

Routing Lab

Project 3

Overview

In this project your group will implement a distance-vector algorithm and a link-state algorithm in the context of a simple routing simulator. Your implementations can mirror the algorithms described in the book, and will consist of only a small number of lines of code. It is important that you understand what is going on before you start, however. While it will be tempting for you and your partner to each separately implement an algorithm, we believe it will be far easier if you collaborate on an algorithm.

Getting the Code

The routing lab is currently separate from Minet, and is available on each lab machine at */opt/routelab-fl2.tar.gz*. Copy it to your */opt* directory and unpack it with:

```
tar -xzvf routelab-fl2.tar.gz
```

This will create a routelab directory, which will contain:

context.cc	SimulationContext (Written for you)
context.h	
demo.topo	A demonstration network topology file
demo.event	A demonstration event file
error.h	
event.cc	Event (Written for you)
event.h	
eventqueue.cc	EventQueue (Written for you)
eventqueue.h	
link.cc	Link (Written for you)
link.h	
Makefile	
messages.cc	RoutingMessage (You will write this)
messages.h	
node.cc	Node
node.h	
distancevector.h	DistanceVector (You will extend this)
distancevector.cc	
linkstate.h	LinkState (You will extend this)
linkstate.cc	
README	
routesim.cc	main program
table.cc	RoutingTable (You will write this)
table.h	
topology.cc	Topology (Written for you)
topology.h	

To compile for the first time, execute “touch .dependencies”. Next, execute “make depend”. Finally, execute “make TYPE=GENERIC”. This will build a single executable “routesim”, which contains no routing algorithm. Thereafter, you should be able to just run “make TYPE=GENERIC”.

To build routesim with your distance vector protocol, execute “make TYPE=DISTANCEVECTOR clean depend all”. To build routesim with your link-state protocol, execute “make TYPE=LINKSTATE clean depend all”.

To execute routesim, do the following:

```
./routesim topologyfile eventfile [singlestep]
```

For example: `./routesim demo.topo demo.event`

We will say more about topology and event files soon. The graphs are drawn automatically by the existing code and if you implement the code correctly should see the routing path from a source node to a destination node in the displayed graph. Single step indicates that routesim should show you every event before it dispatches it, and then wait for you to hit return after it has been dispatched. Even without single step, routesim will pause every time it draws a graph, waiting for you to close the graph window.

Note that routesim uses the *dot* and *dotty* programs to draw graphs. Do “man dot” and “man dotty” for more details.

Event-driven Simulation

Routesim is an event-driven simulator. What this means is that instead of simulating the passage of time directly, it instead jumps from event to event. For example, suppose a node decides to send a routing message to neighbor. If the current time is 100, and the link latency to the neighbor is 10, then instead of simulating time 100.1, 100.2, ..., 109.9, 110, the simulator “posts” an event (the arrival of the message at its neighbor) to occur at time 110. If there are no other events posted for times between 100 and 110, the simulator can jump ahead to 110.

Event-driven simulators are very powerful tools that are widely used in science and engineering. Routesim is implemented in the usual manner for event-driven simulators. There is a priority queue (implemented as a heap), called the event queue, which stores the events in time order. The simulator main loop simply repeatedly pulls the earliest event from the queue and passes it to a handler until there are no more events in the queue. The handler for an event may insert one or more new events into the event queue. For example, the handler for the routing message arrival may update the neighbor node’s distance table and then post a new arrival event for *its* neighbor.

Events in Routesim

Events in routesim come from the topology file, the event file, and from handlers that are executed in response to events. The topology file generally only contains events that construct the network topology (the graph), while the event file generally only contains events that modify link characteristics in the graph, or draw the graph, a path, or a shortest paths tree. In the events and topology files, lines that are blank or whose first character is a ‘#’ are ignored.

Here are events that can occur in a topology file:

```
arrival_time ADD_NODE node_num latency bandwidth
arrival_time DELETE_NODE node_num latency bandwidth
```

```
arrival_time ADD_LINK src_node_num dest_node_num latency bandwidth
arrival_time DELETE_LINK src_node_num dest_node_num latency bandwidth
```

Note that a network topology in Routesim is a *directed* graph. We've included a demonstration network topology file and will release more over time. Note that topology files are very easy to write.

Here are events that can occur in an events file:

```
arrival_time CHANGE_NODE node_num latency bandwidth
arrival_time CHANGE_LINK src_node_num dest_node_num latency bandwidth
arrival_time DRAW_TOPOLOGY
arrival_time DRAW_TREE src_node_num
arrival_time DRAW_PATH src_node_num dest_node_num
arrival_time DUMP_TABLE node_num
```

Note that any DRAW event will cause a window to pop up with a drawing of the topology. The simulation will stall until you close the window.

