FLEXPOP: A POPULARITY-BASED CACHING STRATEGY FOR MULTIMEDIA APPLICATIONS IN INFORMATION-CENTRIC NETWORKING

IKRAM UD DIN

DOCTOR OF PHILOSOPHY
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 University 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

Declaration Associated with This Thesis

Some of the work presented in this thesis have been published or submitted as listed below:

1. **Ikram Ud Din**, Suhaidi Hassan, Adib Habbal, and Nur Haryani Zakaria, "A Popularity-based Caching Strategy for the Future Internet," ITU Kaleidoscope 2016, (To Appear).

2. **Ikram Ud Din**, Suhaidi Hassan, and Adib Habbal, "A Content Placement Scheme for Information-Centric Networking," *Advanced Science Letters*, 21(11), pp. 3484–3486, 2015.

3. **Ikram Ud Din**, Suhaidi Hassan, and Adib Habbal, "Redundancy Elimination in the Future Internet," *Lecture Notes in Computer Science, Springer*, 2016 (To Appear).

4. **Ikram Ud Din**, Suhaidi Hassan, and Adib Habbal, "SocialCCNSim: A Simulator for Caching Strategies in Information-Centric Networking," *Advanced Science Letters*, 21(11), pp. 3507–3511, 2015.

5. **Ikram Ud Din**, Suhaidi Hassan, and Adib Habbal, "Comparison of Caching Strategies on Different Topologies in Information-Centric Networking," *Fourth International Conference on Internet Applications, Protocols and Services* (NETAPPS2015), pp. 37-41, 2015.

6. **Ikram Ud Din**, Suhaidi Hassan, and Adib Habbal, "A Content Eviction Mechanism for Information-Centric Networking," *ARPN Journal of Engineering and Applied Sciences*, 11(5), pp. 3233-3235, 2016.

7. **Ikram Ud Din**, Suhaidi Hassan, and Adib Habbal, "A Mechanism for Reducing

Content Retrieval Delay in the Future Internet," *Fourth International Conference on Internet Applications, Protocols and Services* (NETAPPS2015), pp. 59-62, 2015.

Abstrak

Perangkaian Bertumpuan Maklumat (ICN) adalah senibina Internet masa hadapan yang dominan. Dalam ICN, item kandungan disimpan seketika oleh nod-nod rangkaian seperti penghala. Apabila memori penghala penuh dan tiada lagi ruang untuk kandungan yang baharu tiba, kandungan yang disimpan akan dikeluarkan untuk menangani saiz ruang simpanan penghala yang terhad. Oleh yang demikian, adalah penting untuk membangunkan satu strategi penyimpanan yang berkesan bagi menyimpan kandungan popular untuk jangka masa yang lebih lama. Kajian ini mencadangkan satu strategi penyimpanan yang baharu, dinamakan Penyimpanan Lentur Berdasarkan Popularity (*FlexPop*) bagi penyimpanan kandungan popular. FlexPop mengandungi dua mekanisme iaitu Mekanisme Penempatan Kandungan (CPM) yang bertanggungjawab untuk penyimpanan kandungan dan Mekanisme Pengusiran Kandungan (CEM) yang menangani pengusiran kandungan apabila simpanan penghala penuh dan tiada lagi ruang untuk kandungan yang baharu tiba. Kedua-dua mekanisme ini disahkan melalui Teori Set Kabur, mengikut Kaedah Penyelidikan Reka Bentuk (DRM) yang digunakan dalam penyelidikan ini bagi memastikan kerapian kerja serta keboleh-ulangan di bawah keadaan setanding. Prestasi FlexPop dinilai menggunakan simulasi dan kemudiannya dibandingkan dengan keputusan bagi strategi-strategi Tinggalan Salinan Merata (LCE), ProbCache serta strategi Kandungan Paling Popular (MPC). Keputusan kajian menunjukkan bahawa strategi FlexPop melebihi jangkuan strategi LCE, *ProbCache* dan MPC dari segi kadar sasar simpan, kelewahan, kelengahan perolehan semula kandungan, penggunaan memori dan regangan, yang merupakan metrik-metrik penting (dalam kebanyakan kajian) untuk tujuan penilaian penyimpanan ICN. Hasil yang dipamerkan dalam kajian ini adalah penting untuk membolehkan *FlexPop* diterima oleh pengguna kerana dengannya mereka mampu menentusahkan prestasi ICN sebelum memilih strategi penyimpanan yang sesuai. Justeru, *FlexPop* berpotensi dalam penggunaan ICN untuk Internet masa hadapan umpamanya bagi pengerahan teknologi IoT.

Kata kunci: Perangkaian bertumpuan maklumat, Internet masa hadapan, *FlexPop*, Penempatan kandungan, Pengusiran kandungan

Abstract

Information-Centric Networking (ICN) is the dominant architecture for the future Internet. In ICN, the content items are stored temporarily in network nodes such as routers. When the memory of routers becomes full and there is no room for a new arriving content, the stored contents are evicted to cope with the limited cache size of the routers. Therefore, it is crucial to develop an effective caching strategy for keeping popular contents for a longer period of time. This study proposes a new caching strategy, named Flexible Popularity-based Caching (FlexPop) for storing popular contents. The FlexPop comprises two mechanisms, i.e., Content Placement Mechanism (CPM), which is responsible for content caching, and Content Eviction Mechanism (CEM) that deals with content eviction when the router cache is full and there is no space for the new incoming content. Both mechanisms are validated using Fuzzy Set Theory, following the Design Research Methodology (DRM) to manifest that the research is rigorous and repeatable under comparable conditions. The performance of FlexPop is evaluated through simulations and the results are compared with those of the Leave Copy Everywhere (LCE), ProbCache, and Most Popular Content (MPC) strategies. The results show that the FlexPop strategy outperforms LCE, ProbCache, and MPC with respect to cache hit rate, redundancy, content retrieval delay, memory utilization, and stretch ratio, which are regarded as extremely important metrics (in various studies) for the evaluation of ICN caching. The outcomes exhibited in this study are noteworthy in terms of making FlexPop acceptable to users as they can verify the performance of ICN before selecting the right caching strategy. Thus FlexPop has potential in the use of ICN for the future Internet such as in deployment of the IoT technology.

Keywords: Information-centric networking, Future Internet, FlexPop, Content placement, Content eviction

Acknowledgements

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

"*As for those who strive hard in Us (Our Cause), We will surely guide them to Our Paths. And verily Allah is with the good doers.*"

(Al-Quran - 29:69)

I would like to acknowledge those individuals without whose help this thesis could not have been completed by me. First, I thank my supervisors: Prof. Dr. Suhaidi Hassan and Dr. Adib Habbal. Their assistance throughout the research and supervision during the writing were invaluable. Apart from my devotion, their professionalism, daily meetings, and progress inspection were the main reasons of success. Working with them in the field of ICN increased my understanding and improved my intellection. May Allah give them its reward and make them happy and prosperous in the rest of their life. Next, I would like to extend my thanks to the Chairperson of my viva session: Prof. Dr. Zulaikha Jamaluddin, my thesis reviewers: Prof. Dr. Hj. Mazani Manaf and Associate Prof. Dr. Osman Ghazali for their insightful comments and guidance. I would also like to thank my team members: Abdullahi Ibrahim as forever friend and ICN team member, Mohamed Firdhous for helping me in LyX and Latex during thesis writing, and Dr. Cesar Bernardini for guiding throughout the strenuous exercises of SocialCCNSim simulations that will never be forgotten, and the whole group of Inter-NetWorks Research Laboratory for their motivation all along this research. Finally, I would like to thank my parents, brothers, sisters, and my wife for their support and devotion through all the process of researching and writing this thesis.

