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Minimizing Packet Delay Using Optimal Scheduling Policies in Multi-hop Wireless Networks

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Abstract: In multi-hop wireless networks performance is very important. Analyzing delay performance can help in when the network has fixed routes for data transfer between source and destination. Many complex correlations may result in the multi-hop network. Handling such correlations is to be given paramount important in order to minimize packet delay using efficient scheduling policies. Recently a queue grouping technique was introduced by Gupta et al. in order to analyze delay performance in multi-hop wireless networks. They also used a set based interference model to minimize packet delay. In this paper we implement those concepts practically. We build a prototype application, a custom simulator, in Java platform to demonstrate the proof of concept. The empirical results revealed that the prototype is useful and can be used to build real time applications.

Index Terms: Multi-hop wireless network, wireless mesh network, delay analysis, optimal scheduling

1. INTRODUCTION

In wireless networks it is important to get maximum throughput and utility of the network. There has been much research on it. There are many applications in the real world that use multi-hop wireless networks. They include voice over IP, system design and network control. In all applications delay has its impact on the communications. In fact the delay problem in wireless networks is the open problem to be addressed. In such wireless applications multiple and complex interactions take place. The delay in packets has adverse effect on the performance of the applications that run in multi-hop wireless networks. The delay has to be resolved in order to maximize the performance of such networks. There is interference common in wireless networks. It makes the situation worse. A systematic methodology is required in order to overcome this problem. An efficient scheduling policy should be in place and it has to be analyzed for delay performance with respect lower bound. For the purpose of the research a multi-hop wireless network with many pairs of source and destinations for routing traffic are considered. The sample network considered is as shown in figure 1.

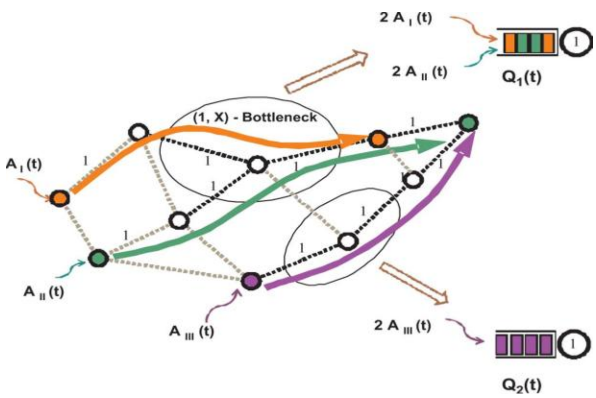

Fig. 1 – Multihop wireless network with bottlenecks (excerpt from [1])

As can be seen in fig. 1, a multihop wireless network is found with bottlenecks. The transmission medium is shared. For this reason the packets are kept in queue before they are sent to

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 9, September 2013

destination. It does mean that packets are to wait for some time whenever required before being transmitted when the routes are free. Scheduling can be made over links in which there is no interference identified. Those links are named as activation vectors. One packet is the unit capacity of any link in the network. Interference in the network has its impact on the delay performance. Single hop traffic with a set of links was explored in [1]. In this paper bottleneck is defined as a set of links in which only one can transmit data while others are to wait. Upper bounds can be used in order to overcome the problem. Our main focus here is using policies that given maximum performance. To achieve this lower bound analysis is considered important. In this connection similar kind of exploration is made in [2]. Close to lower bound performance is considered important. To achieve this we use a scheduling policy known as back-pressure. In this paper we built a prototype application as custom simulator to demonstrate the proof of concept. The experimental results reveal that the proposed approach is useful for real world multi-hop wireless network applications. The remainder of the paper is structured as follows. Section II described proposed system model. Section III provides design of delay efficient policies. Section IV presents experimental results. Section V presents discussion and related work while section VI concludes the paper.

2. PROPOSED SYSTEM MODEL

The proposed system model is described here. For experiments we consider a multi-hop wireless network. We represent the network as G = (V, L) where set of links is denoted by L while the set of nodes is represented by V. N number of flows are considered. Source and destination pairs are associated with each flow. Each link has unit capacity. There is fixed route assumed between the nodes Source (S) and Destination (D). For each flow we compute the exogenous arrival stream as follows.

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

A single unit we considered is the service time of a packet. According to another assumption for each flow exogenous arrival stream is independent. Simultaneous scheduling of multiple links is possible when there is no interference identified. In our simulations two-hop interference is modeled to characterize the behavior of various kinds of MAC protocols. Virtual carrier sensing is also supported by this by using RTS/CTS message.

