Optimal and Near-Optimal Energy-Efficient Broadcasting in Wireless Networks

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Abstract. In this paper we propose an energy-efficient broadcast algorithm for wireless networks for the case where the transmission powers of the nodes are fixed. Our algorithm is based on the multicost approach and selects an optimal energy-efficient set of nodes for broadcasting, taking into account: i) the node residual energies, ii) the transmission powers used by the nodes, and iii) the set of nodes that are covered by a specific schedule. Our algorithm is optimal, in the sense that it can optimize any desired function of the total power consumed by the broadcasting task and the minimum of the current residual energies of the nodes, provided that the optimization function is monotonic in each of these parameters. Our algorithm has non-polynomial complexity, thus, we propose a relaxation producing a near-optimal solution in polynomial time. Using simulations we show that the proposed algorithms outperform other established solutions for energy-aware broadcasting with respect to both energy consumption and network lifetime. Moreover, it is shown that the near-optimal multicost algorithm obtains most of the performance benefits of the optimal multicost algorithm at a smaller computational overhead.

1 Introduction

The cooperative nature of both ad hoc and sensor networks, makes broadcasting one of the most frequently performed primitive communication tasks, used for example in order to disseminate topology information and data collected by the sensors, respectively for each class of networks. Being able to perform these communication tasks in an energy-efficient manner is an important priority for such networks.

We study broadcasting in static wireless networks consisting of nodes that have different but fixed levels of transmission power. Much of the previous related work assumes that nodes are able to adjust their transmission power to any desired level. It is quite common that the nodes comprising ad hoc or sensor networks are not able to dynamically adjust their transmission power, since their processing capabilities are inherently minimal. Therefore, the case of wireless networks with preconfigured transmission power levels at their nodes is a practical issue worth studying.

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In this paper we propose an optimal energy efficient broadcasting algorithm, called Optimal Total and Residual Energy Multicost Broadcast (abbreviated OTREMB) algorithm, for wireless networks consisting of nodes with preconfigured levels of transmission power. Our algorithm is optimal, in the sense that it can optimize any desired function of the total power consumed by the broadcasting task and the minimum of the current residual energies of the nodes, provided that the optimization function is monotonic in each of these parameters. The proposed algorithm takes into account these two energy-related parameters in selecting the optimal sequence of nodes for performing the broadcast, but it has non-polynomial complexity. We also present a relaxation of the optimal algorithm, to be referred to as the Near-Optimal Total and Residual Energy Multicost Broadcast (abbreviated NOTREMB) algorithm, that produces a near-optimal solution to the energy-efficient broadcasting problem in polynomial time.

The performance of the proposed algorithms is evaluated through simulations. We compare the optimal and near-optimal algorithms to other representative algorithms for energy-efficient broadcasting. Our results show that the proposed algorithms outperform the other algorithms by making better use of the network energy reserves. Another important result is that the near-optimal algorithm performs comparably to the optimal algorithm, at a significantly lower computation cost.

The remainder of the paper is organized as follows. In Section 2 we discuss prior related work. In Sections 3 and 4 we present the optimal and near-optimal algorithms introduced in this paper for energy-efficient broadcasting. In Section 5 the simulations setting is outlined and the performance results are presented. Finally, in Section 6 we give the conclusions drawn from our work.

2 Related Work

Energy-efficiency in all types of communication tasks (unicast, multicast, broadcast) has been considered from the perspective of either minimizing the total energy consumption or maximizing the network lifetime. Most versions of both optimization problems are NP-hard [1,2,3]. Two surveys summarizing much of the related work in the field can be found in [4,5].

