Delay Analysis and Optimality of Scheduling in Multi-Hop Wireless Network

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Abstract

The delay is one of the important metric considered in the wireless network and wire-line network.In single hop wire-line network only one hop(router) is present from source to destination .In single hop network the interference problems occurred and the traffic control is difficult,the high amount of delay and the low amount of packet delivery ratio, because of routes changes dynamically and finally leads to low performance of the network.The delay analysis of a packets plays a vital role in the network.In real time applications the fixed time is given, so that the given amount of time all the packets should be delivered from source to destination.In multi-hop wireless network decomposition of packets into multiple paths,if any two nodes meet at same point bottleneck is occurred.In order to overcome from bottleneck used new queuing technique.For knowing the behavior of the each path in the network lower bound analysis is used.Different policies are used for scheduling the packets, which gives better optimality.

Keywords: Single Hop Network, Bottleneck, Back Pressure Policy

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Chapter 1

Introduction

1.1 Introduction

A very high number of studies on multi-hop wire less networks have been taken place for minimizing the delay and increase of throughput and optimality.for huge applications like video (or) voice over IP,embedded network control and system design: metric like delay is very important.The delay performance in multi-hop wireless networks,has been an open challenging task,it is very complex even in the wireless networks.In single hop network different problems are arise like: no perfect policies for assignment of packets,interference,no possibility of choosing another hop. So in order to eradicate the problems the multi-hop [1] networks are designed.In multi-hop packets are decomposed in to multiple paths,if any link failures are occurred the AODV [2],DSR[3] protocols are used for selecting an alternative link.In these using one new queuing technique and lower bound analysis for knowing behavior of the paths,some new analytical technique to calculate lower bounds and delay estimates for wireless networks with single hop network.but this is not applied directly to mult-hop networks due to the difficulty in characterizing the departure process at intermediate links..The packets are scheduled from source to destination, which different scheduling policies are involued.

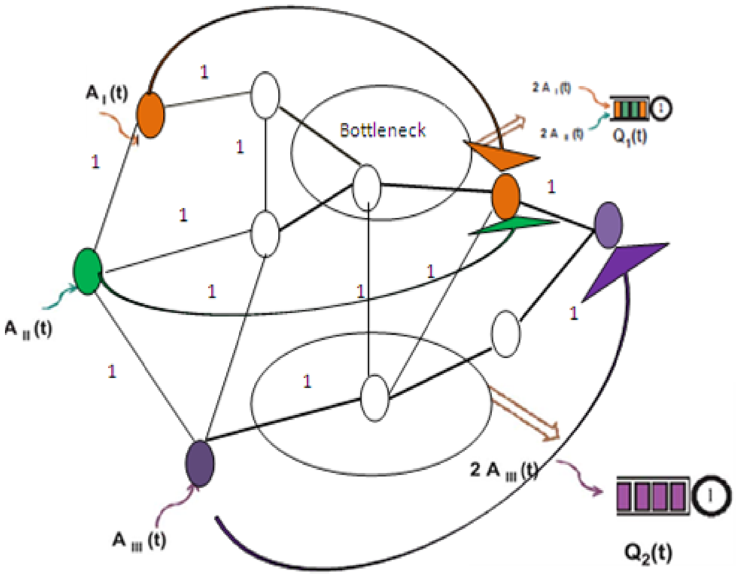

Figure 1.1: (Multi-hop wireless network with flows and bottlenecks)

1.2 Motivation

The demand of new effective networking architecture is increasing with in a growth of network sevices in our society.Severalmetrics are used for judging the network performance .The delay is one of the important metric in the wireless network as well as wireline networks.In real time applications the target is fixed and to perform the task with in the specified.Here no single second should be delayed with in the specified time.some other applications like: Internet , Banking , E-commerce , Crytograpy tasks should be performed efficiently.There are some key points which are choosen for motivation for this work.There are as follows.

- For maintaining effective transmission of data over : Internet , Banking , E-commerce , Cryptography.
- Introducing efficient policies and achieving optimality in soft and hard real time application systems.
- A huge amount of research is going on delay analysis in the network,as delay is a challenging problem facing now a days,so contributing some methods and policies for better end-to-end performance of a networks.

1.3 Problem statement

The main aim of the work is to design a network which gives better utilization of resources and minimizing the delay in the network and gaining optimality. In a wireline network or wireless network delay metric plays a vital role. The ultimate goal is to achieve optimality , decreasing the delay and effective utilization of network. In single hop network,which is existing system having problems of :Interfernce , no possibility of choosing another hop, low packet delivery ratio, no perfect policies of assignment of packets,high amount of load in only single route.

- In single hop network the clique network is used for analyzing the capacity of the link from one hop to another hop.It allows ony one link to schedule at any given time.
- No efficient and perfect policies for scheduling of the packets.

- Queuing size at the links are not known in single hop networks,assigned equally to all links,so that if one requires large queue and another requires small queue,then the waste of size when low packets flowing link assigned large queue.

1.4 Our contribution

In this work , the delay metric has improved drastically.In the existing system the single-hop network uses clique network,which allows interference constraint allow only one link to be scheduled at any given time.Single-hop network only one hop is active,there is no alternative for choosing another hop when any failure is occurred.Using multi-hop network we are attaining optimality and traffic, load problems has been overcome,so finally leads to better performance and resource utilization of the network. The main contributions of the thesis can be given as follows.

