Energy-efficient Packet Transmission over a Multiaccess Channel

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Abstract — **We investigate the minimum-energy packet scheduling problem for the multiaccess channel with K transmitters and a single receiver, assuming that packets arrive at each transmitter's buffer at arbitrary times and must be transmitted within a finite time window. The offline scheduling problem is formulated and found to be a convex optimization problem with linear constraints. An efficient algorithm for finding the optimal offline schedule is presented. An online schedule based on a lookahead buffer is described and shown to perform very closely in terms of average energy per packet to the offline optimal, at the expense of a nearly constant delay.**

I. SUMMARY

The minimum-energy packet scheduling problem was formulated and solved for the single-link and downlink cases in [1] and [2]. This paper investigates the problem for the multiple-access (*i.e.*, uplink) scenario.

Consider two nodes[1] that receive packets into their buffers at arbitrary times, and need to transmit these to a common receiver. Denote the inter-arrival intervals of the merged packet arrival times ξ_i, $i = 1, \ldots, n$, by *epochs*. We assume that when the users transmit at rates R_1 and R_2, the feasible region of average received powers P_1 and P_2 is: $P_1 \geq f(R_1)$, $P_2 \geq f(R_2)$, $P_1 + P_2 \geq f(R_1 + R_2)$, where $f(.)$ is a positive, strictly convex, monotonically increasing, and super-additive function of R. An example of such function is $f(R) = N(2^{2R}-1)+\delta$, $\delta > 0$, which holds for the discrete-time AGN multiaccess channel with noise power N using optimal (Shannon) coding.

Let the energy per transmission for users 1 and 2 be aP_1 and P_2, for some constant $a \geq 1$. The optimal multiaccess packet scheduling problem is to transmit all the packets that have arrived in $[0, T]$ before the deadline T, with minimum total energy.

First we consider the offline version of this problem, when all packet arrival times are known in advance. In this case it can be shown that an optimal multiaccess schedule exists where the rate of a user does not change during an epoch. Thus the offline problem reduces to finding a set of epoch rates $\{R_{1i}, R_{2i}\}_{i=1}^n$, where n is the number of epochs, to:

$$\begin{array}{ll} \text{Minimize } \sum_{i=1}^n \xi_i g(R_{1i}, R_{2i}) & \text{such that} \\ \sum_{i=1}^k R_{ji}\xi_i \leq B \sum_{i=1}^k c_{ji} & j = 1,2,\ k = 1, \ldots, n \end{array}$$

where $g(R_1, R_2) = (a-1)f(R_1) + f(R_1 + R_2)$, $c_{ji} = 1$ if user j gets an arrival at the beginning of data epoch i, and 0 otherwise, and B is the size of a packet in bits.

When $a = 1$, *e.g.*, the transmitters are equidistant to the receiver, there is a strict time-sharing schedule that minimizes the total energy. Such a schedule can be found using the MoveRight algorithm[2]. When $a \neq 1$, time-sharing is strictly suboptimal, and the problem has no closed form solution. Since the problem is convex, well-established convex optimization methods may be used. However, by exploiting the special structure of the problem we developed FlowRight, an efficient algorithm that finds the optimal offline schedule iteratively. Initially, the transmission time of each packet is set equal to the data epoch at the beginning of which the packet arrived. Let the rates obtained in this way be $\{R^0_{1i}\}$ and $\{R^0_{2i}\}$, such that $R^0_{ji} = Bc_{ji}/\xi_i$, $j = 1, 2$, $i = 1, \ldots, n$. Consider the first two data epochs. Keeping the number of bits fixed, update (R^0_{11}, R^0_{21}) to (R^1_{11}, R^1_{21}), where (R^1_{11}, R^1_{21}) is the allocation of rates to the first data epoch that minimizes the overall energy of the pair of data epochs, and reset (R^0_{12}, R^0_{22}) to new values. Moving to the second pair of data epochs, optimally decrease (R^0_{12}, R^0_{22}) to (R^1_{12}, R^1_{22}), and reset the values of (R^0_{13}, R^0_{23}). Similarly obtain (R^1_{1i}, R^1_{2i}) for $i = 1, \ldots, n$. The first *pass* is complete. Next, start from the beginning and update the rates of two data epochs at a time as above. Terminate after pass K, where $K = \min\{k : R^k_{ji} = r^{k-1}_{ji},\ i = 1, \ldots n, \text{ and } j = 1, 2\}$.

An online algorithm that approximates the offline schedule can be obtained using a simple lookahead buffer: buffer all packets that arrive in the interval $[0, L)$. Schedule these packets for departure in the interval $[L, 2L)$, employing the power levels at the optimal corner point of the feasible power region. Continuing with the schedule, packets that arrive in $[L, 2L)$ are buffered to be transmitted in $[2L, 3L)$, and so on.

This online algorithm was compared to the offline optimal through simulations. The average delay per packet for the lookahead algorithm is almost constant around the window size L, and the average energy per packet is reasonably close to the optimal. Hence, by using a simple online algorithm that incurs some fixed delay, it is possible to achieve close to optimal energy-efficiency.

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[1] Results can easily be generalized to more than two nodes.