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A New Approach for Maximizing Performance of Network with Heterogeneous Flows

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Abstract— Communication networks supporting heterogeneous traffic flows should have performance optimization mechanisms. This is essential as there are flows such delay sensitive and delay insensitive flows. Treating both the flows in the same fashion is not a suitable solution. Both the flows are to be treated separately in order to optimize performance in terms of maximizing throughput and reducing congestion.In order to handle the complex flows over communication networks, the existing design models are inadequate. Recently Li et al. proposed a mathematical framework that could handle heterogeneous flows for optimizing network performance. In this paper we implement that framework through simulations. On top of it we also implement a distributed congestion control algorithm for improving throughput and reducing congestion. The empirical results revealed that the framework is effective in improving performance of communication networks.

Index: Terms–Load balancing, heterogeneous flows, routing, and utility maximization

I. INTRODUCTION

Communication networks need mechanisms to optimize the performance of network. As the network accommodates various kinds of flows and new flows may occur dynamically. The network should have the capability to adapt to new flows in order to improve throughput and reduce congestion. For many years many optimization techniques came into existence. For instance the techniques are explored in [1], [2], [3], [4], [5], [6], [7] and [8]. These researchers focused more on the functions to optimize performance of networks. In their experiments two types of flows were identified. They are elastic and inelastic. Elastic flows are the network flows that are delay insensitive while the inelastic flows need immediate attention as they are sensitive to delay. The problem with existing optimization techniques is that they focused on either elastic flows [3], [9], [10], [11] or inelastic flows [12], [13], and [14]. Some researchers studied the integration of the flows in single-hop wireless networks [15], [16], [17] and then it was extended to work in multiple-hop networks [1], [18], and [19]. Later on in [1] co-existence of the flows was studied using a general framework. The common thread which is the main problem in all the previous researches is that they can't handle heterogeneous flows at packet level. Therefore both elastic and inelastic flows compete with each other causing network congestion. In this paper we are implementing the mathematical framework proposed by Li et al. [20] where the flows are treated separately. Importance is given to inelastic flows while the elastic flows are queued as required to reduce congestion in the network. Our work is different from others as the utility maximization solutions earlier gave importance strictly to inelastic flows while elastic flows are to wait long time. We improved this situation be using queuing concept and load balancing algorithms besides giving importance to inelastic flows. Figure 1 shows the difference in handling inelastic and elastic flows.

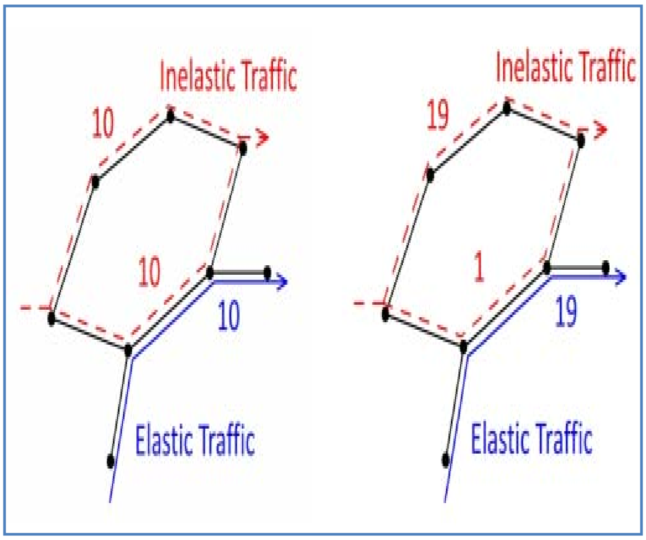

Figure. 1: Handling elastic and inelastic traffic

In this paper we implemented the mathematical framework [20] that treats network flows differently. However, both flows can co-exist perfectly. As our load balancing algorithm takes care of congestion the network performance is maximized in terms of both congestion control and increase in throughput. We built a prototype application which is a custom simulator that demonstrates the proof of concept. The simulation results revealed that the proposed system is capable of improving network performance in the presence of heterogonous network flows and diverse traffic requirements. The remainder of the paper is structured as follows. Section II reviews literature. Section III provides details of proposed work. Section IV presents experimental results while section V concludes the paper.