- In a network some nodes acts as source and destination.Data transmission can be done through different intermediate nodes,In between different problems may occur like traffic ,link failures,heavy load , packet loss. In first contribution the connecting the number of links and intermediate nodes are making to occur bottleneck[4].In every bottleneck node there will be a queue exists, after sending through one link the packets may not completely transmitted, so here another bottleneck is created to transmit the remaining packets which first bottleneck failed to transmit.This process continues till the optimality has gained.The load from one bottleneck to another bottle neck exchanged through correlation operation.
- Second contribution is completely depends on the first contribution.Based on the bottleneck and the packet flow the queue number increases. If the bottlenecks are

increases automatically queues are also increases.

- Third contribution all bottlenecks of the packets are delivered in to destination point.Calculating all links of delay, Next average link delay of information calculated for each and every link.
- Different policies are going to implement and many policies of average delay are calculate here, which policy contains the less amount of average delay is called optimal policy.

1.5 Thesis organization

In this chapter, the introduction and the motivation for delay analysis in the wireless networks or wireline network. Delay metric is one of the challenging task in the wireless network. The organization of the rest of the thesis and a brief outline of the chapters in this thesis are given below.

- In Chapter 2, we are discussed the basic concepts of the single-hop networks and problems occurred in single-hop traffic and the different methods used for gaining optimizing, many policies used for scheduling the packets from source point to destination point in the clique network. And calculating the link capacity using lower bound analysis of each and every link.
- In Chapter 3, Here, we discuss the proposed design that is multi-hop wireless network decomposed in to multiple paths, and new technique which is reduction technique, and queuing technique is also used for scheduling the packets,which can

gives better optimality.

- In Chapter 4, Here, Discussing how to calculate capacity of the each and every link and average delay of the all the links using lower bound analysis in the tandem queue[5] network and clique network.And different scheduling policies for transmission of packets.
- In Chapter 5, Implementation results of the proposed schemes and comparing with the existing methods or policies.
- In Chapter 6, Drawing our conclusion and proposed some additional ideas for our future work.

Chapter 2

Literature Review

2.1 Introduction

In a wireless or wired system, users compete for accessing a shared transmission medium. Since link transmissions can cause mutual interference, the medium access layer (MAC) is needed to schedule the links so that packets can be transmitted with minimal collisions. Different scheduling policies have been studied at the MAC layer with the objective of maximizing the throughput. These schemes are called as throughput-optimal scheduling schemes. However, the delay analysis of these systems has largely been limited. Our focus is to analyze the expected delay for this system. To that end, will derive upper and lower bounds on the expected delay, and also providing an accurate estimate of the expected delay for a well-known and extensively studied throughput-optimal scheme called the maximum weighted matching (MWM).

2.2 Related work

We consider a class of wireless networks with basic interference constraints on the set of links that can be served simultaneously at any time.Here restricting the traffic to be single-hop, but it allows for simultaneous transmissions as long as they satisfy the underlying interference constraints. We start proving a lower bound on the delay performance of any scheduling scheme for this system. Then analyze a large class of throughput optimal policies[6] which have been studied extensively in the literature work. The delay analysis of these systems has been limited to the asymptotic behavior in the heavy traffic regime . Here obtaining a tighter upper bounds on the delay performance for these systems, Using the insights gained by the upper and lower bound analysis to develop an estimate for the expected delay of wireless networks with mutually independent arrival streams operating below the well-known maximum weighted matching (MWM) scheduling policy[7]. We show via simulations results that the delay performance of the MWM policy is often close to the lower bound, which means it is not only throughput optimal, but also provides good delay performance.

To simplify the analysis we restrict the traffic model to single-hop traffic. Under the single-hop traffic model, all packets transmitted on a link are generated by an exogenous arrival process at the source node . As shown in Fig. 1, the exogenous arrivals waiting to be transmitted at each link are queued in their respective queues. The design of scheduling policies which stabilize the system even under single-hop traffic is a challenging task. Intuitively, the scheduler must schedule as many links as possible in every time slot. Such schedulers are called maximal schedulers (as opposed to maximum weighted schedulers that also take the queue length into account). However, even with maximal scheduling,

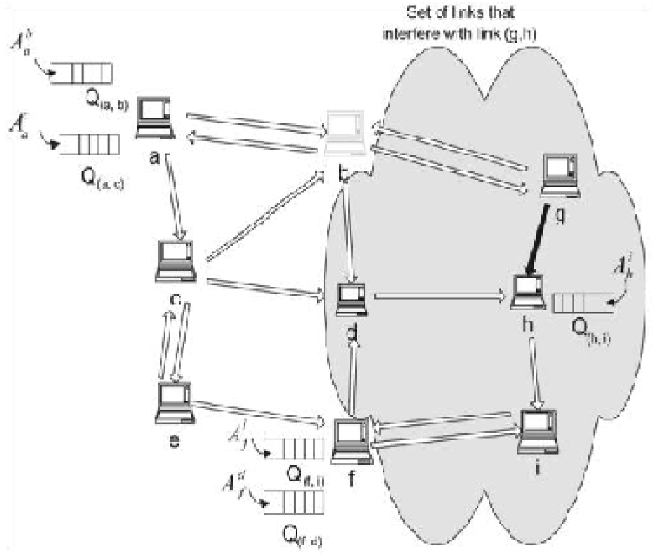

Figure 2.1: (Figure showing a wireless network with single-hop traffic. All packets transmitted on link are exogenous and are queued denotes thequeue length. All the links that interfere with link are shown.)

some of the queue lengths may become unbounded. The reason is that if the scheduler does not use the queue length information, some of the queues may grow large, while others remain very small or become empty. This, in turn, does not allow the scheduler to schedule a large number of queues and leads to instability. Thus, a throughput optimal policy like MWM uses the information of the queue lengths while scheduling the links.

