Broadcast scheduling in packet radio networks using mixed tabu-greedy algorithm

Y. Peng, B.H. Soong and L. Wang

A two-step algorithm to solve the broadcast scheduling problem is presented. The first step employs finding a solution that has a transmission time slot for each station, while the second step attempts to maximise the throughput. Numerical examples that demonstrate the algorithm outperforms existing ones in terms of channel utilisation and packet delay are presented.

Introduction: The broadcast scheduling problem (BSP) is to find a collision-free scheduling of transmissions of all the stations in a minimum number of time slots. The final arrangement of the station transmissions into their allocated time slots is called a frame. Consider a packet radio network (PRN) represented by a graph $G = (V, E)$, where V is the set of nodes and E the set of edges. An $N \times M$ binary matrix S is used to express the frame, where $N = |V|$ is the number of stations in the network and M is the number of time slots in the frame (i.e. the frame length). Element S_{jk} is one if station j is allowed to transmit in time slot k and zero, otherwise. The compatibility matrix F is defined by

$$f_{ij} = \begin{cases} 1, & \text{if stations } i \text{ and } j \text{ are one-hop or two-hop apart} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where $i, j = 1, \ldots, N$.

With the notation introduced above, the standard BSP is formulated as to find frame S_{opt}:

(i) that satisfies constraints

$$\sum_{k=1}^{M} S_{jk} \geq 1 \quad \forall j = 1, \ldots, N \tag{2}$$

$$\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{N} f_{ij} s_{ik} s_{jk} = 0; \tag{3}$$

(ii) with the shortest length, $M_{\min}$;
(iii) yields the maximum throughput, i.e.

$$\tau = \sum_{j=1}^{N} \sum_{k=1}^{M} s_{jk} \tag{4}$$

In this Letter, we propose a two-step algorithm to solve the BSP, which may proceed as follows. First, an initial value for the frame length is estimated from the lower bounds as discussed in [1, 2]. For a given frame length, a tabu search (TS) approach is now applied to search a feasible solution that has one and only one transmission for each station, which we refer to as P1. If such a frame can be found, a shorter frame length is attempted until the lower bound is reached. Next, after such a feasible solution with minimal frame length is found, we use a greedy (GR) method to maximise the throughput for the frame, which we refer to as P2.

TS for P1: Tabu search [3] is a meta-heuristic that guides a local search to explore the solution space beyond local optimality. The basic idea is to forbid certain moves that would return to recently visited solutions, by rendering them tabu.

The search starts with a random initial solution, which is generated by assigning one arbitrary time slot to each station. A conflicting time slot is defined as a time slot that violates at least one interference constraint in a solution. A new solution is in the neighbourhood of the current solution if it differs from the current assignment by exactly one conflicting time slot and the move that produces the new solution is not in the tabu list. The tabu list is a list containing the last several moves carried out. To implement the list, we use a matrix of dimension $N \times M$. When time slot i assigned to station j is changed to a new one k, the pair (j, i) is classified tabu and the initial value of element (j, i) of the tabu list is set to the tabu tenure T. The value of each element of the tabu list decreases by one after an iteration until it becomes zero and then the corresponding move is set free. The tabu tenure is the number of iterations for which the tabu-active status of moves will last. If it is too small, the search procedure will not be effective. If the tenure is too large, it is possible that all the available moves are tabu. Hence, we select the value of the tabu tenure to be

$$T = \alpha(M - 1) \tag{5}$$

where M is the number of time slots in a frame, as defined previously and α typically takes values from 0.25 to 0.75. So T varies with α. By varying the tabu tenure during the search provides one way to induce a balance between closely examining one region and moving to different parts of the solution space.

A tabu attribute can be in a new solution if it satisfies the aspiration criterion. This is to avoid missing good solutions. If a tabu move leads to a solution with a smaller cost than the minimum cost obtained so far, the tabu-active status of the move will be revoked for the current iteration; otherwise the move is discarded and a new move is generated. The search procedure terminates when an interference-free solution is found.

GR for P2: After a feasible solution with one and only one transmission for each station has been obtained, we proceed to maximise the throughput by adding one time slot to the current frame at one time. If it does not cause any interference, the added time slot is preserved; otherwise it is dropped. We start from the first time slot, followed by the second one of the first station. This process is repeated until the last time slot of the last station is attempted.

Simulation results: The performance of our algorithm can be evaluated by two criteria: channel utilisation and packet delay. For a fixed frame length, the channel utilisation is determined by the frame throughput. The packet delay can be calculated with the Pollaczek-Khinchin formula [4], which assumes independent Poisson transmissions by the stations. Three PRNs with 15, 30 and 40 stations, the topologies of which are available in [1], are the demonstrated examples.

Table 1: Throughputs by HNN-GA and TS-GR algorithms

Net. size	M	τ from HNN-GA	τ from TS-GR
15	8	20	20
30	10	35	37
	11	40	43
	12	47	48
40	8	67	68
	9	77	77

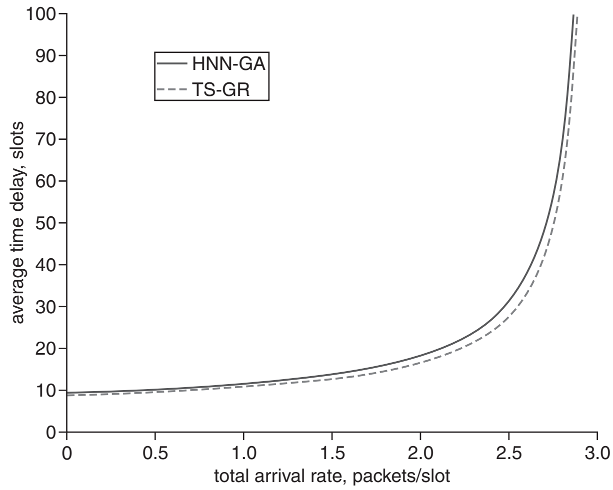

Fig. 1 *Comparison of average time delays by HNN-GA and T-GR algorithms for 30-station case*

We compare the results obtained from our algorithm (TS-GR) with those obtained by the mixed neural-genetic algorithm (HNN-GA) [2]. Table 1 presents the optimal throughputs for the three BSPs and different frame lengths. TS-GR produces better results for 30- and 40-station cases, and the same result for the 15-station case. The time delay is essentially determined by the frame length. Our algorithm does not produce shorter frame lengths, so only small improvements for average time delay are achieved. The results for the three cases share the same characteristic and

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amount of improvement. We show only the comparison for the 30-station case in Fig. 1.

Conclusion: A mixed tabu-greedy algorithm has been successfully implemented to solve the broadcast scheduling problem. Simulation results on three scenarios are presented and compared with the algorithms in [2]. Improvements have been achieved in terms of both channel utilisation and packet delay.

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