A major class of works in the field start with an empty solution which is gradually augmented to a broadcast tree. A seminal work presenting a series of basic energy-efficient broadcasting algorithms, like Minimum Spanning Tree, Shortest Path Tree and Broadcast Incremental Power (BIP), is [7]. The BIP algorithm maintains a single tree rooted at the source node, and new nodes are added to the tree, one by one, on a minimum incremental cost basis. In Broadcast Average Incremental Power (BAIP) algorithm [8] many new nodes can be added at the same step with the average incremental cost defined as the ratio of the minimum additional power required by a node in the current tree to reach these new nodes to the number of new nodes reached. The Greedy Perimeter

Broadcast Efficiency (GPBE) algorithm [9] uses another greedy decision metric, defined as the number of newly covered nodes reached per unit transmission power. In [10], the Minimum Longest Edge (MLE) and the Minimum Weight Incremental Arborescence (MWIA) algorithms are presented. The MLE first computes a minimum spanning tree using as link costs the required transmission powers and then removes redundant transmissions. In MWIA, a broadcast tree is constructed using as criterion a weighted cost that combines the residual energy and the transmission power of each node. In [11], the Relative Neighborhood Graph (RNG) topology is used for broadcasting. In Local Minimum Spanning Tree (LMST) [12] each node builds a one-hop minimum spanning tree. A link is included in the final graph if it selected in the local MSTs of both its edge nodes. In [13] a localized version of the BIP algorithm is presented.

All the aforementioned works assume adjustable node transmission power. One of the few papers that assumes preconfigured power levels for each node is [14], where two heuristics for the minimum energy broadcast problem are proposed: a greedy one, where the criterion for adding a new node in the tree is the ratio of the expended power over the number of the nodes covered by the transmission, and a node-weighted Steiner tree based algorithm.

Local search algorithms perform a walk on broadcast forwarding structures. The walk starts from an initial broadcast topology obtained by some algorithm and in each step, a local search algorithm moves to a new broadcast topology so that the necessary connectivity properties are maintained. The rule used at each step for selecting the next topology is energy-related and the algorithm terminates when no further improvement can be obtained. In [7], the Sweep heuristic algorithm was proposed to improve the performance of BIP by removing transmissions that are unnecessary, due to the wireless broadcast advantage. Iterative Maximum-Branch Minimization (IMBM) [15] starts with a trivial broadcast tree where the source transmits directly to all other nodes and at each step replaces the longest link with a two-hop path that consumes less energy. In [1], EWMA is proposed that modifies a minimum spanning tree by checking whether increasing a node's power so as to cover a child of one of its children, would lead to power savings. The r-Shrink heuristic [16] is applied to every transmitting node and shrinks its transmission radius so that less than r nodes hear each transmission. The LESS heuristic [17] permits a slight increase in the transmission power of a node so that multiple other nodes can stop transmitting or reduce their transmission power.

3 The Optimal Total and Residual Energy Multicost Broadcast Algorithm

The objective of the Optimal Total and Residual Energy Multicost Broadcasting (OTREMB) algorithm is to find, for a given source node, an optimal sequence of nodes for transmitting, so as to implement broadcasting in an energy-efficient way. In particular, it selects a transmission schedule that optimizes any desired function of the total power T consumed by the broadcasting task and the minimum R of the residual energies of the nodes, provided that the optimization function used is monotonic in each of these parameters, T and R.

The OTREMB algorithm's operation consists of two phases, in accordance with the general multicost algorithm [18] on which it is based. In the first phase, the source node u calculates a set of candidate node transmission sequences $\mathcal{S}_u$, called set of non-dominated schedules, which can send to all nodes any packet originating at that source. In the second phase, the optimal sequence of nodes for broadcasting is selected based on the desired optimization function..

3.1 The Enumeration of the Candidate Broadcast Schedules

In the first phase of the OTREMB algorithm, every source node u maintains at each time a set of candidate broadcast schedules $\mathcal{S}_u$. A broadcast schedule $S \in \mathcal{S}_u$ is defined as $S = \{(u_1 = u, u_2, \ldots, u_h), V_S\}$, where $(u_1, u_2, \ldots, u_h)$ is the ordered sequence of nodes used for transmission and $V_S = (R_S, T_S, P_S)$ is the cost vector of the schedule, consisting of: the minimum residual energy R_S of the sequence of nodes $u_1, u_2, \ldots, u_h$, the total power consumption T_S caused when these nodes are used for transmission and the set P_S of network nodes covered when nodes $u_1, u_2, \ldots, u_h$ transmit a packet.

