Advanced Scheduling Algorithm For avoid Collision
In Wireless Sensor Networks

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Abstract

Many emerging mobile wireless applications require peer-to-peer transmissions over an ad hoc network, where the nodes often have different number of antennas, and the channel condition and network topology vary over time. It is important and challenging to develop efficient schemes to distributive coordinate transmission resource sharing among a heterogeneous group of nodes over an infrastructure-free mobile ad hoc network. It is desirable for broadcast operation in wireless ad hoc network to prevent collision and achieve low latency at the same time. In this letter, we propose a greedy broadcast scheduling algorithm based on the graph theory of Maximum Weight Independent Set (MWIS) problem. During each broadcast wave cycle, MWIS is able to find the optimal selection of forwarders so that maximum number of untouched nodes is covered without incurring collision. Numerical results show that this algorithm could produce better performance results than recent 2-step approach. In literature related to broadcast operation, most work has been focused on how to minimize the number of transmissions in a broadcast operation, and collisions were prevented simply through a random back off timer for messages forwarding without consideration in latency performance. A recent work in adopts a 2-step approach (broadcast tree construction plus transmission scheduling), and proposes an algorithm that generates both bounded latency and bounded number of transmissions results.

Index Terms: Wireless ad hoc network, broadcast scheduling, maximum weight independent set.

I. INTRODUCTION

Broadcast operation, during which messages are destined to all network nodes, plays an important role in wireless ad hoc network such as network-wide dissemination of data messages and control messages. Sometimes it is critical for broadcast operation to minimize the latency of one round of dissemination, which is the time from when the message is initiated until it reaches all nodes in the network. Taking Mobile Ad-hoc Network (MANET) for example, low-latency broadcast operation could quickly disseminate an linkbreak message to the whole network so that the topology information needed by the routing module at each node could be updated in time. Besides, emerging real-time applications like spontaneous audio conferencing also require a low-latency broadcast operation to deliver their delay-sensitive traffic over wireless ad hoc networks. In literature related to broadcast operation, most work has been focused on how to minimize the number of transmissions in a broadcast operation, and collisions were prevented simply through a random backoff timer for messages forwarding without consideration in latency performance. Among the limited existing work available on collision-free low-latency broadcast operation, Chlamtac et al. [1] prove that finding optimal solution for minimizing latency in wireless ad hoc network is NP-hard, and propose a phase assignment (or scheduling) algorithm to avoid collision. A recent work in [2] adopts a 2-step approach (broadcast tree construction plus transmission scheduling), and proposes an algorithm that generates both bounded latency and bounded number of transmissions results.

Fig. 1. (a) Sample network with S as source; (b) Weighted conflict graph when building the second
wave cycle (first wave cycle is the one initiated by S); value in parenthesis is weight. Scheduled broadcast operation actually resembles a wave propagation process, and the number of “wave cycle” for completing broadcast operation can be minimized if in every cycle the “wave-front” nodes cover maximum number of new (or untouched) nodes (Heuristic H1 in [1]). Following this kind of greedy strategy, it is possible to construct a low-latency and collision-free broadcast scheduling algorithm, which is able to cover maximum number of untouched nodes in each wave cycle without incurring collision. The algorithm is described in the following Section II. In Section III, the proposed algorithm is evaluated through simulation experiments. Section IV concludes this letter.

II. ALGORITHM DESCRIPTION

As mentioned above, we adopt a greedy approach for our algorithm, and try to make each broadcast wave cycle cover maximum number of untouched nodes without introducing collision. Referring to the sample network in Fig. 1 (a), after the broadcast wave cycle1 from S finishes, potential forwarders that are considered to start a new wave cycle include A, B and C, which can cover 2, 2, and 1 untouched nodes, respectively. Owing to the nature of wireless medium, collision will occur at a node if more than one upstream nodes transmit at the same time instant (i.e. beginning of the same timeslot). By refering back to Fig. 1 (a), A and B could induce collision at D if they both rebroadcast immediately after receiving a message from S (i.e. at the same time instant). It is the same with B and C, whose concurrent transmissions induce collision at F. Therefore, rebroadcasts of A and B, as well as B and C, cannot be scheduled at the same time instant. This collision scenario has been taken into consideration in [1], [2]. Because of potential collision, there exists “conflict” between A and B as well as between B and C, when we try to select forwarders from them. This situation can be transformed into a conflict graph with weighted vertices, as depicted in Fig. 1 (b). In this type of conflict graph, a node’s weight refers to the number of untouched nodes that the node is able to cover, and an edge between two nodes implies that they have conflict. The objective to find a set of forwarders to cover maximum number of untouched nodes for a particular wave cycle is now shifted to find a set of un-adjacent vertices that have maximum total weight in the conflict graph, i.e., to solve the Maximum Weight Independent Set (MWIS) problem in graph theory. Intuitively, set \( \{A, C\} \) is the optimal solution. MWIS problem is NP-hard, and its optimal solution can only be found by “brute-force” (BF) search throughout all combinations of vertices. Some approximate algorithms have been designed to efficiently solve this problem in polynomial time, e.g., the GWMIN2 algorithm in [3]. GWMIN2 selects the vertex with maximum weight ratio in the subgraph induced by that vertex and its neighbors, removes it and its neighbors from graph, and iterates on remaining graph until no vertex left. After finishing selecting forwarders for a particular wave cycle, the next step is to proceed to construct a set of new potential forwarders for next wave cycle. New potential forwarders consist of nodes that are just covered by previous wave cycle as

