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**A MOBILE AGENT AND MESSAGE FERRY MECHANISM
BASED ROUTING FOR DELAY TOLERANT NETWORK**



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Abstract

Delay Tolerant Network (DTN) is a class of networks characterized by long delays, frequent disconnections and partitioning of communication paths between network nodes. Due to the frequent disconnection and network partitioning, the overall performance of the network will be deteriorated sharply. The problem is how to make the network fairly connected to optimize data routing and enhance the performance of a network. The aim of this study is to improve the performance of DTN by minimizing end-to-end delivery time and increasing message delivery ratio. Therefore, this research tackles the problem of intermittent connectivity and network partitioning by introducing Agents and Ferry Mechanism based Routing (AFMR). The AFMR comprises of two stages by applying two schemes: mobile agents and ferry mechanism. The agents' scheme is proposed to deal with intermittent connectivity and network partitioning by collecting the basic information about network connection such as signal strength, nodes position in the network and distance to the destination nodes to minimize end-to-end delivery time. The second stage is to increase the message delivery ratio by moving the nodes towards the path with available network connectivity based on agents' feedback. The AFMR is evaluated through simulations and the results are compared with those of Epidemic, PROPHET and Message Ferry (MF). The findings demonstrate that AFMR is superior to all three, with respect to the average end-to-end delivery time, message delivery ratio, network load and message drop ratio, which are regarded as extremely important metrics for the evaluation of DTN routing protocols. The AFMR achieves improved network performance in terms of end-to-end delivery time (56.3%); enhanced message delivery ratio (60.0%); mitigation of message drop (63.5%) and reduced network load (26.1%). The contributions of this thesis are to enhance the performance of DTN by significantly overcoming the intermittent connectivity and network partitioning problems in the network.

Keywords: Agent based routing, Delay tolerant network, Sporadic connectivity, Store-carry-forward mechanism, Routing protocols.

Abstrak

Rangkaian Toleransi Kelengahan (DTN) adalah satu kelas rangkaian yang mempunyai ciri lengahan yang panjang, pemutusan yang kerap dan pemetakan laluan komunikasi antara nod rangkaian. Oleh kerana pemutusan kerap dan pemetakan rangkaian, prestasi keseluruhan rangkaian akan merosot secara mendadak. Permasalahannya adalah bagaimana untuk menjadikan sesuatu rangkaian itu bersambung dengan baik bagi mengoptimumkan penghalaan data dan meningkatkan prestasi sesuatu rangkaian. Tujuan kajian ini adalah untuk meningkatkan prestasi DTN dengan meminimumkan masa penghantaran hujung ke hujung dan meningkatkan nisbah penghantaran mesej. Oleh itu, penyelidikan ini menangani masalah ketersambungan terputus-putus dan pemetakan rangkaian dengan memperkenalkan mekanisma berdasarkan penghalaan agen dan feri (AFMR). AFMR terdiri daripada dua peringkat dengan menggunakan dua skim: agen bergerak dan mekanisma feri. Skim agen dicadangkan untuk menangani ketersambungan terputus-putus dan pemetakan rangkaian dengan mengumpul maklumat asas mengenai ketersambungan rangkaian seperti kekuatan isyarat, kedudukan nod dalam rangkaian dan jarak nod ke destinasi untuk meminimumkan masa penghantaran hujung ke hujung. Peringkat kedua adalah untuk meningkatkan nisbah penghantaran mesej dengan menggerakkan nod ke laluan dengan ketersambungan rangkaian yang tersedia berdasarkan maklum balas agen. AFMR dinilai melalui simulasi dan keputusannya dibandingkan dengan Epidemik, PRoPHET dan Feri Mesej (MF). Penemuan menunjukkan bahawa AFMR lebih baik daripada ketiga-tiganya, berkenaan dengan purata masa penghantaran hujung ke hujung, nisbah penghantaran mesej, beban rangkaian dan nisbah pengguguran mesej, yang dianggap sebagai metrik yang amat penting untuk penilaian protokol penghala DTN. AFMR berjaya meningkatkan prestasi rangkaian dari segi tempoh penghantaran hujung ke hujung (56.3%); meningkatkan nisbah penghantaran mesej (60.0%); pengurangan pengguguran mesej (63.5%) dan mengurangkan beban rangkaian (26.1%). Sumbangan tesis ini adalah untuk meningkatkan prestasi DTN dengan ketara mengatasi masalah ketersambungan terputus-putus dan masalah pemetakan dalam rangkaian.

Kata kunci: Penghalaan berasaskan agen, Rangkaian toleransi kelengahan, Ketersambungan sporadik, Mekanisma simpanan-bawa-maju, Protokol penghalaan.

Declaration Associated with This Thesis

Some part of the work presented in this thesis have been published and submitted to the following journals and conferences listed below:

[1] **Kawakib Khadyair Ahmed**, Mohd Hasbullah Omar, Suhaidi Hassan "Delay Tolerant Networks," Technical Report UUM/CAS/InterNetWorks/TR2017-02, InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia, 2017.

[2] **Kawakib K. Ahmed**, Mohd. Hasbullah Omar, Suhaidi Hassan "Routing Strategies and Buffer Management in Delay Tolerant Networks", Journal of Telecommunication, Electronic and Computer Engineering (JTEC), Vol. 8, No.10, December 2016. ISSN: 2180-1843.

[3] **Kawakib K. Ahmed**, Mohd. Hasbullah Omar, Suhaidi Hassan "Survey and Comparison of Operating Concept for Routing Protocols in DTN", Journal of Computer Science (JCS), Vol. 12(3), pp. 141-152 (2016), DOI : 10.3844/jcssp.2016.141.152.

[4] **Kawakib K. Ahmed**, Mohd. Hasbullah Omar, Suhaidi Hassan "Routing and Buffer Management in Delay Tolerant Networks", National Workshop on Future Internet Research (FIRES 2016), Malaysia.

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Dedication

For my family . . .

in memory of my brother Hazbar;

my family;

my husband Zeyid; and

our Kids Zeena and Tariq



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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)

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List of Abbreviations

AODV	Ad-hoc On demand Distance Vector
BL	Bundle Layer
DTN	Delay Tolerant Network
DTNRG	Delay Tolerant Networking Research Group
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
DRM	Design Research Methodology
DS-I	Descriptive Study I
DS-II	Descriptive Study II
ER	Epidemic Routing Protocol
FIMF	Ferry Initiated Message Ferry
IPN	Interplanetary Networks
IRTF	Internet Research Task Force
IOT	Internet of Things
MANET	Mobile Ad-hoc Networks
MF	Message Ferry
MV	Meet and Visit
NIMF	Node Initiated Message Ferry
OLSR	Optimized Link-State Routing
PRoPHET	Routing Protocol using History of Encounters and Transitivity
PS	Perspective Study
PSN	Pocket Switching Networks
RF	Radio Frequency
RC	Research Clarification
SnW	Spray and Wait
TCP/IP	Transmission Control Protocol/ Internet Protocol
TTL	Time To Live
TSP	Traveling Salesman Problem
UWN	Underwater Wireless Networks
WSN	Wireless Sensor Networks