Dedication

Dedicated to my whole family . . .

List of Abbreviations

AS	-	Autonomous System
CCN	-	Content-Centric Network
CDN	-	Content Delivery Network
CEM	-	Content Eviction Mechanism
CLS	-	Chunk Caching Location and Searching Scheme
COMET	-	Content Mediator Architecture for Content Aware Network
CPM	-	Content Placement Mechanism
CR	-	Content Router
CS	-	Content Store
CT	-	Comparison Table
DHT	-	Distributed Hash Table
DONA	-	Data Oriented Network Architecture
DoS	-	Denial of Service
DRM	-	Design Research Methodology
DS	-	Descriptive Study
FGPC	-	Fine-Grained Popularity-based Caching
FIB	-	Forwarding Information Base
FIFO	-	First-In-First-Out
FlexPop	-	Flexible Popularity-based Caching
ICN	-	Information-Centric Network
IP	-	Internet Protocol
LAN	-	Local Area Network
LCD	-	Leave Copy Down
LCE	-	Leave Copy Everywhere
LFU	-	Least Frequently Used
LNC	-	Linear Network Coding
LRU	-	Least Recently Used
MADM	-	Multiple Attribute Decision Making
MAUT	-	Multiple Attribute Utility Theory

MCD	-	Move Copy Down
MPC	-	Most Popular Content
NAT	-	Network Address Translation
NCCM	-	Network Coding based Cache Management
NDN	-	Named Data Network
NDO	-	Named Data Object
NetInf	-	Network of Information
PIT	-	Pending Interest Table
PS	-	Prescriptive Study
PSIRP	-	Publish-Subscribe Internet Routing Paradigm
PT	-	Popularity Table
PURSUIT	-	Publisher Subscriber Internet Technology
P2P	-	Peer-to-Peer
RC	-	Research Clarification
SAIL	-	Scalable Adaptive Internet Solution
SAW	-	Simple Additive Weighting
TLRU	-	Time Aware Least Recently Used
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
TSB	-	Time Since Birth
TSI	-	Time Since Inception
VoD	-	Video on Demand
WAN	-	Wide Area Network

Table of Contents

List of Tables

List of Figures

CHAPTER ONE
INTRODUCTION

The existing Internet was intended to address the correspondence demands of a period when a communication network was required to share expensive and rare resources, such as long distance communication links, peripherals, and mainframe computers [1]. The main design rules of the Internet made it possible to connect new systems to the Internet and allowed a remarkable development in its size. However, the inspiring growth of the Internet has offered ascend to new requirements from the design, for example, content dissemination, storage resources, quality of service, mobility, security, scalability, and economics [2]. Moreover, due to its particular implementation and end-to-end approach, the current Internet architecture has many limitations. For example, a variety of add-on patches, such as Point-to-Point (P2P) overlays, Content Delivery Networks (CDNs), Mobile IP, and Network Address Translation (NAT), that were not part of the original design, all violate, in different manners, various features of the initial Internet architecture [3].

Furthermore, the initial protocols and Internet architecture were designed expecting a cooperative and acceptable environment, which is far away from practicality, where lack of privacy and security threats, for example, phishing, Denial of Service (DoS) attacks, and malware, have turned out to be progressively predominant [4]. It has been recently perceived that information-centric usage of the Internet has gained popularity as revealed by the majority being associated with it [5]. This usage brings up a range of design challenges, several of which were not successfully handled by the existing architecture [6]. These challenges include information scarcity, security and liability through controlled information distribution, tussle mediation through information governance, and medium-independent information access.

The contents of the thesis is for internal user only

REFERENCES

[1] G. Xylomenos, C. N. Ververidis, V. Siris, N. Fotiou, C. Tsilopoulos, X. Vasilakos, K. V. Katsaros, G. C. Polyzos *et al.*, "A survey of Information Centric Networking research," *Communications Surveys & Tutorials, IEEE*, vol. 16, no. 2, pp. 1024–1049, 2014.

[2] A. Feldmann, "Internet clean-slate design: What and why?" *ACM SIGCOMM Computer Communication Review*, vol. 37, no. 3, pp. 59–64, 2007.

[3] M. Handley, "Why the Internet only just works," *BT Technology Journal*, vol. 24, no. 3, pp. 119–129, 2006. [Online]. Available: http://www0.cs.ucl.ac.uk/staff/M.Handley/papers/only-just-works.pdf

[4] N. Fotiou, "Information-Centric Networking: Security requirements and solutions," Ph.D. dissertation, School of Information Sciences and Technology, Department of Computer Science, Ahens University of Economics and Business, 2014. [Online]. Available: http://phdtheses.ekt.gr/eadd/handle/10442/34673

[5] V. Jacobson, "A new way to look at networking," *Google Tech Talk*, vol. 30, 2006. [Online]. Available: https://github.com/dominictarr/cyphernet/issues/15

[6] D. Trossen, M. Sarela, and K. Sollins, "Arguments for an Information Centric Networking architecture," *ACM SIGCOMM Computer Communication Review*, vol. 40, no. 2, pp. 26–33, 2010.

[7] J. Rexford and C. Dovrolis, "Future Internet architecture: Clean-slate versus evolutionary research," *Communications of the ACM*, vol. 53, no. 9, pp. 36–40, 2010.

[8] Information-Centric Networking Research Group (ICNRG). [Online]. Available: http://trac.tools.ietf.org/group/irtf/trac/wiki/icnrg

[9] S. Carew, "Users complain, AT&T blames data tsunami," *Reuters Media File*, 2012. [Online]. Available: http://blogs.reuters.com/mediafile/2012/02/14/users-complain-att-blames-data-tsunami/

[10] V. Sourlas, "Replication Management and Cache Aware Routing in Information-Centric Networking," Ph.D. dissertation, Electrical & Computer Engineering, University of Thessaly, Greece, 2013.

[11] Cisco Visual Networking index: Forecast and methodology: 2013-2018, Tech. Rep., June, 2014. [Online]. Available: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html

[12] Visual-Capitalist. What happens in an Internet minute in 2016. [Online]. Available: http://www.visualcapitalist.com/what-happens-internet-minute-2016/

[13] Intel. What happens in an Internet minute. [Online]. Available: http://www.intel.com/content/www/us/en/communications/internet-minute-infographic.html

[14] Internet Live Stats: Accessd: June 1, 2015, Tech. Rep. [Online]. Available: http://www.internetlivestats.com/

[15] K. Pentikousis, B. Ohlman, D. Corujo, G. Boggia, G. Tyson, E. Davies, A. Molinaro, and S. Eum, "Information-Centric Networking: Baseline scenarios," Tech. Rep., 2015. [Online]. Available: http://www.rfc-editor.org/info/rfc7476

[16] J. Seedorf, M. Arumaithurai, A. Tagami, K. Ramakrishnan, and N. Blefari-Melazzi, "Using ICN in disaster scenarios," Internet-Draft-work in progress 02, IETF, Tech. Rep., 2014.

[17] B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher, and B. Ohlman, "A survey of Information-Centric Networking," *Communications Magazine, IEEE*, vol. 50, no. 7, pp. 26–36, 2012.

[18] T. Koponen, M. Chawla, B.-G. Chun, A. Ermolinskiy, K. H. Kim, S. Shenker, and I. Stoica, "A data-oriented (and beyond) network architecture," *ACM SIGCOMM Computer Communication Review*, vol. 37, no. 4, pp. 181–192, 2007.

[19] NSF Named Data Networking project. [Online]. Available: www.named-data.org/

[20] NSF Mobility First project. [Online]. Available: http://mobilityfirst.winlab.rutgers.edu/

[21] CCN Project. [Online]. Available: http://www.ccnx.org/

[22] P. Jokela, A. Zahemszky, C. Esteve Rothenberg, S. Arianfar, and P. Nikander, "LIPSIN: Line speed publish/subscribe inter-networking," in *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 4. ACM, 2009, pp. 195–206.

