

Wireless Transmission Scheduling for Mass Transit

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I. INTRODUCTION

There has been a growing interest in data applications within wireless networks, due to the increase in systems which support them. One topic, which has been the subject of recent research, is scheduling of down-link transmission for data applications in wireless networks. It has been shown that use of channel-aware scheduling on the base-station down-link, in which service is given at each point in time to a mobile user based on its channel capacity, can result in a dramatic increase of both the QoS of each mobile user and the overall system performance [1][2][3].

Models of such systems, and stochastic analysis of system capacity, are based in prior literature on the assumption that the channel capacities of the users are *independent* over time. Such an assumption implies that at each moment it is likely that some users will have high capacity and some low capacity, and that this situation will probably reverse in the future. Thus, dynamic channel-aware scheduling algorithms that (momentarily) prioritize high capacity users can achieve high system throughput and QoS gains.

Our interest is in wireless systems where the *user independence assumption* is significantly *violated*, and where the capacities of a significant number of the users are positively and strongly correlated. Such situations arise, among others, in Mass-transit systems, particularly train systems, which we focus on due to their challenging dynamic behavior and the popularity of train transit.

Providing wireless coverage onboard trains, is classically done by equipping the train with a central antenna unit. The central antenna unit communicates with the terrestrial wireless base-stations in a manner which is similar to the way a standard user does. Additionally, the central antenna unit connects to an internal Onboard Wireless Network (OWN). Each user on board the train connects to the OWN, and all the wireless traffic is channeled through the central antenna unit to/from the base-station.

Due to the high number of active users residing on board a train, the total traffic volume they generate can create a significant load on the base-station, since they all appear in the cell at the same time. One could easily compensate for this by increasing the base-station capacity or adding base-stations. However, since the train remains within the cell for only a small fraction of the time, such an increase is not economical, as the base-station will remain at very low utilization most of

the time. Additionally, from the trains' perspective this issue is a persistent one, occurring in every cell, so discriminating against the train users will result in very poor performance of these users for long durations.

Our purpose is to deal specifically with this bursty traffic nature. We propose mechanisms, as well as base-station scheduling algorithms, for coping with these problems and for providing efficient system operation. To achieve this end, we make use of two factors unique to trains: 1) The predetermined route of the train, and 2) The long body of the train.

II. BUFFER-AND-BURST - A SCHEDULING ALGORITHM

Wireless users on board a train differ from the standard wireless user in that they travel along a predetermined route, at a predictable speed. Since there is a clear correlation between the distance of a user from the closest base-station and the users reception capacity, it is possible to predict, with relatively good accuracy, the expected capacity of a user on board a train at every given moment during his travel. The only information which is unknown ahead of time are the load requirements imposed by the train users. However, since there are numerous users on board the train, it can be assumed that the fluctuation in the imposed load will be relatively minor.

Our objective function is to minimize the number of slots allocated to the train, as to provide that terrestrial users are minimally affected by the train passage through the cell. This, however, is done subject to the constraint that the packets destined to the train are delayed by no more than some predefined duration (w_{max}). This way, the negative effects of the train arrival in each cell are minimized, without compromising the QoS of the train users.

We propose here the Buffer-and-Burst policy (BAB), which can be shown to be optimal up to a constant number of allocated slots. It has an intuitive structure, in which we allow packets to buffer up during low capacity intervals, and then enable efficient (high utilization) transmission during high capacity slots.

In order to deal with the allocation of slots to train users over several cycles of low and high capacity, we use a "divide and conquer" approach. Treating each cycle separately, we devise an optimal allocation for all the packets arriving in the cycle, and then combine these local allocations into one overall allocation. Cycle allocations are similarly achieved by subdivision and recombination of smaller allocation components. Figure 1 roughly depicts this division, where packet

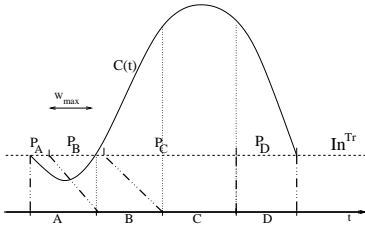


Fig. 1. BAB Capacity Cycle Segmentation

set P_X is transmitted during segment X ($X = A, B, C, D$). During segments A and B the buffer is allowed to fill, and transmission takes place only to avoid delay constraint violation. Segment C is then fully allocated to clear the buffer entirely, and segment D transmits whenever the available capacity matches the amount of buffered packets, ending the cycle with an empty buffer.

