Using QualNet – Part II

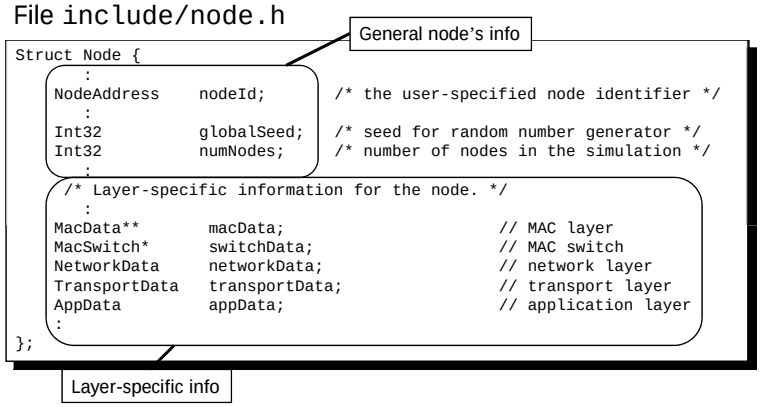
Adding a Custom Protocol

QualNet's Directory Structure

Directory	Contains
addons	Components developed as custom addons for specific customers
bin	Executable and other runtime files such as DLLs
contributed	Models contributed by QualNet customers.
data	Data files for the Wireless library: antenna configurations, modulation schemes and sample terrain
documentation	User Guide, release notes, etc.
gui	Graphical components including icons, Java class files, and GUI configuration.
include	QualNet kernel header files.
interfaces	Code to interface QualNet to 3rd party tools or external networks, such as HLA, STK, or IP networks.
kernel	QualNet kernel objects used during the build process.
lib	3rd party software libraries used during the build process.
libraries	Source code for model libraries such as Developer, Multimedia & Enterprise, & Wireless.
license_dir	License files and license libraries required for the build process.
main	Kernel source files and Makefiles.
scenarios	Sample scenarios.

QualNet Layered Architecture

- The simulation is a collection of network nodes, each with its own protocol stack parameters and statistics accessible from the “Node” structure
  - File `include/node.h`



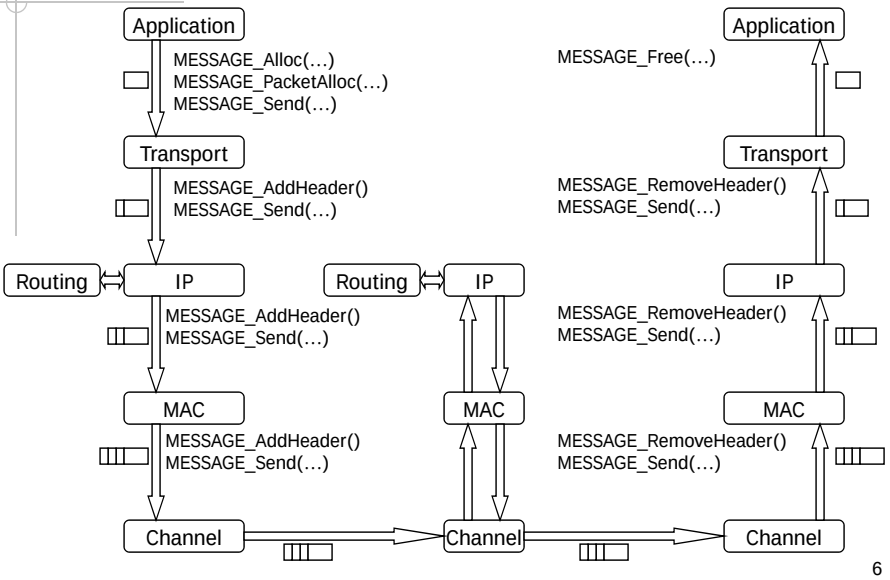
Messages, Packets, and Timers

- A message is a unit defining an interaction between protocols and between nodes
  - File `include/message.h`
- Two types of messages
  - Packets (data or control) – used for communication between nodes
  - Timers – allow protocols to schedule events in a future time