List of Symbols

t_i'	Time when the message is delivered
t_i	Time when the message is created
M_d	Number of messages delivered to a destination
M	Number of messages created in the network
D_{ij}	Average delay
μ_{ij}	Waiting time
c_{ij}	Carrying Time
H	Number of all hops that ferry can traverse



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CHAPTER ONE

INTRODUCTION

The rapid development of wireless communication today has witnessed the growth of numerous types of heterogeneous network. Heterogeneous networks can be defined as networks that connect computers and other devices that operate under different communication protocols and run on diverse operating systems or access technologies. For example, a wireless network which has the ability to maintain its services while switching from wireless LAN to a cellular network is considered as a good model of a wireless heterogeneous network. Heterogeneous networks can also operate in extreme terrestrial environments or mobile conditions which lack continuous network connectivity. The Delay Tolerant Network (DTN) is an approach that seeks to address the technical issues that make communication in heterogeneous networks difficult. The concept of DTN was first proposed by Fall in 2003 [1], and followed by numerous studies in the same field.

The aim of this chapter is to place this study in its context starting with a brief overview of DTN and an outline of its major characteristics in Sections 1.1 and 1.2 respectively. Section 1.3 discusses some motivating factors for studying DTN. The problem statement is presented in Section 1.4, where the current issues and challenges of DTN are addressed. Section 1.5 covers the research questions. The research objectives, scope, steps and research significance are presented in Sections 1.6, 1.7, 1.8, and 1.9 respectively. Finally, the thesis organization is outlined in Section 1.10.

1.1 Delay Tolerant Network

The Internet today successfully connects communication devices throughout the globe. The Transmission Control Protocol/Internet Protocol (TCP/IP) suite has the

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REFERENCES

- [1] K. Fall, "A Delay-Tolerant Network Architecture for Challenged Internets," in *Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications*. ACM, 2003, pp. 27–34.
- [2] I. Joe and S.-B. Kim, "A Message Priority Routing Protocol for Delay Tolerant Networks (DTN) in Disaster Areas," in *International Conference on Future Generation Information Technology*. Springer, 2010, pp. 727–737.
- [3] S. G. Sweetie Soni, "Ways of Disseminating Messages in Delay Tolerant Networks," *International Journal of Computer Science And Technology*, vol. 4, April - June, iSSN : 0976-8491 (Online).
- [4] N. K. Chaubey and P. Mistri, "Routing Protocols in Delay Tolerant Network (DTN): A Critical Study and Comparison," *International Journal in IT and Engineering*, vol. 4, February 2016, iSSN: 2321-1776.
- [5] K. M. Killeen Jr, "GAPR2: A DTN Routing Protocol for Communications in Challenged, Degraded, and Denied Environments," Ph.D. dissertation, Monterey, California: Naval Postgraduate School, 2015.
- [6] P. Juang, H. Oki, Y. Wang, M. Martonosi, L. S. Peh, and D. Rubenstein, "Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet," *ACM Sigplan Notices*, vol. 37, no. 10, pp. 96–107, 2002.
- [7] M. A. Azman, S. H. S. Ariffin, N. Fisal, M. Abbas, M. H. M. Fauzi, and S. K. Syed-Yusof, *Auto Mobile Ad Hoc Mechanism in Delay Tolerant Network*. Cham: Springer International Publishing, 2015, pp. 915–924. [Online]. Available: http://dx.doi.org/10.1007/978-3-319-07674-4_86
- [8] L. You, J. Li, C. Wei, and C. Dai, "A One-hop Information Based Geographic Routing Protocol for Delay Tolerant MANETs," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 20, no. 2, pp. 107–122, 2015.
- [9] V. Mahendran, T. Praveen, and C. S. R. Murthy, *Impact of Persistent Storage on the DTN Routing Performance*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 513–524. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-25959-3_38
- [10] A. E. Al-Fagih and H. S. Hassanein, "Routing Schemes for Delay-Tolerant NeNetworks-An Applications Perspective," *Technical Report*, vol. 588, pp. 1–40, 2012.
- [11] F. Warthman *et al.*, "Delay-and-Disruption-Tolerant Networks (DTNs)," *A Tutorial. V 3.2, Interplanetary Internet Special Interest Group*, 2015.
- [12] J. Dhivya and M. V. Lakshmi, "Delay Tolerant Networks An Emerging Communication Paradigm," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 3, February 2014, iSSN (Online) : 2278-1021 ISSN (Print) : 2319-5940.

- [13] L. Gao, "Routing and Privacy Protection in Human Associated Delay Tolerant Networks," Ph.D. dissertation, 2013.
- [14] N. Bezirgiannidis, "Accurate Estimation of End-To-End Delivery Delay in Space Internets: Protocol Design and Implementation," Ph.D. dissertation, Democritus University of Thrace, Department of Electrical and Computer Engineering Software and Application Development Sector, July 2015.
- [15] S. R. B. Azzuhri, "Towards Tailored and Adaptive Wireless Multi-hop Routing Protocols," Ph.D. dissertation, School of Information Technology and Electrical Engineering, The University of Queensland, 2013.
- [16] S. A. Menesidou, V. Katos, and G. Kambourakis, "Cryptographic Key Management in Delay Tolerant Networks: A Survey," *Future Internet*, vol. 9, no. 3, p. 26, 2017.
- [17] C. Dobre, F. Manea, and V. Cristea, "CAPIM: A Context-aware Platform using Integrated Mobile Services," in *2011 IEEE 7th International Conference on Intelligent Computer Communication and Processing*, Aug 2011, pp. 533–540.
- [18] M. Conti, S. Giordano, M. May, and A. Passarella, "From Opportunistic Networks to Opportunistic Computing," *IEEE Communications Magazine*, vol. 48, no. 9, pp. 126–139, Sept 2010.
- [19] R. Torres, L. Mengual, O. Marban, S. Eibe, E. Menasalvas, and B. Maza, "A Management Ad Hoc Networks Model for Rescue and Emergency Scenarios," *Expert Systems with Applications*, vol. 39, no. 10, pp. 9554 – 9563, 2012. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0957417412003600>
- [20] L. E. Quispe and L. M. Galan, "Behavior of Ad Hoc Routing Protocols, Analyzed for Emergency and Rescue Scenarios, on A real Urban Area," *Expert Systems with Applications*, vol. 41, no. 5, pp. 2565 – 2573, 2014. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0957417413008099>
- [21] I. F. Akyildiz, Özgür B. Akan, C. Chen, J. Fang, and W. Su, "InterPlaNetary Internet: State-of-the-Art and Research Challenges," *Computer Networks*, vol. 43, no. 2, pp. 75 – 112, 2003. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S1389128603003451>
- [22] A. S. Pentland, R. Fletcher, and A. Hasson, "Daknet: Rethinking Connectivity in Developing Nations," *Computer*, vol. 37, no. 1, pp. 78–83, 2004.
- [23] K. Shin, K. Kim, and S. Kim, "Traffic Management Strategy for Delay-Tolerant Networks," *Journal of Network and Computer Applications*, vol. 35, no. 6, pp. 1762 – 1770, 2012. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S1084804512001531>
- [24] D. Gutiérrez-Reina, S. T. Marín, P. Johnson, and F. Barrero, "An Evolutionary Computation Approach for Designing Mobile Ad hoc Networks," *Expert systems with applications*, vol. 39, no. 8, pp. 6838–6845, 2012.

