Minimum Energy Broadcast problem in MANETs

C. Aboue-Nze[1], F. Guinand[1], and Y. Pigné[2]

[1] LITIS - Universit du Havre, 76600 Le Havre
{Frederic.Guinand,Cedric.Aboue-Nze}@univ-lehavre.fr
[2] University of Luxembourg Yoann.Pigne@uni.lu

1 Introduction

Mobile ad hoc networks are composed of mobile devices with limited power resources. Within such networks, stations may use omnidirectional antennas for communicating, such that, if a station u sends a message to a station v then, all nodes located around u, its *neighbors*, can potentially also receive that message. When dealing with energy-saving problems, this property is often called the *wireless multicast advantage*. For stations located far away from the sender, some intermediate nodes, relaying the messages, are needed. Such long-distance communications are said *multi-hops*, and direct neighbors of a stations are called its *1-hop neighbors*. In this paper we are interested in the minimization of energy needed for broadcasting information in a wireless mobile ad-hoc network. When dealing with green computing in wireless ad hoc networks, there exist at least two ways of saving energy: acting on the activity periods of the devices, a.k.a. power mode control, or transmission power control. We focus on the latter. In that context, one important hypothesis is that the power consumption of a station is function of the transmission power which is directly related to the transmission radius (or range) of the station. Thus, performing energy-efficient collective communications like one-to-all (broadcast) or one-to-many (multicast), is a trade-off between long-distance high energy communications reaching many nodes, and short-distance low energy communications reaching less nodes. The problems associated to this trade-off are known as the *minimum energy broadcast/multicast* problems MEB/MEM, also called MPB/MPM (*minimum power broadcast/multicast*). This problem has been proved to be NP-complete [3], hence, existing works consider either exact methods [4, 10] or heuristics.Since 2000, MEB/MEM have been extensively studied. Wieselthier, Nguyen and Ephremides have first proposed a heuristic named *Broadcast Incremental Power* (BIP) for this problem [1]. This iterative greedy algorithm starts from the source node and add to the tree at least one new node at each step. During one step, the algorithm determines the minimum additional power cost to reach at least one new node taking into consideration all the nodes currently belonging to the tree. When the tree is built, another algorithm is applied (called *sweep operation*) to remove unnecessary transmissions in order to reduce the total energy consumption. A performance evaluation of this algorithm was presented in [2]. Since then, many works have been devoted to that problem, investigating classical metaheuristic resolution methods like ant colony optimization [5], simulated annealing [6], etc.[3], however none of them takes into account the mobility of the stations. To our knowledge, the only works dealing with MEB/MEM with mobility are those of Guo and Yang [8] and the one of Wu *et al.* [7]. The problem considered in [7] is not exactly MEM, but they propose a model for dealing with mobility. Their graph-model called *time-lined graph* is a time-oriented layered-graph in which each layer corresponds to the state of the connection graph at a given time step. Due to causality, layers are time-ordered. We propose to consider another model for taking mobility into account: the *evolving graph* model [12].

2 Minimum-Energy Broadcast problem with Mobility

An evolving graph is a structure compiling the whole dynamics of a network by labelling vertices and edges by dates corresponding to periods of presence of such elements in the network. Alternatively, an evolving graph may be defined as "an indexed sequence of subgraphs of a given graph, where the subgraph at a given index point corresponds to the network connectivity at the time interval indicated by the index number" [11]. This model is not directly usable for our problem

