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Novel Scheduling Policy for Delay Analysis of Multi-Hop Wireless Networks

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Abstract

To maximizes the throughput performance of the systems, the scheduling algorithm which is widely used in multi-hop wireless networks and high speed switches need wide range of study. Various studies have subsequently focused on the design of simpler and faster scheduling algorithms which provide performance guarantee on the throughput. Recent results of this, highlights the deficiencies which are arisen due to all these scheduling systems mainly based on throughput. Moreover the development of analytical techniques to study the delay performance of such systems has to provide more focus to maintain the QOS, network design (choice of buffer size, capacity of links) etc. Analyzing the delay performance of multi-hop systems which follow throughput optimal scheduling policies are very difficult due to complex relationship between arrival, service and queue length processes. In this paper, I develop novel techniques for performance analysis of wireless networks and also design novel scheduling policies that are delay-efficient.
Keywords- Back-pressure, Delay Performance, Multi-hop, Throughput Optimal

I. INTRODUCTION

There exist a considerable amount of research [4] on multi-hop wireless networks that focuses on maintaining system stability and maximizing first-order metrics, such as throughput or utility. However, the arguably more important problem of delay optimal scheduling remains largely open, except for specialized scenarios and interference topologies. Even well-known throughput-optimal algorithms like back pressure, suffer from large delays [2]. Furthermore, for a large class of applications such as video or voice over IP, embedded network control and for system design; delay analysis is of prime importance. Due to the limited amount of literature on delay analysis and delay-optimal scheduling problem for general topology wireless networks, the results in the paper can be considered as a quantum advance in the state-of-the-art.

Many throughput-optimal algorithms make their scheduling decisions based on the backlog in the system, which in turn depends on past scheduling decisions and arrival rates. Such cross dependency results in system dynamics that are difficult to Analyse. Due to this reason, the behaviour of throughput-optimal algorithms in terms of finer QoS performance metrics, such as mean delay or probability of buffer overflow, is difficult to quantify. Most results have been restricted to single-hop traffic using order optimal mean delay analysis, heavy traffic analysis and large deviations. Traditional heavy traffic results have focused on a single bottleneck in the system and proving a state-space collapse.

In this paper I introduce novel analytical techniques to relax the interference constraints in the network to derive lower bounds. I develop a queue grouping technique to handle the complex correlations of the service process resulting from the multi-hop nature of the flows, thus circumventing the decades-long open problem of characterizing the departure process of a queue. Also introduce a novel concept of (K, X) - bottlenecks in the network and derive sample path bounds for a group of queues upstream of a bottleneck. I also derive a fundamental lower bound on the system-wide average queuing delay of a packet in multi-hop wireless network, regardless of the scheduling policy used. The lower bound can be used for analysing a large class of arrival processes using known results in the queuing literature. For a network under the primary interference model, their lower bound is tight in an asymptotic sense. For a tandem queuing network, the average delay of a delay-optimal policy numerically coincides with the lower bound provided in this paper. A clique network is a special graph where at most one link can be scheduled at any given time. Using existing results on work conserving queues, we design a delay optimal policy for a clique network and compare it to the lower bound. The lower bound is observed to be accurate via extensive numerical results. Thus, this studies provides a benchmark for designing delay optimal schedulers in general.

The rest of the paper is organized as follows. Section II illustrates the related works. Section III describes the methodology used. Section IV gives a detailed account on the results obtained using the proposed method. Section V discusses about the overall work done in this paper. The conclusion is given in section VI.

II. RELATED WORKS

A. Multi-Hop Networking

Multi-hop or ad hoc, wireless networks use two or more wireless hops to convey information from a source to a destination. There are two distinct applications of multi-hop communication, with common features, but different applications.

Mobile ad hoc networks (MANETS): A mobile ad hoc network consists of a group of mobile nodes that communicate without requiring a fixed wireless infrastructure. In contrast to conventional cellular systems, there is no master-slave relationship between nodes such as base station to mobile users in ad hoc networks. Communication between nodes is performed by direct connection or through multiple hop relays. Mobile ad hoc networks have several practical applications including battlefield communication, emergency first response, and public safety systems. Despite extensive research in networking, many challenges remain in the study of mobile ad hoc networks including development of multiple access protocols that exploit advanced physical layer technologies like MIMO, OFDM, and interference cancellation, analysis of the fundamental limits of mobile ad hoc network capacity, practical characterization of achievable throughputs taking into account network overheads.