[23] B. Ahlgren, M. D'Ambrosio, C. Dannewitz, A. Eriksson, J. Golic, B. Gronvall, D. Horne, A. Lindgren, O. Mammela, M. Marchisio *et al.*, "Second NetInf architecture description," 4ward eu fp7 project, deliverable d-6.2 v2. 0, apr. 2010, fp7-ict-2007-1-216041-4ward/d-6.2." [Online]. Available: http://www.4ward-project.eu/index.php?id=192

[24] B. Ahlgren, M. D'Ambrosio, M. Marchisio, I. Marsh, C. Dannewitz, B. Ohlman, K. Pentikousis, O. Strandberg, R. Rembarz, and V. Vercellone, "Design considerations for a network of information," in *Proceedings of the 2008 ACM CoNEXT Conference*. ACM, 2008, p. 66.

[25] FP7 Publish-Subscribe Internet Technology: PURSUIT project. [Online]. Available: http://www.fp7-pursuit.eu/PursuitWeb/

[26] FP7 CONVERGENCE project. [Online]. Available: http://www.ictconvergence.eu/

[27] FP7 Scalable and Adaptive Internet Solutions: SAIL project. [Online]. Available: http://www.sail-project.eu/

[28] FP7 COntent Mediator architecture for content-aware nETworks: COMET project. [Online]. Available: http://www.comet-project.org/

[29] B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher, and B. Ohlman, "A survey of information-centric networking (draft)," in *Dagstuhl Seminar Proceedings*. Schloss Dagstuhl-Leibniz-Zentrum fÃ1/4r Informatik, 2011.

[30] 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*. ACM, 2009, pp. 1–12.

[31] C. Fang, F. R. Yu, T. Huang, J. Liu, and Y. Liu, "A survey of energy-efficient caching in Information-Centric Networking," *Communications Magazine, IEEE*, vol. 52, no. 11, pp. 122–129, 2014.

[32] N. Laoutaris, H. Che, and I. Stavrakakis, "The LCD interconnection of LRU caches and its analysis," *Performance Evaluation*, vol. 63, no. 7, pp. 609–634, 2006.

[33] C. Bernardini, T. Silverston, and O. Festor, "MPC: Popularity-based caching strategy for Content Centric Networks," in *Communications (ICC), 2013 IEEE International Conference on*. IEEE, 2013, pp. 3619–3623.

[34] 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*. ACM, 2012, pp. 15–26.

[35] K. Thar, T. Z. Oo, C. Pham, S. Ullah, D. H. Lee, and C. S. Hong, "Efficient forwarding and popularity based caching for Content Centric Network," in *Information Networking (ICOIN), 2015 International Conference on*. IEEE, 2015, pp. 330–335.

[36] 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*. IEEE, 2014, pp. 166–171.

[37] H. Li, H. Nakazato, A. Detti, and N. B. Melazzi, "Popularity proportional cache size allocation policy for video delivery on CCN," in *Networks and Communications (EuCNC), 2015 European Conference on*. IEEE, 2015, pp. 434–438.

[38] K. Lei, J. Wang, and J. Yuan, "An entropy-based probabilistic forwarding strategy in Named Data Networking," in *Communications (ICC), 2015 IEEE International Conference on*. IEEE, 2015, pp. 5665–5671.

[39] J. Garcia-Reinoso, I. Vidal, D. Diez, D. Corujo, and R. L. Aguiar, "Analysis and enhancements to probabilistic caching in Content-Centric Networking," *The Computer Journal*, p. bxv010, 2015.

[40] H. Wu, J. Li, and J. Zhi, "MBP: A max-benefit probability-based caching strategy in Information Centric Networking," in *Communications (ICC), 2015 IEEE International Conference on*. IEEE, 2015, pp. 5646–5651.

[41] I. Psaras, W. K. Chai, and G. Pavlou, "Probabilistic in-network caching for Information-Centric Networks," in *Proceedings of the second edition of the ICN workshop on Information-centric networking*. ACM, 2012, pp. 55–60.

[42] Y. Xu, Z. Wang, Y. Li, T. Lin, W. An, and S. Ci, "Minimizing bandwidth cost of CCN: A coordinated in-network caching approach," in *Computer Communication and Networks (ICCCN), 2015 24th International Conference on*. IEEE, 2015, pp. 1–7.

[43] Y. Xu, Z. Wang, Y. Li, F. Chen, T. Lin, and W. Niu, "Request routing through collaborative in-network caching for bandwidth optimization: A methodology," *Transactions on Emerging Telecommunications Technologies*, 2015.

[44] D. Perino, M. Varvello, and K. P. Puttaswamy, "ICN-RE: Redundancy elimination for Information-Centric Networking," in *Proceedings of the second edition of the ICN workshop on Information-Centric Networking*. ACM, 2012, pp. 91–96.

[45] M. Rezazad and Y. Tay, "CCNDNS: A strategy for spreading content and decoupling NDN caches," *IFIP Networking, Toulouse, France May*, pp. 20–22, 2015.

[46] X. Zhang, N. Wang, V. G. Vassilakis, and M. P. Howarth, "A distributed in-network caching scheme for P2P-like content chunk delivery," *Computer Networks*, vol. 91, pp. 577–592, 2015.

[47] V. Sourlas, P. Georgatsos, P. Flegkas, and L. Tassiulas, "Partition-based caching in Information Centric Networks," in *Computer Communications Workshops (INFOCOM WKSHPS), 2015 IEEE Conference on*. IEEE, 2015, pp. 396–401.

[48] G. Ma, Z. Chen, and K. Zhao, "A cache management strategy for content store in Content Centric Network," in *Networking and Distributed Computing (ICNDC), 2013 Fourth International Conference on*. IEEE, 2013, pp. 94–99.

[49] L. Wang, S. Bayhan, and J. Kangasharju, "Optimal chunking and partial caching in Information Centric Networks," *Computer Communications*, vol. 61, pp. 48–57, 2015.

[50] D. Kim, S.-W. Lee, Y.-B. Ko, and J.-H. Kim, "Cache capacity-aware content centric networking under flash crowds," *Journal of Network and Computer Applications*, vol. 50, pp. 101–113, 2015.

[51] S. Saha, A. Lukyanenko, and A. Ylä-Jääski, "Efficient cache availability management in Information-Centric Networks," *Computer Networks*, vol. 84, pp. 32–45, 2015.

[52] M. Mangili, F. Martignon, and S. Paraboschi, "A cache-aware mechanism to enforce confidentiality, trackability and access policy evolution in Content-Centric Networks," *Computer Networks*, vol. 76, pp. 126–145, 2015.

[53] B. Azimdoost, G. Farhadi, N. Abani, and A. Ito, "Optimal in-network cache allocation and content placement," in *Computer Communications Workshops (INFOCOM WKSHPS), 2015 IEEE Conference on*. IEEE, 2015, pp. 263–268.

[54] C. Miao, H. Zhang, H. Zhou, P. Dong, and S. Shen, "Super node routing strategy in Content-Centric Networking," *Transactions of Tianjin University*, vol. 21, pp. 122–128, 2015.

[55] H. Salah and T. Strufe, "CoMon: An architecture for coordinated caching and cache-aware routing in CCN," in *Consumer Communications and Networking Conference (CCNC), 2015 12th Annual IEEE*. IEEE, 2015, pp. 663–670.