Finding Average Delay Lower Bounds

For any given multi-hop wireless network a methodology is followed. According to this, lower bounds pertaining to system wide average packet delay are computed. Then the flows that come into the network dynamically are divided into many groups that eventually pass through a bottleneck in the multi-hop wireless network. The intention in the analysis of the flows is to minimize the delay system wide. When a flow reaches a bottleneck lower bound is found in the sum of queues in case of downstream and up stream. The statistics of exogenous arrival processes are collected in order to compute the lower bound pertaining to average delay. Ultimately the bottlenecks are reduced to a single-queue system that can simplify the delay analysis. Moreover, a greedy algorithm is built which takes two inputs namely bottlenecks and flows and generate lower bound pertaining to average packet delay.

Greedy Partitioning Algorithm

This is the algorithm used to convert the whole multi-hop wireless network into multiple single-queue systems and find the bound on expected delay.

Algorithm 1: Greedy Partitioning Algorithm

1: $Z \leftarrow \{1, 2 \ldots N\}$
2: BOUND $\leftarrow 0$
3: **repeat**
4: Find the (K, X)-bottleneck which maximizes $\mathbf{E}[D_X]$
5: BOUND $\leftarrow$ BOUND $+ \Lambda_X \mathbf{E}[D_X]$
6: $Z \leftarrow Z \setminus i : i \in X$
7: **until** $Z = \Phi$
8: **return** $\frac{\text{BOUND}}{\sum_{i=1}^{N} \lambda_i}$

Listing 2: shows greedy partitioning algorithm

For optimal partition is used in dynamic program. However, this approach exhibits much computational overhead. In order to achieve this, greedy algorithm issued in this paper. Listing 1 shows the algorithm for partitioning.

3. DESIGN OF DELAY-EFFICIENT POLICIES

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Designing very efficient scheduler is very essential in case of multi-hop wireless networks. Improvement of performance of multi-hop wireless networks is possible by using delay efficient policies. However, doing this is very challenging and difficult task in multihop wireless networks such as clique and tandem. The following criteria must be satisfied by delay efficient scheduler.

- High throughput has to be achieved by controlling delay.
- Multiple flows are to be allowed by allocating resources properly in order to avoid starvation of resources.

The chosen network for experiments is dynamic in nature with plethora of interactions and multiple flows. In this context, it is not easy to achieve the criteria given above. The reason is that the proposed schemes do not have prior knowledge on flows and interactions in the multi-hop wireless network. We explored [3] and [4] and used back-pressure policy in our approach. This policy is widely used in wireless networks for solving many problems as explored in [5] and [4]. Such policy is realized by research communications to be important in terms of complexity of interactions, delay and network stability in the presence of various flows in the network. For managing queues the proposed policy is used. This has to be made from source to destination. This is achieved using a value named "Differential Backlog". For every link, this value is used as weight which is used further in scheduling. The link which has highest weight is considered for scheduling. For this reason the policy is known as back-pressure policy which has been widely applied in the industry for various kinds of multi-hop wireless networks.

Back-Pressure Policy

Back-pressure policy is used to find large delays. The backlogs appear larger from the destination. The packets are flown from large to small queues. It is also the fact that some of the links are kept idle. Due to this larger delays are formed and lead to more delay at bottlenecks. Various network topologies are used for experiments. The topologies considered include cycle, tandem queue, tree and dumbbell. Larger delays are resulted when bottlenecks grow longer in upstream queues. Reduction of delay is observed in tandem and clique topologies when priority of packets is increased close to destination. This concept is known as LBFS rule in case of wireless networks [6]. It is also similar to the policy as explored in [2].

4. EXPERIMENTAL RESULTS

We built a custom simulator in Java platform which demonstrates the proof of concept. The environment used for the implementation and experiments is a PC with 4GB RAM, Core 2 dual processor running Windows 7 operating system. We used the prototype to analyze the back-pressure policy along with lower bounds. We also compare maximal policy [7], [8] and back-pressure policy. We generated graphs for given interference model. As part of our prototype we also implemented greedy algorithm for better performance. The experiments are made with diverse flows in the network. We used the analysis procedure as proposed in [9].