We've included a demonstration event file and will release more. Also note that these are easy to write.

After the topology file has been loaded and executed, routesim will post a CHANGE_LINK for each link to the node from which the link emerges. These events occur at a large negative arrival time, well before the events in the event file. The point of these events is to inform each of your nodes (through a call to Node::LinkHasBeenUpdated(), see below) of its outgoing links.

Finally, your code is allowed to post routing message arrival events. Essentially, you only need to write handlers for CHANGE_LINK events and routing message arrival events. More about this later.

Note that although each link event contains both bandwidth and latency numbers, your algorithms will determine shortest paths using only the link latencies.

A Node of One's Own

To implement a routing algorithm in Routesim, you will extend the *Node* class and write implementations of the *Table* and *RoutingMessage* classes. You will wrap your implementation code in #ifdefs so that the code can be compiled using each of your algorithms. For example:

```
class Table {
...
#ifdef GENERIC
...
#elif LINKSTATE
...
#endif
...
our generic table code
};
```

The make file will add -D\$(TYPE) to each compilation to choose one of the implementations.

Note that although Node contains a pointer to the simulation context for internal reasons, you are NOT PERMITTED to ask the simulation context about topology. Your routing algorithm runs in a node and can talk only to that node's neighbors.

The Node Class

The node class is a parent class that has been subclassed for both distancevector and linkstate algorithms. You can find these subclasses in `distancevector.[h|cc]` and `linkstate.[h|cc]`.

To fully implement these subclasses you will need to complete four functions for each algorithm in each subclass file:

`void ALGO::LinkHasBeenUpdated(const Link *l)` is called to inform you that an outgoing link connected to your node has just changed its properties. A pointer to a copy of the new Link is sent to you so that you'll know the new latency to that particular neighbor. Don't bother deleting the link. The framework will do this for you. You may want to update your tables and send further messages to your neighbors.

`void ALGO::ProcessIncomingRoutingMessage(const RoutingMessage *m)` is called when a routing message arrives at a node. In response, you may send further routing messages using `SendToNeighbors` or `SendToNeighbor`. You may also update your tables. Don't bother deleting the routing message. The framework will do this.

`Node *ALGO::GetNextHop(const Node *dest) const` is called when the simulation wants to know what your node currently thinks is the next hop on the path to the destination node. You should consult your routing table and then return the correct next node for reaching the destination. The pointer returned should be to a *copy* of the next node. The framework will eventually delete this.

`Table *ALGO::GetRoutingTable() const` is called when the simulation wants to get a *copy* of your current routing table. The framework will eventually delete the table. We expect your routing table to be able to print itself.

Your implementation will consist of implementations of these four functions, as well as implementations of *Table* and *RoutingMessage*.

Timeouts

`void ALGO::Timeout()` is called when you have requested that a timeout event be delivered to your node (see below).

Your node can call the following functions. If you'd like to get control back at a point in the future, you can do this using

```
void Node::SetTimeout(const double timefromnow)
```

This will cause `Node::Timeout()` to be called at time `now+timefromnow`.

Posting Events for routing messages

In response to a link update, your algorithm needs to send a routing message to your neighbors. For this you need to post events to the event simulator. The event will be of the type `ROUTING_MESSAGE_ARRIVAL`. To send a routing message to a particular neighbor, you need to get

the latency of the link connecting to that neighbor and then post an event at time `now+latency_of_link_to_node`.

Following functions may be helpful to achieve this:

FindMatchingLink: In file `topology.cc`, this helps to retrieve a link with certain attributes, from the set of all links in the graph.

GetOutgoingLinks: In file `topology.cc`, this returns a queue of outgoing links for a particular node. Note that you need the link information to find the latency of the link so that you can schedule the event at the proper time.

PostEvent: Posts a new event. Defined in `eventqueue.cc`, it takes an argument of type *Event*, which contains all the details of the event. The *Event* class is defined in `event.h`. It takes in four arguments: event time, eventtype, the pointer to node object which will handle the event, data. Data here will be the pointer to the routing message you want to send.

GetTime(): Returns the current time in the event simulator.

To post events to multiple neighbors, you need to post an event for each node.

The posting of these events should cause `Node::ProcessIncomingRoutingMessage()` to be called at time `now + latency_of_link_to_node`.

