: January 2015 hufs,"

[22] D. A. Farber and R. D. Lachman, "Data processing system using substantially unique identifiers to identify data items, whereby identical data items have the same identifiers," Nov. 2 1999. US Patent 5,978,791.

[23] D. O. Coileain and D. Omahony, "Accounting and accountability in content distribution architectures: A survey," *ACM Computing Surveys (CSUR)*, vol. 47, no. 4, p. 59, 2015.

[24] J. Ren, L. Li, H. Chen, S. Wang, S. Xu, G. Sun, J. Wang, and S. Liu, "On the deployment of information-centric network: Programmability and virtualization," in *Computing, Networking and Communications (ICNC), 2015 International Conference on*, pp. 690–694, IEEE, 2015.

[25] R.-I. Ciobanu, C. Dobre, and F. Xhafa, "Data modeling for socially based routing in opportunistic networks," in *Modeling and Processing for Next-Generation Big-Data Technologies*, pp. 29–55, Springer, 2015.

[26] E. AbdAllah, H. S. Hassanein, and M. Zulkernine, "A survey of security attacks in information-centric networking," *IEEE*, pp. 1441 – 1454, 2015.

[27] P. Gasti, G. Tsudik, E. Uzun, and L. Zhang, "Dos and ddos in named data networking," in *Computer Communications and Networks (ICCCN), 2013 22nd International Conference on*, pp. 1–7, IEEE, 2013.

[28] N. Fotiou, Y. Thomas, V. A. Siris, and G. C. Polyzos, "Security requirements and solutions for integrated satellite-terrestrial information-centric networks," in *Advanced Satellite Multimedia Systems Conference and the 13th Signal Processing for Space Communications Workshop (ASMS/SPSC), 2014 7th*, pp. 106–113, IEEE, 2014.

[29] G. Paul, F. Hutchison, and J. Irvine, "Security of the maidsafe vault network," in *Wireless World Research Forum Meeting 32 (WWRF32)*, 2014.

[30] C. Yi, J. Abraham, A. Afanasyev, L. Wang, B. Zhang, and L. Zhang, "On the role of routing in named data networking," in *Proceedings of the 1st international conference on Information-centric networking*, pp. 27–36, ACM, 2014.

[31] J. Li, H. Wu, B. Liu, J. Lu, Y. Wang, X. Wang, Y. Zhang, and L. Dong, "Popularity-driven coordinated caching in named data networking," in *Proceedings of the eighth ACM/IEEE symposium on Architectures for networking and communications systems*, pp. 15–26, ACM, 2012.

[32] R. Margolies, A. Sridharan, V. Aggarwal, R. Jana, N. Shankaranarayanan, V. A. Vaishampayan, and G. Zussman, "Exploiting mobility in proportional fair cellular scheduling: Measurements and algorithms," in *INFOCOM, 2014 Proceedings IEEE*, pp. 1339–1347, IEEE, 2014.

[33] J. Erman, A. Gerber, K. Ramadrishnan, S. Sen, and O. Spatscheck, "Over the top video: the gorilla in cellular networks," in *Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference*, pp. 127–136, ACM, 2011.

[34] A. Afanasyev, P. Mahadevan, I. Moiseenko, E. Uzun, and L. Zhang, "Interest flooding attack and countermeasures in named data networking," in *IFIP Networking Conference, 2013*, pp. 1–9, IEEE, 2013.

[35] Q. Xu, S. Mehrotra, Z. Mao, and J. Li, "Proteus: network performance forecast for real-time, interactive mobile applications," in *Proceeding of the 11th annual international conference on Mobile systems, applications, and services*, pp. 347–360, ACM, 2013.

[36] R. K. Mok, X. Luo, E. W. Chan, and R. K. Chang, "Qdash: a qoe-aware dash system," in *Proceedings of the 3rd Multimedia Systems Conference*, pp. 11–22, ACM, 2012.

[37] Z. Zhu, C. Bian, A. Afanasyev, V. Jacobson, and L. Zhang, "Chronos: Serverless multi-user chat over ndn," tech. rep., NDN, Technical Report NDN-0008, 2012.