When node u_i transmits a packet at distance r_i, the energy expended is taken to be proportional to r_i^a, where a is a parameter that takes values between 2 and 4. Because of the broadcast nature of the medium and assuming omni-directional antennas, a packet being sent or forwarded by a node can be correctly received by any node within range r_i of the transmitting node u_i. Therefore, broadcast communication tasks in these networks correspond to finding a sequence of transmitting nodes, instead of a sequence of links as it is common in the wireline world. The assumption of omni-directional antennas is not necessary for the proposed algorithms to work, provided that we know the set of nodes $D(u_i)$ that can correctly decode a packet transmitted by node u_i; the performance results to be presented in Section 5, however, assume that omni-directional antennas are used.

In general, the routing process, regardless of whether unicasting, multicasting or broadcasting is performed, involves two levels: the information exchange level and the algorithmic level. Information exchange protocols deal with collecting and disseminating network state information, while algorithms calculate the optimal way to perform the desired communication task using this information. Our focus is on the broadcast algorithmic level and do not consider issues regarding the collection of the network information. This way we give lower bounds on the energy efficiency of the proposed solutions.

Initially, each source node u has only one broadcast schedule $\{\emptyset, (\infty, 0, u)\}$, with no nodes, infinite node residual energy, zero total power consumption, while the set of covered nodes contains only the source. The candidate broadcast schedules from source node u are calculated as follows:

1. Each broadcast schedule $S = \{(u_1, u_2, \ldots, u_{i-1}), (R_S, T_S, P_S)\}$ in the set of non-dominated schedules $\mathcal{S}_u$ is extended, by adding to its sequence of transmitting nodes a node $u_i \in P_S$ that can transmit to some node u_j not contained in P_S. If no such nodes u_i and u_j exist, we proceed to the final step.

   Then the schedule S is used to obtain an extended schedule S' as follows:
   - node u_i is added to the sequence $u_1, u_2, \ldots, u_{i-1}$ of transmitting nodes
   - $R_{S'} = \min(R_i, R_S)$, where R_i is the residual energy of node u_i
   - $T_{S'} = T_S + T_i$, where T_i is the (fixed) transmission power of node u_i
   - the set of nodes $D(u_i)$ that are within transmission range from u_i are added to the set P_S.
   - the extended schedule $S' = \{(u_1, \ldots, u_{i-1}, u_i), (\min(R_S, R_i), T_S + T_i, P_S \cup D(u_i))\}$ obtained in the way described above is added to the set $\mathcal{S}_u$ of candidate schedules.
2. Next, a *domination relation* between the various broadcast schedules of source node u is applied, and the schedules found to be dominated are discarded. In particular, a schedule S_1 is said to *dominate* a schedule S_2 when $T_1 < T_2$, $R_1 > R_2$ and $P_1 \supset P_2$. In other words schedule S_1 dominates schedule S_2 if it covers a superset of nodes than the one covered by S_2, using less total transmission power and with larger minimum residual energy on the nodes it uses. All the schedules found to be dominated by another schedule are discarded from the set $\mathcal{S}_u$.
3. The procedure is repeated, starting from the first step 1, for all broadcast schedules in $\mathcal{S}_u$ that meet the above conditions. If no schedule $S \in \mathcal{S}_u$ can be extended further, we go to the final step.
4. Among the schedules in $\mathcal{S}_u$ we form the subset of schedules S for which P_S includes all network nodes. This subset is called the *set of non-dominated schedules* for broadcasting from source node u, and is denoted by $\mathcal{S}_{u,\mathcal{B}}$.

Note that the node residual energy is a restrictive cost parameter, since its minimum value on the nodes used by a schedule defines the schedule's residual energy, while the node transmission power is an additive cost parameter. This is because the residual energy on a set of nodes is more accurately characterized by its minimum value among all nodes in the set, while the power consumed by a set of nodes is described by the sum of their transmission powers.