[56] H. Wu, J. Li, and J. Zhi, "Could end system caching and cooperation replace in-network caching in CCN?" in *Proceedings of the 2015 ACM Conference on Special Interest Group on Data Communication*. ACM, 2015, pp. 101–102.

[57] J. M. Batalla, A. Beben, and Y. Chen, "Optimized decision algorithm for Information Centric Networks," *Telecommunication Systems*, pp. 1–9, 2015.

[58] C. Bernardini, "Strategies de cache basees sur la popularite pour Content Centric Networking," Ph.D. dissertation, Universite de Lorraine, France, 2015. [Online]. Available: http://www.theses.fr/2015LORR0121

[59] D. Perino and M. Varvello, "A reality check for content centric networking," in *Proceedings of the ACM SIGCOMM workshop on Information-centric networking*. ACM, 2011, pp. 44–49.

[60] G. Rossini, D. Rossi, M. Garetto, and E. Leonardi, "Multi-terabyte and multi-gbps information centric routers," in *IEEE INFOCOM 2014-IEEE Conference on Computer Communications*. IEEE, 2014, pp. 181–189.

[61] S. Arianfar, P. Nikander, and J. Ott, "Packet-level caching for information-centric networking," in *ACM SIGCOMM, ReArch Workshop*, 2010.

[62] J. Hourcade, R. Saracco, I. Wahlster, and R. Posch, "Future Internet 2020: Visions of an industry expert group," *European Commission Information Society and Media*, vol. 5, 2009. [Online]. Available: http://www.future-internet.eu/fileadmin/documents/reports/FI_Panel_Report_v3.1_Final.pdf

[63] M. Zhang, H. Luo, and H. Zhang, "A survey of caching mechanisms in Information-Centric Networking." [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=7080842

[64] The CCNx protocol. [Online]. Available: http://www.ccnx.org/

[65] W. Wong, M. Giraldi, M. F. Magalhães, and J. Kangasharju, "Content routers: Fetching data on network path," in *Communications (ICC), 2011 IEEE International Conference on*. IEEE, 2011, pp. 1–6.

[66] D. Kutscher, S. Eum, K. Pentikousis, I. Psaras, D. Corujo, D. Saucez, T. Schmidt, and M. Waehlisch, "ICN research challenges," *Work in progress*, 2015. [Online]. Available: https://tools.ietf.org/html/draft-irtf-icnrg-challenges-03

[67] M. Draxler and H. Karl, "Efficiency of on-path and off-path caching strategies in information centric networks," in *Green Computing and Communications (GreenCom), 2012 IEEE International Conference on*. IEEE, 2012, pp. 581–587.

[68] X. Tang and S. T. Chanson, "Coordinated en-route web caching," *Computers, IEEE Transactions on*, vol. 51, no. 6, pp. 595–607, 2002.

[69] H. Shen and S. Xu, "Coordinated en-route web caching in multiserver networks," *Computers, IEEE Transactions on*, vol. 58, no. 5, pp. 605–619, 2009.

[70] M. R. Korupolu and M. Dahlin, "Coordinated placement and replacement for large-scale distributed caches," *Knowledge and Data Engineering, IEEE Transactions on*, vol. 14, no. 6, pp. 1317–1329, 2002.

[71] L. Fan, P. Cao, J. Almeida, and A. Z. Broder, "Summary cache: A scalable wide-area web cache sharing protocol," *IEEE/ACM Transactions on Networking (TON)*, vol. 8, no. 3, pp. 281–293, 2000.

[72] G. M. Voelker, E. J. Anderson, T. Kimbrel, M. J. Feeley, J. S. Chase, A. R. Karlin, and H. M. Levy, "Implementing cooperative prefetching and caching in a globally-managed memory system," in *ACM SIGMETRICS Performance Evaluation Review*, vol. 26, no. 1. ACM, 1998, pp. 33–43.

[73] B.-G. Chun, K. Chaudhuri, H. Wee, M. Barreno, C. H. Papadimitriou, and J. Kubiatowicz, "Selfish caching in distributed systems: a game-theoretic analysis," in *Proceedings of the twenty-third annual ACM symposium on Principles of distributed computing*. ACM, 2004, pp. 21–30.

[74] N. Laoutaris, O. Telelis, V. Zissimopoulos, and I. Stavrakakis, "Distributed selfish replication," *Parallel and Distributed Systems, IEEE Transactions on*, vol. 17, no. 12, pp. 1401–1413, 2006.

[75] M. Rabinovich, J. Chase, and S. Gadde, "Not all hits are created equal: Cooperative proxy caching over a wide-area network," *Computer Networks and ISDN Systems*, vol. 30, no. 22, pp. 2253–2259, 1998.

[76] V. Pacifici and G. Dan, "Content-peering dynamics of autonomous caches in a Content-centric Network," in *INFOCOM, 2013 Proceedings IEEE*. IEEE, 2013, pp. 1079–1087.

[77] ——, "Selfish content replication on graphs," in *Proceedings of the 23rd International Teletraffic Congress*. International Teletraffic Congress, 2011, pp. 119–126.

[78] G. Dan, "Cache-to-cache: Could ISPs cooperate to decrease peer-to-peer content distribution costs?" *Parallel and Distributed Systems, IEEE Transactions on*, vol. 22, no. 9, pp. 1469–1482, 2011.

[79] G. Rossini and D. Rossi, "Coupling caching and forwarding: Benefits, analysis, and implementation," in *Proceedings of the 1st international conference on Information-centric networking*. ACM, 2014, pp. 127–136.

[80] D. Applegate, A. Archer, V. Gopalakrishnan, S. Lee, and K. K. Ramakrishnan, "Optimal content placement for a large-scale VoD system," in *Proceedings of the 6th International Conference*. ACM, 2010, p. 4.

[81] J. Garcia-Luna-Aceves, A. Dabirmoghaddam, and M. Mirzazad-Barijoug, "Understanding optimal caching and opportunistic caching at" the edge" of Information-Centric Networks," in *Proceedings of the 1st international conference on Information-centric networking*, 2014.

[82] J. Dai, Z. Hu, B. Li, J. Liu, and B. Li, "Collaborative hierarchical caching with dynamic request routing for massive content distribution," in *INFOCOM, 2012 Proceedings IEEE*. IEEE, 2012, pp. 2444–2452.

[83] D. Corujo, R. L. Aguiar, I. Vidal, J. Garcia-Reinoso, and K. Pentikousis, "Research challenges towards a managed Information-Centric Network of Things," in *Networks and Communications (EuCNC), 2014 European Conference on*. IEEE, 2014, pp. 1–5.

[84] D. Karger, E. Lehman, T. Leighton, R. Panigrahy, M. Levine, and D. Lewin, "Consistent hashing and random trees: Distributed caching protocols for relieving hot spots on the world wide web," in *Proceedings of the twenty-ninth annual ACM symposium on Theory of computing*. ACM, 1997, pp. 654–663.

[85] G. Barish and K. Obraczke, "World wide web caching: Trends and techniques," *IEEE Communications magazine*, vol. 38, no. 5, pp. 178–184, 2000.

[86] A. Rowstron and P. Druschel, "Storage management and caching in past, a large-scale, persistent peer-to-peer storage utility," in *ACM SIGOPS Operating Systems Review*, vol. 35, no. 5. ACM, 2001, pp. 188–201.

[87] C. Williamson, "On filter effects in web caching hierarchies," *ACM Transactions on Internet Technology (TOIT)*, vol. 2, no. 1, pp. 47–77, 2002.

[88] M. Rabinovich and O. Spatscheck, *Web caching and replication*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2002. [Online]. Available: http://www.amazon.com/Web-Caching-Replication-Michael-Rabinovich/dp/0201615703

[89] C. Kumar and J. B. Norris, "A new approach for a proxy-level web caching mechanism," *Decision Support Systems*, vol. 46, no. 1, pp. 52–60, 2008.