II. PROPOSED MATHEMATICAL FRAMEWORK

The mathematical framework proposed in [20] has been implemented and presented in this paper. However, the framework is briefly explained here. The aim of the mathematical framework is network optimization. Network optimization is meant for improving the performance of network. Performance improvement is made in terms of increasing the existing throughput and gets rid of congestion problems. The proposed network is assumed to have two kinds of network flows in heterogeneous settings. One kind of flow is sensitive to delay while the other is not sensitive to delay. Both are to be handled simultaneously providing priority to inelastic flows gracefully. Queuing concept is adapted to control elastic flows. Queue evaluation for decision making is made as follows.

$$p_l[t+1] \;=\; (p_l[t] + y_l[t] + z_l[t] - c_l)^+,$$

Network stability is computed as follows.

$$\limsup_{T\to\infty} \frac{1}{T}\sum_{t=0}^{T-1} \mathbb{E}\left(q_{\mathbf{R}}[t]\right) \le B,$$

With respect to network optimization two types of optimizations have been made with mathematical frameworks. They are known as stochastic model and heuristic fluid model. The network optimization problem according to stochastic module is represented as follows.

$$\begin{aligned} \max_{\{\mathbf{x}[t]\ge 0\}_{t\ge 0}} \quad & \sum_{f_e\in\mathcal{F}_e} U_e(\bar{x}_e) \\ s.t. \quad & \text{The Queue Evolution as in}(1), \\ & \text{Network Stability as in}(2), \\ & \sum_{r=1}^{|\mathcal{R}_i|} x_i^{(r)}[t] = A_i[t], \forall f_i \in \mathcal{F}_i, \forall t > 0. \end{aligned}$$

The heuristic fluid model appears as follows.

$$\begin{aligned} \max_{\mathbf{x}\ge 0} \quad & \sum_{f_e\in\mathcal{F}_e} U_e(x_e) \\ s.t. \quad & y_l(\mathbf{x}_e) + z_l(\mathbf{x}_i) \le c_l, \forall l \in \mathcal{L} \\ & \sum_{r=1}^{|\mathcal{R}_i|} x_i^{(r)} = a_i, \forall f_i \in \mathcal{F}_i \end{aligned}$$

These models can be used to optimize the network performance. It is also possible to have mechanisms to have congestion control. For achieving this we used the joint congestion control and load balancing algorithm that takes care of load balancing.

III. CONGESTION CONTROL AND LOAD BALANCING ALGORITHM

The congestion control and load balancing algorithm serves dual purposes such as load balancing and congestion control. The algorithm helps in improving network optimization. The algorithm tacks care of controlling congestion and thus performance is improved. It also balances the load among the nodes that will improve the throughput further. The algorithm is as shown in figure 2.

Joint Congestion Control and Load Balancing Algorithm for the FNO problem:

- Queue evolution for link l:

$$\dot{p}_l(t) := \frac{\mathrm{d}p(t)}{\mathrm{d}t} = (z_l(t) + y_l(t) - c_l)^+_{p_l(t)},$$

where $(v(t))^+_{p(t)}$ is zero if $v(t) < 0$ and $p(t) = 0$; and $v(t)$ otherwise.

- Congestion Controller for elastic flow f_e:

$$x_e(t) = U_e'^{-1}\left(q_{\mathbf{R}_e}(t)\right).$$

- Load Balancing implemented for inelastic flow f_i:

$$\dot{x}_i^{(r)}(t) = \left(\bar{q}_i(t) - q_{\mathbf{R}_i^{(r)}}(t)\right)^+_{x_i^{(r)}(t)},$$

where $\bar{q}_i(t)$ satisfies

$$\sum_{r=1}^{|\mathcal{R}_i|}\left(\bar{q}_i(t) - q_{\mathbf{R}_i^{(r)}}(t)\right)^+_{x_i^{(r)}(t)} = 0,$$

and $\sum_{r=1}^{|\mathcal{R}_i|} x_i^{(r)}(0) = a_i$.

Figure. 2: Congestion control and load balancing algorithm

As seen in figure 2, the algorithm works intelligently as it can have queuing concept for links, congestion controlling mechanisms for elastic flows while load balancing is implemented for inelastic flows. The congestion control and load balancing algorithm with virtual queuing concept is presented in figure 3.