![Fig. 2. Pseudo-code of proposed algorithm.](image-url)
well as nodes that are left unscheduled in previous set of potential forwarders. Nodes that do not have untouched neighbors can be taken out from potential forwarders set, since their weights are zero. The algorithm iterates and stops when there is no untouched node left in the network. Its pseudo-code is illustrated in Fig. 2. The running time of building conflict graph is bounded by $O(n^3)$ whereas the running time of GWMIN2 is bounded by $O(n^2)$, thus the proposed algorithm with GWMIN2 implemented has running time bounded by $O(n^3)$ where $n$ is the number of nodes.

III. NUMERICAL RESULTS

The proposed algorithm is evaluated in Matlab, with bruteforce (BF) and GWMIN2 available for calculating MWIS.

![Fig. 3. Performance result of $D_{\text{max}}$ with respect to network depth, summarized using boxplot: bold line segment refers to median, max whisker length is 1.5 times of interquartile range, ‘+’ refers to outlier, and the number sitting above each boxplot is the mean value; result of BF in 100-node scenario is not available owing to its extremely long simulation time. Performance metrics include the maximum delay time (i.e. maximum number of timeslots) for a broadcast operation to complete (as denoted by $D_{\text{max}}$) and the number of transmitting nodes (including source). If we let $Di$ denote the depth (or the number of hops) between source and a node $i$, the network depth as viewed from source is equal to $\text{Max}(Di)$. Clearly, network depth represents an upper bound of the best performance of $D_{\text{max}}$, and thus it makes sense to evaluate the difference between $D_{\text{max}}$ and $\text{Max}(Di)$. $\text{Max}(Di)$ can be easily found through Breadth First Search (BFS). In simulation, nodes are randomly deployed to form a connected graph in a 100x100 square area with transmission range equal to 20. We perform three scenarios by setting the number of nodes to 50, 75 and 100, and these scenarios have average degree of 5.2, 7.7 and 10.4, respectively. 500 runs are executed for each scenario. The most bottom left node of each network is selected as source for each run, in order to obtain a large network depth and consistent wave propagation pattern. Fig. 3 presents the results of $D_{\text{max}}$ with respect to network depth, i.e. $D_{\text{max}}$ minus $\text{Max}(Di)$. It is clear that our proposed algorithm, no matter implemented with either BF or GWMIN2 method for computing MWIS, outperforms the 2-step algorithm of [2] in both performance metrics. Because of its approximation for selecting MWIS, GWMIN2 is not able to cover as many untouched nodes as BF does during each wave cycle. Hence, GWMIN2 suffers a higher $D_{\text{max}}$ result than BF, but the difference is quite small. In contrast, BF requires a slightly larger number of transmissions to complete a broadcast operation than GWMIN2 does, as depicted in Fig. 4. During each wave cycle, although BF achieves an optimal coverage of untouched nodes through enumerating all forwarder sets, it could not guarantee that the average number of untouched nodes covered by a single transmission is also optimal. Therefore, BF is not able to produce an optimal performance of the number of transmissions, which is crucial in view of power consumption. On the other hand, GWMIN2 strikes a balance between the two metrics’ performance, and gives us a smaller number of transmissions than BF, albeit not significantly. As the number of nodes increases and network becomes denser, simulation results show that the gap between $D_{\text{max}}$ and network depth would become exacerbated. That is because, during each wave cycle, more potential untouched nodes are prohibited from being covered in dense network as a result of higher probability of
collision. Similarly, the number of transmissions will also increase as network becomes denser, but at a rate much lower than that of the increasing number of total nodes. That is attributed in large part to the increased average number of untouched nodes covered by a single transmission.

IV. CONCLUSION
In this letter, we propose a greedy broadcast scheduling algorithm based on MWIS to minimize latency without incurring collision in wireless ad hoc network. Simulation results show that our approach is better than recent 2-step algorithm in term of both D-max and the number of transmissions. Furthermore, despite of its approximation, GWMIN2 can efficiently produce comparable performance result to that of BF method whose running time is exponential. It shall be noted that, similar like the algorithm in [2], our algorithm relies on the knowledge of overall network topology. Hence design of distributed scheduling algorithm for broadcast operation is a worthwhile topic of our future work.

REFERENCES