Multi-hop cellular networks: Cellular systems conventionally employ single hops between mobile units and the base station. As cellular systems evolve from voice centric to data centric communication, edge-of-cell throughput is becoming a significant concern. This problem is accentuated in systems with higher carrier frequencies (more path loss) and larger bandwidth (larger noise power). A promising solution to the problem of improving coverage and throughput is the use of relays. Several different relay technologies are under intensive investigation including fixed, mobile relays (other users opportunistically agree to relay each other's' packets), as well as mobile fixed relays (fixed relays that are mounted on buses or trains and thus moving). There has been extensive research on multi-hop cellular networks the last few years under the guise of relay networks or cooperative diversity. The use of relays, though, impacts almost every aspect of cellular system design and optimization including: scheduling, handoff, adaptive modulation, ARQ, and interference management. These topics are under intense investigation.

B. Backpressure Routing

Tssailus and Ephermides originally proposed the backpressure scheduling policies in [4]. Since then the scheduling policies have been an active area of research. The original scheduling policy schedules the maximum weighted independent set of all links in the network and is an NP-complete problem. Thus suboptimal but simpler designs of scheduling policies have been widely investigated. Among them, the most popular is a greedy scheduling policy which sequentially admits links to a schedule in a greedy fashion. The research in this area can be categorized in two broad classes: First, some research is focused on finding the guaranteed fraction of the capacity region that a scheduling algorithm can achieve. A greedy scheduling policy attains at least half of the capacity region. Greedy scheduling attains the full capacity region in several different networks. Greedy scheduling policies empirically perform nearly as well as an optimal scheduling policy. All these schemes assume an omniscent centralized controller which makes scheduling decisions. This is an unrealistic assumption in ad hoc networks where nodes make their network decisions autonomously. The second class of research in scheduling policies addresses this issue and presents designs of distributed scheduling algorithm. Distributed versions of greedy scheduling policies are recently presented in. Tssailus provided randomized scheduling schemes that attain the maximum throughput region, which can be implemented in fully distributed manner using gossip-based algorithms. Unfortunately, these schemes have large control overhead as all nodes require substantial amount of information exchange among each other. Recently proposed a CSMA based distributed backpressure scheduling that requires no information exchange among nodes. However, the proposed algorithm utilizes learning-based mechanism to converge to an optimal schedule after reasonable amount of time. Under varying traffic conditions, such algorithm may not converge to a favorable schedule.

Neely presented a generalized version of backpressure policy which takes routing and scheduling decisions jointly. Though he presented the policy as a joint routing and power control technique, the power control technique can be seen as a generalized version of scheduling. He also proposed a backpressure policy which does joint rate control, routing, and scheduling. There have been numerous versions of backpressure policies which do rate control, routing, scheduling, and power control jointly or in an independent manner. Some notable works that do not talk about backpressure specifically but have similar objectives and can be extended to backpressure policies. Most of these techniques utilize convex optimization to find the resource allocation solutions.

After the idea of backpressure routing is proposed, the issue of high end-to-end delay is recognized and addressed in some later works. A few previous works deal with combining shortest path routing with backpressure routing [2, 3]. [3] Presents a heuristic algorithm which uses a combined metric of differential queue backlog (to be defined later) and hop count to determine the next hop. [3] Presents an algorithm which provably minimizes the average length of routes used for packet forwarding. Though both of these algorithms are throughput optimal, they may still choose longer paths to forward the packets when there is a traffic burst for a small time interval. Thus, their routing scheme may suffer from high delay in some realistic scenarios. Most works in backpressure policies so far rely on standard mathematical techniques in optimization and control systems and are difficult to apply to practical systems directly. Recently, there have been some efforts to adapt backpressure policies for practical wireless networks. Some practical implementation of backpressure schemes (joint routing and rate control) have been proposed recently. These works focus on achieving throughput-optimality; delay is not their main concern.

