This qualifying exam has six questions over two days. Each question has multiple sub-questions.

The exam has two parts. Part I has three questions and is to be completed by 5 p.m. on April 1, 2010. Part II has three questions and is to be completed by 5 p.m. on April 2, 2010. Your answers must be typed. Submit each part of the exam as a single PDF to aglass@cc.gatech.edu.

Some parts of each question are open ended; you should do your best in providing as complete an answer as possible covering as many angles as you can see to the question.

1 Interdomain Routing

The Internet today does routing through a combination of intra-domain routing (aka IGP) and inter-domain routing (aka EGP). This question deals with various aspects of inter-domain routing.

(a) In its early days the Internet used a single routing protocol throughout. Explain why the IGP/EGP framework was found to be beneficial for the Internet. What are its advantages and disadvantages (if any) over the use of a single routing protocol throughout.

(b) In today’s Internet, there are legal and illegal interdomain paths. Explain what types of paths are illegal and explain why. What is the main mechanism in BGP4 for enforcing illegal paths.

(c) What is Hot Potato Routing? Explain the following regarding Hot Potato Routing, use examples when necessary:

1. What is Hot Potato Routing?
2. Why is it a desirable default?
3. When is it desirable to override hot-potato routing?
4. How does the BGP4 path selection algorithm allow for the control of whether hot-potato routing is used?

(d) Consider the following statement: “AS path prepending is used extensively in the Internet to control routing.”

1. What is AS path prepending and why would it be used?
2. Describe how you would go about verifying the truth of this statement?
2 Network Architecture

(a) Explain the meaning of “narrow waist” in the context of network architecture.

(b) Consider a proposal for a new Internet architecture where the narrow waist is a 140-byte SMS message. Describe a design for the functionality of the stack above and below such a narrow waist and comment on the advantages and disadvantages of making such a change.

3 Traffic Engineering

(a) One possible goal of intradomain traffic engineering is to minimize maximum utilization of any link within an ISP network. Explain why this might be a desirable goal. Also explain the disadvantages to this objective and give at least two other objectives that an ISP might have.

(b) Suppose you have an origin-destination traffic matrix, $M$, where $M_{sd}$ represents the traffic volume between the source and destination during some time interval. Write down a linear system involving this traffic matrix, a routing matrix $R$, and the link loads, $l$, that explains the relationship between the traffic demand matrix and the link loads. Assume no multipath routing at this point.

(c) Suppose now that you wanted to adjust IGP link weights on the links within your ISP to minimize maximum traffic utilization on any of the links. Write down your goal as an optimization problem that includes (1) an objective function; and (2) constraints. Explain how you might go about solving this optimization.

(d) Typically, a traffic flow to a destination cannot be “split”—that is, all traffic destined for some destination $d$ must follow the same path. Equal cost multipath (ECMP), however, allows different flows take different paths to a particular network destination. Explain how ECMP works, and adjust the constraints in your optimization formulation to allow for such splitting.

(e) Now, suppose that instead of simply optimizing for utilization, you wanted to optimize for both utilization and the cost of carrying traffic on the ISP backbone. First, explain the costs associated with carrying traffic on backhaul links, and how they are likely to vary by link. Second, adjust your objective function to incorporate cost.

(f) Finally, let’s assume that you wanted to design a routing protocol that took into account link loads and traffic costs and automatically adjusted the forwarding paths through the network. Consider two ways to do this:

- Periodically collect the link loads, and tune the IGP link weights according to the objective function. (cf. Thorup et al., “Traffic Engineering With Traditional IP Routing Protocols”).
- Periodically collect the link loads, compute the optimal flow assignment, and directly install flow table entries into routers corresponding to those flows (cf. Handigol et al., “Plug-n-Serve: Load-Balancing Web Traffic using OpenFlow”).

Discuss the benefits and drawbacks to each of these two approaches.