- [25] V.-D. Le, H. Scholten, and P. Havinga, "Unified Routing for Data Dissemination in Smart City Networks," in *Internet of Things (IOT), 2012 3rd International Conference on the*. IEEE, 2012, pp. 175–182.
- [26] M. Conti and M. Kumar, "Opportunities in Opportunistic Computing," *Computer*, vol. 43, no. 1, pp. 42–50, Jan 2010.
- [27] H. Haddadi, P. Hui, T. Henderson, and I. Brown, "Targeted Advertising on the Handset: Privacy and Security Challenges," in *Pervasive Advertising*. Springer, 2011, pp. 119–137.
- [28] M. Tubaishat and S. Madria, "Sensor Networks: An Overview," *IEEE potentials*, vol. 22, no. 2, pp. 20–23, 2003.
- [29] L. Gao, S. Yu, T. H. Luan, and W. Zhou, *Delay Tolerant Networks*. Cham: Springer International Publishing, 2015, ch. Introduction, pp. 1–7. [Online]. Available: http://dx.doi.org/10.1007/978-3-319-18108-0_1
- [30] B. Gu, "Communication in Disruption Tolerant Networks: Models, Analyses and Routing," Ph.D. dissertation, The University of Alabama TUSCALOOSA, 2011.
- [31] F. Warthman *et al.*, "Delay-and Disruption-Tolerant Networks (DTNs)," *A Tutorial. V. 2.0, Interplanetary Internet Special Interest Group*, June 2012.
- [32] W. Sun, C. Liu, and D. Wang, "On Delay-Tolerant Networking and Its Application," in *Proceedings of 2011 International Conference on Computer Science and Information Technology (ICCSIT 2011)*, 2011.
- [33] D. Wick and T. Braun, "Delay Tolerant Networks in A Nutshell," *Bachelor Thesis, University of Bern*, 2007.
- [34] N. Mehta and M. Shah, "Performance of Efficient Routing Protocol in Delay Tolerant Network: A Comparative Survey," *International Journal of Future Generation Communication and Networking*, vol. 7, pp. 151–158, 2014.
- [35] [Online]. Available: <https://irtf.org/concluded/dtnrg>
- [36] K. Fall, K. L. Scott, S. C. Burleigh, L. Torgerson, A. J. Hooke, H. S. Weiss, R. C. Durst, and V. Cerf, "Delay-Tolerant Networking Architecture," 2007.
- [37] S. Burleigh, "Bundle Protocol Specification," NASA Jet Propulsion Laboratory, Tech. Rep., November 2007.
- [38] M. Ramadas, S. Burleigh *et al.*, "Licklider Transmission Protocol-Specification," 2008.
- [39] S. Jero, H. Kruse, and S. Ostermann, "Datagram Convergence Layers for the Delay-and Disruption-Tolerant Networking (DTN) Bundle Protocol and Licklider Transmission Protocol (LTP)," 2014.
- [40] J. Ott, M. Demmer, and S. Perreault, "Delay-Tolerant Networking TCP Convergence-Layer Protocol," 2014.

- [41] C. M. Hirata, "A Novel Congestion Control Framework for Delay and Disruption Tolerant Networks," Ph.D. dissertation, Instituto Tecnológico de Aeronáutica, 2015.
- [42] P. Gantayat and S. Jena, "Delay Tolerant Network-A Survey," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 4, July 2015.
- [43] P. G. K. K. Suresh, "Prediction Based Routing With History Based Replication for Disruption Tolerant Network," *Research Journal of Applied Sciences, Engineering and Technology*, pp. 102–108, 2015.
- [44] S. Jain, K. Fall, and R. Patra, "Routing in a Delay Tolerant Network," in *Proceedings of the 2004 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, ser. SIGCOMM '04. New York, NY, USA: ACM, 2004, pp. 145–158. [Online]. Available: <http://doi.acm.org/10.1145/1015467.1015484>
- [45] O. Gnawali, M. Polyakovt, P. Bose, and R. Govindan, "Data Centric, Position-based Routing in Space Networks," in *Aerospace Conference, 2005 IEEE*. IEEE, 2005, pp. 1322–1334.
- [46] S. Merugu, M. Ammar, and E. Zegura, "Space-Time Routing in Wireless Networks with Predictable Mobility," *College of Computing, Georgia Tech, Tech. Rep. GIT-CC-04-07*, 2004.
- [47] R. Handorean, C. Gill, and G.-C. Roman, "Accommodating Transient Connectivity in Ad hoc and Mobile Settings," in *Pervasive*, vol. 3001. Springer, 2004, pp. 305–322.
- [48] M. Karimzadeh, "Efficient Routing Protocol in Delay Tolerant Networks (DTNs)," Master's thesis, Tampereen teknillinen yliopisto, June 2011.
- [49] T. Abdelkader, K. Naik, A. Nayak, N. Goel, and V. Srivastava, "A Performance Comparison of Delay-Tolerant Network Routing Protocols," *IEEE Network*, vol. 30, no. 2, pp. 46–53, March 2016.
- [50] C. Sobin, V. Raychoudhury, G. Marfia, and A. Singla, "A Survey of Routing and Data Dissemination in Delay Tolerant Networks," *Journal of Network and Computer Applications*, vol. 67, pp. 128–146, 2016.
- [51] P. M. Asuquo, "A Decentralised and Context-aware Trust Management Scheme for Resource-Constrained Emergency Communications," Ph.D. dissertation, University of Surrey, 2018.
- [52] H. S. Modi and N. K. Singh, "Survey of Routing in Delay Tolerant Networks," *International Journal of Computer Applications (0975–8887)*, vol. 158, no. 5, January 2017.
- [53] S. Mittal and P. Kaur, "Performance Comparison of AODV, DSR and ZRP Routing Protocols in MANET's," in *Advances in Computing, Control, Telecommunication Technologies, 2009. ACT'09. International Conference on*. IEEE, 2009, pp. 165–168.

