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An Approach to Congestion Control for Wireless Ad-Hoc Networks

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***Abstract*—we study joint design of end-to-end congestion control and Per-link medium access control (MAC) in ad-hoc networks. In the current scenario wireless communication is emerging the world. Wireless Ad Hoc networks demands for higher intermediate node supports for long-range communication. Wireless Ad Hoc network is an emerging communication approach. Ad Hoc networks are usually defined as an autonomous system of nodes connected by wireless links and communicating in a multi-hop fashion. The wireless ad-hoc networks are for easy of deployment without centralized administration or fixed infrastructure, to achieve the goal of less interference communication. In wireless Ad-hoc network the connections between the wireless links are not fixed but dependent on channel conditions as well as the specific medium access control (MAC). The channel medium and transmission links are affected by the interference, delay, and buffer overflow these may cause the network congestion. To avoid network congestion various congestion control methods were developed in past but they were performed less control of end-to-end congestion and less in per link connection control. To overcome the above problems and to improve the resource allocation an efficient method has to be developed.**

***Keywords*—Ad-hoc networks, random access, wireless networks, congestion control**

1. INTRODUCTION

AD-HOC wireless networks are usually defined as an autonomous system of nodes connected by wireless links and communicating in a multi-hop fashion. The benefits of ad-hoc networks are ease of deployment thereby enabling an inexpensive way to achieve the goal of ubiquitous communications. One of the fundamental tasks that an ad hoc network should often perform is congestion control. Congestion control is the mechanism by which the network bandwidth is distributed across multiple end-to-end connections. Its main objective is to limit the delay and buffer overflow caused by network congestion and provide tradeoffs between efficient and fair resource allocation.

Congestion is an unwanted situation and is disastrous for a data transmission system as it manifests itself as depletion of resources that are critical to the operation of the system. These resources can be CPU, buffer space, bandwidth etc.. congestion control makes sure that the system is running at its rated capacity, even with the worst case overload situations. Doing this enables optimal usage of resources for all the nodes in the system with a measurable quality-of- service (QOS). In ad hoc wireless networks the link capacities are “elastic”. Most routing schemes for ad hoc networks select paths that minimize hop count, but it leads to congestion at some region, while other regions are not fully utilized. To use the wireless spectrum more efficiently, multiple paths based on the pattern of traffic demand and interference among links should be considered.

Wireless channel is a shared medium and interference limited. Link is only a logical concept and links are correlated due to the interference with each other. In wireless network flows can compete even if they don’t share a wireless link in their paths. Thus, in ad hoc wireless networks the contention relations between link-layer flows provide fundamental constraints for resource allocation.

In wireless networks the joint design of congestion and media access control is naturally formulated using the network utility maximization framework considering the new constraints that arise from channel contention. In wire line networks with fixed capacities, congestion control is implemented at the transport layer and is often designed separately from functions of other layers. Useful mathematical models and tools based on convex optimization and control theory have been developed, which cast congestion control algorithms as decentralized primal-dual schemes to solve network utility maximization problems.

In the NUM framework, each end-user (or source) has its utility function and link bandwidths are allocated so that network utility (*i.e.*, the sum of all users’ utilities) is maximized. A utility function can be interpreted as the level of satisfaction attained by a user as a function of resource allocation. Efficiency of resource allocation algorithms can thus be measured by the achieved network utility.

2. MODELING AND PRELIMINARIES

We consider an ad hoc wireless network represented by an undirected graph $G = (N,L)$, where N is the set of nodes and L is the set of logical links. Each source node s has its utility function $Us(xs)$, which is a function of its transmitting data rate $xs \in [0,\infty)$ and we assume it is continuously differentiable, increasing, and strictly concave. For its communication, each source uses a subset $L(s)$ of links. Let $Lout(n)$ denote the set of outgoing links from node n, and $Lin(n)$ the set of incoming links to node n. We define S as the set of all sources and $S(l)$ as the subset of sources that are traversing link l. We assume static topology (the nodes are in a fixed position). Also, each link has finite capacity cl when it is active, i.e. we implicitly assume that the wireless channel is fixed or some underlying mechanism masks the channel variation. Wireless transmissions are interference-limited. All links transmit at rate cl for the duration they hold the channel.