[38] C. Yi, A. Afanasyev, L. Wang, B. Zhang, and L. Zhang, "Adaptive forwarding in named data networking," *ACM SIGCOMM computer communication review*, vol. 42, no. 3, pp. 62–67, 2012.

[39] J. Jiang, V. Sekar, and H. Zhang, "Improving fairness, efficiency, and stability in http-based adaptive video streaming with festive," in *Proceedings of the 8th international conference on Emerging networking experiments and technologies*, pp. 97–108, ACM, 2012.

[40] S. K. Fayazbakhsh, Y. Lin, A. Tootoonchian, A. Ghodsi, T. Koponen, B. Maggs, K. Ng, V. Sekar, and S. Shenker, "Less pain, most of the gain: Incrementally deployable icn," in *ACM SIGCOMM Computer Communication Review*, vol. 43, pp. 147–158, ACM, 2013.

[41] J. R. P. S. A. Ghodsi, T. Koponen and S. Shenker, "Naming in content-oriented architectures," in *Proceedings of the ACM SIGCOMM workshop on Information-centric networking*, pp. 1–6, ACM, 2011.

[42] K. D. Babu, M. Somu, and N. Rengarajan, "A replacement policy for buffer management in iptv services," 2013.

[43] Cisco, "Cisco visual networking index: Forecast and methodology," 2014.

[44] Citrix, "Mobile analytics report," 2014.

[45] K. Arora and D. Rao, "Web cache page replacement by using lru and lfu algorithms with hit ratio: A case unification.," *International Journal of Computer Science & Information Technologies*, vol. 5, no. 3, 2014.

[46] K. Shah, A. Mitra, and D. Matani, "An 0 (1) algorithm for implementing the lfu cache eviction scheme," tech. rep., Technical report, 2010." http://dhruvbird. com/lfu. pdf, 2010.

[47] A. Patil, M. Prakash, and A. Nimkar, "First-in not referenced first-out page replacement algorithm," in *Proceedings of the International Conference & Workshop on Emerging Trends in Technology*, pp. 443–446, ACM, 2011.

[48] W. Ali, S. M. Shamsuddin, and A. S. Ismail, "A survey of web caching and prefetching," *International Journal of Advances in Soft Computing and its Application*, vol. 3, no. 1, pp. 18–44, 2011.

[49] M. K. Madi, *Replica Creation Algorithm for Data Grids*. PhD thesis, Universiti Utara Malaysia, 2012.

[50] B. Jeannet, T. Jeron, and T. Le, "Abstract interpretation of fifo channels," 2005.

[51] D. Grund and J. Reineke, "Precise and efficient fifo-replacement analysis based on static phase detection," in *Real-Time Systems (ECRTS), 2010 22nd Euromicro Conference on*, pp. 155–164, IEEE, 2010.

[52] M. S. Haque, J. Peddersen, and S. Parameswaran, "Ciparsim: Cache intersection property assisted rapid single-pass fifo cache simulation technique," in *Proceedings of the International Conference on Computer-Aided Design*, pp. 126–133, IEEE Press, 2011.

[53] N. Duong, R. Cammarota, D. Zhao, T. Kim, and A. Veidenbaum, "Score: A score-based memory cache replacement policy," in *JWAC 2010-1st JILP Worshop on Computer Architecture Competitions: cache replacement Championship*, 2010.

[54] M. S. Haque, J. Peddersen, A. Janapsatya, and S. Parameswaran, "Dew: a fast level 1 cache simulation approach for embedded processors with fifo replacement policy," in *Proceedings of the Conference on Design, Automation and Test in Europe*, pp. 496–501, European Design and Automation Association, 2010.

[55] M. Esmalifalak, Z. Han, and L. Song, "Effect of stealthy bad data injection on network congestion in market based power system," in *Wireless Communications and Networking Conference (WCNC), 2012 IEEE*, pp. 2468–2472, IEEE, 2012.

