it. When studying the graphs for dropping strategies, we observe that they use between 3.8 and 2.2 copies depending on strategy and buffer size. To achieve a high delivery ratio, a data object has to be resent after it has been dropped from the buffer. The difference to the Infinite Buffers case of 2.2 is due to the dropping strategy, when the dropped objects have to be copied again. With a smaller buffer size, more objects have to be dropped and replaced than for bigger buffer sizes. The No Buffer strategy does not have any relay buffer. The object is copied directly to the interested party. MF has the lowest overhead compared to other dropping strategies with a high delivery ratio. MF is also the strategy with the highest delivery ratio. To summarize, storage space is traded against forwarding overhead and with less objects dropped, less objects have to be resent.

6. RELATED WORK

Related congestion management work has been done in the area of host-centric Delay Tolerant Networking. In DTN, a node guarantees to forward a bundle (message) to a new custodian or deliver it to the destination. When a bundle is accepted, it cannot be dropped since there is no copy left at the sender. Seligman et al. propose to handle storage congestion at custody nodes by migrating bundles to alternative custodians [12]. Instead of migrating already stored bundles, Zhang et al. [13] propose a congestion management scheme that takes active decisions on whether to accept a custody bundle to avoid congestion. In our Haggle system, there is no commitment of guaranteed delivery, data objects are replicated in each forwarding step.

Balasubramanian et al. [1] and Krifa et al. [7, 6] have studied routing in a DTN as an allocation problem to avoid congestion and possible dropping of a bundle. Joint scheduling is done by using global information. Global information is either propagated through the network [1] or acquired by statistical learning [7, 6]. Both proposals can optimize dissemination to a specific metric, e.g., average delay or delivery probability.

Lindgren et al. [9] evaluate queuing policies based on local forwarding counters and transient forwarding probabilities, using PRoPHET. They show that probabilities can be used in buffer management to increase the delivery ratio. With weights reflecting the number of copies they also show how PRoPHET can be made more energy efficient per packet delivery. An evaluation is performed in a host-centric and intermittently connected network.

7. CONCLUSIONS

We have evaluated dropping strategies at congested nodes for data-centric opportunistic networks in different community scenarios. In such networks congestion avoidance, buffer handling, and choice of data object to drop must be based on local information. Nodes do not have complete information of the interests of other nodes in the network since Node Descriptions will only spread between nodes that share interests.

From the experimental evaluation, we conclude that the MF strategy (which drops the data object with the highest number of replications made at the local node) performs overall best with respect to delivery ratio, delay, and overhead at a congested node, i.e., when there is not enough buffer space for relaying objects. Furthermore, using local replication information when dropping gives a higher delivery rate compared to using local interest information. The strategy to randomly select a data object to drop comes surprisingly close to the best cases in our measurements. This shows that already with a small relay buffer, performance gains can be achieved with a dropping strategy where data objects often are exchanged.

8. ACKNOWLEDGMENTS

This research was funded by the ResumeNet project under the EU grant FP7-224619 and the Haggle project under the EU grant IST-4-027918.

9. REFERENCES

[1] A. Balasubramanian, B. Levine, and A. Venkataramani. DTN routing as a resource allocation problem. *SIGCOMM Comput. Commun. Rev.*, 37(4):373–384, 2007.

[2] P. R. Barham, B. Dragovic, K. A. Fraser, S. M. Hand, T. L. Harris, A. C. Ho, E. Kotsovinos, A. V.S. Madhavapeddy, R. Neugebauer, I. A. Pratt, and A. K. Warfield. Xen 2002. Technical Report UCAM-CL-TR-553, University of Cambridge, Computer Laboratory, January 2003.

[3] F. Bjurefors, P. Gunningberg, E. Nordström, and C. Rohner. Interest dissemination in a searchable data-centric opportunistic network. In *European Wireless Conference, 2010*, pages 889–895, 2010.

[4] S. Floyd and V. Jacobson. Random early detection gateways for congestion avoidance. *IEEE/ACM Trans. Netw.*, 1:397–413, August 1993.

[5] P. Hui and J. Crowcroft. Bubble rap: Forwarding in small world DTNs in ever decreasing circles, 2007.

[6] A. Krifa, C. Barakat, and T. Spyropoulos. Optimal Buffer Management Policies for Delay Tolerant Networks. In *SECON*, page 10, 2008.

[7] A. Krifa, C. Barakat, and T. Spyropoulos. An optimal joint scheduling and drop policy for delay tolerant networks. In *WoWMoM*, pages 1–6. IEEE Computer Society, 2008.

[8] V. Lenders, G. Karlsson, and M. May. Wireless ad hoc podcasting. In *SECON*, June 2007.

[9] A. Lindgren and K.S. Phanse. Evaluation of queueing policies and forwarding strategies for routing in intermittently connected networks. In *COMSWARE, 2006*, pages 1–10, 2006.

[10] E. Nordström, P. Gunningberg, and C. Rohner. Haggle: a data-centric network architecture for mobile devices. In *MobiHoc S3 '09*, pages 37–40. ACM, 2009.

[11] J. Scott, P. Hui, J. Crowcroft, and C. Diot. Haggle: A networking architecture designed around mobile users. In *IFIP WONS 2006*, 2006.

[12] M. Seligman, K. Fall, and P. Mundur. Alternative custodians for congestion control in delay tolerant networks. In *CHANTS '06*, pages 229–236. ACM, 2006.

[13] G. Zhang, J. Wang, and Y. Liu. Congestion management in delay tolerant networks. In *WICON '08*, pages 1–9. ICST, 2008.