Most of the analysis of scheduling policies for the wireless systems has been limited to stability results. A stable scheduling policy is guaranteed to put the average queue lengths in the system finite, but the tightness of the upper bound on the average queue length is not well known. One techniques used for deriving upper bounds on the average queue length for these systems is the method of Lyapunov drifts[8]. However, these results are provided only a limited understanding of the delay of the system. For example, it has been shown in that the maximal matching policies achieve delay for networks with single-hop independent

Poisson traffic when the input load is in the reduced capacity region. However, for arbitrary networks, this region may be only a small fraction of the capacity region. Informally, the (maximum) capacity region is the set of mean flow rate vectors such that there exists a scheduling rule making the queue length process stable.

2.2.1 Different Policies working procedure in multi-hop networks:

Much of the analysis for multi-hop wireless networks has been limited to establishing the stability of the system. Whenever there exists a scheme that can stabilize the system for a given load, the back-pressure policy[9] [10] is also guaranteed to keep 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, we have taken an important step towards the expected delay analysis of these systems.

2.2.2 Heavy traffic regime using fluid models:

Fluid models[11] [12] have typically been used to either establish the stability of the system or to study the workload process in the heavy traffic regime. It has been shown in that the maximum-pressure policy (similar to the back-pressure policy) minimizes the workload process for a stochastic processing network in the heavy traffic regime when processor splitting is allowed.

2.2.3 Stochastic Bounds using Lyapunov drifts:

This method is developed[13] [14] in and is used to derive upper bounds on the average queue length for these systems. However, these results are order results and provide only a limited characterization of the delay of the system. For example, it has been shown in that the maximal matching policies achieve O(1) delay for networks with single-hop traffic when the input load is in the reduced capacity region. This analysis however, has not been extended to the multi-hop traffic case, because of the lack of an analogous Lyapunov function for the back-pressure policy.

2.2.4 Large Deviations:

Large deviation results for cellular and multi-hop systems with single hop traffic have been obtained in to estimate the decay rate of the queue-overflow probability. Similar analysis is much more difficult for the multi-hop wireless network considered here, due to the complex interactions between the arrival, service, and backlog process.

Traditional heavy traffic results have focused on a single bottleneck in the system and proving a state space collapse. We have shown in that it in general, it is impossible to avoid idling in these systems.

2.3 Clique network

A clique network is one in which the interference constraints allow only one link to be scheduled at any given time.It mainly uses for knowing the capacity of the link from one hop to neighbour hop.so that the scheduling of the packets can be done. for example, in the down-link of a base station which employs relays to increase coverage and/or data rates[15]. Suppose there are N flows in the clique network[16]. An example network with six flows is shown in Fig. 3. Every link lies in the interference range of the other and hence only one link can be scheduled at any given time.

2.4 Policies used in single-hop traffc

In a wireless network or wireline network data transmission can be done from source point to destination point. Between different intermediate nodes are present , each and every node one queue must be exist. When packets are arrived at the queue ,it must be scheduled using any policies. Here in single-hop wireless network two policies are used for scheduling the packets.There are as follows.

- Shortest remaining processing time(SRPT)
- Last buffer first serve (LBFS)
- First buffer first serve (FBFS)

2.4.1 Shortest remaining processing time(SRPT):

This is one of the policy used for scheduling the packets. It schedules based on the priority and which packet will transfer by less time to the destination point.In the existing system the clique network uses SRPT policy [17] [18] and not achieved the complete optimality

2.4.2 Last buffer first serve (LBFS):

The last buffer first serve(LBFS) policy [19] is a well known popular scheduling policy for re-entrant lines. In this policy the priority order given to the buffers contending for a service at a machine is the reverse to the order in which they are visited by a part. That is , a buffer receives priority overall contending buffers which are upstream of it. This policy is stable whenever the arrival rates are with in capacity.

2.4.3 First buffer first serve(FBFS):

In many situations First buffer first serve policy is optimal. FBFS we mean that every worker works on the job that is earliest or, respectively, latest buffer (or station) among the buffers it is qualified to serve that service is, FBFS. When there is a contention among workers for the same job, the worker that can do the corresponding job fastest(on average) is given priority.

2.5 Conclusion:

In single-hop wireless network the interference and the traffic problems[20] are mainly creating the challenging task in the delay metric in any wireless network.using different policies and methods are used for getting optimality solution.but the complete optimal solution is not attaining in single-hop network, So the new design is used which gets better optimality in wireless network or wire line network.

Chapter 3

Proposed Model:

3.1 Introduction:

This describes system model. We consider a wireless network which is represented as G = (V, L) where set of nodes in the network is represented by V and L can denotes the set of links. One Unit capacity is associated with each link. We consider N number of flows. Each flow contains source and destination pairs (si, di). We assume a constant route between source node and destination nodes. Exogenous arrival stream of each flow is computed as.

$$\{A_i(t)\}_{t=1}^{\infty}$$

The service time of a packet is considered as a single unit. Another assumption is that the exogenous arrival stream of each flow is independent one. Set of links where mutual interference is not caused and thus can be scheduled simultaneously are known as activations. Two hop interference model is used in the simulation studies it can model the behavior of large class of MAC protocols. It is because it supports virtual carrier sensing which makes use of CTS/RTS messages.

