Multiple Access and Time Division: A New Look

Yalin Evren Sagduyu and Anthony Ephremides
Electrical and Computer Engineering Dept. and Institute for Systems Research
University of Maryland, College Park, MD 20742, USA
{sagduyuy, tony}@eng.umd.edu

Abstract — **In this paper, we rediscover the value of scheduled access through a detailed foray into the questions of throughput and energy consumption for MAC protocols in ad hoc wireless networks, where the optimal channel access scheduling is NP-complete [1]. We propose a two-layered time-division heuristic of receiver activation and Group TDMA as polynomial-time solutions to throughput and energy-efficient link scheduling and resource allocation in networks with dynamically changing transmitter-receiver pairs.**

I. Introduction

Layer I: Under the assumptions of (a) no simultaneous transmission and reception, and (b) common circular transmission (and interference) ranges of radius r, a topology-based greedy heuristic determines receiver sets to be activated in separate time intervals depending on the residual battery energy.

Layer II: After activating each receiver group separately, the Group TDMA scheme (introduced for two-destination systems in [2]) allocates interfering node groups (with packets addressed to different destinations) within disjoint time fractions to decouple feedback from different destinations. The linear programming formulation with reliable feedback contributes simplicity to suboptimal but throughput-efficient solutions.

II. Energy-efficient receiver activation

The minimum-energy node initiates the first receiver group and designates any node within reception range as transmitter via exchange of control packets. We exclude nodes selected as transmitter or receiver from receiver candidates and continue with transmitter-receiver assignments, until all nodes are chosen as transmitter or receiver for the given activation period. We determine different receiver groups, until each node is assigned as receiver once in a full cycle of activation periods.

We use the residual battery energy to determine activation order and duration of each receiver group G_i. Node energies are dedicated in equal amounts to transmissions at any receiver in transmission range. $E_m(G_i)$ is the energy available for transmissions to G_i before activation period m and RG_m is activated as the mth receiver group within time fraction t_m.

Theorem 1 *To extend the system lifetime, i.e. the minimum value of* m *such that* $\min_i E_m(G_i) = 0$*, new receiver activation period* $m{+}1$ *is initiated if* $E_{m+1}(RG_m) < E_{m+1}(G_i)$*, for any* $G_i \neq RG_m$*, and* $RG_m = \arg\max_i E_m(G_i)$ *as* $\lim t_m \to 0, \forall m$.

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III. Throughput-efficient group TDMA

We assume infinite unbuffered nodes. Each packet arrives at a "new" node and is addressed to any receiver in transmission range with equal probability. For slotted transmissions to any activated receiver, we consider the collision channel model with immediate feedback on channel outputs of idle, success and collision. For activated receiver group G_i, Group TDMA partitions the rest of nodes into disjoint transmitter groups $\{G_{i,k}\}$ eliminating interference at non-intended receivers and relies on arbitrary MAC protocol (with maximum stable throughput $S_{\max}$ for single destination) to resolve primary collisions among transmissions from $\{G_{i,k}\}$ at intended destinations. $R_{i,k}$ is the actively operating subset of G_i, if $G_{i,k}$ is activated within $x_{i,k}$ fraction of time. $\sum_{k=1}^{c_i} x_{i,k} = 1$, c_i is the number of distinct transmitter groups, and $f_{i,k}(j)$ is the fraction of traffic generated by the subset of $G_{i,k}$ with packets destined to $R_{i,k}(j)$, which is the jth element of $R_{i,k}$.

Theorem 2 *The stable throughput* λ_i *for* G_i *needs to satisfy for any* $1 \le k \le c_i :\ \lambda_i f_{i,k}(j) \le x_{i,k} S_{\max},\ \forall j : R_{i,k}(j) \in R_{i,k}$. *The optimal temporal allocation by Group TDMA is*

$$x^*_{i,k} = \frac{\max_{j:R_{i,k}(j)\in R_{i,k}} f_{i,k}(j)}{\sum_{k=1}^{c_i} \max_{j:R_{i,k}(j)\in R_{i,k}} f_{i,k}(j)}, \quad k \in \{1, ..., c_i\}\,.$$

and the total value λ^*_i *of maximum stable throughput for* G_i *is*

$$\lambda^*_i = \frac{S_{\max}}{\sum_{k=1}^{c_i} \max_{j:R_{i,k}(j)\in R_{i,k}} f_{i,k}(j)}\,.$$

In tandem networks of length L *or planar networks of area* A,

$$\frac{S_{\max}L}{4r} \le \lambda^*_i \le \frac{S_{\max}L}{2r} \quad or \quad \frac{S_{\max}A}{(3\sqrt{3}+\pi)r^2} \le \lambda^*_i \le \frac{S_{\max}A}{\pi r^2}\,.$$

Theorem 3 *At most* 3 *and* 13 *distinct colors are needed in tandem* ($c_i = 3$) *and planar* ($c_i = 13$) *networks to color links to neighbor receivers with different colors. After receiver activation, the scheduling problem formulated as link coloring can be solved in polynomial time by the distributed Group TDMA.*

For numerical results, we consider 1000 static, unbuffered nodes with 10^6 units of initial energy. Each transmission requires πr^2 energy units. Packets are generated according to Poisson distribution and FCFS algorithm resolves primary conflicts. Depending on $2r/L$ or $\pi r^2/A$ in tandem or planar networks, Group TDMA increases throughput (over simultaneous operation of nodes) up to 34 or 48%, and energy-efficient receiver activation extends system lifetime up to 21 or 35%.

References

[1] E. Arikan "Some Complexity Results about Packet Radio Networks," *IEEE Trans. Inform. Theory*, vol. IT-30, pp. 681-685, July 1984.

[2] G. D. Nguyen, J.E. Wieselthier, and A. Ephremides, "Collision-Resolution Algorithms for Multiple Destinations in Wireless Networks," in *Proc. Conf. Inform. Sci. and Syst.*, John Hopkins Univ., Baltimore, MD, March 2003.