A node can discover its neighbors and outgoing links using

```
deque<Node*> *Node::GetNeighbors()  
deque<Link*> *Node::GetOutgoingLinks()
```

It is safe to delete the dequeues that are returned.

Notice that link-state works by flooding, meaning that you'll want to flood a link update (and a routing message) to all of your neighbors. Similarly, when a path gets updated in a distance vector algorithm, all neighbors need to be informed.

For the Link State algorithm, you will also need to implement Dijkstra's Algorithm to find the shortest path to nodes from a source node and store them in the routing table for each node.

The Table Class

This class contains the routing table. The routing table is different for `DISTANCEVECTOR` and `LINKSTATE` as described in class. Note that STL data structures can be quite useful here especially *vector* and *map*. Vectors can be used to store an unbounded array. Maps can be used to associate a value for each node in the graph, like the latency to each neighbor. For example the cost table for `LINKSTATE` can be specified as `map<int, double> costtable` which maps a double to an int. You should also know how iterators work if you plan to use these data structures.

The RoutingMessage Class

This class implements the routing messages which will be sent by each node to its neighbors. You need to carefully think what will go inside these routing messages depending on the routing algorithm you are implementing. LINKSTATE routing messages contain more information than DISTANCEVECTOR routing messages.

Each of these three classes has a Print function which helps you in debugging your code. By implementing this function you can output your class in whatever way you want, using *cout*.

General approach to implementing a routing algorithm

1. Make sure you understand what routesim (TYPE=GENERIC) is doing.
2. Read the link.h file to understand the *Link* class.
3. Develop a Table class. This should provide you with what you need to implement the GetNextHop() and GetRoutingTable() calls. It should also be updatable, as its contents will change with link updates and routing messages.
4. Extend the Node subclass data structure to include your table (in either distancevector.h or linkstate.h)
5. Implement ALGO::GetNextHop() and ALGO::GetRoutingTable() in either distancevector.h or linkstate.h
6. Develop your routing message. Think about where your routing message will go. There are subtleties involved in flooding, in particular.
7. Implement ALGO::LinkHasBeenUpdated
8. Implement ALGO::ProcessRoutingMessage()
9. Implement ALGO::TimeOut(), if needed.

Suggestions and Hints

- Since there are two routing algorithms, it will be tempting for you and your partner to each implement an algorithm independently. WE STRONGLY SUGGEST THAT YOU DO NOT DO THIS. It'll take some time to understand the framework, and that will be made a lot easier if the two of you work together. Furthermore, after you implement the first algorithm, you'll find the second to be a lot easier.
- You will probably find it easier to implement the distance vector algorithm first since it doesn't require any node-local representation of the topology.
- Your implementations should not assume limits on the number of nodes and edges. On the other hand, it does not have to be blindingly fast. You may find it very useful to leverage STL components such as vector. For example `map<map<int, int> >` would give you an extensible table for the distance vector algorithm.
- For the link-state algorithm, simple Dijkstra is fine. Don't worry about making the graph implementation fancy. The graph implementation in topology.cc is probably going to limit your performance anyway.
- For link-state, you will need to implement flooding to convey a link update received by your node to all other nodes in the network. The simulator will only deliver link updates to the node from which the link is outgoing.
- You're going to have two rather different implementations of Node, Table, and RoutingMessage, link-state and distance-vector. You should separate these implementations using separate files or #ifs as shown above.
- Keep it simple. You won't be graded on performance. It is possible to write each algorithm in 200 lines of code or so.

Mechanics

- Your code must work on the lab machines.
- If we run `make TYPE=DISTANCEVECTOR` clean depend all, we must get a `routesim` that implements distance vector. The same command with `TYPE=LINKSTATE` should give us a `routesim` that implements link-state.
- Please email your project to jacklange@cs.pitt.edu. You will be expected to provide `messages.cc`, `node.cc`, `table.cc`, header files for each of three `.cc` codes, and a `README`. If you modify our Makefile for some reason, you should hand that in too. The `README` should include the names of the project team, a brief specification of work undertaken by each member, and anything specific about your submission that you want to inform the grader.

Things That May Help You

- Chapter 4 of your book.
- An understanding of BGP and OSPF. Although the algorithms you're implementing here are not for hierarchical routing, they are asynchronous, with each node acting independently, and this presents many of the same issues as in BGP and OSPF.
- The handout "Make in a Nutshell"
- The C++ Standard Template Library. Herb Schildt's "STL Programming From the Ground Up" is a good introduction.