Mobility Tracking for Energy-Conserving Routing in Wireless Ad Hoc Networks: Empirical Bounds

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Abstract— **This paper concerns the benefits of using motion tracking for selecting energy-conserving routes in delay-tolerant applications. We start from Grossglauser and Tse's observation that delay can be traded for energy efficiency in selecting a route. Our goal is to find an empirical upper bound on the energy savings by assuming that each node accurately knows or predicts its future trajectory. We investigate the effect of varying the amount of future information on routing. Such a bound may prove useful in deciding how far to look ahead, and thus how much complexity to invest in mobility tracking.**

I. Introduction

Wireless ad hoc networks (henceforth *WN*s) are a class of peer-to-peer reconfigurable wireless networks. In general, any pair of connected nodes may communicate with one another, using intermediate nodes to store and forward frames. The curse of having a flat hierarchy is that the capacity of the network is expended forwarding other nodes' data [5].

In this paper, we focus on WNs with a large number of nodes with delay-tolerant applications. Under these circumstances, suitably delaying forwarding can greatly increase the transport capacity or, equivalently, the lifetime of the network [4].

II. Routing

Faced with the task of establishing a route in a WN, one's first thought might be to apply a table-driven shortest-path algorithm. While this works in small networks with slowly moving nodes, it is not efficient. When location information is available, such as offered by GPS, another option is to use geographic routing [14], [19]. The algorithm's intuitive appeal has won it popularity; the essence of the method is simply to forward frames in the direction of the destination. When this is not possible, a contingency plan is employed, often at a steep cost in traffic and delay, or the link is dropped.

III. Mobility Tracking

By mobility tracking we refer to the act of keeping track of a node's position in order to estimate where it will be in the future. In the simple case, which we study here, each node tracks only itself. In the general case, each node tracks some other nodes, using a distributed algorithm. Research on mobility tracking in the context of WNs has usually focused on dead reckoning [11], [17], only recently considering more sophisticated approaches involving machine learning [1], [18]. Greater attention has been paid to this issue by the robotics community [2], [20] and the pervasive computing community [7], [12].

IV. Scalability Issues

Routing in WNs, especially with a large number of nodes, requires a different approach from those in fixed networks. The reason is that conventional routing algorithms attempt to minimize the number of hops without concern for the overhead incurred by the routing algorithm's traffic. This strategy is not successful in WNs because the routing overhead consitutes a greater fraction of the overall traffic. So much so, that it imposes a fundamental limit on the scalability of WNs [5], [6], [8]–[10], [13], [15]. Furthermore, different applications may demand optimizing different metrics (e.g., throughput, delay, reliability, network lifetime). The rapidly changing topology exacerbates the problem, as the location manager struggles to maintain accurate estimates of the nodes' location. This assumes that reducing the end-to-end delay is a priority. If not, then it is actually possible to increase the transport capacity [5] by using diversity routing [4] or diversity coding [16].

V. Algorithm

To the best of our knowledge, the closest results are those of Perevalov and Blum, where they analyze the impact of delay on throughput in [16]. However, they assume that only one intermediate is forwarded through and that diversity routing and diversity coding are used, as originally suggested by Grossglauser and Tse [4]. In contrast, we are interested in characterizing the energy savings by providing future location information, for two cases:

1) Only one's own future is known.
2) The future of one's neighbors is also known.

Our goal is simply to make the best forwarding decision for geographic routing (i.e., next hop) in order to extend the lifetime of the network. We intend to determine the energy savings of a simulated WN with respect to the amount of future knowledge and maximum permissible delay. We consider the network lifetime [3] and the end-to-end route power [21].

VI. Future Work

This paper is a first step towards developing a distributed mobility tracking algorithm. The next step is to use machine learning algorithms, and compare their results with the upper bound. A metric should be developed to compare the efficacy of the algorithms, while accounting for their complexities. Efforts to this end are under way.

For even greater savings, mobility tracking may be augmented by the following machine learning methods:

- Traffic-tracking: to avoid channel contention.
- Energy-tracking: to maintain connectivity by knowing how much battery is left.
- Map-construction: to avoid dead ends with geographic routing.

REFERENCES

[1] ABDELSALAM, W. AND EBRAHIM, Y., *Managing Uncertainty: Modeling Users in Location-Tracking Applications*, IEEE Pervasive Computing, vol. 3, no. 3, pp. 60–65, Jul./Sep. 2004 DOI:10.1109/MPRV.2004.1321030 [PDF].

[2] BENNEWITZ, M., BURGARD, W., CIELNIAK, G. AND THRUN, S., *Learning Motion Patterns of People for Compliant Robot Motion*, The International Journal of Robotics Research, vol. 24, no. 1, pp. 31–48, Jan. 2005 DOI:10.1177/0278364904048962 [PDF].

[3] CHANG, J.-H. AND TASSIULAS, L., *Energy Conserving Routing in Wireless Ad-Hoc Networks*, Proceedings of the 19. IEEE INFOCOM (Tel Aviv, Israel), vol. 1, pp. 22–31, Mar. 26–30 2000 DOI:10.1109/INFCOM.2000.832170 [PDF].

[4] GROSSGLAUSER, M. AND TSE, D. N., *Mobility Increases the Capacity of Ad-hoc Wireless Networks*, ACM/IEEE Transactions on Networking, vol. 10, no. 4, pp. 477–486, Aug. 2002 DOI:10.1109/TNET.2002.801403 [PDF].