Joint Congestion Control and Load Balancing Algorithm for FNO-VQ problem:

- Virtual queue evolution for a link l:

Elastic flows: $\dot{\theta}_l(t) = (z_l(t) + y_l(t) - \rho_1 c_l)^+_{\theta_l(t)}$;

Inelastic flows: $\dot{\gamma}_l(t) = (z_l(t) - \rho_2 c_l)^+_{\gamma_l(t)}$.

- Congestion Controller for elastic flow f_e:

$$x_e(t) = U_e'^{-1}\left(s_{\mathbf{R}_e}(t)\right),$$

where $s_{\mathbf{R}_e}(t) = \sum_{l:\mathbf{R}_e[l]=1}\theta_l(t)$ is the aggregated virtual queue length of the elastic flow.

- Load Balancing implemented for inelastic flow f_i:

$$\dot{x}_i^{(r)}(t) = \left(\bar{\mu}_i(t) - \mu_{\mathbf{R}_i^{(r)}}(t)\right)^+_{x_i^{(r)}(t)},$$

where $\mu_{\mathbf{R}}(t) = \sum_{l:\mathbf{R}[l]=1}(\theta_l(t) + \gamma_l(t))$, $\bar{\mu}_i(t)$ satisfies

$$\sum_{r=1}^{|\mathcal{R}_i|}\left(\bar{\mu}_i(t) - \mu_{\mathbf{R}_i^{(r)}}(t)\right)^+_{x_i^{(r)}(t)} = 0$$

and $\sum_{r=1}^{|\mathcal{R}_i|} x_i^{(r)}(0) = a_i$.

Figure. 3: Congestion control and load balancing algorithm with virtual queue

As seen in figure 3, the algorithm works intelligently as it can have queuing concept for links, congestion controlling mechanisms for elastic flows while load balancing is implemented for inelastic flows. Implementation of virtual key is the additional concept in this algorithm.

IV. EXPERIMENTAL RESULTS

Experiments are made in terms of throughput and congestion control in the presence of heterogeneous flows. The experiments are made using a custom simulator built by us. The simulator demonstrates the proof of concept. The environment used for the prototype implementation is a PC with 4GB RAM, core 2 dual processor running Windows 7 operating system. The simulation results are presented in fig 4.

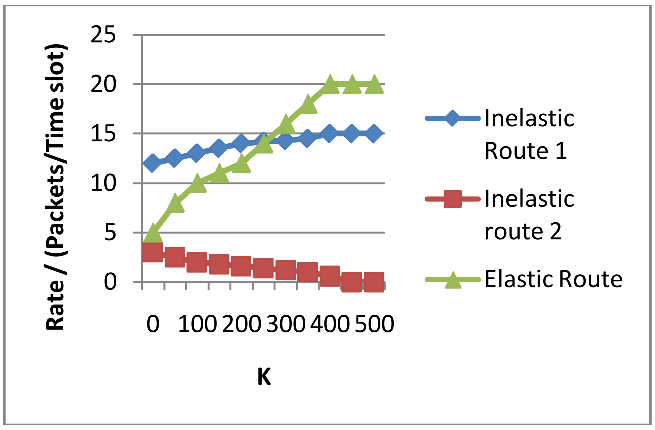

Figure. 4: Simulation results

As can be seen in figure 4, it is evident that the experiment is made with elastic and inelastic flows. The packet transmission rate has been presented. There is robust coexistence of flows in the network with high performance in maximization of throughput and avoiding congestion.

V. CONCLUSION

In this paper we explored network optimization problem in the presence of heterogeneous traffic flows and diverse user requirements. The traffic flows could be either delay sensitive or delay insensitive. We built a mathematical framework to analyze network traffic and take necessary steps to control traffic based on the needs of the users over network towards the network flows. We also built a congestion control algorithm that takes care of controlling congestion and the throughput of the network gets increased dramatically. The aim of this paper is to improve network performance in terms of congestion and throughput. Queuing mechanism has been implemented to balance the elastic (delay insensitive) and inelastic (delay sensitive) flows with diverse requirements. The framework also takes care of dynamic routing that helps in optimizing resource consumption. We built a custom simulator to demonstrate the proof of concept. The empirical results revealed that the proposed approach is effective.

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