3.2 The Selection of the Optimal Broadcast Schedule

In the second phase of the OTREMB algorithm, an optimization function $f(V_S)$ is applied to the cost vector V_S of every non-dominated schedule $S \in \mathcal{S}_{u,\mathcal{B}}$ of source node u, produced in the first phase. The optimization function combines the cost vector parameters to produce a scalar metric representing the cost of using the corresponding sequence of nodes for broadcasting. The schedule with the minimum cost is selected. In the performance results described in Section 5, the optimization function used is

$$f(S) = \frac{T_S}{R_S}, \text{for } S \in \mathcal{S}_{u,\mathcal{B}},$$

which favors, among the schedules that cover all nodes, those that consume less total energy T_S and whose residual energy R_S is larger.

Other optimization functions could also be used, depending on the interests of the network. Also, our algorithm, with straight-forward modifications, can include parameters other than the transmission power and the residual energies of the nodes. For example, we can include as a cost parameter the number h_S of transmissions required by schedule S to complete the broadcast (which is also related to the broadcast delay, in the absence of other traffic and queueing delays in the network), and the optimization function used could also incorporate this parameter when deciding the optimal schedule. The only requirement is that the optimization function has to be monotonic in each of its parameters (e.g., an increasing function of T_S and h_S, a decreasing function of R_S, etc).

Theorem 1. *If the optimization function $f(V_S)$ is monotonic in each of the parameters involved, the OTREMB algorithm finds the optimal broadcast schedule.*

Proof. Since $f(V_S)$ is monotonic in each of its parameters, the optimal schedule has to belong to the set of non-dominated schedules (a schedule S_1 that is dominated by a schedule S_2, meaning that it is worse than S_2 with respect to all the parameters, cannot optimize f). Therefore, it is enough to show that the set $\mathcal{S}_u$ computed in Steps 1-3 of OTREMB includes all the non-dominated schedules for broadcasting from node u.

We let $S = ((u_1, u_2, \ldots, u_h), (R_S, T_S, P_S))$ be a non-dominated schedule that has minimal number of transmissions h among the schedules not produced by OTREMB. Then for the schedule $S' = ((u_1, u_2, \ldots, u_{h-1}), (R_{S'}, T_{S'}, P_{S'}))$ we have that $R_S = \min(R_{S'}, R_h)$, $T_S = T_{S'} + T_h$, and $P_S = P_{S'} \cup D(u_h)$. The fact that S is non-dominated and was not produced by OTREMB, implies that S' was not produced by OTREMB either. Since S is a non-dominated schedule with minimal number of transmissions among those not produced by OTREMB, and S' was not produced by OTREMB and uses less transmissions, this means that S' is dominated. However, since S is non-dominated, this means that S' is also non-dominated (otherwise, the schedule S'' that dominates S', in the sense that it has $T_{S''} < T_{S'}$, $R_{S''} > R_{S'}$ and $P_{S''} \supset P_{S'}$, extended by the transmission from node u_h would dominate S), which is a contradiction. □

The OTREMB algorithm solves the energy-efficient broadcasting problem optimally and has non-polynomial complexity. The complexity of the OTREMB multicost algorithm is related to the number of different non-dominated schedules S produced by the first phase of the algorithm. This number increases exponentially to the number n of wireless nodes, since the set of covered nodes P_S can take 2^n different values. Moreover, based on [6] the complexity of any multicost algorithm using one additive (T) and one restrictive (R) parameter is polynomial. So, there are cases where, in the second phase of the OTREMB algorithm, the optimization function f is applied to an exponential large number of schedules S. This leads to exponential execution time and to non-polynomial worst case complexity.