Message-Related API Functions

MESSAGE_Alloc()	Allocate a message and provide it with standard event, layer, protocol info
MESSAGE_InfoAlloc()	Allocate additional user-specified space for optional information about the event
MESSAGE_PacketAlloc()	Allocate space for the packet within the message
MESSAGE_AddHeader()	Add a header to the packet (usually called by each layer in the protocol stack)
MESSAGE_RemoveHeader()	Remove a header from the packet
MESSAGE_AddVirtualPayload()	Add virtual payload to a Message (increase tx delay without increasing array size)
MESSAGE_Duplicate()	Copy the message, including its packet and user-specified space (info field)
MESSAGE_Send()	Send the message as an event to the specified layer and protocol
MESSAGE_Free()	Free the message, once it has reached its final destination

Packet Life Cycle



Creating Messages

```
Message*
MESSAGE_Alloc(
   Node *node,

   int layerType,

   int protocol,

   int eventType);
```

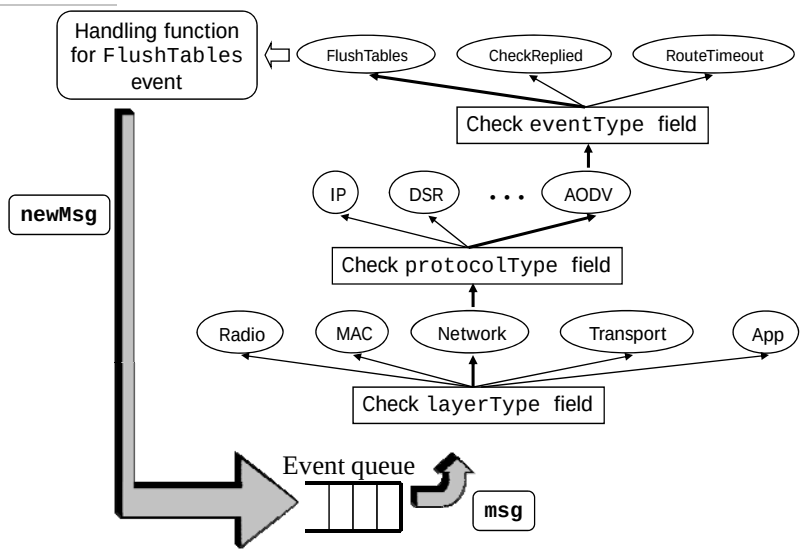
A pointer to the node creating the message

The stack layer at which this message will be processed next
e.g., NETWORK_LAYER

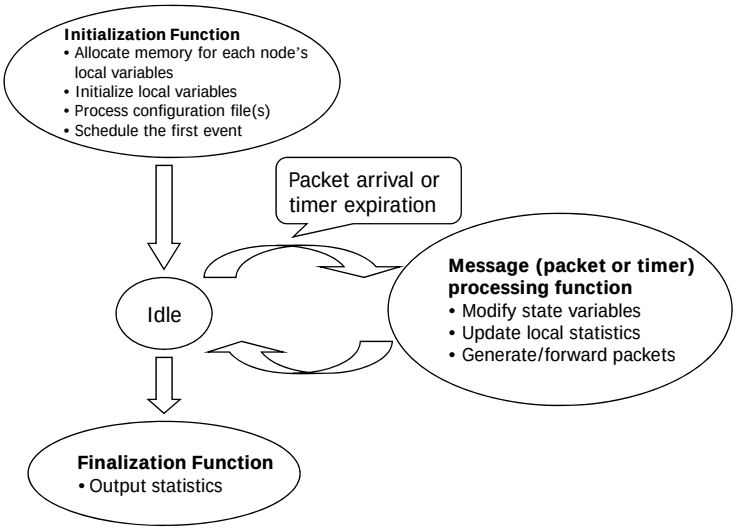
The specific protocol at the layer which will process this message
e.g., ROUTING_PROTOCOL_DSR