Finally the issue of delay performance and implementation of back pressure algorithm is addressed in a few past works. [1] [2] [3], provides a good tutorial on this issue. [1] Propose an interesting strategy which uses to introduce the best scheduling policies for delay analysis.

C. Challenges for Backpressure Policies

As presented in the previous section, a backpressure policy makes packet forwarding decisions based on the deferential queue backlog only. Backpressure routing utilizes all possible paths between source and destination to avoid congestion on any single path. Though this property is instrumental in achieving higher throughput when traffic load is high, backpressure routing will use longer routes and even looping routes when the traffic load is light. This leads to large unnecessary end-to-end packet delay. Moreover, using longer routes in such cases wastes network resources. Routing-loop formation is another drawback of backpressure routing. In many real time applications like voice and video, high end-to-end packet delay is unacceptable. Often in such applications, a packet received with high delay is no better than packet loss. We could prevent high end-to-end delay in backpressure routing by not forwarding the packets on longer paths. But we still want to maintain the sufficient routes for any source-destination pair to provide adequate load balancing in case of high traffic load. Generally, these two objectives conflict with each other because few short routes exist in the network.

A second problem in many backpressure schemes is the assumption of a simplistic interference model. As stated before, the scheduling algorithm heavily depends upon the interference. Most past work exploits graph-theoretic techniques to design a scheduling algorithm.

A major advantage of graph theoretic techniques is that a graph abstraction of the network is quite useful for higher layer protocol design. However, previous graph-theoretic scheduling approaches works adopt a disk-based interference model which assumes that interference ends abruptly at some boundary and does not propagate further. This model underestimates interference by ignoring the accumulative interference due to far away transmissions. Sometimes, it overestimates the interference as well by not allowing close-by links. Thus the claimed performance of a scheduling policy using disk based interference model is questionable. The signal to interference and noise ratio (SINR) model is more accurate, but it is complex to design a scheduling policy for such model. Implementing backpressure in a distributed way is another challenge. Backpressure scheduling is the main bottleneck as all nodes have to make the scheduling decisions jointly and they need to share a lot of information to reach a final schedule. Some distributed backpressure scheduling algorithms are proposed in the literature. Unfortunately, they are complex to implement and have high overhead. It is a big challenge to implement distributed backpressure scheduling which is simple and has low control overhead. Backpressure routing utilizes multiple routes simultaneously to deliver packets to the destination. Due to this phenomenon, packets at the destination may be received out of sequence. Transport layer protocols like TCP originally designed for wired networks see this out-of-order delivery as a sign of congestion and ask the source node to perform flow control. This is known as the packet reordering problem. Thus if backpressure routing (or any load-balancing routing) is used along with TCP, we must ensure that packet reordering doesn't take place or mitigate TCP response to out-of-order packet delivery.

In this paper, I am highlighting the major drawbacks of back pressure algorithm as the delay performance.

III. PROPOSED SYSTEM

A. Network Model

Define a graph G = (V;E) representing the network. V is the set of nodes and E is the set of undirected links in the network. For the sake of simplicity, we consider the primary interference model where all disjoint links in the network can be activated simultaneously. This further implies that a node cannot transmit to or receive from more than one node at a time. This interference model is sometimes referred as node exclusive interference model. Every node maintains an internal queue for every known destination in the network to facilitate backpressure-based routing .We can reduce the complexity of this queuing architecture. Time is divided into equal slots. All links have equal rate of one packet per slot. Most of these assumptions are for the sake of clarity and ease of the simulation and are not restrictions on our proposed technique.

B. Methodology

Let e:=(a,b) be a link of interest. Suppose that flow i passes through link e and that nodes a and b are at a distance of j and j+1 hops, respectively, from the from the source node si In our notation e :=(vij,vij+1). Define the differential back log of flow i passing through a link e :=(vij,vij+1) as

$$\nabla Q_i^e = (Q_i^{j_i})^\alpha - (Q_i^{j_i+1})^\alpha, \qquad \text{for some } \alpha > 0.$$

I next propose a delay efficient dynamic scheduling algorithm, BPMaxWeight, as described in Algorithm 1. BPMaxWeight can be viewed as a generalization of the well-known back-pressure algorithm in [4] to broadcast wireless networks.