3.2 Characterizing the bottlenecks:

Link interference causes certain bottlenecks to be formed in the system. We define a (K, X)-bottleneck to be a set of links X ⊂ L such that no more than K of its links can be scheduled simultaneously. For example identify cliques[21] [22] in the conflict graph as the bottlenecks. This corresponds to a set of links, among which only one link can scheduled at any given time. We call these links as exclusive sets. We discuss another type of bottleneck in the case of a cycle graph with 5 nodes, where not more than two links can be scheduled simultaneously. Some of the important exclusive sets for wireless grid example under the 2-hop interference model. We use the indicator function to indicate whether the flow i passes through the (K, X)-bottleneck, i.e.,

$$\mathbf{1}_{i \in X} = 1 \text{ if i} \in \text{X}$$

$$\text{0 otherwise}$$

The total flow rate Λ_X crossing the bottleneck X is given by:

$$\Lambda_X = \sum_{i=1}^{N} \mathbf{1}_{i \in X}(\lambda_i)$$

Let the flow i enter the (K, X)-bottleneck at the node $v_i^{k_i}$ and leave it at the node $v_i^{l_i}$. Hence, (l_i-k_i) equals the number of links in the (K, X)-bottleneck that are used by flow i. We define λ_X and $A_X(t)$ as follows:

$$\lambda_X = \sum_{i=1}^{N} \mathbf{1}_{i \in X}(l_i - k_i)(\lambda_i)$$

$$A_X(t) = \sum_{i=1}^{N} \mathbf{1}_{i \in X}(l_i - k_i)(A_X(i))$$

3.3 REDUCTION TECHNIQUE:

The reduction technique is the main work in this chapter,here this technique in the wireless network from source node to destination node every link will have queues for scheduling the packets.In this work reduction technique is used for making decrease of delay in the network which the ultimate goal is to achieve better optimality with low delay.

In the network we create a bottleneck node and sends all the packets through that link and through that bottleneck node,if we achieve complete optimality then no need creating another bottleneck,if we didn't achieve the optimality we create another bottleneck and send the remaining packets through that,So this process continues till all the packets are reached to the destination then we can say that optimality has been gained.

we describe the methodology to derive lower bounds on the average size of the queues corresponding the flows that pass through a (K, X)-bottleneck. By definition, the number of links/packets scheduled in the bottleneck, $I_X(t)$ is not more than K, that is:

$$\sum_{i=1}^{N} \mathbf{1}_{i \in X} \sum_{j=k_t}^{l_t - 1} I_i^j(t) = I_X(t) \leq K$$

A flow i passes through multiple links in X. Among all of the flows that pass through X, let F_X denote the maximum number of the links in the (K, X)-bottleneck that are used by any single flow, that is:

$$F_X = max_{i=1}^{N} \mathbf{1}_{i \in X}(l_i - k_i)$$

Let $S_i^k(t)$ denote the sum of the queue lengths of the first k queues of flow i at time t, that is:

$$S_i^k(t) = \sum_{j=0}^{k} Q_i^j(t)$$

The sum of queues of upstream of each and every link in X at time t is given by $S_X(t)$ and satisfies the following property.

$$S_X(t) = \sum_{i=1}^{N} \mathbf{1}_{i \in X} \sum_{j=k_t}^{l_t-1} S_i^j(t) \geq \sum_{i=1}^{N} \mathbf{1}_{i \in X} \sum_{j=k_t}^{l_t-1} Q_i^j(t) \geq \sum_{i=1}^{N} \mathbf{1}_{i \in X} \sum_{j=k_t}^{l_t-1} I_i^j(t) = I_X(t)$$

3.4 REDUCED SYSTEM:

Here considering a single server with a single system, and giving input as $A_X(t)$. The server can serve maximum K packets, which is in bottleneck node queue. And let $Q_X(t)$ be the queue length of the system at time t. The queue evolution of the reduced systems can be given as equation as follows.

$$Q_X(t+1) = (Q_X(t) - K)^+ + A_X(t)$$

where $(x)^+$ = x if x > 0

0 otherwise

The reduction procedure is explained in Fig. 3 where we have been reduced one of the bottlenecks in the grid example shown in Fig. 4. Flows II, IV and VI pass through exclusive set using two, three and two hops of the exclusive sets respectively. The corresponding G/D/1 system is kept by the exogenous arrival streams $2A_{II}(t)$, $3A_{IV}(t)$ and $2A_{VI}(t)$.

In a basic grid topology, each and every node in the network is connected with two neighbors along greater than or equal to one dimensions. If the network is one-dimensional,