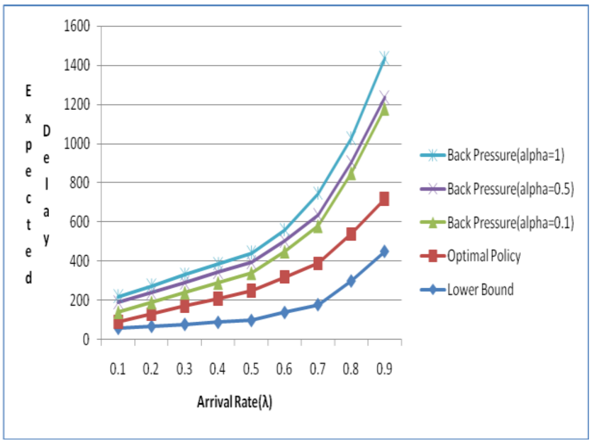

Fig.3. Simulation results for Tandem Queue

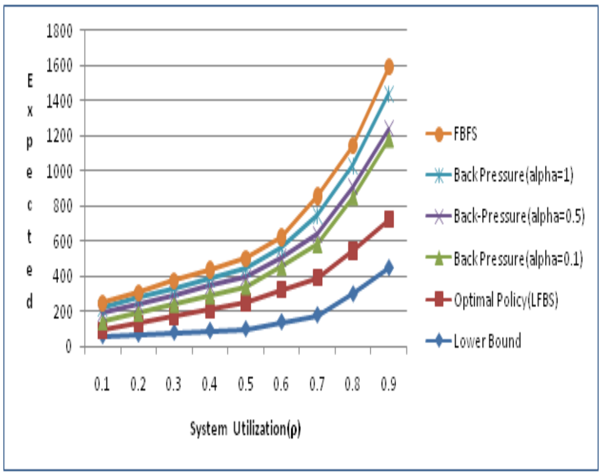

Fig.4: Shows simulation results for clique

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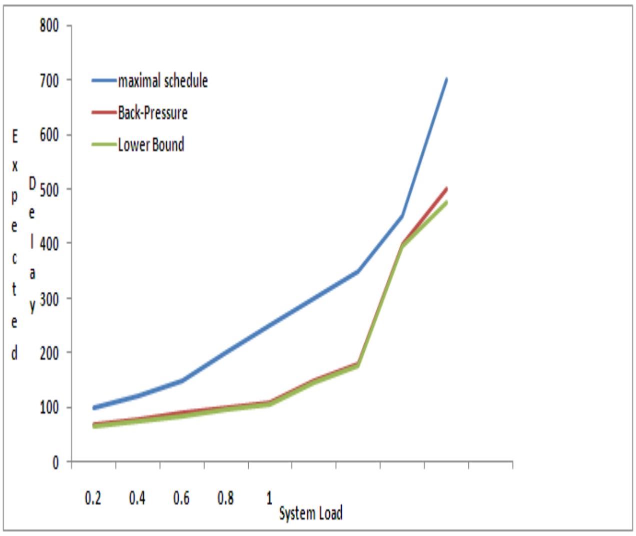