[56] N. Jiang, D. U. Becker, G. Michelogiannakis, and W. J. Dally, "Network congestion avoidance through speculative reservation," in *High Performance Computer Architecture (HPCA), 2012 IEEE 18th International Symposium on*, pp. 1–12, IEEE, 2012.

[57] D. Kliazovich, P. Bouvry, and S. U. Khan, "Dens: data center energy-efficient network-aware scheduling," *Cluster computing*, vol. 16, no. 1, pp. 65–75, 2013.

[58] H. Khadilkar and H. Balakrishnan, "Network congestion control of airport surface operations," *Journal of Guidance, Control, and Dynamics*, vol. 37, no. 3, pp. 933–940, 2014.

[59] A. E. Cohen, J.-H. Lin, and K. K. Parhi, "Variable data rate (vdr) network congestion control (ncc) applied to voice/audio communication," *Computer Networks*, vol. 56, no. 4, pp. 1343–1356, 2012.

[60] R. Cominetti and C. Guzman, "Network congestion control with markovian multipath routing," *Mathematical Programming*, vol. 147, no. 1-2, pp. 231–251, 2014.

[61] M. Rossi, G. Vigano, and D. Moneta, "Hosting capacity of distribution networks: Evaluation of the network congestion risk due to distributed generation," in *Clean Electrical Power (ICCEP), 2015 International Conference on*, pp. 716–722, IEEE, 2015.

[62] C. P. Sahu, P. S. Yadav, S. Ahuja, R. Prasad, and A. Garg, "Optimistic congestion control to improve the performance of mobile ad hoc network," in *Advance Computing Conference (IACC), 2013 IEEE 3rd International*, pp. 394–398, IEEE, 2013.

[63] M. H. Cheung, R. Southwell, and J. Huang, "Congestion-aware network selection and data offloading," in *Information Sciences and Systems (CISS), 2014 48th Annual Conference on*, pp. 1–6, IEEE, 2014.

[64] V. Joseph and G. De Veciana, "Stochastic networks with multipath flow control: impact of resource pools on flow-level performance and network congestion," *ACM SIGMETRICS Performance Evaluation Review*, vol. 39, no. 1, pp. 61–72, 2011.

[65] D. Kim, S. Yoo, and S. Lee, "A network congestion-aware memory subsystem for manycore," *ACM Transactions on Embedded Computing Systems (TECS)*, vol. 12, no. 4, p. 110, 2013.

[66] L. T. Blessing and A. Chakrabarti, *DRM, a design research methodology*. Springer Science & Business Media, 2009.

[67] A. M. M. Habbal and S. Hassan, "A model for congestion control of transmission control protocol in mobile wireless ad hoc networks," *Journal of Computer Science*, vol. 9, no. 3, p. 335, 2013.

[68] G. Grassi, D. Pesavento, G. Pau, L. Zhang, and S. Fdida, "Navigo: Interest forwarding by geolocations in vehicular named data networking," *arXiv preprint arXiv:1503.01713*, 2015.

[69] S. Hassan, W. Elbreiki, M. Firdhous, and A. M. M. Habbal, "End-to-end networks vs named data network: A critical evaluation," *Jurnal Teknologi*, vol. 72, no. 5, 2015.

[70] H. Park, H. Jang, and T. Kwon, "Popularity-based congestion control in named data networking," in *Ubiquitous and Future Networks (ICUFN), 2014 Sixth International Conf on*, pp. 166–171, IEEE, 2014.

[71] D. Posch, B. Rainer, and H. Hellwagner, "Saf: Stochastic adaptive forwarding in named data networking," *arXiv preprint arXiv:1505.05259*, 2015.

[72] K. Wang, J. Chen, H. Zhou, Y. Qin, and H. Zhang, "Modeling denial-of-service against pending interest table in named data networking," *International Journal of Communication Systems*, vol. 27, no. 12, pp. 4355–4368, 2014.