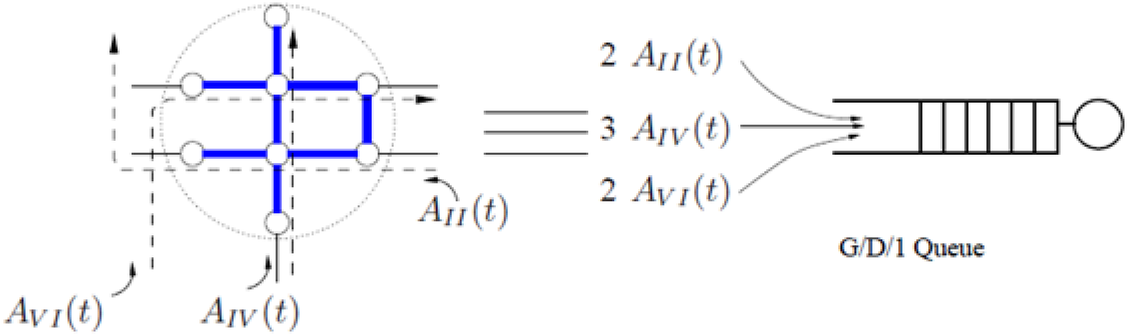

Figure 3.1: Reducing the Bottlenecks in the Grid Network

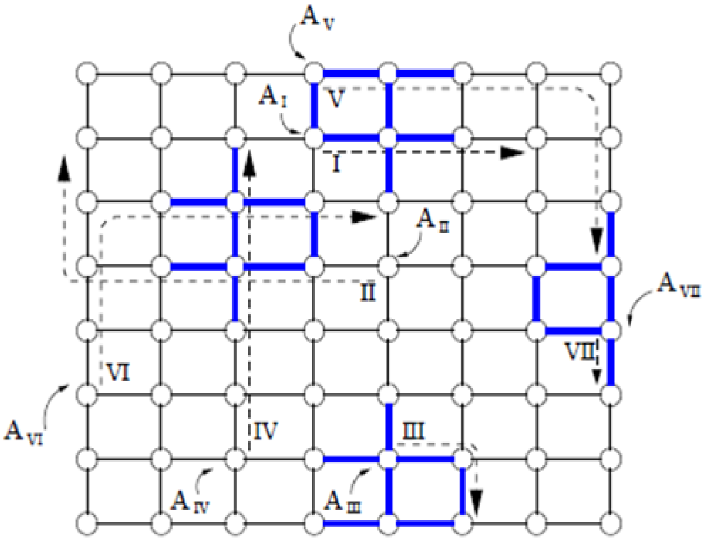

Figure 3.2: A Grid Network with Multiple Flows

the chain of nodes is connected to form a circular loop, the output topology is known as a ring. Network systems like FDDI use two counter-rotating token-passing rings to get high reliability and performance.

3.5 CONCLUSION:

In multi-hop wireless network we are decomposing the packets in to multiple paths, In between the intermediate nodes are exists creating the different bottlenecks intentionally and achieving the optimality through it.The reduction technique plays an important role in the minimizing the delay in the wireless network and gaining the optimality solution of it. Here we considered only multi-hop network and using different queues and the downstream and upstream of the queues are considered and reduced the bottlenecks of the system, When the bottlenecks are reduced there will be increase in the arrival time of the packets from source point to destination point.

Chapter 4

Calculating the delays using Lower Bound Analysis and Back Pressure Policy for Scheduling

4.1 Introduction:

In multi-hop wireless network delay calculation can be done through lower bounds analysis,here calculating each and every link capacity using lower bound analysis,after calculating the capacity of the links the sender can have an idea of how many packets should transmit in particular link,so that the delay can be decreased. In multi-hop network one source node and one destination point are fixed,so the packets which are transmitted can get in to the intermediate nodes,every node is having a queue to schedule the packet based on the priority or any other constraint scheduling has been done, we need perfect policies for scheduling the packets to achieve better optimality.

4.2 DERIVING LOWER BOUND ON EXPECTED DELAY:

Lower bound on the expected delay of the flows passing through bottleneck as a simple function of the expected delay of the reduced system. In the analysis, to bound the queuing upstream of the bottleneck and a simple bound on the queuing downstream of the bottleneck. we derive a lower bound on the expected delay of the flows passing through the bottleneck.

Let E[D_X] be the expected value of queuing delay for the G/D/1 system with input as $A_X(t)$. Further E[D_X] be the expected delay of the flows passing through X.

$$E[A] \geq \frac{E[\tilde{A}]}{F_X} + \frac{\sum_{i=1}^{N} \mathbf{1}_{i \in X} \lambda_i (|P_i| - l_i)}{\Lambda_X}$$

where A = D_X

After calculating the lower bonus of the every link, then the sender can get an idea of packet to be allocated to the particular link.Here another concept has proposed that flow partition of the network, The lower bounds are useful for flow partition of the packets to the different paths.After Knowing the expected capacity of the links the transmission process can be started , so that the delay of the network is decreases and also the packet delivery ratio increases.

4.3 FLOW PARTITIONING:

Let Z be the set of flows flowing in the system. Let π be a partition on $\mathbf{Z}$ such that the each element $p \in \pi$ is a set of flows passing through a same (K_p, X_p)-bottleneck. The expected delay of the flows in p can be lower bounded using Corollary. A system-wide lower bound on the expected delay of the packets, E[D].The mathematical representation can be given as

$$\mathrm{E[D]} \geq \frac{\sum_{p\in X} \frac{\lambda_{X_p} E[\tilde{A}]}{F_{X_p}} + \sum_{i=1}^{N} \mathbf{1}_{i\in X} \lambda_i (|P_i| - l_i)}{\sum_{i=1}^{N} \lambda_i}$$

$$\text{where A} = D_{X_p}$$

Our main objective is to compute a partition so that the lower bound on E[D] can be maximized. The optimal partition can be computed using a dynamic program, but the computation costs can be high in the number of flows in the worst case. Now presenting a greedy algorithm which computes a lower bound on the average delay for the system containing different multiple bottlenecks.

Assume that we have pre-computed a list of (K, X)- bottlenecks in the system. Algorithm 1 proceeds by greedily searching for a set of flows $p \subset z$ and the respective (K_p, X_p)-bottleneck that can yields the maximum lower bound. The value of the variable BOUND is increased and the flows in p are then removed from Z. The process is repeated until every flows are removed. Thus, we obtain a decomposition of the wireless network into several single queue systems[23], and obtain a bound on the expected delay.

Algorithm: Greedy Partitioning Algorithm .

```
Z ¸$1, 2, 3...N$
BOUND ¸ 0
repeat
Find the (K,X)-bottleneck which maximizes E[$D_X$]
BOUND ¸ BOUND + $\Lambda_X E[D_X]$
Z ¸ Z \i : i ∈ X
```

```
7: until Z = $\phi$
8: return $\frac{BOUND}{\sum_{i=1}^{N} \lambda_i}$
```

4.4 DELAY EFFICIENT SCHEDULING POLICY:

The delay efficient scheduling policy is one of the important task in the multi-hop wireless network.Here we are using some delay policies used on simple networks like clique and tandem queue networks,It is very difficult when we applied on the multi-hop networks. Every scheduling policy must satisfy the following properties.

4.5 MAXIMUM THROUGHPUT:

This is very important because, if the scheduling policy is not providing guarantee high throughput then the delay can become infinite under heavy loading.