[5] GUPTA, P. AND KUMAR, P. R., *The Capacity of Wireless Networks*, IEEE Transactions on Information Theory, vol. 46, no. 2, pp. 388–404, Mar. 2000 DOI:10.1109/18.825799 Corrections in [10].

[6] GUPTA, P. AND KUMAR, P. R., *Towards an Information Theory of Large Networks: An Achievable Rate Region*, IEEE Transactions on Information Theory, vol. 49, no. 8, pp. 1877–1894, Aug. 2003 DOI:10.1109/TIT.2003.814480 [PDF].

[7] HIGHTOWER, J. AND BORRIELLO, G., *Particle Filters for Location Estimation in Ubiquitous Computing: A Case Study*, *Lecture Notes in CS*, vol. 3205, pp. 88–106, Springer-Verlag, Oct. 2004 [Online] [PDF] (Proc. UbiComp 2004).

[8] JOVIČIĆ, A., VISWANATH, P. AND KULKARNI, S. R., *Upper Bounds to Transport Capacity of Wireless Networks*, IEEE Transactions on Information Theory, vol. 50, no. 11, pp. 2555–2565, Nov. 2004 DOI:10.1109/TIT.2004.836936 [PDF].

[9] KAIL, E., NÉMETH, G. AND TURÁNYI, Z. R., *Throughput of Ideally Routed Wireless Ad Hoc Networks*, Proceedings of the 2. IEEE/ACM MobiHoc (Long Beach, CA), pp. 271–274, Oct. 4–5 2001 DOI:10.1145/501449.501457 [PDF].

[10] KUMAR, P. R., *A Correction to the Proof of a Lemma in "The capacity of wireless networks"*, IEEE Transactions on Information Theory, vol. 49, no. 11, pp. 3117, Nov. 2003 DOI:10.1109/TIT.2003.818407 [PDF].

[11] KUMAR, V. AND DAS, S. R., *Performance of Dead Reckoning-Based Location Service for Mobile Ad Hoc Networks*, Wiley Wireless Communications and Mobile Computing, vol. 4, no. 2, pp. 189–202, Mar. 2004 DOI:10.1002/wcm.163 [PDF].

[12] KWOK, C., FOX, D. AND MEILĂ, M., *Real-Time Particle Filters*, Proceedings of the IEEE, vol. 92, no. 3, pp. 469–484, Mar. 2004 DOI:10.1109/JPROC.2003.823144 [PDF].

[13] LÉVÊQUE, O. AND TELATAR, I. E., *Information-Theoretic Upper Bounds on the Capacity of Large Extended Ad Hoc Wireless Networks*, IEEE Transactions on Information Theory, vol. 51, no. 3, pp. 858–865, Mar. 2005 DOI:10.1109/TIT.2004.842576 [PDF].

[14] MAUVE, M., WIDMER, J. AND HARTENSTEIN, H., *A Survey on Position-Based Routing in Mobile Ad Hoc Networks*, IEEE Network, vol. 15, no. 6, pp. 30–39, Nov./Dec. 2001 DOI:10.1109/65.967595 [PDF].

[15] NEELY, M. J. AND MODIANO, E., *Capacity and Delay Tradeoffs for Ad-Hoc Mobile Networks*, IEEE Transactions on Information Theory, vol. 51, no. 6, Jun. 2005 [Online] [PDF] Accepted for publication.

[16] PEREVALOV, E. AND BLUM, R. S., *Delay-Limited Throughput of Ad Hoc Networks*, IEEE Transactions on Communications, vol. 52, no. 11, pp. 1957–1968, Nov. 2004 DOI:10.1109/TCOMM.2004.836587 [PDF].

[17] SON, D., HELMY, A. AND KRISHNAMACHARI, B., *The Effect of Mobility-Induced Location Errors On Geographic Routing In Mobile Ad Hoc Sensor Networks: Analysis and Improvement Using Mobility Prediction*, IEEE Transactions on Mobile Computing, vol. 3, no. 3, pp. 233–245, Jul./Aug. 2004 DOI:10.1109/TMC.2004.28 [PDF].

[18] SONG, L., KOTZ, D., JAIN, R. AND HE, X., *Evaluating Location Predictors with Extensive Wi-Fi Mobility Data*, Proceedings of the 23. IEEE INFOCOM, pp. 1414–1424, Mar. 7–11 2004 [Online] [PDF].

[19] STOJMENOVIC, I., *Position-Based Routing Algorithms in Ad Hoc Networks*, IEEE Communications Magazine, vol. 40, no. 7, pp. 128–134, Jul. 2002 DOI:10.1109/MCOM.2002.1018018 [PDF].

[20] VASQUEZ, D. AND FRAICHARD, T., *Motion Prediction for Moving Objects: A Statistical Approach*, Proceedings of the IEEE ICRA, vol. 4, pp. 3931–3936, Apr. 26–1 May 2004 [Online] [PDF].

[21] XUE, Y. AND LI, B., *A Location-Aided Power-Aware Routing Protocol in Mobile Ad Hoc Networks*, Proceedings of the 44. IEEE GLOBECOM (San Antonio, TX), vol. 5, pp. 2837–2841, Nov. 25–29 2001 DOI:10.1109/GLOCOM.2001.965947 [PDF].