1) Algorithm1: BPMaxWeight Scheduling with Fixed Routing

At each time slot t;

for $z \in \mathcal{Z}$ do
$w_i J=0, \forall (i,J) \in \varepsilon_H;$
for(i,J) such that $z_i J=1$ do
for each $j \in J$ do
$p_j=m_{ij}\Pi_{k \in J:Q_k(t)<Q_j(t)}(1-m_{ik})$
end for
$w_{iJ}=\sum_{j \in J} p_j \max(Q_i(t)-Q_j(t),0)$
end for
$w(z)= \sum_{(i,j) \in \varepsilon_H} w_{iJ}$
end for
Schedule $z(t)=\arg\max_{z \in \mathcal{Z}} w(z)$ for transmission
The following procedure describes the flow of packets from source to destination.
At time slot t:

1) Step 1: Each node n maintains a separate queue of packets for each destination d; its length is denoted $Q_{nd}(t)$. Each link is assigned a weight:

$w(z)= \sum_{(i,j) \in \varepsilon_H} w_{iJ}$

2) Step 2:Scheduling rule:

Scheduling can be done based on algorithm

3) Step 3:For each activated link $(n_j) \in \pi^*(t)$. We remove cn_j packets from $Q_{nd^*nj}(t)$ and transmit to $Q_{jd^*nj}(t)$.

IV. RESULTS

Technologies like JAVA, J2mewtk is used to demonstrate the proposed backpressure algorithm. For demonstration, first we have to enter the distance between nodes. BPMaxWeight scheduling algorithm schedules the packets and also calculate the delay. Message flow through the intermediate node can be shown with the help of J2mewtk. The following screen shots give the working of proposed algorithm.