4.6 RESOURCE ALLOCATION EQUALLY:

The network resources must be shared among the available flows, so not to starve some of the flows. Also, non-interfering links in the network have to be scheduled so that some links are not starved for service. Starvation can leads to an increase in the average delay in the system.

4.7 BACK PRESSURE POLICY:

In back pressure policy the back logs of queues are stored and sending the packets depends up on the capacity of the link to the destination point.When we create a bottleneck the data coming from different link will go through one link after crossing the bottleneck,So here all packets can not transmit due to low capacity of the link, Here we used priority based scheduling like sending some packets which is having short processing time for that using Last buffer first serve policy(LBFS) and First buffer first serve policy(FBFS) and also Back Pressure policy, So that we can achieve better optimality of the packets to the destination.

The back-pressure policy may lead to large delays since the backlogs are larger from the destination point to the source point. The packets are routed only from a larger queue to a smaller queue and some of the links may have to remain idle until this condition is happened. Hence, it is likely that all the queues upstream of a bottleneck will increase long leading to larger delays. A common observation of the optimal policies for the clique and the tandem network is that increasing the priority of packets which are close to the destination reduces the delay. In the aspect of wire-line (stochastic-processing) networks this is known as the Last Buffer First Serve (LBFS). the average delay in the system can be reduced close to the fundamental lower bound. For a tandem queue network, as goes to zero, the delay performance of the back-pressure policy numerically coincides with that of the delay optimal policy and also the lower bound provided in this paper. Here given a formal information of the back-pressure policy. Let e := (a, b) a link of interest. Suppose that flow I passes through a link e and that nodes a and b are at a distance of j and j +1 hops, respectively, from the source node si. In our notation, e := (v_i^j, v_i^{j+1}). Define the differential backlog ∇Q i.e. of flow i passing through a link e = (v_i^j, v_i^{j+1}) as $\nabla Q_i^e = (Q_i^j)^\alpha - (Q_{i+1}^j)^\alpha$ for some $\alpha > 0$

4.8 FLOW SCHEDULING:

For each link e $\in$ L, find the flow with the maximum differential backlog and assign the calculated weights to each and every link.

4.9 LINK SCHEDULING:

The scheduling is done to a particular link is completely based on the capacity of the link which it can transmission the packets from source node to destination node.

4.10 CLIQUE NETWORK WITH BOTTLENECK AND DYNAMIC QUEUE:

A clique network is one in which the interference constraints allow only one link to be scheduled at any given time.It mainly uses for knowing the capacity of the link from one hop to neighbor hop.so that the scheduling of the packets can be done. for example, in the down-link of a base station which employs relays to increase coverage and/or data rates. Suppose there are N flows in the clique network. An example network with six flows is shown in Fig. 4.1. Every link lies in the interference range of the other and hence only one link can be scheduled at any given time.

Every link in the interference range[**?**] of the other and hence only one link can scheduled

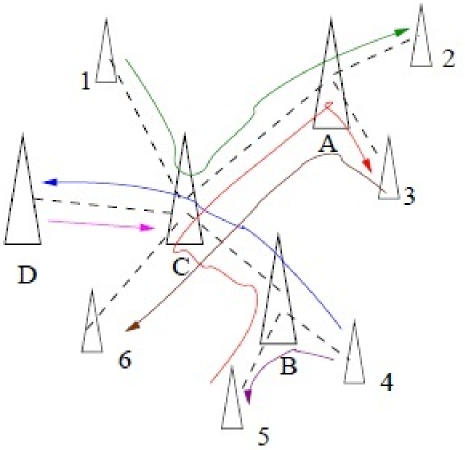

Figure 4.1: An Clique Network with Interference Constraints

at any given time interval. It is well known that the Shortest Remaining Processing Time (SRPT) policy is delay optimal in a work conserving queue with preemption. we can design a scheduling policy that minimizes the total number of packets in the system all times for every any sequence of arrivals. This is also known as sample path delay optimality. particular, we will show that for the given network, scheduling,the packet which is closest to its destination is optimal.

Let h be the maximum number of hops, and i is the number of links flow can takes in the clique network.

$$h = max_{i=1}^{N} |P_i|$$

4.11 CONCLUSION:

In the multi-hop wireless network calculating the delay and the capacity can be done through lower-bound analysis, if the network doesn't have any idea about the arrival time and the link capacity it is difficult to get the complete optimality solution,So here back pressure policy used for scheduling the packets in the clique network as well as tandem queue network.These are the simple networks to implement the policies rather than the complex network.Hence using the back pressure policy and the lower bound analysis we are getting the better optimality and increasing the throughput.

Chapter 5

Implementation and Results

In this chapter completely discussing about the the comparision results of different policies used in scheduling the packets. First we will check the result of comparision of First Buffer First Serve(FBFS) and Shortest Remaining Processing Time(SRPT).In the below graph it is showing that the SRPT showing the better performance of the end-to-end delay, Here two parameters are taken that is ,In x-axis Initial time of the packets in seconds are taken and in the y-axis complete end-to-end delay are taken. In the initial time of the packets the two policies FBFS and SRPT are showing same end-to-end delay after increasing the times the policies are varying and SRPT gives the better optimality and the low delay in the network.