- [54] N. Sarkar, W. G. Lo *et al.*, “A study of MANET Routing Protocols: Joint Node Density, Packet Length and Mobility,” in *Computers and Communications (ISCC), 2010 IEEE Symposium on*. IEEE, 2010, pp. 515–520.
- [55] D.-W. Kum, J.-S. Park, Y.-Z. Cho, and B.-Y. Cheon, “Performance Evaluation of AODV and DYMO Routing Protocols in MANET,” in *Consumer Communications and Networking Conference (CCNC), 2010 7th IEEE*. IEEE, 2010, pp. 1–2.
- [56] B. Milic, N. Milanovic, and M. Malek, “Prediction of Partitioning in Location-aware Mobile Ad hoc Networks,” in *Proceedings of the 38th Annual Hawaii International Conference on System Sciences*. IEEE, 2005, pp. 306c–306c.
- [57] Z. Lin, “Augmenting Mobility Simulation by Public Transport: A Case Study for the ONE Simulator,” Master’s thesis, Aalto University School of Electrical Engineering, 2015.
- [58] E. P. Jones and P. A. Ward, “Routing Strategies for Delay-Tolerant Networks,” *Submitted to ACM Computer Communication Review (CCR)*, 2006.
- [59] D. R. Dabhi, Apexa A., “Analysis of Different Buffer Management Strategies in Delay Tolerance Network Routing,” *International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC)*, vol. 5, pp. 149–152, November 2017, iSSN: 2321-8169.
- [60] A. S. Patil and P. J. Kulkarni, “Exploiting Social Relations for Efficient Routing in Delay Tolerant Network Environment,” *International Journal of Computer Sciences and Engineering*, vol. 6, February 2018, e-ISSN: 2347-2693.
- [61] E. P. C. Jones, “Practical Routing in Delay-Tolerant Networks,” Master’s thesis, Electrical and Computer Engineering, University of Waterloo, 2006.
- [62] K. Fall and S. Farrell, “DTN: An Architectural Retrospective,” *IEEE Journal on Selected Areas in Communications*, vol. 26, no. 5, pp. 828–836, 2008.
- [63] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, and H. Weiss, “Delay Tolerant Networking Architecture,” *RFC4838*, April, 2007.
- [64] C. Mergenci, “Routing in Delay Tolerant Networks with Periodic Connections,” Ph.D. dissertation, Bilkent University, August 2010.
- [65] T. Saadawi, “A Delay Tolerant Networking Architecture for Airborne Networking,” DTIC Document, Tech. Rep., 2010.
- [66] M. J. Z. de Barros, “Impact of Delay-Tolerant Network Support in Wireless Local Area Networks,” 2014.
- [67] A. Galati, “Delay Tolerant Networking in A Shopping Mall Environment,” Ph.D. dissertation, University of Nottingham, 2011.
- [68] I. Psaras, L. Wood, and R. Tafazolli, “Delay-Disruption-Tolerant Networking: State of the Art and Future Challenges,” *University of Surrey, Technical Report*, 2010.

- [69] A. E. Shoghri, "Augur: A Delay Aware Forwarding Protocol for Delay-Tolerant Networks," Master's thesis, The University of Queensland, School of Information Technology and Electrical Engineering, 2016.
- [70] G. Sandulescu, "Resource-Aware Routing In Delay and Disruption-Tolerant Networks," Ph.D. dissertation, The Faculty of Sciences, Technology and Communication, University of Luxembourg, 2011.
- [71] C. Perkins and E. Royer, "Ad-hoc on-Demand Distance Vector Routing," in *Proc. 2nd IEEE Workshop on Mobile Computer Systems and Applications*, pp. 90–100.
- [72] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva, "A performance Comparison of Multi-hop Wireless Ad hoc Network Routing Protocols," in *Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking*. ACM, 1998, pp. 85–97.
- [73] A. Tønnesen, "Implementing and Extending the Optimized Link State Routing Protocol," Master's thesis, 2004.
- [74] A. Palma, P. R. Pereira, P. R. Pereira, and A. Casaca, "Multicast Routing Protocol for Vehicular Delay-Tolerant Networks," in *2012 IEEE 8th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Oct 2012, pp. 753–760.
- [75] M. J. Khabbaz, C. M. Assi, and W. F. Fawaz, "Disruption-Tolerant Networking: A Comprehensive Survey on Recent Developments and Persisting Challenges," *IEEE Communications Surveys Tutorials*, vol. 14, no. 2, pp. 607–640, Second 2012.
- [76] Z. Zhang, "Routing in Intermittently Connected Mobile Ad hoc Networks and Delay Tolerant Networks: Overview and Challenges," *IEEE Communications Surveys & Tutorials*, vol. 1, no. 8, pp. 24–37, 2006.
- [77] A. Keranen, J. Ott, and T. Karkkainen, "The ONE Simulator for DTN Protocol Evaluation," in *Proceedings of the 2nd international conference on simulation tools and techniques*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2009, p. 55.
- [78] S. Yamamura, A. Nagata, and M. Tsuru, "Store-carry-forward Based Networking Infrastructure: Vision and Potential," in *Intelligent Networking and Collaborative Systems (INCoS), 2011 Third International Conference on*. IEEE, 2011, pp. 594–599.
- [79] F. Warthman *et al.*, "Delay-Tolerant Networks (DTNs)," A Tutorial. V.1.1, May 2003.
- [80] P. Bijal, D. Krupa, and P. Vyomal, "Delay Tolerant Network," *International Journal of Emerging Technology and Advanced Engineering*, vol. 3, December 2013, iSSN 2250-2459. [Online]. Available: <http://www.ijetae.com/>

- [81] M. R. AlamMd. and B. Minz, "Routing in Delay Tolerant Networks," May 2012. [Online]. Available: <http://ethesis.nitrkl.ac.in/3559/>
- [82] W. Sun, Q. Liu, and K. Li, "Research on Congestion Management in Delay-Tolerant Networks," *International Conference on Computer Science and Information Technology (ICCSIT)*, vol. 51, 2011.
- [83] C. Liu, "Distributed Databases Synchronization in Named Data Delay Tolerant Networks," Master's thesis, University of MINHO, Department of Informatics, October 2016.
- [84] S. Grover, A. Pancholi, and S. Arora, "FSR: Ferry-based Secure Routing Algorithm for Delay Tolerant Networks," *International Journal Of Engineering And Computer Science*, vol. 3, pp. 6104–6108, May 2014, iSSN:2319-7242.
- [85] L. Aidi and J. Changsu, "Delay Tolerant Network," 2012, school of Information and Communication Technology, KTH, Stockholm, Sweden.
- [86] J. G. Filho, A. Patel, B. L. A. Batista, and J. Celestino, "A systematic Technical Survey of DTN and VDTN Routing Protocols," *Computer Standards & Interfaces*, vol. 48, pp. 139 – 159, 2016, special Issue on Information System in Distributed Environment. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0920548916300393>
- [87] D. Akilbekov, "Management in Delay Tolerant Networks," Master's thesis, Stockholm, Sweden, 2011.
- [88] M. Ho and K. Fall, "Poster: Delay Tolerant Networking for Sensor Networks," in *Proc. of IEEE Conference on Sensor and Ad Hoc Communications and Networks*, 2004.
- [89] S. H. Bouk, S. H. Ahmed, and D. Kim, "Delay Tolerance in Underwater Wireless Communications: A Routing Perspective," *Mobile Information Systems*, no. 6574697, p. 9, 2016.
- [90] C. P. Mayer, *Hybrid Routing in Delay Tolerant Networks*. KIT Scientific Publishing, 2012.
- [91] F. Herbertsson, "Implementation of A Delay-Tolerant Routing Protocol in the Network Simulator NS-3," 2010.
- [92] K. K. Ahmed, M. H. Omar, and S. Hassan, "Survey and Comparison of Operating Concept for Routing Protocols in DTN," *Journal of Computer Science*, vol. 12, pp. 141–152, 2016.
- [93] A. Sudarsono and T. Nakanishi, "A Secure Data Exchange System in Wireless Delay Tolerant Network Using Attribute-Based Encryption," *Journal of Information Processing*, vol. 25, pp. 234–243, 2017.
- [94] A. Makke, "Pervasive Service Provisioning in Intermittently Connected Hybrid Networks," Ph.D. dissertation, Lorient, 2015.