[90] B. Ager, F. Schneider, J. Kim, and A. Feldmann, "Revisiting cacheability in times of user generated content," in *INFOCOM IEEE Conference on Computer Communications Workshops, 2010*. IEEE, 2010, pp. 1–6.

[91] 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," *Relatório Técnico NDN-0001, Xerox Palo Alto Research Center-PARC*, 2010.

[92] A. Dabirmoghaddam, M. M. Barijough, and J. Garcia-Luna-Aceves, "Understanding optimal caching and opportunistic caching at the edge of information-centric networks," in *Proceedings of the 1st international conference on Information-centric networking*. ACM, 2014, pp. 47–56.

[93] H. Jeon, B. Lee, and H. Song, "On-path caching in Information-Centric Networking," in *Advanced Communication Technology (ICACT), 2013 15th International Conference on*. IEEE, 2013, pp. 264–267.

[94] G. Xylomenos, X. Vasilakos, C. Tsilopoulos, V. A. Siris, and G. C. Polyzos, "Caching and mobility support in a publish-subscribe internet architecture," *Communications Magazine, IEEE*, vol. 50, no. 7, pp. 52–58, 2012.

[95] 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*. IEEE, 2013, pp. 1–10.

[96] 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*. ACM, 2013, pp. 27–32.

[97] Z. Li and G. Simon, "Time-shifted tv in content centric networks: The case for cooperative in-network caching," in *Communications (ICC), 2011 IEEE International Conference on*. IEEE, 2011, pp. 1–6.

[98] H. Che, Y. Tung, and Z. Wang, "Hierarchical web caching systems: Modeling, design and experimental results," *Selected Areas in Communications, IEEE Journal on*, vol. 20, no. 7, pp. 1305–1314, 2002.

[99] The Binomial Distribution. [Online]. Available: http://www.hamilton.ie/ollie/EE304/Binom.pdf

[100] L. Ramaswamy and L. Liu, "An expiration age-based document placement scheme for cooperative web caching," *Knowledge and Data Engineering, IEEE Transactions on*, vol. 16, no. 5, pp. 585–600, 2004.

[101] E. J. Rosensweig and J. Kurose, "Breadcrumbs: Efficient, best-effort content location in cache networks," in *INFOCOM 2009, IEEE*. IEEE, 2009, pp. 2631–2635.

[102] Y. Li, T. Lin, H. Tang, and P. Sun, "A chunk caching location and searching scheme in Content Centric Networking," in *Communications (ICC), 2012 IEEE International Conference on*. IEEE, 2012, pp. 2655–2659.

[103] G. Zhang, B. Tang, X. Wang, and Y. Wu, "An optimal cache placement strategy based on content popularity in Content Centric Network," *Journal of Information & Computational Science*, vol. 11, no. 8, pp. 2759–2769, 2014.

[104] S. Eum, K. Nakauchi, Y. Shoji, and N. Nishinaga, "CATT: Cache aware target identification for ICN," *Communications Magazine, IEEE*, vol. 50, no. 12, pp. 60–67, 2012.

[105] S. Eum, K. Nakauchi, M. Murata, Y. Shoji, and N. Nishinaga, "CATT: Potential based routing with content caching for ICN," in *Proceedings of the 2nd ACM SIGCOMM workshop on Information-centric networking*. ACM, 2012, pp. 49–54.

[106] W. K. Chai, D. He, I. Psaras, and G. Pavlou, "Cache less for more in Information-Centric Networks (Extended Version)," *Computer Communications*, vol. 36, no. 7, pp. 758–770, 2013.

[107] J. Sung, J.-K. K. Rhee, and S. Jung, "Lightweight caching strategy for wireless content delivery networks," *IEICE Communications Express*, vol. 3, no. 4, pp. 150–155, 2014.

[108] J. Wang, J. Ren, K. Lu, J. Wang, S. Liu, and C. Westphal, "An optimal cache management framework for Information Centric Networks with network coding," in *Networking Conference, 2014 IFIP*. IEEE, 2014, pp. 1–9.

[109] M. Bilal and S.-G. Kang, "Time Aware Least Recent Used (TLRU) cache management policy in ICN," in *Advanced Communication Technology (ICACT), 2014 16th International Conference on*. IEEE, 2014, pp. 528–532.

[110] K. Cho, M. Lee, K. Park, T. T. Kwon, Y. Choi, and S. Pack, "WAVE: Popularity-based and collaborative in-network caching for Content-oriented Networks," in *Computer Communications Workshops (INFOCOM WKSHPS), 2012 IEEE Conference on*. IEEE, 2012, pp. 316–321.

[111] Z. Ming, M. Xu, and D. Wang, "Age-based cooperative caching in Information-Centric Networking," in *Computer Communication and Networks (ICCCN), 2014 23rd International Conference on*. IEEE, 2014, pp. 1–8.

[112] X. Hu and J. Gong, "Distributed in-network cooperative caching," in *Cloud Computing and Intelligent Systems (CCIS), 2012 IEEE 2nd International Conference on*, vol. 2. IEEE, 2012, pp. 735–740.

[113] W. Tianming, C. Le, Y. Boyang, and P. Jianping, "MPCS: A mobility/popularity-based caching strategy for Information Centric Networks," in *Global Communications Conference (GLOBECOM), 2014 IEEE Conference on*. IEEE, 2014, pp. 4629–2634.

[114] M. Ong, M. Chen, T. Taleb, X. Wang, and V. Leung, "FGPC: Fine-grained popularity-based caching design for Content Centric Networking," in *Proceedings of the 17th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems*. ACM, 2014, pp. 295–302.

[115] G. Carofiglio, M. Gallo, L. Muscariello, and D. Perino, "Modeling data transfer in Content-Centric Networking," in *Proceedings of the 23rd international teletraffic congress*. International Teletraffic Congress, 2011, pp. 111–118.

[116] I. Psaras, R. G. Clegg, R. Landa, W. K. Chai, and G. Pavlou, "Modelling and evaluation of CCN-caching trees," in *NETWORKING 2011*. Springer, 2011, pp. 78–91.

[117] L. Muscariello, G. Carofiglio, and M. Gallo, "Bandwidth and storage sharing performance in Information Centric Networking," in *Proceedings of the ACM SIGCOMM workshop on Information-centric networking*. ACM, 2011, pp. 26–31.

[118] G. Carofiglio, V. Gehlen, and D. Perino, "Experimental evaluation of memory management in Content-Centric Networking," in *Communications (ICC), 2011 IEEE International Conference on*. IEEE, 2011, pp. 1–6.

[119] 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, no. 4. ACM, 2013, pp. 147–158.

[120] Y. Thomas and G. Xylomenos, "Towards improving the efficiency of ICN packet-caches," in *Heterogeneous Networking for Quality, Reliability, Security and Robustness (QShine), 2014 10th International Conference on*. IEEE, 2014, pp. 186–187.

[121] A. Gharaibeh, A. Khreishah, I. Khalil, and J. Wu, "Asymptotically-optimal incentive-based en-route caching scheme," *arXiv preprint arXiv*, vol. 1404, 2014. [Online]. Available: http://arxiv.org/pdf/1404.4639.pdf

[122] J. M. Wang, J. Zhang, and B. Bensaou, "Intra-AS cooperative caching for Content-Centric Networks," in *Proceedings of the 3rd ACM SIGCOMM workshop on Information-centric networking*. ACM, 2013, pp. 61–66.

[123] 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*. ACM, 2014, pp. 37–46.

[124] W.-X. Liu, S.-Z. Yu, Y. Gao, and W.-T. Wu, "Caching efficiency of Information-Centric Networking," *IET networks*, vol. 2, no. 2, pp. 53–62, 2013.