4 The Near-Optimal Total and Residual Energy Multicost Broadcast Algorithm

The OTREMB algorithm finds the schedule that optimizes the desired optimization function $f(V_S)$, but it has non-polynomial complexity, since the number of non-dominated schedules generated by the first phase of the algorithm can be exponential. In order to obtain a polynomial time algorithm, we relax the domination condition so as to obtain a smaller number of candidate schedules. In particular, we define a *pseudo-domination* relation among schedules, according to which a schedule S_1 *pseudo-dominates* schedule S_2, if $T_1 < T_2$, $R_1 > R_2$, and $|P_1| > |P_2|$, where T_i, R_i, $|P_i|$ are the total transmission power, the residual energy of the broadcast nodes and the cardinality of the set of nodes covered by schedule S_i, $i = 1, 2$, respectively. When this pseudo-domination relationship is used in step 2 of the OTREMB algorithm, it results in more schedules being pruned (not considered further) and smaller algorithmic complexity. In fact, by weakening the definition of the domination relationship the complexity of the algorithm becomes polynomial (this can easily be shown by arguing that T_i, R_i and $|P_i|$ can take a finite number of values, namely, at most as many as the number of nodes). The decrease in time complexity, however, comes at the price of losing the optimality of the solution. We will refer to this this near-optimal variation of the OTREMB algorithm, as the Near-Optimal Total and Residual Energy Multicost Broadcast algorithm (abbreviated NOTREMB).

The set of covered nodes P_S can take n different values, where n is the number of wireless nodes. As a result the number of different non-dominated schedules S increases polynomially to n, leading to a polynomial complexity for the NOTREMB algorithm.

5 Performance Results

5.1 Simulation Setting

We implemented and evaluated the proposed algorithms, using the Network Simulator ns-2 [19]. We use a 4×4 two-dimensional grid network topology of 16 stationary nodes with distance of 50 meters between neighboring nodes. Each node's transmission radius is fixed at a value uniformly distributed between 50 and 100 meters.

The performance of the OTREMB and NOTREMB algorithms is evaluated in comparison to established solutions for energy-efficient broadcasting like the BIP algorithm [7], the MWIA algorithm [10] that constructs a minimum spanning tree using as link cost the ratio of the transmission power over the residual energy of the transmitting node, and the BAIP heuristic, which uses as criterion for the addition of a node in the tree the power consumed when using the corresponding link over the number of newly covered nodes. The BAIP heuristic corresponds to the Greedy-h heuristic [14], which, to the best of our knowledge, is the best solution proposed so far for energy-efficient broadcasting when the nodes' transmission power is fixed.

The broadcasting strategies are evaluated under the packet evacuation model, where each node starts with a certain amount of initial energy and a given number of packets to be broadcasted. In our experiments the initial energy E_0 is taken to be equal for all nodes (5, 10 and 100 Joules). Each node broadcasts 200-1000 packets (at steps of 200).

In addition to the evacuation model, we also evaluate the proposed algorithms under the infinite time horizon model. In this model, the time axis is divided into rounds of a dynamic duration. At the beginning of each round the node energy levels are restored to a certain value and a constant number of additional packets to be broadcasted is inserted in every node, to be routed together with any packets whose broadcast was not completed in the previous rounds. Each round terminates (and a new round begins) when the residual energy of at least half of the network nodes falls below a limit. This way nodes are prevented from running out of energy and thus dropping the packets stored in their queues.

5.2 Packet Evacuation Model

In the packet evacuation model, each node starts with a certain amount of initial energy and a given number of packets to be broadcasted. We study the performance of the aforementioned algorithms until all packets are successfully broadcasted or until no more transmission can take place to the lack of energy reserves.

As far as the average number of transmissions h required to complete a broadcast is concerned (Figure 1a), OTREMB outperforms all the other algorithms, with NOTREMB achieving only slightly larger h. BAIP also seems to perform similarly to OTREMB and NOTREMB, but this is rather misleading, since as it will be shown below (see Figure 2) BAIP does not successfully complete the same number of broadcasts with these schemes.