Combining these optimal localized allocations could possibly result, of course, in a suboptimal overall allocation. We solve this potential problem by showing that combination of optimal allocations can exceed the global optimal allocation by at most a small constant per cycle. Specifically, Buffer-and-Burst generates an allocation which exceeds the optimal allocation by at most 4 slots, and simulation (Fig. 3) has shown it to require, for some delay constraints, approximately one-third of the slots required by static allocation algorithms, which transmit when the buffer reaches some predefined filled percentile (The figure shows the competitive ratio w.r.t. the best such algorithm).

III. MASS - A NEW ARCHITECTURE

Trains can reach considerable lengths, such that at any given moment in time the reception capacities at different points along the train may significantly vary. Exploiting this property, we propose a new train wireless architecture, termed Multi-Antenna Spatially-Separated (MASS). It consists of a multiplicity of reception antennas placed on the external train hull (Fig. 2), and transmitting at each allocated slot *only* to the antenna with the highest reception capacity, denoted $C(t)$.

Such an architecture would obviously increase the reception potential of the train users. The capacity fluctuations experienced by the train users are, however, greatly affected by the exact deployment of these antennas. The optimal deployment, with respect to some specified performance measure, is in itself determined by the network structure and the specific layout of the train tracks. An optimal deployment is therefore difficult to find, and even when found would be very sensitive to changes in the network, thus being likely to cause a potential decrease in future performance.

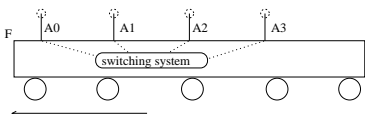


Fig. 2. MASS architecture

Our goal is to devise a stable deployment (i.e. relatively unaffected by changes in the network) which will also achieve close-to-optimal performance. Specifically, let the *uniform antenna deployment* be the deployment in which the antennas are equidistantly distributed along the train hull. We show that the uniform antenna deployment yields close-to-optimal performance for the following three measures:

- *Maximize Min-Slot-Capacity* - $\min_{t \in \{1, \dots, T\}} C(t)$.
- *Maximize Total-Slot-Capacity* - $\sum_{t \in \{1, \dots, T\}} C(t)$.
- *Minimal Buffer-and-Burst allocation*

The process of proving these properties of the uniform antenna deployment is divided into two stages. First, we show that such a deployment is optimal for the hypothetical scenario of a base-station network consisting of one base-station only. In the next stage we discuss conditions on the layout of the antennas and base-stations which, when met, ensure that the single base-station perspective is valid also for the entire network. Simulation has been applied to demonstrate the reduction in allocation cost when combining BAB and MASS. As can be seen in Fig. 3, for short allowable delay the introduction of a single additional antenna can allow the train to make due with 2/3 of the slots required by the single antenna architecture.

In addition to being optimal when employing the *BAB* policy, the uniform deployment also expands the range of traffic types this policy can support. The uniform deployment spreads the additional capacity evenly over time, thereby reducing the intervals between capacity peaks. Thus, by using n antennas instead of one, the delay constraint may be reduced by a factor of n , allowing support of additional traffic types.

Delay Const.	BAB / Static	BAB + MASS (2 Ant.) / BAB
4 sec.	0.41	0.63
6 sec.	0.40	0.66
8 sec.	0.32	0.80
10 sec.	0.32	0.83

Fig. 3. Simulation results. The expected amount of slots allocated by BAB for each slot allocated by the best static algorithm, and the same for comparing BAB alone to the combination of BAB and MASS with 2 antennas.

IV. FUTURE RESEARCH

The approach taken in the *BAB* policy gives complete priority to those users on board the train, for the reasons presented above. The effects of this policy on the cell-based users, as well as alternative policies which explicitly incorporate the needs of cell-based users into the algorithm, have yet to be analyzed in depth. These would specifically require developing new ways of comparing the QoS experienced by these two different types of users.

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