Assume that each node cannot transmit or receive simultaneously, and can transmit to or receive from at most one adjacent node at a time. Since each node has a limited transmission range, contention among links for the shared medium is location-dependent. Spatial reuse is possible only when links are sufficiently far apart. Define two types of sets, *LI* (*n*) and *NI* (*l*), to capture the location dependent contention relations, where *LI* (*n*) is the set of links whose receptions are affected adversely by the transmission of node *n*, excluding outgoing links from node *n*, and *NI* (*l*) is the set of nodes whose transmission fail the reception of link *l*, excluding the transmit node of link *l*. Also note that $l \in LI(n)$ if and only if $n \in NI(l)$. Time is slotted in intervals of equal unit length and the *i*-th slot refers to the time interval [*i, i* + 1), where *i* = 0, 1. . . i.e., transmission attempts of each node occur at discrete time instances *i*. In this a MAC protocol is developed based on random access with probabilistic (re-)transmissions. At the beginning of a slot, each node *n* transmits data with probability *qn*. When it determines to transmit data, it selects one of its outgoing links $l \in Lout(n)$ with probability *pl/qn*, where *pl* is the link persistence probability;

$$\sum_{l\in L_{out}(n)} p_l = q_n, \forall n$$

$$\begin{aligned} \max \ & \sum_s U_s(x_s) \\ \text{s.t.} \ & \sum_{s\in S(l)} x_s \le \eta_l := c_l p_l \prod_{k\in N^I(l)} (1-q_k), \forall l \\ & \sum_{l\in L_{out}(n)} p_l = q_n \le 1, \forall n \\ & 0 \le p_l \le 1, \forall l, \\ & x_s \ge 0, \forall s, \end{aligned} \qquad (1)$$

Where $\eta = \{\eta_l | l \in L\}$ link throughputs given p and q, since the term $p_l \prod_{k\in N^I(l)} (1-q_k)$ is the probability that a packet is transmitted over link *l* and successfully received by its receiver.

The problem formulation in (1) entails congestion control at the network layer (finding x), and contention control at the MAC layer (finding p and q). The two layers are coupled through the first constraint in (1), which asserts that for each link *l*, the aggregate source rate $\sum_{s\in S(l)} x_s$ does not exceed the link throughput. The transport layer source rates and the MAC layer transmission probabilities should be jointly optimized to maximize the aggregate source utility. Due to the first constraint, (1) is in general a non-convex and non-separable problem, which is difficult to optimize over both x and p, q in a distributed way directly. Under certain conditions, it can be transformed into a convex one by taking the logarithm on both sides of the first constraint and replacing the rate variables by their logarithmic counterparts, i.e., Z*s* = log(*xs*). This yields a new

$$\log(\sum_{s\in S(l)} e^{z_s}) - \log(c_l) - \log p_l - \sum_{k\in N^I(l)} \log(1-q_k) \le 0, \forall l. \qquad (2)$$

constraint $\log(\sum_{s\in S(l)} e^{z_s})$, although it is a convex function.

We introduce a set of new variable

$$\alpha = \{\alpha_{ls} | 0 \le \alpha_{ls} \le 1, \sum_{s\in S(l)} \alpha_{ls} = 1, l \in L, s \in S(l)\}, \qquad (3)$$

where each *αls* can be interpreted as the fraction of the overall traffic on link *l* contributed by source s

$$\begin{aligned} \text{s.t.} \ & z_s - \log \alpha_{ls} - \log c_l - \log p_l \\ & - \sum_{k\in N^I(l)} \log(1-q_k) \le 0, \forall l, \forall s \in S(l) \\ & 0 \le \alpha_{ls} \le 1, \sum_{s\in S(l)} \alpha_{ls} = 1, \forall l, \forall s \in S(l) \\ & \sum_{l\in L_{out}(n)} p_l = q_n \le 1, \forall n \\ & 0 \le p_l \le 1, \forall l, \end{aligned} \qquad (4)$$

Lemma 1: If *gs*(*xs*) < 0, then *Us* (Z*s*) is a strictly concave function of Z*s*.

$$g_s(x_s) = \frac{d^2 U_s(x_s)}{dx_s^2} x_s + \frac{U_s(x_s)}{dx_s}, \qquad (5)$$

