

Queuing Delay Analysis in Multi-Hop Wireless Networks

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Abstract — A Multi-hop wireless network is a wireless network adopting multihop wireless technology without deployment of wired backhaul links. In multi-hop wireless networks, the routes between source and destination pairs are relatively fixed. In such networks, a metric called delay is of prime importance. But the delay analysis of multi-hop wireless networks has largely been an open problem. This problem is notoriously difficult even in the context of wireline networks, primarily because of the complex interactions in the network (e.g., superposition, routing, departure, etc.) that make its analysis amenable only in very special cases like the product form networks. Maximizing the network throughput, or equivalently, attaining the maximum stability region of the network, through appropriately scheduling is a key design goal in wireless networks. But the problem of delay analysis further exacerbated by the mutual interference inherent in wireless networks which, complicates both the scheduling mechanisms and their analysis. This paper focuses on the delay analysis of a queue length based scheduling policy in multi-hop wireless network.

Keywords— Delay, Throughput, Queue, Wireless Network.

I. INTRODUCTION

A multi-hop wireless network [1] is a network of computers and devices (*nodes*) which are connected by wireless communication *links*. The links are most often implemented with digital packet radios. Because each radio link has a limited communications range, many pairs of nodes cannot communicate directly, and must forward data to each other via one or more cooperating intermediate nodes. A source node transmits a packet to a neighboring node with which it can communicate directly. The neighboring node in turn transmits the packet to one of its neighbors, and so on until the packet is transmitted to its ultimate destination. Each link that a packet is sent over is referred to as a *hop*; the set of links that a packet travels over from the source to the destination is called a *route* or *path*. Routes are discovered by running a distributed *routing protocol* on the network.

Fig.1 shows an example of a multi-hop wireless network. These networks are often called ‘mesh’ networks, in reference to the topology formed by the links and nodes. Typically a mesh network does not operate in isolation, and often has one or more gateways that connect it to a larger internet.

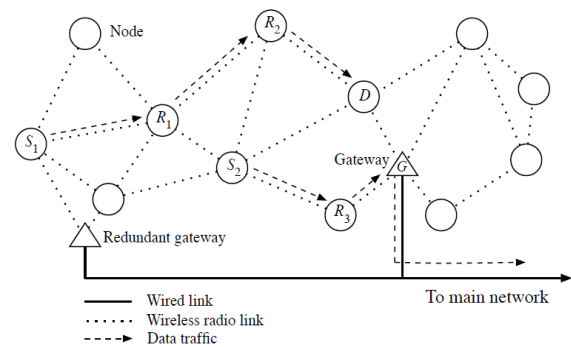


Fig.1. A multi-hop wireless network. Node S_1 sends data to node D via cooperating nodes R_1 and R_2 , while node S_2 sends data out of the network via node R_3 and the gateway G .

A large number of studies on wireless networks have been devoted to system stability and throughput maximization [2][8]. These schemes are often called throughput-optimal scheduling schemes. The delay performance [3] of these systems, however, has largely been an open problem. The analysis of scheduling policies [4] is difficult because of correlations among mutually interfering queues. Moreover, throughput optimal algorithms like Maximum Weighted Matching (MWM) use the queue length information while making the scheduling decisions. This results in complex interactions of arrival, service, and backlog processes and significantly complicates the analysis. This paper focuses on the delay analysis of queue length based scheduling policy [5][6] in multi-hop wireless networks.

II. RELATED WORK

Consider multi-hop wireless network with multiple source-destination pairs, given routing and traffic information. Each source injects packets in the network, which traverses through the network until it reaches the destination. For example, a multi-hop wireless network with three flows is shown in Figure 2. The exogenous arrival processes $AI(t)$, $AII(t)$ and $AIII(t)$ correspond to the number of packets injected in the system at time t . A packet is queued at each node in its path where it waits for an opportunity to be transmitted. Since the transmission medium is shared, concurrent transmissions can interfere with each others’ transmissions. The delay performance of any scheduling policy is primarily limited by the interference [7], which causes many bottlenecks to be formed in the network.

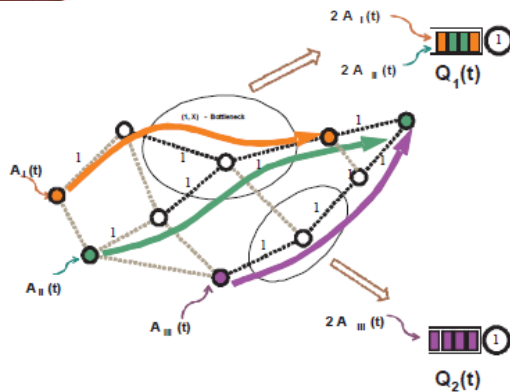


Fig.2. A typical multi-hop wireless network with multiple flows, each having exogenous arrivals at the source. Some of the important bottlenecks have been highlighted.

Consider a wireless network $G = (V, L)$, where V is the set of nodes and L is the set of links. Each link has unit capacity. There are N flows, each distinguished by its source destination pair (s_i, d_i) . There is a fixed route (set of links) between the source s_i and corresponding destination d_i . Each route is a simple path. Each packet has a deterministic service time equal to one unit. The exogenous arrivals at each source are assumed to be independent. Let $A(t) = (A_1(t), \dots, A_N(t))$ represent the vector of exogenous arrivals, where $A_i(t)$ is the number of packets injected into the system by the source s_i during time slot t (for $i \in 1, \dots, N$). Let $\lambda = (\lambda_1, \dots, \lambda_N)$ represent the corresponding long-term average arrival rate vector. The path on which flow i is routed is specified as

$$P_i := (v_i^0, v_i^1, \dots, v_i^j, \dots, v_i^{|P_i|})$$

where v_j^i is a node at a j -hop distance from the source node s_i .