- [95] A. Lindgren, A. Doria, and O. Schelén, "Probabilistic Routing in Intermittently Connected Networks," *ACM SIGMOBILE mobile computing and communications review*, vol. 7, no. 3, pp. 19–20, 2003.
- [96] C. Liu and J. Wu, "Scalable Routing in Delay Tolerant Networks," in *Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing*. ACM, 2007, pp. 51–60.
- [97] E. P. C. Jones, L. Li, J. K. Schmidtke, and P. A. S. Ward, "Practical Routing in Delay-Tolerant Networks," *IEEE Transactions on Mobile Computing*, vol. 6, no. 8, pp. 943–959, Aug 2007.
- [98] R. Ramanathan, R. Hansen, P. Basu, R. Rosales-Hain, and R. Krishnan, "Prioritized Epidemic Routing for Opportunistic Networks," in *Proceedings of the 1st international MobiSys workshop on Mobile opportunistic networking*. ACM, 2007, pp. 62–66.
- [99] S. Ali, J. Qadir, and A. Baig, "Routing protocols in Delay Tolerant Networks-A survey," in *2010 6th International Conference on Emerging Technologies (ICET)*, Oct 2010, pp. 70–75.
- [100] M. M. Qirtas, Y. Faheem, and M. H. Rehmani, "Throwboxes in Delay Tolerant Networks: A Survey of Placement Strategies, Buffering Capacity, and Mobility Models," *Journal of Network and Computer Applications*, 2017.
- [101] N. I. Dopico, Á. Gutiérrez, and S. Zazo, "Performance Analysis of A Delay Tolerant Application for Herd Localization," *Computer Networks*, vol. 55, no. 8, pp. 1770–1783, 2011.
- [102] N. Benamar, M. Benamar, and J. M. Bonnin, "Routing Protocols for DTN in Vehicular Environment," in *Multimedia Computing and Systems (ICMCS), 2012 International Conference on*. IEEE, 2012, pp. 589–593.
- [103] S. Cha, E. Talipov, and H. Cha, "Data Delivery Scheme for Intermittently Connected mobile Sensor Networks," *Computer Communications*, vol. 36, no. 5, pp. 504–519, 2013.
- [104] A. Hafid, S. Sulistyo, A. U. A. Wibowo, and I. W. Mustika, "Performance Evaluation of DTN Protocols for Vehicular Network by Variations in Buffer Size," in *Information Technology and Electrical Engineering (ICITEE), 2016 8th International Conference on*. IEEE, 2016, pp. 1–5.
- [105] T. Supriya and C. Pramila, "Analytical Study of Spray and Wait Routing Protocol in Delay Tolerant Networks," *International Journal of Advanced Technology in Engineering and Science*, vol. 02, July 2014, iISSN 2348-7550.
- [106] E. Bulut, Z. Wang, and B. K. Szymanski, "Minimizing Average Spraying Cost for Routing in Delay Tolerant Networks," in *Proc. 2nd Annual Conference of International Technology Alliance, ACITA, London, UK, September 2008*, pp. 70–77.

- [107] P. G. Rotti, "Opportunistic Lookahead Routing Protocol for Delay Tolerant Networks," Master's thesis, Information Science and Engineering, Visvesvaraya Technological University, 2012.
- [108] L. Tang, Q. Zheng, J. Liu, and X. Hong, "Selective Message Forwarding in Delay Tolerant Networks," *Mobile Networks and Applications*, vol. 14, no. 4, pp. 387–400, 2009.
- [109] A. Rajaei, "Efficient and flexible Geocasting for Opportunistic Networks," Ph.D. dissertation, University of Sussex, 2016.
- [110] C. B. Desai, V. N. Pandya, and S. K. Hadia, "A Survey on Knowledge Based Classification of Different Routing Protocols in Delay Tolerant Networks," *International Journal of Computer Science and Mobile Computing*, vol. 2, no. 3, pp. 83–88, March 2013, 2320088X.
- [111] A. Demers, D. Greene, C. Hauser, W. Irish, J. Larson, S. Shenker, H. Sturgis, D. Swinehart, and D. Terry, "Epidemic Algorithms for Replicated Database Maintenance," in *Proceedings of the sixth annual ACM Symposium on Principles of distributed computing*. ACM, 1987, pp. 1–12.
- [112] I. Cardei, C. Liu, and J. Wu, "Routing in Wireless Networks with Intermittent Connectivity," *Encyclopedia of Wireless and Mobile Communications*. CRC Press, Taylor & Francis, 2007.
- [113] A. Vahdat, D. Becker *et al.*, "Epidemic Routing for Partially Connected Ad hoc Networks," Technical Report CS-200006, Duke University, Tech. Rep., 2000.
- [114] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and Wait: An efficient Routing Scheme for Intermittently Connected Mobile Networks," in *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*. ACM, 2005, pp. 252–259.
- [115] Y. Wang, S. Jain, M. Martonosi, and K. Fall, "Erasure-Coding Based Routing for Opportunistic Networks," in *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*. ACM, 2005, pp. 229–236.
- [116] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Single-Copy Routing in Intermittently Connected Mobile Networks," in *Sensor and Ad Hoc Communications and Networks, 2004. IEEE SECON 2004. 2004 First Annual IEEE Communications Society Conference on*. IEEE, 2004, pp. 235–244.
- [117] —, "Spray and focus: Efficient mobility-assisted Routing for Heterogeneous and Correlated Mobility," in *Pervasive Computing and Communications Workshops, 2007. PerCom Workshops' 07. Fifth Annual IEEE International Conference on*. IEEE, 2007, pp. 79–85.
- [118] D. Reina, R.-I. Ciobanu, S. Toral, and C. Dobre, "A multi-Objective Optimization of Data Dissemination in Delay Tolerant Networks," *Expert Systems with Applications*, vol. 57, pp. 178–191, 2016.

