The Impact of User Information on Power-Delay Tradeoffs in Bursty Packetized Systems

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Abstract — **We explore the power-delay tradeoff for a time-slotted multiple user system with random packet arrivals and limited sharing of user queue information. We analyze the average power consumption to minimize delay with full and only local queue information, as well as without regards to delay. A simple scheme with one bit of global queue information is presented. The scheme uses superposition coding to afford reliably received in the presence of collisions and can achieve power-delay trade-offs between minimizing energy and minimizing delay.**

I. Introduction

The time-slotted ALOHA system models systems with bursty arrivals. Its use is motivated by its simplicity in that there is no coordination amongst users. The capacity region of such systems when allowing coding of packets *and* variable reliably received rates has recently been introduced [1] and is in general independent of burstiness and user queue information sharing. Delay and power consumption, however, are not in general independent of burstiness and user queue information.

II. Model

Each transmitter $\{x_i\}_{i=1}^2$ has a power constraint P and they share a discrete-time additive multiple access channel with additive i.i.d. noise $w \sim \mathcal{N}(0, \sigma_N^2)$:

$$y[k] = \sum_{i=1}^{2} x_i[k] + w[k].$$

Time slots are very long in terms of transmissions so that data may be coded to achieve rates near information-theoretic bounds. We denote $C_{\sigma_N^2}(x)$ $\left(C^{-1}_{\sigma_N^2}(x)\right)$ as the capacity (minimum power required) to transmit at power (rate) x for memoryless noise of variance σ_N^2. Packets of length b arrive to each user's transmission buffers according to an independent Bernoulli process of probability p. Thus each user's arrival rate (in bits per transmission) is $\lambda = \frac{pb}{n}$. A user's queue (of infinite capacity) contains all packets not yet successfully transmitted. Delay is measured in slots beyond the slot in which the packet arrived. This is a discrete time controlled stochastic system; for stability purposes we assume $C_{\sigma_N^2}(2P) > 2\lambda$.

III. Boundaries of the Power-Delay Tradeoff Region

To minimize delay to 0 slots with global queue information, the average amount of aggregate power consumed is

$$P^{(1)}_{min} \xrightarrow[a.s.]{} p^2 C^{-1}_{\sigma_N^2}\left(\frac{2b}{n}\right) + 2p(1-p) C^{-1}_{\sigma_N^2}\left(\frac{b}{n}\right).$$

With only local queue knowledge, the minimum average power consumption is given by

$$P^{(2)}_{min} \xrightarrow[a.s.]{} \left(1-(1-p)^2\right) C^{-1}_{\sigma_N^2}\left(\frac{2b}{n}\right).$$

To stably minimize average power consumption in the absence of delay constraints, we have

$$P^{(3)}_{min} \xrightarrow[a.s.]{} C^{-1}_{\sigma_N^2}\left(\frac{2pb}{n}\right) = C^{-1}_{\sigma_N^2}(2\lambda).$$

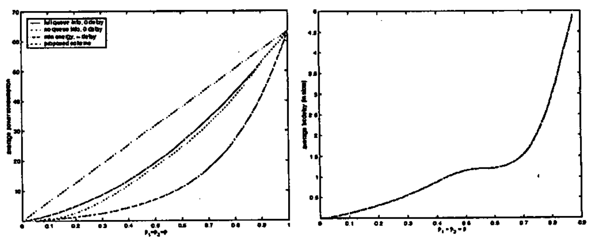

Figure 1: (left) expected power consumption for different schemes and (right) delay for proposed scheme

IV. A System with Limited Queue Information

We now present a coding scheme that addresses the burstiness of packet arrivals by affording variable reliably received rates with very limited queue information. When all queue lengths are small, users employ a superposition coding scheme that affords reliably received rates even in the presence of a collision, and larger rates when others do not transmit (see [1]). When any user's queue crosses the threshold η, users transmit using a multiple access scheme. By varying η and the superposition coding scheme parameters, the power-delay operating points may approach all the boundaries mentioned in the previous section.

Lyapunov function techniques similar to those in [2] along with Little's Law provide bounds on the expected delay $\overline{T}$:

$$\frac{p^+_{\min}(\nu^+_{\min})^2}{4\lambda\gamma} \le \overline{T} \le \frac{b}{\lambda} + \min\Bigg(\frac{p^+_{\max}\nu^+_{\max}(\nu^+_{\max}+\nu^-_{\max})}{\lambda\gamma}, \frac{\tilde{\nu}^+_{\max}+\nu^-_{\max}}{\lambda} + \frac{p^+_{\max}\tilde{\nu}^+_{\max}(\tilde{\nu}^+_{\max}+\nu^-_{\max})}{\lambda\gamma}\Bigg).$$

References

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[2] D. Bertsimas, D. Gamarnik, and J. N. Tsitsiklis. Performance of multiclass Markovian queueing networks via piecewise linear Lyapunov functions. *Annals of Applied Probability*, 11(4):1384–1428, 2001.

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