The overall energy expenditure of the algorithms is depicted in Figure 1b, where the node average residual energy R at the end of the experiment is shown, for the case of initial energy equal to 5 Joules. Generally, the energy reserves of the nodes decrease as the number of packets broadcasted increases. In this case that the nodes have finite energy reserves, R stops decreasing when a certain

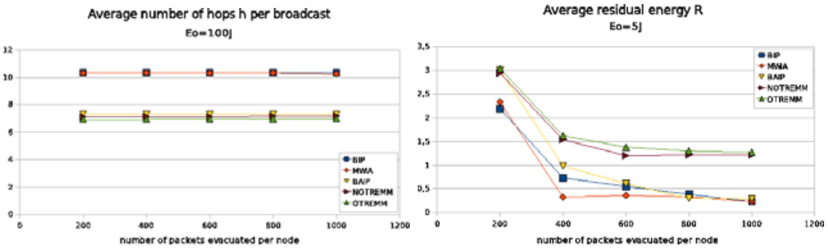

Fig. 1. (a) The average number of transmissions h per broadcast for all the algorithms evaluated when the nodes initial energy is equal to 100 Joules. (b) The average residual energy R at the end of the experiment for all the algorithms evaluated when the nodes initial energy is equal to 5 Joules.

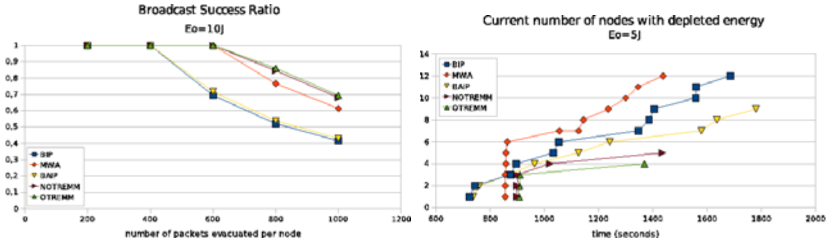

Fig. 2. (a) The broadcast success ratio p for all the algorithms evaluated when the nodes initial energy is equal to 10 Joules, (b) the current number of nodes L with depleted energy for all the algorithms evaluated when the nodes initial energy is equal to 5 Joules

number of packets (400-600 packets per node, depending on the scheme used) are broadcasted in the network. This happens because, beyond this point, many nodes run out of energy and the network gets disconnected. As a result, regardless of the increase in the incoming traffic no more packet transmissions can take place and energy consumption does not grow further. The OTREMB and NOTREMB algorithms utilize the node energy reserves more efficiently, compared to the rest of the algorithms, resulting in a higher residual energy R at the end of an evacuation period. Even though OTREMB selects the most energy-efficient set of nodes for broadcasting, NOTREMB achieves comparable results. This strengthens our belief that the NOTREMB algorithm may be preferable in practice to the OTREMB algorithm, obtaining most of the performance benefits of the optimal algorithm at a smaller computational cost.

Figure 2a depicts the broadcast success ratio p for all the algorithms considered. Clearly, OTREMB, with NOTREMB being only slightly inferior, outperforms all the other algorithms. The performance of the BIP and BAIP algorithms starts degrading even for small traffic load, and only the MWIA algorithm stays close to the OTREMB and NOTREMB algorithms. The characteristic enabling MWIA to also perform rather well is that its selection criterion is dynamic, since it involves the time-varying current residual energy of the nodes. In contrast, the BIP and BAIP algorithms do not change their broadcast paths and, therefore, they quickly exhaust the node energy reserves. The OTREMB and NOTREMB algorithms spread traffic more uniformly across the network, with nodes remaining operational and able to broadcast packets for longer times, as the following results will also indicate.

The longer network lifetime achieved by the OTREMB and NOTREMB algorithms compared to the other broadcast algorithms can be observed in Figure 2b, where the current number of nodes L with depleted energy reserves is presented as a function of time. The OTREMB and NOTREMB algorithms clearly result in fewer nodes running out of energy compared to the other algorithms. Furthermore, these nodes run out of energy later than they do in the other algorithms. The BIP algorithm seems to have the worst performance. MWIA manages to spread energy consumption uniformly across a subset of network nodes, and therefore when these nodes run out of energy, they do so almost simultaneously. The BAIP algorithm performs better than MWIA and BIP, but significantly worse than OTREMB and NOTREMB with respect to network lifetime.