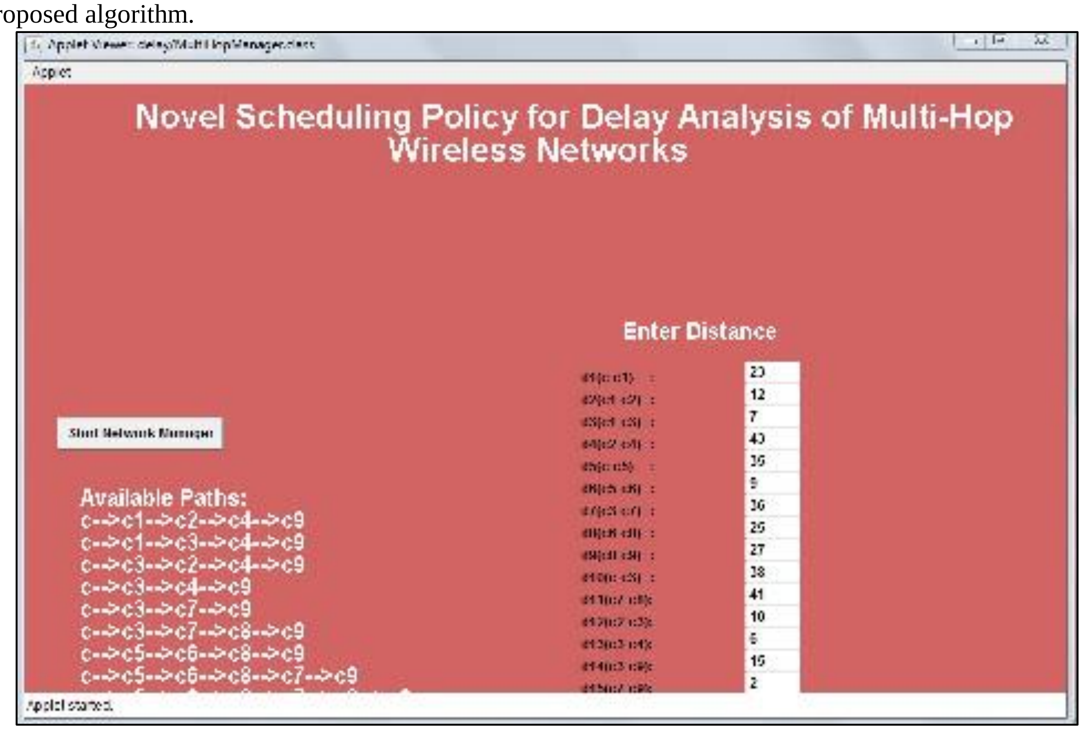

Fig. 1: Enter Distance Value

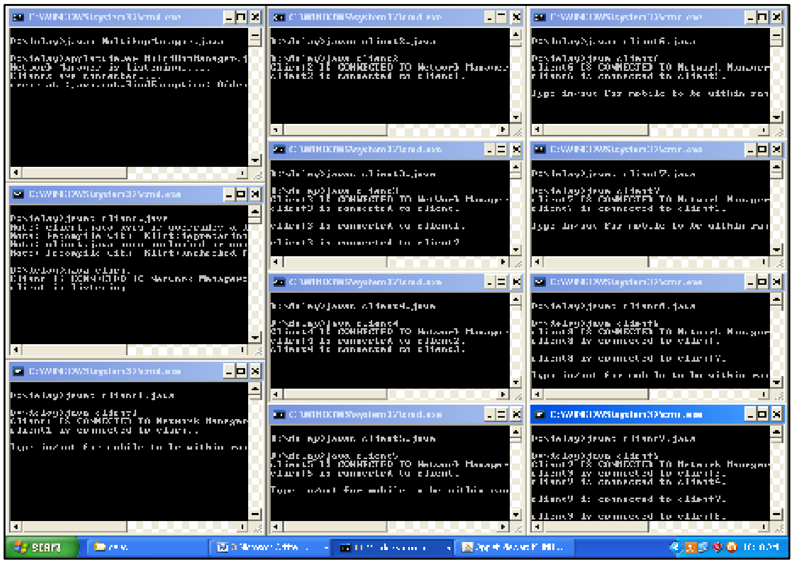

Fig. 2: Run Clients

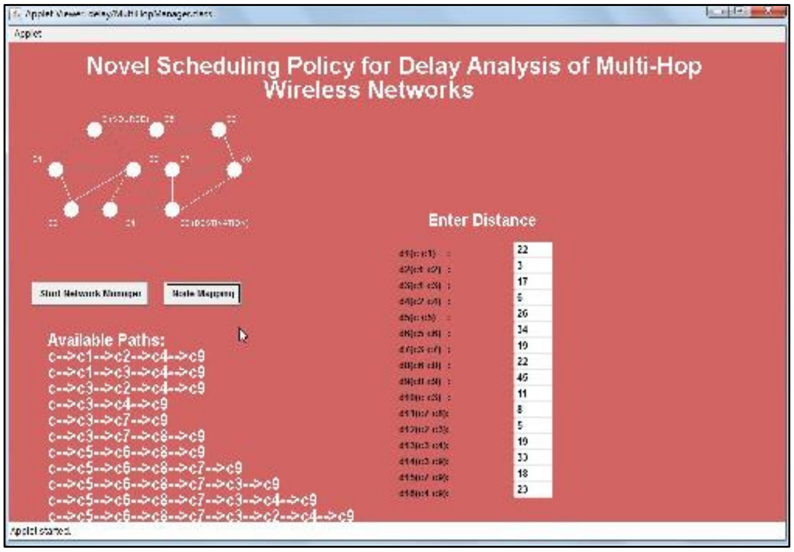

Fig. 3: Node Mapping

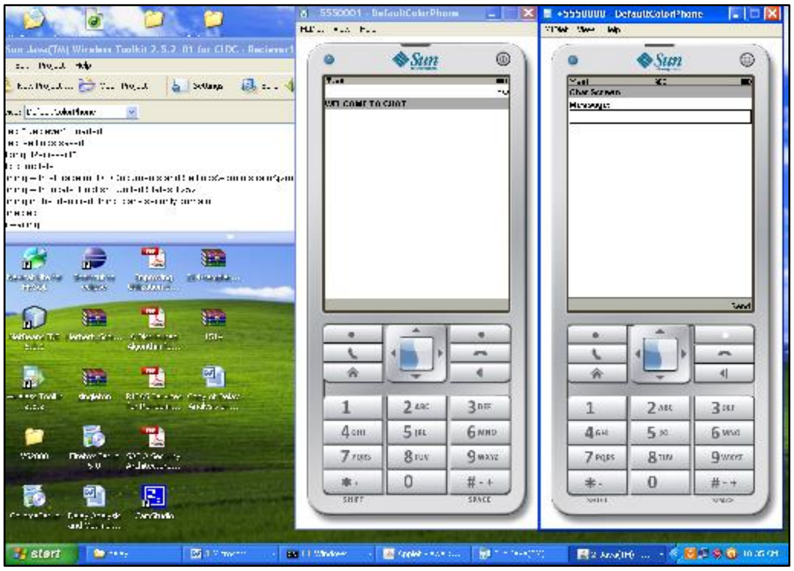

Fig. 4: Send a Message

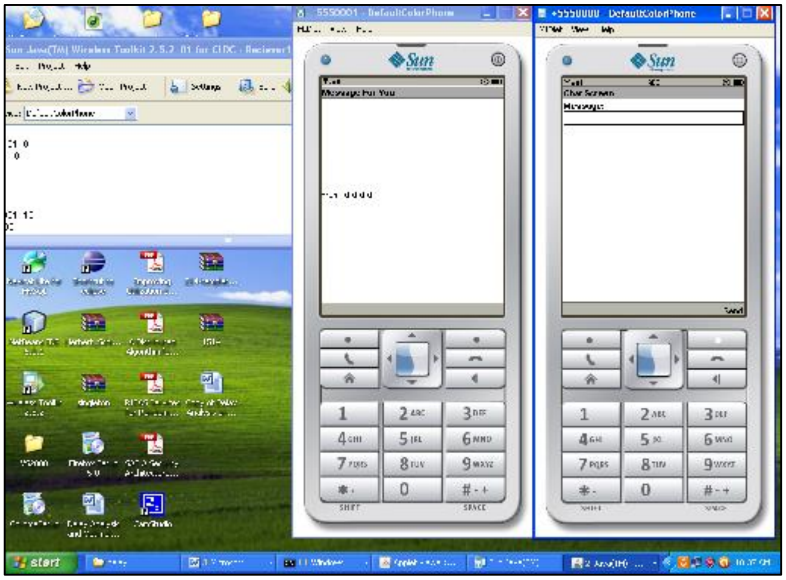

Fig. 5: Receive a Message

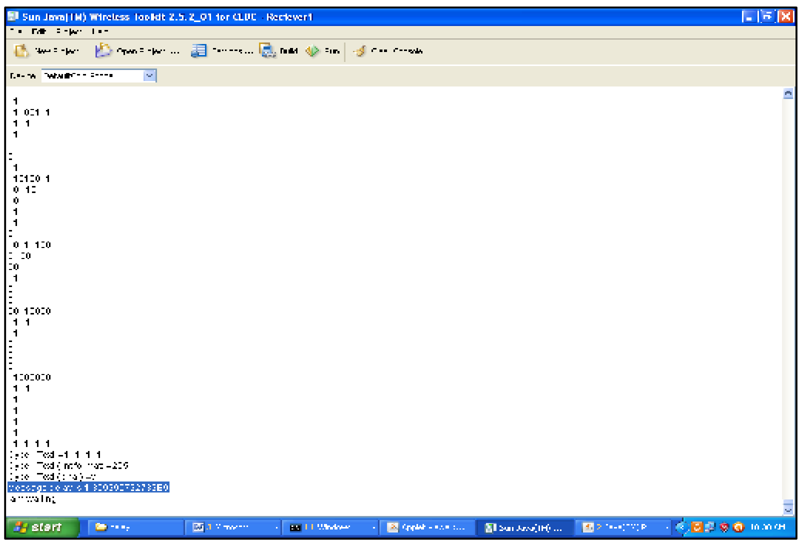

Fig. 6: Display the Delay

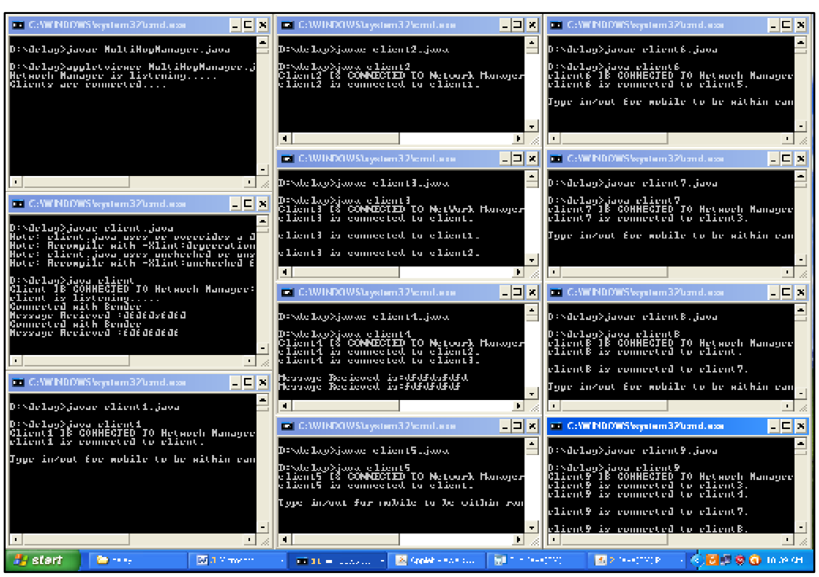

Fig. 7: Message Flow through Intermediate Nodes

V. DISCUSSION

Much of the delay analysis for multi-hop wireless networks has been limited to establishing the stability of the system. But the back-pressure policy can make the system stable. Hence, it is referred to as a throughput-optimal policy. It also has the advantage of being a myopic policy in that it does not require knowledge of the arrival process. In this paper, I have taken an important step toward the expected delay analysis of these systems. The implementation of this proposed algorithm includes a large class of applications like video or voice over IP, embedded network control.