- [119] A. Ismailov, "Network Monitoring in Delay Tolerant Network," Master's thesis, KTH, School of Computer Science and Communication (CSC), 2015.
- [120] J. Guan, Q. Chu, and I. You, "The Social Relationship Based Adaptive Multi-Spray-and-Wait Routing Algorithm for Disruption Tolerant Network," *Mobile Information Systems*, 2017.
- [121] J. Burgess, B. Gallagher, D. Jensen, and B. N. Levine, "MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks," in *INFOCOM*, vol. 6, 2006, pp. 1–11.
- [122] B. Burns, O. Brock, and B. N. Levine, "MV Routing and Capacity Building in Disruption Tolerant Networks," in *Proceedings IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies.*, vol. 1, March 2005, pp. 398–408 vol. 1.
- [123] J. Leguay, T. Friedman, and V. Conan, "DTN Routing in A Mobility Pattern Space," in *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking.* ACM, 2005, pp. 276–283.
- [124] J. Ghosh, H. Q. Ngo, and C. Qiao, "Mobility Profile Based Routing within Intermittently Connected Mobile Ad hoc Networks (ICMAN)," in *Proceedings of the 2006 international conference on Wireless communications and mobile computing.* ACM, 2006, pp. 551–556.
- [125] M. Musolesi, S. Hailes, and C. Mascolo, "Adaptive Routing for Intermittently Connected Mobile Ad hoc Networks," in *Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks.* IEEE, 2005, pp. 183–189.
- [126] D. Patel and R. Shah, "Improved PROPHET Routing Protocol in DTN," *International Research Journal of Engineering and Technology (IRJET)*, vol. 03, no. 06, June 2016, e-ISSN: 2395 -0056 p-ISSN: 2395-0072.
- [127] S. Kaur, S. Bansal, S. Kaur, and S. Bansal, "Design and Implementation of Improved Routing Algorithm for Energy Consumption in Delay Tolerant Network," *International Journal for Innovative Research in Science & Technology*, vol. 3, no. 07, pp. 122–127, December 2016, iISSN (online): 2349-6010.
- [128] R. Thakur and K. Bansal, "Delay Tolerant Networks: An Analysis of Routing Protocols with ONE Simulator," *International Journal of Computer Network and Information Security*, vol. 8, no. 12, p. 51, 2016.
- [129] M. Kaviani, "Energy-aware Forwarding Strategies for Delay Tolerant Networking (DTN) Routing Protocols," Ph.D. dissertation, Queensland University of Technology, 2016.
- [130] A. Dziekonski and R. O. Schoeneich, "DTN Routing Algorithm for Networks with Nodes Social Behavior," *International Journal of Computers, Communications & Control*, vol. 11, no. 4, 2016.

- [131] B. Burns, O. Brock, and B. N. Levine, "MORA Routing and Capacity Building in Disruption Tolerant Networks," *Ad hoc networks*, vol. 6, no. 4, pp. 600–620, 2008.
- [132] M. Karimzadeh, M. Gholibeigi, D. Moltchanov, and Y. Koucheryavy, "Information Delivery in Delay Tolerant Networks," 2011.
- [133] Q. Li and D. Rus, "Sending Messages to Mobile Users in Disconnected Ad-hoc Wireless Networks," in *Proceedings of the 6th annual international conference on Mobile computing and networking*. ACM, 2000, pp. 44–55.
- [134] W. Zhao, M. Ammar, and E. Zegura, "A Message Ferrying Approach for Data Delivery in Sparse Mobile Ad hoc Networks," in *Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing*. ACM, 2004, pp. 187–198.
- [135] W. Peng, B. Zhao, W. Yu, C. Wu, and X. Yan, "Ferry Route Design with Delay Bounds in Delay-Tolerant Networks," in *2010 10th IEEE International Conference on Computer and Information Technology*, June 2010, pp. 281–288.
- [136] M. Kawecki and R. O. Schoeneich, "Mobility-based Routing Algorithm in Delay Tolerant Networks," *EURASIP Journal on Wireless Communications and Networking*, no. 1, p. 81, 2016.
- [137] R. Suganthe and P. Balasubramanie, "Improving QoS in Delay Tolerant Mobile Ad hoc Network using Multiple Message Ferries," *Network Protocols and Algorithms*, vol. 3, no. 4, pp. 32–53, 2011.
- [138] Y. M. Alroqi, "A novel Ferry Assisted Greedy Perimeter Stateless Routing Protocol (FA-GPSR) for Ad-hoc Networks in Remote Locations," Ph.D. dissertation, Nottingham Trent University, 2015.
- [139] Z. Ren, C.-m. Liu, H.-j. Lei, and J.-b. Li, "An Effective Energy-Saving Approach for Ferry Routing in Opportunistic Networks," in *Proceedings of the 2012 International Conference on Information Technology and Software Engineering*. Springer, 2013, pp. 109–117.
- [140] R. J. D'Souza and J. Jose, "Routing Approaches in Delay Tolerant Networks: A Survey," *International Journal of Computer Applications*, vol. 1, no. 17, pp. 8–14, February 2010, published By Foundation of Computer Science.
- [141] D. Jea, A. Somasundara, and M. Srivastava, "Multiple Controlled Mobile Elements (Data Mules) for Data Collection in Sensor Networks," in *Distributed Computing in Sensor Systems*. Springer, 2005, pp. 244–257.
- [142] Y. Gu, D. Bozdag, E. Ekici, F. Özgüner, and C.-G. Lee, "Partitioning based Mobile Element Scheduling in Wireless Ssensor Networks," in *SECON*. Citeseer, 2005, pp. 386–395.
- [143] R. Viswanathan, J. Li, and M. C. Chuah, "Message Ferrying for Constrained Scenarios," in *Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks*, June 2005, pp. 487–489.

- [144] M. C. P. Y. Chuah, "A Message Ferrying Scheme with Differentiated Services," November 2005.
- [145] K. A. Harras and K. C. Almeroth, "Inter-Regional Messenger Scheduling in Delay Tolerant Mobile Networks," in *Proceedings of the 2006 International Symposium on on World of Wireless, Mobile and Multimedia Networks*. IEEE Computer Society, 2006, pp. 93–102.
- [146] W. Zhao and M. H. Ammar, "Message Ferrying: Proactive Routing in Highly-Partitioned Wireless Ad hoc Networks," in *The Ninth IEEE Workshop on Future Trends of Distributed Computing Systems, 2003. FTDCS 2003. Proceedings.*, May 2003, pp. 308–314.
- [147] W. Zhao, M. Ammar, and E. Zegura, "Controlling the Mobility of Multiple Data Transport Ferries in A delay-Tolerant Network," in *Proceedings IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies.*, vol. 2, March 2005, pp. 1407–1418 vol. 2.
- [148] M. M. Bin Tariq, M. Ammar, and E. Zegura, "Message Ferry Route Design for Sparse Ad Hoc Networks with Mobile Nodes," in *Proceedings of the 7th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, ser. MobiHoc '06. New York, NY, USA: ACM, 2006, pp. 37–48. [Online]. Available: <http://doi.acm.org/10.1145/1132905.1132910>
- [149] H. Miura, D. Nishi, N. Matsuda, and H. Taki, *Message Ferry Route Design Based on Clustering for Sparse Ad hoc Networks*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 637–644. [Online]. Available: https://doi.org/10.1007/978-3-642-15390-7_66
- [150] T. Wang and C. P. Low, "Dynamic Message Ferry Route (dMFR) for Partitioned MANETs," in *2010 International Conference on Communications and Mobile Computing*, vol. 3, April 2010, pp. 447–451.
- [151] R. Jha and S. Iyer, "Mobile Agents for E-commerce," Master's thesis, KR School of Information Technology, Indian Institute of Technology, Bombay, 2002.
- [152] P. Kadera, "Methods for Development of Industrial Multi-Agent Systems," Ph.D. dissertation, Faculty of Electrical Engineering of Czech Technical University in Prague, 2015.
- [153] M. Baik, K. Yang, J. Shon, and C. Hwang, *Message Transferring Model between Mobile Agents in Multi-region Mobile Agent Computing Environment*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2003, pp. 517–526. [Online]. Available: http://dx.doi.org/10.1007/3-540-45036-X_52
- [154] K. Miller and G. Mansingh, "Comparing the Use of Mobile Intelligent Agents vs Client Server Approach in a Distributed Mobile Health Application," *Journal of Computers*, vol. 10, November 2015.