Given that the condition of Lemma 1 is satisfied, problem (4) is indeed a convex problem, and all log rates are decoupled, enabling the dual decomposition. To proceed, we apply duality theory and associate Lagrange multipliers. Let us define the Lagrangian function

$$\begin{aligned} L(\boldsymbol{\lambda}, \mathbf{z}, \mathbf{p}, \mathbf{q}, \boldsymbol{\alpha}) &= \sum_{s\in S} U_s'(z_s) \\ & - \sum_{l\in L} \sum_{s\in S(l)} \lambda_{ls} \Big(z_s - \log[\alpha_{ls} c_l p_l \prod_{k\in N^I(l)} (1-q_k)] \Big) \\ &= \sum_{s\in S} \Big(U_s'(z_s) - \lambda^s z_s \Big) + \sum_{l\in L} \lambda^l \log c_l \\ & + \sum_n \sum_{l\in L_{out}(n)} \sum_{s\in S(l)} \lambda_{ls} \log \alpha_{ls} \\ & + \sum_n \Bigg(\sum_{l\in L_{out}(n)} \lambda^l \log p_l + \sum_{l\in L^I(n)} \lambda^l \log(1-q_n) \Bigg), \end{aligned} \qquad (6)$$

where $\lambda^s := \sum_{l\in L(s)} \lambda_{ls}$, $\lambda^l := \sum_{s\in S(l)} \lambda_{ls}$, $\boldsymbol{\lambda} := \{\lambda_{ls} | s \in S, l \in L(s)\}$, and $\mathbf{z} := \{z_s | s \in S\}$.

The Lagrangian dual function is

$$D(\boldsymbol{\lambda}) = \max_{\substack{0 \le \alpha_{ls} \le 1, \sum_{s\in S(l)} \alpha_{ls} = 1, \forall l, \forall s \in S(l) \\ \sum_{l\in L_{out}(n)} p_l = q_n \le 1, \forall n \\ 0 \le p_l \le 1, \forall l}} L(\boldsymbol{\lambda}, \mathbf{z}, \mathbf{p}, \mathbf{q}, \boldsymbol{\alpha}), \qquad (7)$$

And the dual problem to (4) is

D: minD(*λ*). *(8)*

The maximization in (7) for a given *λ* can be decomposed into three sub problems:

One at each source and the other two at each node. The source sub problem is

$$\max_{z_s} \big(U_s'(z_s) - \lambda^s z_s \big), \forall s \in S. \qquad (9)$$

If we interpret the Lagrange multiplier *λls* as the price per unit of log bandwidth charged by link *l* to source *s*, then the source strategy is to maximize its net benefit $U_s(Z_s) - \lambda_s Z_s$, since $\lambda_s z_s$ is just the sum bandwidth cost charged by all links on its path if source s transmits at log rate z_s. Since $U_s(Z_s)$ is strictly concave over Z_s, a unique maximize exists.

The other two subproblems at each node n for every outgoing link l □ $Lout(n)$ are, respectively

$$\max_{0\le\alpha_{ls}\le 1, \sum_{s\in S(l)}\alpha_{ls}=1} \sum_{s\in S(l)} \lambda_{ls}\log\alpha_{ls}, \forall l\in L_{out}(n), \quad (10)$$

and

$$\max_{\substack{\sum_{l\in L_{out}(n)} p_l = q_n \le 1 \\ 0\le p_l\le 1}} \sum_{l\in L_{out}(n)} \lambda^l \log p_l + \sum_{l\in L^I(n)} \lambda^l \log(1-q_n). \quad (11)$$

Proposition 2: Given $\boldsymbol{\lambda}$, the $\boldsymbol{\alpha}(\boldsymbol{\lambda})$ solving problem (10) is (for node n and link l □ $Lout(n)$)

$$\alpha_{ls}(\boldsymbol{\lambda}) = \begin{cases} \frac{\lambda_{ls}}{\sum_{s\in S(l)}\lambda_{ls}}, & \text{if } \sum_{s\in S(l)}\lambda_{ls}\neq 0 \\ \frac{1}{|S(l)|}, & \text{if } \sum_{s\in S(l)}\lambda_{ls} = 0 \end{cases}, \quad (12)$$

and the $\mathbf{p}(\boldsymbol{\lambda}), \mathbf{q}(\boldsymbol{\lambda})$ solving problem (11) are

$$p_l(\boldsymbol{\lambda}) = \begin{cases} \frac{\lambda^l}{\sum_{l'\in L_{out}(n)}\lambda^{l'} + \sum_{l'\in L^I(n)}\lambda^{l'}}, & \text{if } k(n)\neq 0 \\ \frac{1}{|L_{out}(n)|+|L^I(n)|}, & \text{if } k(n)=0 \end{cases}, \quad (13)$$