[3] see [9] for a survey for the period 2000-2007

since the presence of edges directly depends on the nodes' positions and on the transmission radius of the nodes which are part of the problem description. In [11] the authors consider a dynamic network in which nodes and edges can go to sleep and wake-up according to a fixed time schedule. In that configuration, power mode control and no mobility, the determination of a minimum spanning tree is an NP-Hard problem. The problem we are interested in is the minimization of energy for broadcasting when a fixed set of n stations move around in a square area. In the static context, we consider a set of n wireless-enable stations equipped with omnidirectional antennas located in a square area. All the stations are identical. We neglect the energy used for processing and for signal reception, only the transmission is counted. The transmission power is limited to a maximum value $p_{\max}$. The signal received by a station t from a source s is equal to $\frac{p_s}{d^{\alpha}_{s,t}}$, where $d_{s;t}$ is the euclidian distance between s and t, p_s is the transmission power of s and α $(2 \leq \alpha \leq 4)$ is a signal weakening factor. Without loss of generality, the signal is considered received by t if and only if $\frac{p_s}{d^{\alpha}_{s,t}} \geq 1$, thus, $p_s \geq d^{\alpha}_{s,t}$. Let us denote $\mathcal{S}$ the set of nodes and $\mathcal{P} = \{p_i \mid i \in \mathcal{S}\}$ the set of transmission power of the nodes. If d_{ij} denotes the distance between node i and node j, then: $\mathcal{P}$ is a solution to the problem if and only if $\forall i \in \mathcal{S}, \exists j \in \mathcal{S},$ such that $p_j \geq d^{\alpha}_{i,j}$. The goal of the optimization problem is to determine the best solution $\mathcal{P}$ such that $\sum_{i \in \mathcal{S}} p_i$ is minimum.

For the formulation of the dynamic version of the problem, we consider evolving graphs with edges labelled with couples (time instant,distance). We assume that the broadcast can be achieved during one time instant corresponding to a subgraph of the evolving graph, as soon as this subgraph is connected. But the broadcast can also be achieved during a longer time interval and nodes may transmit information several times (at most one per time instant), and at different transmission power. We propose several heuristics for computing solutions. In the first one, only the source is able to transmit information. The second one is an improved version of the *broadcast incremental power* method [1] based on the construction of a multicast tree from the set of multicast trees built at each time instant by the *BIP* method. Finally, the obtained trees are improved by a local search procedure. Computions and simulations are currently under progress and results will be presented at the conference.

References

1. J. E. Wieselthier, G. D. Nguyen and A. Ephremides. On the construction of energy-efficient broadcast and multicast trees in wireless networks. Proceedings of Infocom 2000. Pages 585-594.
2. P.-J. Wan, G. Calinescu, X.-Y. Li, and O. Frieder. Minimum Energy Broadcast Routing in Static Ad Hoc Wireless Networks. ACM/Springer Wireless Networks. Vol. 8, number 6, pages 607-617. 2002.
3. Mario Cagalj Jean-Pierre Hubaux Christian Enz. Minimum-Energy Broadcast in All-Wireless Networks: NP-Completeness and Distribution Issues. Proceedings of ACM MobiCom, pages 172-182. 2002.
4. Arindam K. Das, Robert J. Marks, Mohamed El-Sharkawi, Payman Arabshahi, Andrew Gray. Minimum Power Broadcast Trees for Wireless Networks: Integer Programming Formulations. Proceedings of Infocom 2003.
5. Arindam K. Das, Robert J. Marks, Mohamed El-Sharkawi, Payman Arabshahi, Andrew Gray. The Minimum Power Broadcast Problem in Wireless Networks: an Ant Colony System Approach. Proceedings of IEEE CAS workshop on wireless communications and networking. 2002.
6. Roberto Montemanni and Luca Maria Gambardella and Arindam K. Das. The Minimum Power Broadcast problem in Wireless Networks: a Simulated Annealing approach. In Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC), vol. 4, pages 2057-2062. 2005.
7. Y. Wu, P. A. Chou, S.-Y. Kung. Minimum-Energy Multicast in Mobile Ad Hoc Networks using Network Coding. IEEE Transactions on Communications. Vol. 53, No. 11, pp. 1906-1918, 2005.
8. Song Guo, Victor Leung, Oliver Yang. A Distributed Minimum Energy Multicast Algorithm in MANETs. Proceedings of WoWMoM, pp.134-142, 2006.
9. Song Guo and Oliver W.W. Yang. Energy-aware multicasting in wireless ad hoc networks: A survey and discussion. Computer Communications. Vol. 30, pages 2129-2148. 2007.
10. Valeria Leggieri, Paolo Nobili and Chefi Triki. Minimum Power Multicasting problem in Wireless Networks. Mathematical Methods of Operations Research 68(2), pp. 295-311, 2008.
11. Afonso Ferreira and Aubin Jarry. Complexity of Minimum Spanning Tree in Evolving Graphs and the Minimum-Energy Broadcast Routing Problem. Proceedings of WiOpt. 2004.
12. Afonso Ferreira. Building a Reference Combinatorial Model for MANETs. IEEE Networks. Vol. 18, No 5, pages 24-29. 2004.