Fig. 5: shows simulation results for dumbbell topology

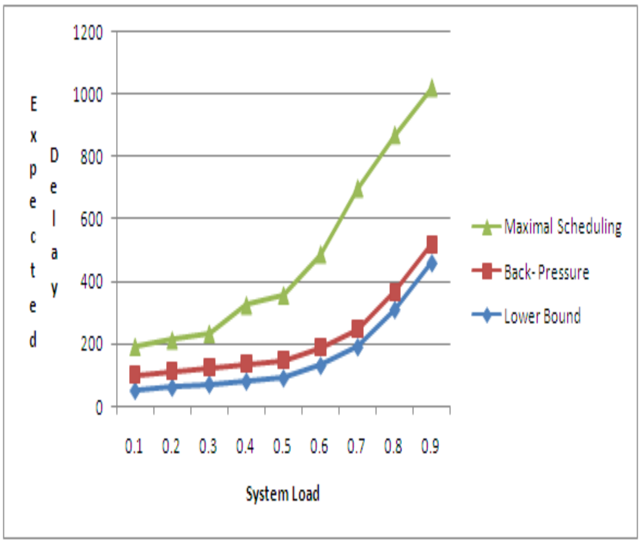

Fig. 6: shows simulation results for tree topology

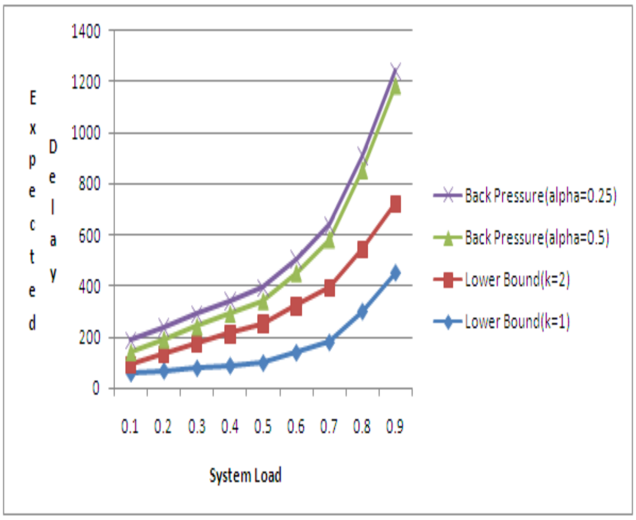

Fig. 7: shows simulation results for cycle topology

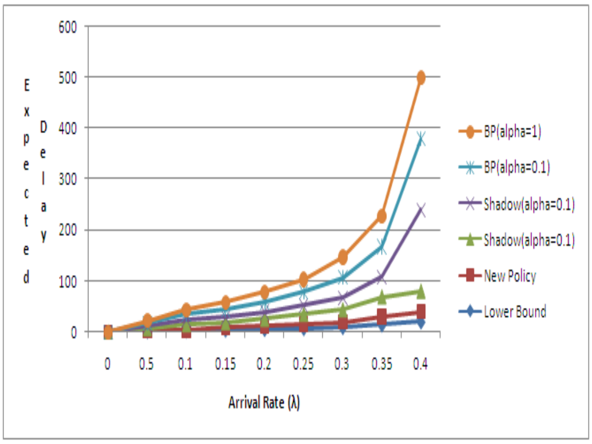

Fig 8: Simulation results for linear network

5. DISCUSSION AND RELATED WORK

There has been focused research on wireless networks [4], [5], [8]. However, they gave importance to the stability of the network system. Back-pressure policy was used for developing schemes for stability. Their policy is also known as throughput – optimal policy. But this paper focuses on the delay analysis to maximize throughput in the network. Fluid models are also used to increase stability in the network systems. Upper bound derivation methods are used in [5], [10], [11] and [12] based on the stochastic bounds and Lyapunoy drifts. Large deviation results are calculated for cellular systems as explored in [13] and [14]. However, making this kind of analysis is cumbersome as there are complex interactions. Therefore in this paper our approach different which is used to model the wireless network as single queuing system. Thus analysis of lower bound has been made easy. The essential features are captured from wireless network along with this back-pressure policy. The significance of the lower bound analysis is that it supports multiple flows over network [9]. Another factor is the ability to identity bottlenecks which has influence in the performance of the proposed approach. Exclusive sets and their characterization [15] are beneficial for delay analysis. However, it is not adequate to get optimal lower bounds. It is very challenging to develop a delay optimal scheduling policy to get rid of drawbacks. Some schemes to overcome the problem are explored in [16]. In [17] also a policy was proposed to demonstrate the delay for the given flows. On the quasi reversible networks were used for experiments.

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"Paissonation Scheme" was proposed in [17] but it could not deliver goods. In order to overcome these problems we implemented lower bound analysis in this paper which works for multiple flows in the network. In [18] an algorithm is given which is used for switches. The simulation results reveal that the delay value is proportional to alpha value. It is used for heavy traffic analysis also [19]. These researches only focused on single-hop networks. In this paper we focus on the multi-hop wireless networks for the experiments.

6. CONCLUSION

In this paper we focused on the delay analysis of a multi-hop wireless network. Analyzing delay and proposing optimal scheduling policies is very important to solve the open problem of delay performance. In this paper we implement the concepts provided by Gupta et al. [1]. The focus here is lower bound analysis in order to identity and reduces bottlenecks present in wireless network with multiple hops. We implemented scheduling policies that can improve performance of the network by reducing bottlenecks. We made a general analysis that can be used for various classes of arrival processes. Our work also has support for channel variations. Near optimal policies could be made by identifying bottlenecks accurately. We built a prototype application in Java platform which simulates the concept effectively. The empirical results reveal that the application is effective and can be used in the real world.

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