The event that this message represents
e.g., MSG_NETWORK_FlushTables

Message Processing



QualNet's Protocol Modeling



Adding a Protocol to QualNet

- Determine what layer your protocol will operate at
- Implement four/five main functions
  - Initialization function
  - Packet/event handling functions
  - Router function (for routing protocol)
  - Finalization function
- Hook up the above functions to the protocol dispatching functions of the corresponding layer

Example: Adding a New Routing Protocol

- Simplified Routing Information Protocol (SRIP)
  - Table-driven, distance vector protocol
  - Using periodic route update, no triggered update, no split horizon
  - Working properly in static networks with only a small number of nodes (no node failure)
  - Supporting only one interface (wireless) per node

Distributed Bellman-Ford Algorithm

- What local information is maintained by each node?

Routing Table

Destination	Next hop	Cost
:	:	:

Initial routing table for *A*

Destination	Next hop	Cost
A	*A*	0
B	-	∞
:	-	∞

- What information is exchanged between neighboring nodes?

Route Advertisement

Destination	Cost
:	:

- How a node processes a route advertisement?
  - Node *A* updates its entry for destination *D* only when the advertised cost to *D* is lower than its current cost

SRIP Header File (`routing_srip.h`)

```
#ifndef _SRIP_H_
#define _SRIP_H_

#define SRIP_INFINITY  16
-------------------------------------------------------------------------
typedef struct srip_table_entry
{
   NodeAddress  destination;
   NodeAddress  nextHop;
   unsigned int distance;
} SripTableEntry;
-------------------------------------------------------------------------
typedef struct srip_str
{
   clocktype       updateInterval;
   SripTableEntry* routingTable;

   /* statistic */
   unsigned int numRouteUpdatesBroadcast;
} SripData;
-------------------------------------------------------------------------
void SripInit(Node* node, SripData** sripPtr,
              const NodeInput* nodeInput, int interfaceIndex);
void SripHandleProtocolEvent(Node* node, Message* msg);
void SripHandleProtocolPacket(Node* node, Message* msg,
                              NodeAddress sourceAddress);
void SripFinalize(Node *node);
void SripRouterFunction(Node* node, Message* msg, NodeAddress destAddr,
                        NodeAddress previousHopAddress, BOOL* packetWasRouted);

#endif
```

Routing table entry

Local SRIP variables per nodes

Function prototypes to be recognized by QualNet's network layer (IP)

SRIP Initialization Function

- Called when each node is initialized by QualNet

```
void SripInit(Node*            node,
              SripData**       sripPtr,
              const NodeInput* nodeInput,
              int              interfaceIndex)
{
   int i; BOOL retVal;
   Message* newMsg;
   SripData* srip;
-------------------------------------------------------------------
   if (MAC_IsWiredNetwork(node, interfaceIndex))
      ERROR_ReportError("SRIP supports only wireless interfaces");

   if (node->numberInterfaces > 1)
      ERROR_ReportError("SRIP only supports one interface of node");
-------------------------------------------------------------------
   /* allocate memory for SRIP's variables for this node */
   srip = (SripData*) MEM_malloc(sizeof(SripData));
   (*sripPtr) = srip;
-------------------------------------------------------------------
   /* read parameter from the configuration file */
   IO_ReadTime(node->nodeId,
               ANY_ADDRESS,
               nodeInput,
               "SRIP-UPDATE-INTERVAL",
               &retVal,
               &(srip->updateInterval));
   if (retVal == FALSE)
      ERROR_ReportError("SRIP-UPDATE-INTERVAL not specified!");
```

Make sure the node has exactly one wireless interface

Allocate memory for local SRIP variables within each node

Read SRIP parameter from the main config file

(to be continued)