5.3 Infinite Time Horizon Model

In the infinite time horizon setting, the broadcasting strategies are evaluated assuming packets and energy are generated over an infinite time horizon, according to a round-based scenario. At the beginning of each round, the node energy reserves are restored to a certain level, and an equal number of packets N to be broadcasted is generated at every node. A round terminates when the residual energy of at least half of the network nodes falls below a certain safety limit. Packets that are not successfully broadcasted during a round, continue from the point they stopped (e.g., a node with residual energy levels below the safety limit) in the following round(s) until their broadcast is completed. The succession of rounds continues until the network reaches steady-state, or until it becomes inoperable (unstable). We evaluate the algorithms using the broadcast success ratio p and the average broadcast delay D as performance metrics.

Figure 3a presents the broadcast success ratio p at steady state, for a different number of broadcast packets N inserted at each node per round. We observe that even for relatively light traffic inserted in each round, the BIP, the MWIA and the BAIP algorithms are not able to successfully broadcast all the packets generated. In particular, the BIP scheme remains stable for load up to $N = 15$ packets per node per round, and the BAIP scheme for load up to $N = 17$ packets per node per round. The MWIA scheme performs slightly better, remaining stable for up to $N = 19$ packets per node per round. The OTREMB and NOTREMB schemes have the maximum stability region (maximum broadcast throughput) and remain stable for up to $N = 21$ packets per node per round. By taking into account energy-related cost parameters and switching through multiple energy-efficient paths, both OTREMB and NOTREMB spread energy consumption more evenly and increase the volume of broadcast traffic that can be successfully served. The NOTREMB algorithm performs comparably to the OTREMB algorithm, and only for the heavier loads of incoming traffic its success ratio p falls significantly below that of the optimal algorithm. This is important, considering the great gain in computational effort achieved when using the NOTREMB instead of the OTREMB algorithm.

Figure 3b shows the average broadcast delay D, measured in packet times, at steady state for all the algorithms evaluated, as a function of the number of broadcast packets inserted in the network per node and per round. Recall that the broadcast delay D includes the delays incurred by a packet during all the rounds that elapse from the time it is generated until the time it reaches all the nodes in the network. As it can be seen from Figure 3b, the delay versus traffic load curves of the BIP, MWIA and BAIP algorithms are above those of the OTREMB and the NOTREMB algorithms. Since packets whose broadcast is not completed during a round fill the node queues and congest the network, the average delay of the BIP, MWIA and BAIP algorithms quickly becomes very large. Naturally, when the traffic load inserted increases beyond each scheme's

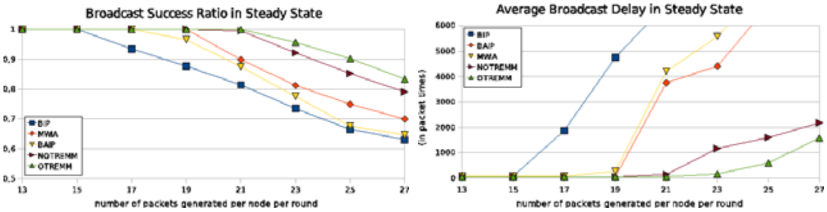

Fig. 3. (a) The broadcast success ratio p, and (b) the average broadcast delay D in the steady-state of the algorithms evaluated, for a different number of broadcast packets N inserted in the network

maximum stable throughput, the delays will also become unbounded, and the success ratio p will start falling. The OTREMB and the NOTREMB algorithms have smaller average delay D and remain stable for higher loads than the other schemes considered. Again, the NOTREMB algorithm manages to achieve similar performance to that of the OTREMB algorithm, and only at the end its performance deteriorates.

6 Conclusions

We studied energy-aware broadcasting in wireless networks, and proposed an optimal (OTREMB) and a near-optimal (NOTREMB) algorithm, based on the multicost concept. We evaluated the performance of the proposed algorithms and compared it to that of established heuristics. Our results show that the proposed multicost algorithms outperform the other heuristic algorithms considered, consuming less energy and successfully broadcasting more packets to their destination, under both the packet evacuation and the infinite time horizon model. An interesting conclusion drawn from our simulations is that the near-optimal multicost algorithm, NOTREMB, has similar performance to that of the optimal multicost algorithm, OTREMB, while having considerably smaller execution time.

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