- [155] V. Kumari, P. Rajput, S. Pundhir, and M. Rafiq, "Web Crawler Based on Secure Mobile Agent," *Research Journal of Computer Systems Engineering*, vol. 3, no. 03, pp. 419–423, 2012.
- [156] R. S. Chowhan, "Mobile Agent Programming Paradigm and its Application Scenarios," *International Journal of Current Microbiology and Applied Sciences*, vol. 7, no. 5, pp. 3269–3273, 2018.
- [157] S. Bhattarai, "Development of A Security Framework for HTML5-Based Mobile Agents," Master's thesis, Tampere University of Technology, 2016.
- [158] S. Lee, "Mobile Agents," Agent based software engineering, University of Calgary, Tech. Rep., 2009.
- [159] B. Bhatia, M. Soni, and P. Tomar, "Role of Mobile Agents in the Layered Architecture of Mobile Ad-hoc Networks," *International Journal of Computer Network and Information Security*, vol. 7, no. 11, p. 37, 2015.
- [160] A. Belghiat, E. Kerkouche, A. Chaoui, and M. Beldjehem, "Mobile Agent-Based Software Systems Modeling Approaches: A Comparative Study," *Journal of computing and information technology*, vol. 24, no. 2, pp. 149–163, 2016.
- [161] S. Bendoukha, "Multi-Agent Approach for Managing Workflows in an Inter-Cloud Environment," Ph.D. dissertation, Faculty of Mathematics, Computer Science and Natural Sciences, Department of Computer Science, University of Hamburg, November 2016.
- [162] H. Tian and H. Shen, "Mobile Agents Based Topology Discovery Algorithms and Modelling," in *7th International Symposium on Parallel Architectures, Algorithms and Networks, 2004. Proceedings.*, May 2004, pp. 502–507.
- [163] K. Khanfar, "Mobile Agent: A Comparison Review," *International Journal of Computer Science and Mobile Computing*, vol. 4, pp. 122–127, July 2015.
- [164] V. K. Sharma and S. S. Bhadauria, "Agent based Congestion Control Routing for Mobile Ad-hoc Network," in *Trends in network and communications*. Springer, 2011, pp. 324–333.
- [165] A. D. G. L. S. Lutimath, Nagaraj M., "A Survey of Ant based Routing Algorithms for Mobile Ad- hoc Network," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 2, no. 8, August 2012, iSSN: 2277 128X.
- [166] R. RoyChoudhury, S. Bandyopadhyay, and K. Paul, "A Distributed Mechanism for Topology Discovery in Ad hoc Wireless Networks using Mobile Agents," in *Proceedings of the 1st ACM international symposium on Mobile ad hoc networking & computing*. IEEE Press, 2000, pp. 145–146.
- [167] N. Migas, W. J. Buchanan, and K. A. McCartney, "Mobile Agents for Routing, Topology Discovery, and Automatic Network Reconfiguration in Ad-hoc Networks," in *10th IEEE International Conference and Workshop on the Engineering of Computer-Based Systems, 2003. Proceedings.*, April 2003, pp. 200–206.

- [168] W. Chen and Y. Zhang, "A Multi-Constrained Routing Algorithm Based on Mobile Agent for MANET Networks," in *2009 International Joint Conference on Artificial Intelligence*, April 2009, pp. 16–19.
- [169] C. Borrego Iglesias, "A Mobile Code-based Multi-Routing Protocol Architecture for Delay and Disruption Tolerant Networking," Ph.D. dissertation, Universitat Autònoma de Barcelona. Departament d'Enginyeria de la Informàtica i les Comunicacions, March 2013.
- [170] C. Borrego and S. Robles, "A store-Carry-Process-and-Forward Paradigm for Intelligent Sensor Grids," *Information Sciences*, vol. 222, pp. 113–125, 2013.
- [171] R. Martínez-Vidal, S. Castillo-Pérez, S. Robles, M. Cordero, A. Viguria, and N. Giuditta, *Mobile-Agent Based Delay-Tolerant Network Architecture for Non-critical Aeronautical Data Communications*. Cham: Springer International Publishing, 2013, pp. 513–520. [Online]. Available: http://dx.doi.org/10.1007/978-3-319-00551-5_61
- [172] M. Nekovee and B. B. Bogason, "Reliable and Efficient Information Dissemination in Intermittently Connected Vehicular Adhoc Networks," in *2007 IEEE 65th Vehicular Technology Conference - VTC2007-Spring*, April 2007, pp. 2486–2490.
- [173] L. T. Blessing and A. Chakrabarti, *DRM: A Design Research Methodology*. Springer, 2009.
- [174] P. Offermann, O. Levina, M. Schönherr, and U. Bub, "Outline of A Design Science Research Process," in *Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology*. ACM, 2009, p. 7.
- [175] A. Habbal, "TCP Sintok: Transmission Control Protocol With Delay-based Loss Detection and Contention Avoidance Mechanisms for Mobile Ad Hoc Networks," Ph.D. dissertation, Universiti Utara Malaysia, 2014.
- [176] C. Hoffman, "Comprehensive Introduction to Intelligent Software Agents for Professional Accountants," August 2016.
- [177] O. Balci, "Verification Validation and Accreditation of Simulation Models," in *Proceedings of the 29th conference on Winter simulation*. IEEE Computer Society, 1997, pp. 135–141.
- [178] R. G. Sargent, "Verification and Validation of Simulation Models," in *Proceedings of the 37th conference on Winter simulation*. Winter Simulation Conference, 2005, pp. 130–143.
- [179] R. Jain, *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling*. Wiley, 1991. [Online]. Available: <https://books.google.iq/books?id=HetQAAAAMAAJ>
- [180] J. Mo, *Performance Modeling of Communication Networks with Markov Chains*. Morgan & Claypool Publishers, 2010.