[125] T.-M. Pham, M. Minoux, S. Fdida, M. Pilarski *et al.*, "Optimization of content caching in Content-Centric Network," 2014. [Online]. Available: http://hal.upmc.fr/hal-01016470/file/caching_Paper_ICN_Final.pdf

[126] N. B. Melazzi, A. Detti, M. Arumaithurai, and K. Ramakrishnan, "Internames: A name-to-name principle for the Future Internet," in *Heterogeneous Networking for Quality, Reliability, Security and Robustness (QShine), 2014 10th International Conference on*. IEEE, 2014, pp. 146–151.

[127] 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*. ACM, 2011, pp. 112–115.

[128] L. Zhang, J. Zhao, and Z. Shi, "LF: A caching strategy for named data mobile ad hoc networks," in *Proceedings of the 4th International Conference on Computer Engineering and Networks*. Springer, 2015, pp. 279–290.

[129] V. G. Vassilakis, M. F. Al-Naday, M. J. Reed, B. Alzahrani, K. Yang, I. D. Moscholios, M. D. Logothetis *et al.*, "A cache-aware routing scheme for Information Centric Networks," in *Communication Systems, Networks & Digital Signal Processing (CSNDSP), 2014 9th International Symposium on*. IEEE, 2014, pp. 721–726.

[130] J. Garcia-Luna-Aceves, "A fault-tolerant forwarding strategy for interest-based information centric networks," in *IFIP Networking Conference (IFIP Networking), 2015*. IEEE, 2015, pp. 1–9.

[131] Y. Li, H. Xie, Y. Wen, C.-Y. Chow, and Z.-L. Zhang, "How much to coordinate? optimizing in-network caching in Content-Centric Networks," *Network and Service Management, IEEE Transactions on*, vol. 12, no. 3, pp. 420–434, 2015.

[132] L. T. Blessing and A. Chakrabarti, *DRM, a Design Research Methodology*. Springer, 2009. [Online]. Available: http://www.springer.com/us/book/9781848825864

[133] A. Habbal, "TCP-Sintok: Transmission Control Protocol with loss detection and contention avoidance mechanisms for ad hoc networks," Ph.D. dissertation, School of Computing, Universiti Utara Malaysia, 2014. [Online]. Available: http://etd.uum.edu.my/4442/13/s92256_abstract.pdf

[134] Methodology for Computer Science. [Online]. Available: http://www.uio.no/studier/emner/matnat/ifi/INF9970/h09/undervisningsmateriale/ResearchMethods-CS.pdf

[135] S.-J. Chen and C.-L. Hwang, *Fuzzy multiple attribute decision making methods*. Springer, 1992. [Online]. Available: http://link.springer.com/book/10.1007%2F978-3-642-46768-4

[136] P. TalebiFard and V. C. Leung, "A data fusion approach to context-aware service delivery in heterogeneous network environments," *Procedia Computer Science*, vol. 5, pp. 312–319, 2011.

[137] P. Talebi Fard, "An Information Centric Networking approach to context-aware dissemination of services and information," Ph.D. dissertation, University of British Columbia, 2014. [Online]. Available: https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0167484

[138] M. Guizani, A. Rayes, B. Khan, and A. Al-Fuqaha, *Network modeling and simulation: A practical perspective*. John Wiley & Sons, 2010. [Online]. Available: http://as.wiley.com/WileyCDA/WileyTitle/productCd-0470035870.html

[139] *IEEE Standards Board, IEEE recommended practice for distributed interactive simulation 2013: Verification, validation, and accreditation*, IEEE Standard 1278.4-1997, January 2010. [Online]. Available: https://standards.ieee.org/findstds/standard/1730.1-2013.html

[140] D. Thomas, A. Joiner, W. Lin, M. Lowry, and T. Pressburger, "The unique aspects of simulation verification and validation," in *Aerospace Conference, 2010 IEEE*. IEEE, 2010, pp. 1–7. [Online]. Available: http://ti.arc.nasa.gov/m/profile/ttp/ieee_aero_2010.pdf

[141] R. G. Sargent, "Validation and verification of simulation models," in *Simulation Conference, 2004. Proceedings of the 2004 Winter*, vol. 1. IEEE, 2004. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5679166&tag=1

[142] C. Bernardini. SocialCCNSim. [Online]. Available: https://github.com/mesarpe/socialccnsim

[143] OPNET Modeler. [Online]. Available: http://www.riverbed.com/my/products/steelcentral/opnet.html?redirect=opnet

[144] R. Jain, "The art of computer system performance analysis: Techniques for experimental design, measurement, simulation and modeling," *New York: John Willey*, 1991. [Online]. Available: http://as.wiley.com/WileyCDA/WileyTitle/productCd-0471503363.html

[145] S. Hassan, "Simulation-based performance evaluation of TCP-friendly protocols for supporting multimedia applications in the Internet," Ph.D. dissertation, University of Leeds (School of Computing), 2002. [Online]. Available: http://myto.upm.edu.my/myTO/myto/15/paparthesis/161367.html

[146] O. M. Al-Momani, "Dynamic redundancy forward error correction mechanism for the enhancement of Internet-based video streaming," Ph.D. dissertation, School of Computing, Universiti Utara Malaysia, 2010. [Online]. Available: http://etd.uum.edu.my/2523/

[147] O. Ghazali, "Scalable and smooth TCP-friendly receiver-based layered multicast protocol," Ph.D. dissertation, School of Computing, Universiti Utara Malaysia, 2008. [Online]. Available: http://etd.uum.edu.my/1291/2/Osman_Ghazali.pdf

[148] C. Williamson, "Internet traffic measurement," *Internet Computing, IEEE*, vol. 5, no. 6, pp. 70–74, 2001.

[149] B. L. Ong, "A hybrid mechanism for SIP over IPv6 macromobility and micromobility management protocols," Ph.D. dissertation, School of Computing, Universiti Utara Malaysia, 2008. [Online]. Available: http://etd.uum.edu.my/1256/

[150] The Network Simulator - ns-2. [Online]. Available: http://www.isi.edu/nsnam/ns/

[151] A discrete-event network simulator - ns-3. [Online]. Available: https://www.nsnam.org/

[152] J. Jaseem, "Performance comparison between ad hoc on demand distance vector and dynamic source routing protocols with security encryption using OPNET," 2012. [Online]. Available: http://scholarworks.rit.edu/cgi/viewcontent.cgi?article=1609&context=theses

[153] CCNx Simulator. [Online]. Available: http://www.ccnx.org/

[154] CCNPLS. CCN Packet Level Simulator. [Online]. Available: https://code.google.com/p/ccnpl-sim/

[155] R. Chiocchetti, D. Rossi, and G. Rossini, "ccnSim: An highly scalable CCN simulator," in *Communications (ICC), 2013 IEEE International Conference on*. IEEE, 2013, pp. 2309–2314.

[156] A. Afanasyev, I. Moiseenko, L. Zhang *et al.*, "ndnSIM: NDN simulator for NS-3," *University of California, Los Angeles, Tech. Rep*, 2012. [Online]. Available: http://named-data.net/wp-content/uploads/TRndnsim.pdf

[157] ICN Simulator: A Simulator based on the Blackadder paltform. [Online]. Available: http://privatewww.essex.ac.uk/~nvasta/ICNSim.htm

[158] A. Varga and R. Hornig, "An overview of the OMNeT++ simulation environment," in *Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2008, p. 60.

[159] 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*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2014, pp. 66–75.

[160] T. R. Henderson, S. Roy, S. Floyd, and G. F. Riley, "ns-3 project goals," in *Proceeding from the 2006 workshop on ns-2: the IP network simulator*. ACM, 2006, p. 13.