VI. CONCLUSION AND FUTURE DIRECTIONS

The back-pressure algorithm, while being throughput optimal, is not useful in practice for adaptive routing since the delay performance can be really bad. In my work, I have focused on a class of throughput-optimal network policies called backpressure policies. These policies use cross-layer optimization and do scheduling and routing jointly. Though these policies were proposed about twenty years ago, they are still not suitable for many practical applications, particularly for wireless ad hoc networks. In this work, I address the main problems of backpressure-based techniques. I proposed a new technique for backpressure routing which addresses the problem of high end-to-end delay in routing. My solution achieves nearly the same throughput region as the capacity region achieved by the optimal backpressure policy. My packet forwarding scheme can be implemented with any generic routing protocol.

However this approach has a significant weakness because its implementation requires per flow queues. This fact affects the scalability of the algorithm. To reduce this problem, we have to reduce the queuing structure complexity. Future works can continue to overcome this weakness.

REFERENCES

[1] Gagan Raj Gupta, Ness B Shroff, ”Delay Analysis and Optimality of Scheduling Policies for Multihop Wireless Networks”, IEEE/ACMTransactionsonNetworking,vol.19, No.1,February 2011
[2] Lei Ying, Sanjay Shakkottai, Aneesh Reddy, “On Combining Shortest Path and Back Pressure Routing Over Multihop Wireless Networks”,IEEE/ACM Transactions on Networking, vol. 19, No. 3, June 2011
[3] Loc X Bui, R Srikant and Alexander Stolyar “A Novel Architecture for Reduction of Delay and Queuing Structure Complexity in the Back-Pressure Algorithm”, IEEE/ACM Transactions on Networking,vol.19,No.6,December 2011
[4] T. Leandros and A. Ephremides, “Stability properties of Constrained queueing systems and scheduling policies for maximum throughput in multihop radio networks,” IEEE Trans. Autom. Control, vol. 37, no. 12, pp. 1936–1948, Dec. 1992.
[5] Gupta, Gagan Raj “Delay efficient control policies for Wireless networks”, SIGMETRICS-Student thesis panel copyright, 2009.