and

$$q_n(\boldsymbol{\lambda}) = \begin{cases} \frac{\sum_{l'\in L_{out}(n)}\lambda^{l'}}{\sum_{l'\in L_{out}(n)}\lambda^{l'} + \sum_{l'\in L^I(n)}\lambda^{l'}}, & \text{if } k(n)\neq 0 \\ \frac{|L_{out}(n)|}{|L_{out}(n)|+|L^I(n)|}, & \text{if } k(n)=0 \end{cases}, \quad (14)$$

where $k(n) := \sum_{l'\in L_{out}(n)}\lambda^{l'} + \sum_{l'\in L^I(n)}\lambda^{l'}$.

Now we are ready to solve the dual problem (8) using a projected sub gradient method. At each node n for $Lout(n)$ and $S(l)$, the outgoing link prices for sources involved are adjusted as follows

$$\lambda_{ls}(t+1) = \left[\lambda_{ls}(t) - \gamma(t)\frac{\partial D}{\partial\lambda_{ls}}(\boldsymbol{\lambda}(t))\right]^+, \quad (15)$$

Where $[a]+ := \max\{0, a\}$ and $\gamma(t) > 0$ is a step size. '+' denotes the projection onto the set + of non-negative real numbers.

According to Dan skin's theorem, we have

$$\frac{\partial D}{\partial\lambda_{ls}} = \log c_l + \log\alpha_{ls} + \log p_l + \sum_{k\in N^I(l)}\log(1-q_k) - z_s. \quad (16)$$

Substituting (16) into (15), we obtain the following adjustment rule for link l ε $Lout(n)$ at each node n

$$\lambda_{ls}(t+1) = \Big[\lambda_{ls}(t) + \gamma(t)\Big(z_s(\boldsymbol{\lambda}(t)) - \log c_l - \log\alpha_{ls}(\boldsymbol{\lambda}(t)) - \log p_l(\boldsymbol{\lambda}(t)) - \sum_{k\in N^I(l)}\log(1-q_k(\boldsymbol{\lambda}(t)))\Big)\Big]^+. \quad (17)$$

ALGORITHM

1) Create a random network.
2) After creating a network, the distance between each node to all other nodes are found by using Euclidean distance method.
   d=sqrt ((x1-x2) ^2+(y1-y2)^2)
3) Find the neighbor list of each node is used.
4) The neighboring list in order to find the path between each source and destination using DSR routing protocol is implement.
5) Checks for the best optimal path from the various paths obtained in the evaluation of route.

Algorithm at source s

6) Receives from the network the sum $\lambda^s(t) = \sum_{l\in L(s)}\lambda_{ls}(t)$ of link prices in s's path;

7) Computes the new log rate using
$z_s(t+1) = \arg\max_{z_s}(U'_s(z_s) - \lambda^s(t)z_s);$

8) Communicates the new log rate $Z_s(t+1)$ to all links $l\in L(s)$ on s's path.

Algorithm at Node n:

9) Receives log rates $Z_s(t)$ from all sources s $\cup_{l\in L_{out}(n)}S(l)$ that go through the outgoing links of node n

10) Receives prices $\lambda^{l'}(t), \forall l' \in L^I(n)$ from the neighboring nodes n' *where* $l' \in L_{out}(n')$;

11) Calculates $\alpha_{ls}(t), p_l(t), q_n(t), \forall l\in L_{out}(n), \forall s\in L(s),$ according to Proposition 2;

12) Computes new prices
$\lambda_{ls}(t+1) = [\lambda_{ls}(t) + \gamma(t)(Z_s(\lambda(t)) - \log c_l - \log \alpha_{ls}(\lambda(t)) - \log p_l(\lambda(t)) - \sum_{NI(l)}\log(1-q_k(\lambda(t)))]+.$

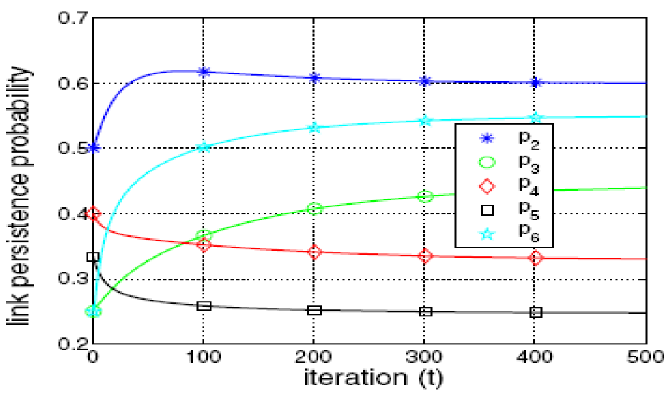
For each outgoing link $l\in L_{out}(n)$, communicates new Prices $\lambda_{ls}(t+1)$ to all sources s $\in S(l)$ that use link l *and* $\lambda^l(t+1)$ to all nodes in $N^I(l)$. For the convergence and optimality of this distributed algorithm, have the following result.