[161] PAL Project. [Online]. Available: http://palproject.org.uk/

[162] C. Bernardini, T. Silverston, and O. Festor, "SONETOR: A social network traffic generator," in *Communications (ICC), 2014 IEEE International Conference on*. IEEE, 2014, pp. 3734–3739.

[163] J. Ren, W. Qi, C. Westphal, J. Wang, K. Lu, S. Liu, and S. Wang, "MAGIC: A distributed MAx-Gain In-network Caching strategy in information-centric networks," in *Computer Communications Workshops (INFOCOM WKSHPS), 2014 IEEE Conference on*. IEEE, 2014, pp. 470–475.

[164] W. K. Chai, D. He, I. Psaras, and G. Pavlou, "Cache less for more in Information-Centric Networks," in *Volume 7289 of the series Lecture Notes in Computer Science (NETWORKING 2012)*. Springer, 2012, pp. 27–40. [Online]. Available: http://link.springer.com/chapter/10.1007/978-3-642-30045-5_3

[165] J. Leskovec and A. Krevl, "SNAP Datasets: Stanford large network dataset collection," Jun. 2014. [Online]. Available: http://snap.stanford.edu/data

[166] J. Leskovec and J. J. Mcauley, "Learning to discover social circles in ego networks," in *Advances in neural information processing systems*, 2012, pp. 539–547. [Online]. Available: http://cs.stanford.edu/people/jure/pubs/circles-nips12.pdf

[167] Stanford Network Analysis Project (SNAP). [Online]. Available: http://snap.stanford.edu/data/egonets-Facebook.html

[168] LastFM: A UK-based music website found in 2002. [Online]. Available: http://www.last.fm/

[169] I. Cantador, P. Brusilovsky, and T. Kuflik, "Second workshop on information heterogeneity and fusion in recommender systems (hetrec2011)." in *RecSys*, 2011, pp. 387–388. [Online]. Available: http://ir.ii.uam.es/reshet/pub/recsys11d.pdf

[170] J. Guo, W. Xiang, and S. Wang, "Reinforce networking theory with OPNET simulation," *Journal of Information Technology Education: Research*, vol. 6, no. 1, pp. 215–226, 2007.

[171] A. C. Onwutalobi, "TCP congestion control," Department of Computer Science, University of Helsinki, Tech. Rep., 2005. [Online]. Available: https://www.academia.edu/18593436/TCP_Congestion_Control

[172] M. Hassan and R. Jain, *High performance TCP/IP networking*. Prentice Hall, 2003. [Online]. Available: https://www.cse.wustl.edu/~jain/books/ftp/tcp_fm.pdf

[173] I. Ud, Din, S. Hassan, and A. Habbal, "SocialCCNSim: A simulator for caching strategies in Information Centric Networking," *Advanced Science Letters*, vol. 21, no. 11, pp. 3507–3511, 2015.

[174] D. Rossi and G. Rossini, "Caching performance of Content Centric Networks under multi-path routing (and more)," *Relatório técnico, Telecom ParisTech*, 2011. [Online]. Available: http://netlab.pkusz.edu.cn/wordpress/wp-content/uploads/2011/10/

[175] C. Fricker, P. Robert, J. Roberts, and N. Sbihi, "Impact of traffic mix on caching performance in a Content-Centric Network," in *Computer Communications Workshops (INFOCOM WKSHPS), 2012 IEEE Conference on*. IEEE, 2012, pp. 310–315.

[176] C. Dannewitz, "Netinf: An Information-Centric design for the Future Internet," in *Proc. 3rd GI/ITG KuVS Workshop on The Future Internet*, 2009. [Online]. Available: http://www-old.cs.uni-paderborn.de/fileadmin/Informatik/AG-Karl/Publications/KuVS-NetInf-Dannewitz.pdf

[177] W. K. Wong, L. Wang, and J. Kangasharju, "Neighborhood search and admission control in cooperative caching networks," in *Global Communications Conference (GLOBECOM), 2012 IEEE*. IEEE, 2012, pp. 2852–2858.

[178] L. Wang, S. Bayhan, and J. Kangasharju, "Effects of cooperation policy and network topology on performance of in-network caching," *Communications Letters, IEEE*, vol. 18, no. 4, pp. 680–683, 2014.

[179] Y. Xu, Y. Li, T. Lin, Z. Wang, W. Niu, H. Tang, and S. Ci, "A novel cache size optimization scheme based on manifold learning in Content Centric Networking," *Journal of Network and Computer Applications*, vol. 37, pp. 273–281, 2014.

[180] J. Ardelius, B. Gronvall, L. Westberg, and A. Arvidsson, "On the effects of caching in access aggregation networks," in *Proceedings of the second edition of the ICN workshop on Information-centric networking*. ACM, 2012, pp. 67–72.

[181] A. Ravi, P. Ramanathan, and K. M. Sivalingam, "Integrated network coding and caching in information-centric networks: revisiting pervasive caching in the ICN framework," *Photonic Network Communications*, vol. 30, no. 3, pp. 416–427, 2015.

[182] A. Anand, C. Muthukrishnan, A. Akella, and R. Ramjee, "Redundancy in network traffic: findings and implications," *ACM SIGMETRICS Performance Evaluation Review*, vol. 37, no. 1, pp. 37–48, 2009.

[183] A. Anand, V. Sekar, and A. Akella, "Smartre: An architecture for coordinated network-wide redundancy elimination," in *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 4. ACM, 2009, pp. 87–98.

[184] A. Anand, A. Gupta, A. Akella, S. Seshan, and S. Shenker, "Packet caches on routers: the implications of universal redundant traffic elimination," in *ACM SIGCOMM Computer Communication Review*, vol. 38, no. 4. ACM, 2008, pp. 219–230.

[185] E. Zohar, I. Cidon, and O. O. Mokryn, "The power of prediction: Cloud bandwidth and cost reduction," in *ACM SIGCOMM Computer Communication Review*, vol. 41, no. 4. ACM, 2011, pp. 86–97.

[186] N. T. Spring and D. Wetherall, "A protocol-independent technique for eliminating redundant network traffic," *ACM SIGCOMM Computer Communication Review*, vol. 30, no. 4, pp. 87–95, 2000.

[187] S. Ullah and C. S. Hong, "Probabilistic in-networking chunk marking and caching for Information-Centric Networks," *2013 Korea Information Science Society 40th Annual General Meeting and Fall Conference*, pp. 964–966, 2013.

[188] L. Wang, W. Wong, and J. Kangasharju, "In-network caching vs. redundancy elimination," *CoRR*, vol. abs/1311.7421, 2013. [Online]. Available: http://arxiv.org/abs/1311.7421

[189] R. S. Antunes, M. B. Lehmann, R. B. Mansilha, C. Esteve Rothenberg, L. P. Gaspary, and M. P. Barcellos, "Ccnrel: Leveraging relations among objects to improve the performance of CCN," in *Integrated Network Management (IM), 2015 IFIP/IEEE International Symposium on*. IEEE, 2015, pp. 199–206.

[190] Y. Wang, K. Lee, B. Venkataraman, R. L. Shamanna, I. Rhee, and S. Yang, "Advertising cached contents in the control plane: Necessity and feasibility," in *Computer Communications Workshops (INFOCOM WKSHPS), 2012 IEEE Conference on*. IEEE, 2012, pp. 286–291.

[191] Q. N. Nguyen, M. Arifuzzaman, T. Miyamoto, and S. Takuro, "An optimal information centric networking model for the future green network," in *Autonomous Decentralized Systems (ISADS), 2015 IEEE Twelfth International Symposium on*. IEEE, 2015, pp. 272–277.