In the below graph the using three policies Back pressure, SRPT , FBFS showing different variations on different time,when in the initial time the three policies are performing equally.After increasing the time the delays of the policies are varying simultaneously.If we observed in the graph that Back pressure policy is showing low amount of end-to-end delay.By this results we can say that Back pressure policy is the

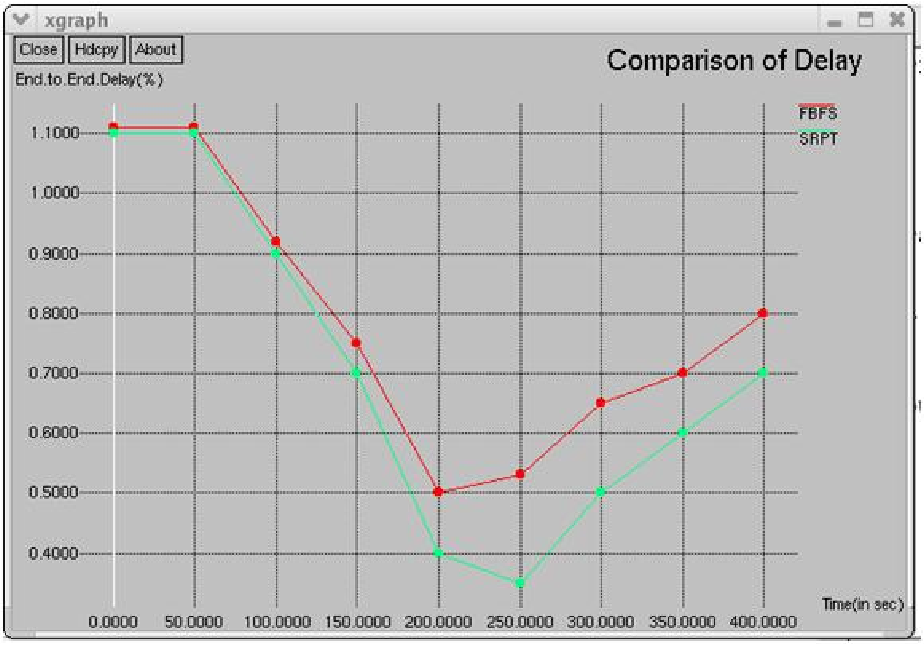

Figure 5.1: Comparing Delays Between FBFS and SRPT Policies

better optimal policy in the network.