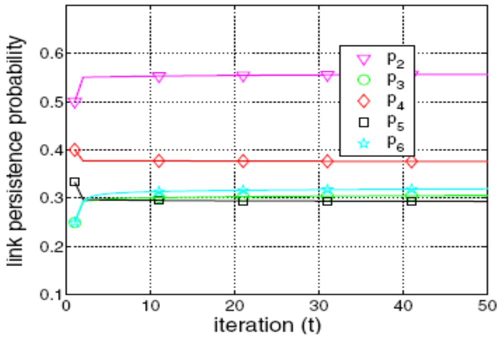
If the following condition is satisfied at the optimal dual solution λ^*

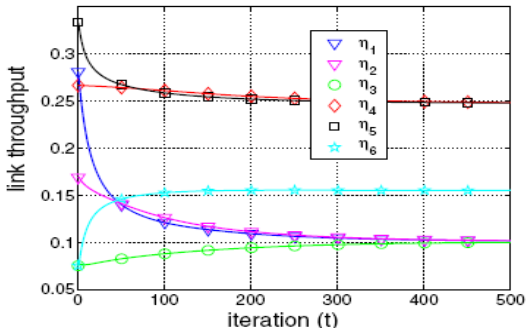
$$k^*(n) = \sum_{l\in L_{out}(n)}\sum_{s\in S(l)}\lambda^*_{ls} + \sum_{l\in L^I(n)}\sum_{s\in S(l)}\lambda^*_{ls} \neq 0, \forall n\in N$$

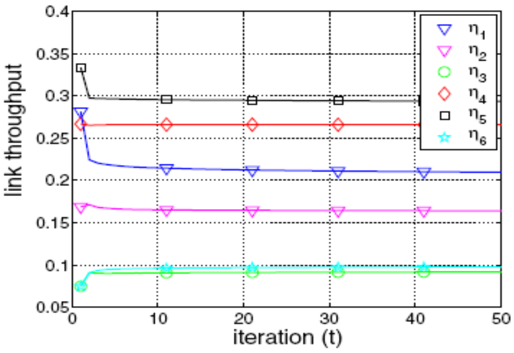
And λ^* denotes a minimize of the dual problem (8), then step sizes $\{\gamma(t)\}_{t=0}^{\infty}$ exist to guarantee $\lim_{t\to\infty}\boldsymbol{\lambda}(t) = \boldsymbol{\lambda}^*$

The evolution of link persistence probabilities and link throughputs.









The joint control algorithm can be implemented as follows. Each link l (or its transmission node tl) updates its persistence probability $pl(t)$, and concurrently, each source updates its data rate $xs(t)$.To calculate the sub gradient in (6), each link needs information only from link k, $k\varepsilon LI$, *i.e.*, from links whose transmissions are interfered from the transmission of link l, and those links are in the neighborhood of link l. To calculate the sub gradient in (7), each source needs information only from link l, $l\varepsilon L(s)$, *i.e.*, from links on its routing path. Hence, to perform the algorithm, each source and link need only local information through limited message passing and the algorithm can be implemented in a distributed way. At the transmitter node of each link to update the persistence probability of that link, and does not need to be passed among the nodes. There is no need to explicitly pass around the values of persistence probabilities

CONCLUSION

We studied the joint design of congestion and contention control for wireless ad hoc networks. While the original problem is non-convex and coupled, provided a decoupled and dual-decomposable convex formulation, based on which sub gradient-based cross-layer algorithms were derived to solve the dual problem in a distributed fashion for non-logarithmic utilities. These algorithms decompose vertically in two layers, the network layer where sources adjust their end-to-end rates, and the MAC layer where links update persistence probabilities. These two layers interact and are coordinated through link prices. We used random network topology in wireless ad hoc network.

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