[192] J. Wang, "A survey of web caching schemes for the Internet," *ACM SIGCOMM Computer Communication Review*, vol. 29, no. 5, pp. 36–46, 1999.

[193] D. Wessels and K. Claffy, "RFC 2186: Internet Cache Protocol (ICP), version 2, September 1997," *Status: INFORMATIONAL*. [Online]. Available: https://tools.ietf.org/html/rfc2186

[194] ——, "RFC 2187: Application of Internet Cache Protocol (ICP), version 2, September 1997," *Status: INFORMATIONAL*, vol. 233, p. 234. [Online]. Available: https://tools.ietf.org/html/rfc2187

[195] S. Michel, K. Nguyen, A. Rosenstein, L. Zhang, S. Floyd, and V. Jacobson, "Adaptive web caching: towards a new global caching architecture," *Computer Networks and ISDN systems*, vol. 30, no. 22, pp. 2169–2177, 1998.

[196] E. Nygren, R. K. Sitaraman, and J. Sun, "The akamai network: a platform for high-performance internet applications," *ACM SIGOPS Operating Systems Review*, vol. 44, no. 3, pp. 2–19, 2010.

[197] T. Krenc, O. Hohlfeld, and A. Feldmann, "An Internet census taken by an illegal botnet: A qualitative assessment of published measurements," *ACM SIGCOMM Computer Communication Review*, vol. 44, no. 3, pp. 103–111, 2014.

[198] L. A. Zadeh, "Fuzzy sets," *Information and control*, vol. 8, no. 3, pp. 338–353, 1965. [Online]. Available: http://www.cs.berkeley.edu/~zadeh/papers/Fuzzy%20Sets-Information%20and%20Control-1965.pdf

[199] K. R. MacCrimmon, "Decision making among multiple-attribute alternatives: A survey and consolidated approach," DTIC Document, Tech. Rep., 1968. [Online]. Available: https://www.rand.org/content/dam/rand/pubs/research_memoranda/2009/RM4823.pdf

[200] C.-L. Hwang and K. Yoon, *Multiple attribute decision making, methods and applications: A state-of-the-art survey*. Springer, 1981. [Online]. Available: http://link.springer.com/book/10.1007%2F978-3-642-48318-9

[201] H. Kwakernaak, "An algorithm for rating multiple-aspect alternatives using fuzzy sets," *Automatica*, vol. 15, no. 5, pp. 615–616, 1979. [Online]. Available: http://www.sciencedirect.com/science/article/pii/0005109879900104

[202] A. Easton, "One-of-a-kind decisions involving weighted multiple objectives and disparate alternatives," *Multiple criteria decision making (1st ed.). University of South Carolina Press: Columbia*, pp. 657–667, 1973.

[203] K. Katsaros, G. Xylomenos, and G. C. Polyzos, "MultiCache: An overlay architecture for Information-Centric Networking," *Computer Networks*, vol. 55, no. 4, pp. 936–947, 2011.

[204] M. Diallo, S. Fdida, V. Sourlas, P. Flegkas, and L. Tassiulas, "Leveraging caching for Internet-scale content-based publish/subscribe networks," in *Communications (ICC), 2011 IEEE International Conference on*. IEEE, 2011, pp. 1–5.

[205] H. Yao, C. Fang, C. Qiu, C. Zhao, and Y. Liu, "A novel energy efficiency algorithm in green mobile networks with cache," *EURASIP Journal on Wireless Communications and Networking*, vol. 2015, no. 1, pp. 1–9, 2015.

[206] E. Triantaphyllou and C.-T. Lin, "Development and evaluation of five fuzzy multiattribute decision-making methods," *international Journal of Approximate reasoning*, vol. 14, no. 4, pp. 281–310, 1996.

[207] L. Saino, "On the Design of Efficient Caching Systems," Ph.D. dissertation, University College London, UK, 2015. [Online]. Available: http://discovery.ucl.ac.uk/1473436/1/thesis-final.pdf

[208] L. Breslau, P. Cao, L. Fan, G. Phillips, and S. Shenker, "Web caching and zipf-like distributions: Evidence and implications," in *INFOCOM'99. Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 1. IEEE, 1999, pp. 126–134.

[209] M. Gallo, B. Kauffmann, L. Muscariello, A. Simonian, and C. Tanguy, "Performance evaluation of the random replacement policy for networks of caches," in *ACM SIGMETRICS Performance Evaluation Review*, vol. 40, no. 1. ACM, 2012, pp. 395–396.

[210] M. Won and R. Stoleru, "A low-stretch-guaranteed and lightweight geographic routing protocol for large-scale wireless sensor networks," *ACM Transactions on Sensor Networks (TOSN)*, vol. 11, no. 1, p. 18, 2014.

[211] L. Wang, A. Hoque, C. Yi, A. Alyyan, and B. Zhang, "OSPFN: An OSPF based routing protocol for Named Data Networking," *University of Memphis and University of Arizona, Tech. Rep*, 2012. [Online]. Available: http://new.named-data.net/wp-content/uploads/TROSPFN.pdf

[212] G. Carofiglio, M. Gallo, L. Muscariello, and M. Papali, "Multipath congestion control in Content-Centric Networks," in *Computer Communications Workshops (INFOCOM WKSHPS), 2013 IEEE Conference on*. IEEE, 2013, pp. 363–368.

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

[214] L. A. Adamic and B. A. Huberman, "The web's hidden order," *Communications of the ACM*, vol. 44, no. 9, pp. 55–60, 2001.

[215] N. B. Ellison *et al.*, "Social network sites: Definition, history, and scholarship," *Journal of Computer-Mediated Communication*, vol. 13, no. 1, pp. 210–230, 2007.

[216] L. A. Adamic and B. A. Huberman, "Zipf's law and the Internet," *Glottometrics*, vol. 3, no. 1, pp. 143–150, 2002. [Online]. Available: http://www.hpl.hp.com/research/idl/papers/ranking/adamicglottometrics.pdf

[217] C. Bernardini, T. Silverston, and O. Festor, "Socially-aware caching strategy for Content Centric Networking," in *Networking Conference, 2014 IFIP*. IEEE, 2014, pp. 1–9.

[218] A. L. Van Den Wollenberg, "Redundancy analysis an alternative for canonical correlation analysis," *Psychometrika*, vol. 42, no. 2, pp. 207–219, 1977. [Online]. Available: http://link.springer.com/article/10.1007/BF02294050

[219] J. Xu and X.-C. Zhu, "A load-balancing and energy-aware routing protocol for MANET accessing Internet," in *2009 Eighth IEEE International Conference on Dependable, Autonomic and Secure Computing*. IEEE, 2009, pp. 571–574.

[220] D. Rossi, G. Rossini *et al.*, "On sizing CCN content stores by exploiting topological information." in *INFOCOM Workshops*, 2012, pp. 280–285. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6193506&tag=1

[221] 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*. ACM, 2011, pp. 1–6.

[222] A. Wolman, M. Voelker, N. Sharma, N. Cardwell, A. Karlin, and H. M. Levy, "On the scale and performance of cooperative web proxy caching," in *ACM SIGOPS Operating Systems Review*, vol. 33, no. 5. ACM, 1999, pp. 16–31.

[223] S. Ihm and V. S. Pai, "Towards understanding modern web traffic," in *Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference*. ACM, 2011, pp. 295–312.

[224] D. Kutscher, S. Eum, K. Pentikousis, I. Psaras, D. Corujo, D. Saucez, T. Schmidt, and M. Waehlisch, "ICN research challenges," *Work in progress*, 2014. [Online]. Available: https://tools.ietf.org/html/draft-kutscher-icnrg-challenges-02