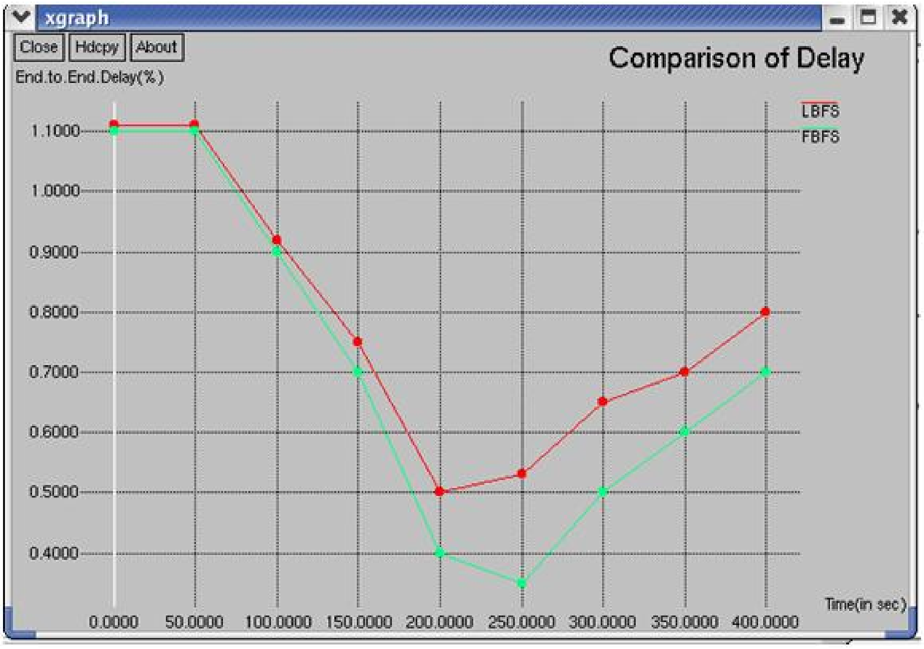

Figure 5.2: Comparing delays between LBFS FBFS policies

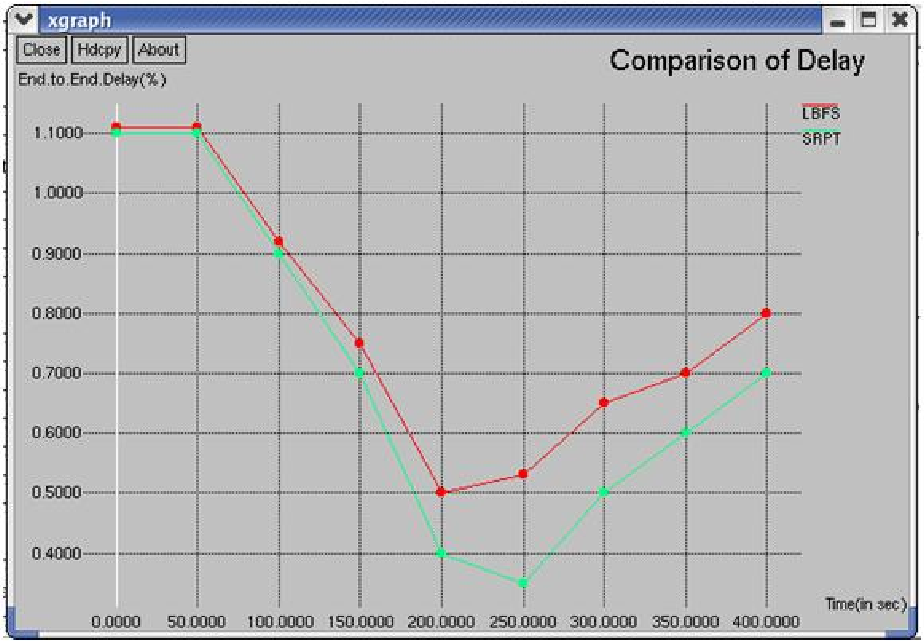

Figure 5.3: Comparing the delay between LBFS AND SRPT

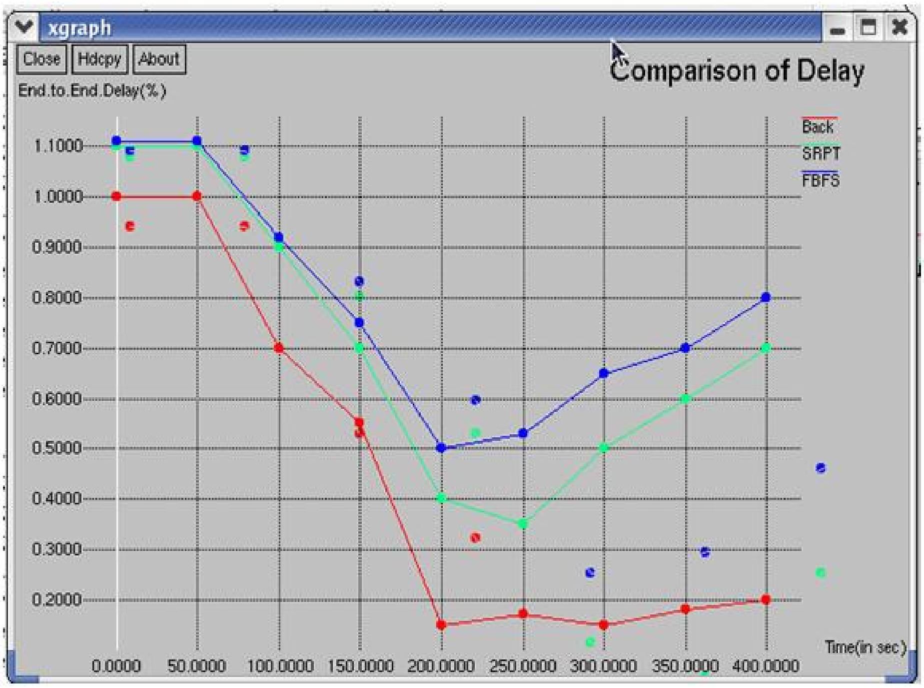

Figure 5.4: Comparing the delays with three policies BACK PRESSURE POLICY, SRPT , FBFS.

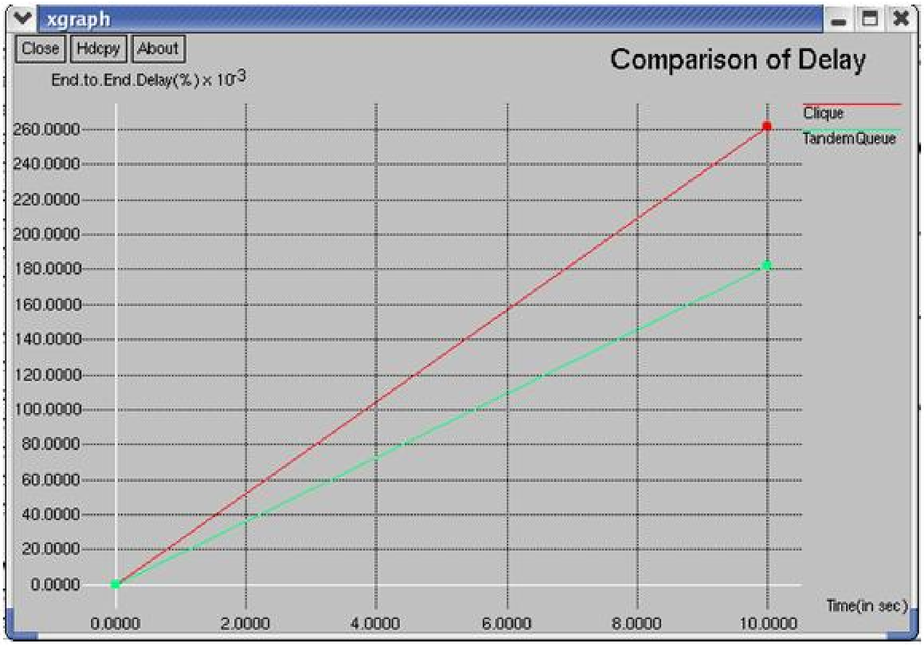

Figure 5.5: Comparing the two networks(clique,tandem network) of delays using the above three policies

Chapter 6

Conclusion

The delay analysis of wireless networks is largely a wider problem. In fact, even in the wire line setting, obtaining analytical results on the delay beyond the product form types of networks has been great challenges. These are further exacerbated in the wireless setting due to difficulty of scheduling needed to mitigate interference. Thus, new approaches are required to address the delay problem in multi-hop wireless systems. To this end, we develop a new better approach to reduce the bottlenecks in a multi-hop wireless to single queue systems to carry out the lower bound analysis. For a special class of wireless systems (cliques), we are able to apply known techniques to obtain a sample path delay-optimal scheduling policy. We also obtained a policies that minimize a function of queue lengths at all times on a sample path basis. Further, for a tandem queuing network, we show mathematically that the expected delay of a previously well known delay-optimal policy coincides with the lower bound. The analysis is very general and gives a large scale of arrival processes. Also, the main analysis can be readily extended to handle channel variations. The main difficulty however is in identifying the bottlenecks in the system. The lower bound not only helps in identifying near-optimal policies, but also help in the design of a delay-efficient policy as indicated by the numerical studies.

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