- [181] J.-Y. Le Boudec, *Performance Evaluation of Computer and Communication Systems*. EPFL Press, Lausanne, Switzerland, 2010.
- [182] R. Jain, *The art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling*. John Wiley & Sons, 1990.
- [183] M. S. Obaidat and N. A. Boudriga, *Fundamentals of Performance Evaluation of Computer and Telecommunications Systems*. John Wiley & Sons, 2010.
- [184] Y. Yuan *et al.*, “Modeling and Simulation Best Practices for Wireless Ad hoc Networks,” in *Simulation Conference, 2003. Proceedings of the 2003 Winter*, vol. 1. IEEE, 2003, pp. 685–693.
- [185] K. Velten, *Mathematical Modeling and Simulation: Introduction for Scientists and Engineers*. John Wiley & Sons, 2009.
- [186] A. Doosti and A. M. Ashtiani, “Mathematical Modeling: A New Approach for Mathematics Teaching in Different Levels,” *Produtos Educacionais no ensino de Física e de Matemática*, 2009.
- [187] K. Soetaert, T. Petzoldt, R. W. Setzer *et al.*, “Solving Differential Equations in R: Package deSolve,” *Journal of Statistical Software*, vol. 33, no. 9, pp. 1–25, 2010.
- [188] J. Anzures-Cabrera and J. Higgins, “Graphical Displays for Meta-Analysis: An Overview with Suggestions for Practice,” *Research Synthesis Methods*, vol. 1, no. 1, pp. 66–80, 2010.
- [189] S. Bajaj, L. Breslau, D. Estrin, K. Fall, S. Floyd, P. Halder, M. Handley, A. Helmy, J. Heidemann, P. Huang *et al.*, “Improving Simulation for Network Research,” 1999.
- [190] E. Weingartner, H. vom Lehn, and K. Wehrle, “A Performance Comparison of Recent Network Simulators,” in *2009 IEEE International Conference on Communications*, June 2009, pp. 1–5.
- [191] O. Mohd Hasbullah, “An Innovative Signal Detection Algorithm in Facilitating The Cognitive Radio Functionality For Wireless Regional Area Network Using Singular Value Decomposition,” Ph.D. dissertation, Universiti Utara Malaysia, College of Arts Sciences, 2011.
- [192] S. Hassan, W. Elbreiki, M. Firdhous, and A. Monzer, “End-to-End Networks Vs Named Data Network: A Critical Evaluation,” *Jurnal Teknologi*, vol. 72, no. 5, 2015.
- [193] X. Chang, “Network simulations with OPNET,” in *Simulation Conference Proceedings, 1999 Winter*, vol. 1. IEEE, 1999, pp. 307–314.
- [194] 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.
- [195] A. Varga, "OMNeT++," *Modeling and Tools for Network Simulation*, pp. 35–59, 2010.
 - [196] K. Fall and K. Varadhan, "The Network Simulator (Ns-2)," URL: <http://www.isi.edu/nsnam/ns>, 2007.
 - [197] G. F. Riley and T. R. Henderson, "The ns-3 Network Simulator," *Modeling and tools for network simulation*, pp. 15–34, 2010.
 - [198] "Ns-3 networking simulator ns-3 model library," Tech. Rep., 2016. [Online]. Available: <https://www.nsnam.org/docs/models/ns-3-model-library>.
 - [199] G. F. Lucio, M. Paredes-Farrera, E. Jammeh, M. Fleury, and M. J. Reed, "OPNET Modeler and Ns-2: Comparing the Accuracy of Network Simulators for Packet-level Analysis using A Network Testbed," *WSEAS Transactions on Computers*, vol. 2, no. 3, pp. 700–707, 2003.
 - [200] 2015. [Online]. Available: <https://omnetpp.org/>
 - [201] J. Pan and R. Jain, "A Survey of Network Simulation Tools: Current Status and Future Developments," *Washington University in St. Louis, Tech. Rep*, 2008.
 - [202] M. Kumar and N. Babu, "A Simple Analysis on Novel Based Open Source Network Simulation Tools for Mobile Ad Hoc Networks," *Int. J. Adv. Res. Comput. Sci. Softw. Eng.*, vol. 3, no. 9, pp. 856–862, 2013.
 - [203] W. A. Kamil, R. Alubady, and S. A. Nor, "Simulation-based Performance of Transport Protocols Using MPEG-4 Traffics over 4G Network."
 - [204] H. Casanova, A. Giersch, A. Legrand, M. Quinson, and F. Suter, "Versatile, Scalable, and Accurate Simulation of Distributed Applications and Platforms," *Journal of Parallel and Distributed Computing*, vol. 74, no. 10, pp. 2899–2917, 2014.
 - [205] M. Hassan and R. Jain, *High Performance TCP/IP Networking*. Prentice Hall, 2003, vol. 29.
 - [206] Y. Harrati and A. Abdali, "MaxHopCount: A New Drop Policy to Optimize Messages Delivery Rate in Delay Tolerant Networks," *International Journal of Interactive Multimedia and Artificial Intelligence*, vol. 4, no. 1, 2017.
 - [207] S. A. Hadiwardoyo and A. J. Santos, "Deploying Public Surface Transit to Forward Messages in DTN," in *2015 International Wireless Communications and Mobile Computing Conference (IWCMC)*. IEEE, 2015, pp. 1329–1335.
 - [208] F. Li, C. Tian, T. Li, and Y. Wang, "Energy Efficient Social Routing Framework for Mobile Social Sensing Networks," *Tsinghua Science and Technology*, vol. 21, no. 4, pp. 363–373, 2016.

- [209] T. Abdelkader, K. Naik, and A. Nayak, "An Eco-friendly Routing Protocol for Delay Tolerant Networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2010 IEEE 6th International Conference on*. IEEE, 2010, pp. 450–457.
- [210] A. Gupta, "Routing in Delay Tolerant Networks (DTNs)," September 2013.
- [211] S. Dilip Tambe, M. Pramila, and P. Chawan, "Analytical Study of Spray and Wait Routing Protocol in Delay Tolerant Network," vol. 2, pp. 2348–7550, 07 2014.
- [212] M. Min and N. Oo, "Mobile Agent-based Information Retrieval for Shopping Assistant," *Proceedings of 2015 International Conference on Future Computational Technologies (ICFCT'2015)*, pp. 211–217, 2015.
- [213] K. Kouser and A. Sunita, "A comparative Study of K Means Algorithm by Different Distance Measures," *International Journal of Innovative Research in Computer and Communication Engineering*, vol. 1, 2013.
- [214] W. Wang, F. Guo, F. Zheng, W. Tang, and J. Wang, "Research on routing protocols and simulation analysis for opportunistic networks," *International Journal of Multimedia and Ubiquitous Engineering*, vol. 10, no. 3, 2015.
- [215] W. Zhao, "Routing and Network Design in Delay Tolerant Networks," Ph.D. dissertation, Georgia Institute of Technology, College of computing, December 2006.
- [216] G. Osman, "Scaleable and Smooth TCP-Friendly Receiver-Based Layered Multicast Protocol," Ph.D. dissertation, Universiti Utara Malaysia, 2008.
- [217] O. M. D. Al-Momani, "Dynamic Redundancy Forward Error Correction Mechanism for The Enhancement of Internet-based Video Streaming," Ph.D. dissertation, Universiti Utara Malaysia, 2010.
- [218] K. Massri, "Data Delivery in Delay Tolerant Networks," Ph.D. dissertation, Sapienza University of Rome, 2013.
- [219] A. El Shoghri, B. Kusy, R. Jurdak, and N. Bergmann, "Augur: A Delay Aware Forwarding Protocol for Delay-Tolerant Networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2015 IEEE 11th International Conference on*. IEEE, 2015, pp. 460–467.