[73] B. Han, X. Wang, N. Choi, T. Kwon, and Y. Choi, "Amvs-ndn: Adaptive mobile video streaming and sharing in wireless named data networking," in *Computer Communications Workshops (INFOCOM WKSHPS), 2013 IEEE Conference on*, pp. 375–380, IEEE, 2013.

[74] L. Saino, I. Psaras, and G. Pavlou, "Hash-routing schemes for information centric networking," in *Proceedings of the 3rd ACM SIGCOMM workshop on Information-centric networking*, pp. 27–32, ACM, 2013.

[75] F. Dobrian, A. Awan, D. Joseph, A. Ganjam, J. Zhan, V. Sekar, I. Stoica, and H. Zhang, "Understanding the impact of video quality on user engagement," *Communications of the ACM*, vol. 56, no. 3, pp. 91–99, 2013.

[76] N. Lv, D. Zhang, *et al.*, "On performance of cache policies in named data networking," in *2013 International Conference on Advanced Computer Science and Electronics Information (ICACSEI 2013)*, Atlantis Press, 2013.

[77] G. Tyson, S. Kaune, S. Miles, Y. El-khatib, A. Mauthe, and A. Taweel, "A trace-driven analysis of caching in content-centric networks," in *Computer Communications and Networks (ICCCN), 2012 21st International Conference on*, pp. 1–7, IEEE, 2012.

[78] X. Zheng, M. Veeraraghavan, N. S. Rao, Q. Wu, and M. Zhu, "Cheetah: Circuit-switched high-speed end-to-end transport architecture testbed," 2005.

[79] M. Badov, A. Seetharam, J. Kurose, V. Firoiu, and S. Nanda, "Congestion-aware caching and search in information-centric networks," in *Proceedings of the 1st international conference on Information-centric networking*, pp. 37–46, ACM, 2014.

[80] T. Lauinger, N. Laoutaris, P. Rodriguez, T. Strufe, E. Biersack, and E. Kirda, "Privacy implications of ubiquitous caching in named data networking architectures," tech. rep., Technical report, TR-iSecLab-0812-001, iSecLab, 2012.

[81] S. Wang, J. Bi, J. Wu, Z. Li, W. Zhang, and X. Yang, "Could in-network caching benefit information-centric networking?," in *Proceedings of the 7th Asian Internet Engineering Conference*, pp. 112–115, ACM, 2011.

[82] M. Conti, P. Gasti, and M. Teoli, "A lightweight mechanism for detection of cache pollution attacks in named data networking," *Computer Networks*, vol. 57, no. 16, pp. 3178–3191, 2013.

[83] Y. Wang, Z. Li, G. Tyson, S. Uhlig, and G. Xie, "Optimal cache allocation for content-centric networking," in *Network Protocols (ICNP), 2013 21st IEEE International Conference on*, pp. 1–10, IEEE, 2013.

[84] J. Ran, N. Lv, D. Zhang, Y. Ma, and Z. Xie, "On performance of cache policies in named data networking," in *International Conference on Advanced Computer Science and Electronics Information*, pp. 668–671, 2013.

[85] S. Wang, J. Bi, and J. Wu, "On performance of cache policy in information-centric networking," in *Computer Communications and Networks (ICCCN), 2012 21st International Conference on*, pp. 1–7, IEEE, 2012.

[86] Y. Jin and Y. Wen, "Paint: Partial in-network transcoding for adaptive streaming in information centric network," in *Quality of Service (IWQoS), 2014 IEEE 22nd International Symposium of*, pp. 208–217, IEEE, 2014.

[87] N. Megiddo and D. S. Modha, "Outperforming lru with an adaptive replacement cache algorithm," *Computer*, vol. 37, no. 4, pp. 58–65, 2004.

[88] E.-S. M. El-Alfy and A. Orwani, "The need for a unified framework for evaluating web cache replacement strategies," in *GCC Conference & Exhibition, 2009 5th IEEE*, pp. 1–5, IEEE, 2009.

[89] C. Yao, L. Fan, Z. Yan, and Y. Xiang, "Long-term interest for realtime applications in the named data network," *Proceedings of the AsiaFI*, 2012.