III. DERIVING LOWER BOUNDS ON AVERAGE DELAY

This section presents a derivation for lower bounds on the average packet delay for a given multi-hop wireless network. Certain bottlenecks are formed in multi-hop wireless networks due to link interference. Define a bottleneck to be a set of links $X \subset L$ such that no more than one of its links can be scheduled simultaneously. Our idea of bottleneck is equivalent to identifying cliques in the conflict graph.

The Algorithm 1 maintains a table $T(i)$ which indicates the number of times link i has been used in the bottleneck. The value of $T(i)$ is initialized to C_i . The algorithm proceeds by greedily searching for a bottleneck that yields the maximum lower bound. For each link in the chosen bottleneck, the value of $T(i)$ is decremented by 1 and the process is repeated until the table T has a non zero entry. Thus it decomposes the wireless network into several single queue systems. The average delay of the system can then be easily computed. Note that the decomposition obtained by the greedy algorithm is not the optimal decomposition. The optimal decomposition can alternately

be obtained by using a dynamic programming approach with the cost of increased computation complexity.

Algorithm 1 Computing the Lower Bound

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1: for  $i = 1$  to  $N$  do
2:  $T(i) = C_i$ 
3: end for
4: BOUND = 0
5: repeat
6: Find the bottleneck which maximizes  $E[QX]$ 
7: BOUND = BOUND +  $E[QX]$ 
8: for all  $i \in X$  do
9:  $T(i) = T(i) - 1$ 
10: end for
11: until  $\forall i, T(i) = 0$ 
12: return BOUND

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Here, $QX(t)$ be the queue length of this system at time t . The expected queue length of the reduced system,

$$E[Q_X] \geq \frac{E[A_X^2] - 2\lambda_X^2 + \lambda_X}{2(1 - \prod_{i \in X} (1 - p_i)) - \lambda_X}$$

The lower bound may be loose on account of the following. We assume that the queueing in the bottlenecks is independent of each other, which may not be possible because of interference. Moreover, in the derivation of the lower bound by the reduction technique, we have neglected the non-empty queue constraints by grouping the arrivals into a single queue, and hence we underestimate the delay. Since the exclusive sets do not completely characterize the capacity region of the network, it may also be expected that if the input load is close to a boundary of the capacity region C , which is different from the boundaries generated by the exclusive sets, the lower bound may perform poorly. Thus, in certain cases, the delay of the system under MWM policy may be close to infinity while the lower bound is much smaller. This motivates the development of an upper bound for the system, which is tight in the sense that whenever the upper bound goes to infinity, the delay of the system under a throughput optimal policy also becomes infinite.

IV. DESIGNING DELAY-EFFICIENT SCHEDULERS

A delay efficient scheduler must satisfy the following properties:

- It must guarantee high throughput.
- Network resources must be shared among the flows.

The following illustrates the delay optimal policy for a clique network.

In a clique network, one link can be scheduled at any given time. This is due to the interference constraints in that network. Consider figure 3. Suppose that there are n flows in the clique network. Figure 3 shows a clique network with 6 flows. Every link lies in the interference range of the other and hence only one link can be scheduled at any given time.

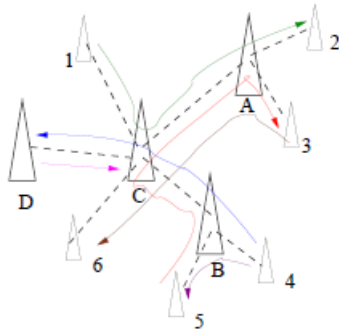


Fig.3. Clique network with 6 flows.

In such a network the optimality is achieved by scheduling the packet which is closest to its destination.

V. CONCLUSION

A multi-hop wireless network is a network of computers and devices (nodes) which are connected by wireless communication links. Compare to the previous Delay performance to reduce is an important metric in determining the throughput of multi-hop wireless networks. To maximize the throughput of a multi-hop wireless network, efficient scheduling schemes are needed. But the problem of delay performance complicates the scheduling schemes due to the interference in wireless networks. This paper focus on the lower bound on the delay analysis in a multi-hop wireless networks.

REFERENCES

- [1] Atul Adya, Paramvir Bahl, Jitendra Padhye, Alec Wolman, and Lidong Zhou. A multi-radio unification protocol for IEEE 802.11 wireless networks. Technical Report MSR-TR-2003-44, Microsoft Research, July 2003.
- [2] P. Chaporkar, K. Kar, and S. Sarkar. Throughput guarantees through maximal scheduling in wireless networks. In 43rd Annual Allerton Conference on Communication, Control, and Computing, 2005.
- [3] G. R. Gupta and N. B. Shroff. Delay analysis for wireless networks with single hop traffic and general interference constraints. *IEEE Transactions on Networking*, 18:393 – 405, April 2010.
- [4] G. R. Gupta. Delay Efficient Control Policies for Wireless Networks. Ph.D. Dissertation, Purdue University, 2009.
- [5] H. Dupuis and B. Hajek. A simple formula for mean multiplexing delay for independent regenerative sources. *Queueing Systems Theory and Applications*, 16:195–239, 1994.
- [6] I. Keslassy and N. McKeown. Analysis of scheduling algorithms that provide 100% throughput in input-queued switches. In 39th Annual Allerton Conference on Communication, Control, and Computing, Monticello, Illinois, October 2001.
- [7] K. Jain, J. Padhye, V. Padmanabhan, and L. Qiu. Impact of interference on multi-hop wireless network performance. In *MOBICOM*, 2003.
- [8] Baruch Awerbuch, David Holmer, and Herbert Rubens. High throughput route selection in multi-rate ad hoc wireless networks. Technical report, Johns Hopkins University, Computer Science Department, March 2003. Version 2.