ISIT 2003, Yokohama, Japan, June 29 – July 4, 2003

MAC Layer Wireless Multicast: Theory and Approaches

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I. Introduction

We develop the theory behind wireless MAC layer multicast and obtain throughput optimal transmission policies that provide desired loss and power characteristics. Key idea is to exploit the broadcast nature of wireless channel, i.e, a sender can reach all the receivers in a MAC layer multicast group with a single transmission. Though the broadcast nature of wireless transmissions provides a possible approach to improve the efficiency of the multicast communication, it also imposes critical challenges. A multicast specific challenge is that some but *not all* the receivers may be ready to receive on account of the interference caused by the transmissions in their neighborhood. The readiness state of a receiver depends on the network load. A transmission policy, which does not transmit until all the receivers are ready may have to wait long and hence it may provide low system throughput. On the other hand, if the sender transmits when only a few receivers are ready, then the transmitted packet will be lost at the receivers that were not ready. This packet loss may not be acceptable. *Hence, the policy decision in this case is when should a sender transmit.*

Further, a sender may achieve required loss characteristics by transmitting a packet several times till sufficient number of receivers receive the packet. But additional power consumption in this case at the sender imposes a limit on the number of such transmissions.

We consider a single multicast session in isolation. The impact of the network on the multicast session is modeled by considering random receiver readiness states. In each slot, we assume that a receiver is ready with probability (w.p.) p. Further, the number of arrivals in each slot is assumed to be iid with expectation denoted by λ.

II. Main Results

Definition 1 *A reward(loss) for a packet is the number of receivers that receive(do not receive) the packet successfully. Loss constraint specifies the average acceptable loss per packet in the system. Throughput for a transmission policy is defined as the reward achieved by the policy per unit time.*

Definition 2 *A system is said to be stable if the mean queue length is bounded.*

Definition 3 *A single-threshold transmission policy(T) is the one that transmits a packet only when T or more receivers are ready. Let $\mathbf{E}[S_T]$ be the expected service time for a single-threshold transmission policy(T).*

Definition 4 *A two-threshold transmission policy(T,q) is the one that sets threshold T for a given transmission w.p. q or a threshold $T+1$ w.p. $1-q$ and transmits in accordance with the threshold.*

First we consider a case, where power constraints allow only one transmission per packet. We show that a two-threshold policy(T,q) maximizes the system throughput. Maximizing system throughput is equivalent to minimizing the expected packet loss at a receiver when the system is stable.

Proposition 1 *A two-threshold policy(T,q) maximizes the system throughput in the class of stable policies, where*

$$T = \arg\max_{0\le j\le G}\{\mathbf{E}[S_j] \le \frac{1}{\lambda}\} \textit{ and} \tag{1}$$

$$\begin{aligned} q &= \frac{\mathbf{E}[S_{T+1}] - \frac{1}{\lambda}}{\mathbf{E}[S_{T+1}] - \mathbf{E}[S_T]} \textit{ if } T < G \\ &= 1 \textit{ o.w.} \end{aligned} \tag{2}$$

We note that any given loss constraint can be achieved in the system as the sender can always wait till the desired number of receivers are ready. But if the waiting time is large, then the system may not remain stable. Thus the above policy may violate the loss constraint even though it minimizes the loss in the class of stable policies. Hence we also analyze unstable systems to obtain throughput optimal policy subject to the required loss constraint. For unstable systems, throughput optimal policy does not necessarily minimize loss.

Proposition 2 *For the appropriate values of parameters T and q [1], a two-threshold policy(T,q) maximizes the throughput subject to satisfying the required loss constraint L.*

The threshold based throughput optimal policies proposed above need knowledge of system statistics. When such knowledge is not available, we propose an asymptotically throughput optimal on-line approach that chooses threshold values based on the sender's queue length. Let Q denote the queue length at the sender and Δ be some fixed positive integer. For $T \ge 2$, threshold is set to T if $(G-T)\Delta \le Q < (G-T+1)\Delta$ and threshold is set to 1 if $Q \ge (G-1)\Delta$. Denote the throughput under proposed policy by Λ_Δ and the optimal throughput by Λ_{opt}.

Proposition 3 *If $E[S_1] < \frac{1}{\lambda}$, then the throughput of the proposed queue length based policy approaches optimal throughput w.p. 1 as Δ goes to infinity, i.e.*

$$\lim_{\Delta\to\infty} \Lambda_\Delta = \Lambda_{opt} \quad \textit{w.p. 1.} \tag{3}$$

Now, we allow up to K transmissions per packet, where K is determined by the power constraints. The retransmissions, when used judiciously, can reduce the expected time required for achieving a certain reward. Reducing the expected time will allow us to obtain higher reward per transmission without violating system stability, thereby increasing the system throughput. We propose a *dynamic threshold* policy that chooses a threshold for every transmission dynamically based on the outcomes of the previous transmissions. We show that this policy minimizes the expected time required to achieve a certain reward [1].

*The authors have been supported in part by NSF grant ANI01-06984.

References

[1] P. Chaporkar and S. Sarkar, "MAC Layer Multicast: Theory Approaches and Protocols" *Technical Report*, University of Pennsylvania, 2002.