SRIP Initialization Function

(continued)

```
   /* allocate and initialize the routing table for this node */
   /* Note: (n+1) entries are allocated for convenience       */
   srip->routingTable = (SripTableEntry*)
       MEM_malloc(sizeof(SripTableEntry)*(node->numNodes+1));
   for (i = 1; i <= node->numNodes; i++) {
      srip->routingTable[i].destination = i;
      srip->routingTable[i].nextHop     = INVALID_ADDRESS;
      srip->routingTable[i].distance    = SRIP_INFINITY;
   }
   srip->routingTable[node->nodeId].nextHop  = node->nodeId;
   srip->routingTable[node->nodeId].distance = 0;
-------------------------------------------------------------------------
   /* Initialize statistic */
   srip->numRouteUpdatesBroadcast = 0;
-------------------------------------------------------------------------
   /* Tell IP to use our function to route packets */
   NetworkIpSetRouterFunction(node,
                              &SripRouterFunction,
                              interfaceIndex);
-------------------------------------------------------------------------
   /* schedule the very first route update broadcast     */
   /* after a random delay of 0 ~ srip->updateInterval-1 */
   newMsg = MESSAGE_Alloc(node, NETWORK_LAYER,
               ROUTING_PROTOCOL_SRIP, MSG_NETWORK_RTBroadcastAlarm);
   RandomSeed startupSeed;
   RANDOM_SetSeed(startupSeed, node->globalSeed, node->nodeId,
                  ROUTING_PROTOCOL_SRIP, interface);
   clocktype delay = RANDOM_nrand(startupSeed)%srip->updateInterval;
   MESSAGE_Send(node, newMsg, pc_nrand(node->seed)%srip->updateInterval);
}
```

Initialize routing table

Initialize statistic

Register router function with IP

Schedule the first route advertisement timer

SRIP Event Handling Function

- Called when a node's timer expires

```
void SripHandleProtocolEvent(Node* node, Message* msg)
{
   int i, numEntries = 0, pktSize;
   Message*  newMsg;
   char*     pktPtr;
-------------------------------------------------------------------------
   /* Obtain a pointer to the local variable space */
   SripData* srip = (SripData*)
      NetworkIpGetRoutingProtocol(node, ROUTING_PROTOCOL_SRIP);
-------------------------------------------------------------------------
   for (i = 1; i <= node->numNodes; i++) {
      if (srip->routingTable[i].distance < SRIP_INFINITY)
         numEntries++;
   }
-------------------------------------------------------------------------
   newMsg = MESSAGE_Alloc(node, 0, 0, 0);
   pktSize = sizeof(unsigned int) + sizeof(SripTableEntry)*numEntries;
   MESSAGE_PacketAlloc(node, newMsg, pktSize, TRACE_ANY_PROTOCOL);
   pktPtr = newMsg->packet;
   memcpy(pktPtr, &numEntries, sizeof(unsigned int)); /* number of entries */
   pktPtr += sizeof(unsigned int);

   /* Fill the packet with the valid table entries */
   for (i = 1; i <= node->numNodes; i++) {
      if (srip->routingTable[i].distance < SRIP_INFINITY) {
         memcpy(pktPtr, &(srip->routingTable[i]), sizeof(SripTableEntry));
         pktPtr += sizeof(SripTableEntry);
      }
   }
```

Obtain pointer to local variable space

Count the number of valid entries

Prepare a route advertisement packet

(to be continued)

SRIP Event Handling Function

(continued)

```
   /* Send the route update packet to MAC layer */
   NetworkIpSendRawMessageToMacLayer(
      node,               /* node pointer */
      newMsg,             /* raw message */
      node->nodeId,       /* source address */
      ANY_DEST,           /* destination address */
      0,                  /* priority for CONTROL packet */
      IPPROTO_SRIP,       /* IP Protocol */
      1,                  /* TTL */
      DEFAULT_INTERFACE,  /* output interface */
      ANY_DEST);          /* next hop address */
-------------------------------------------------------------------------
   /* update statistic */
   srip->numRouteUpdatesBroadcast++;
-------------------------------------------------------------------------
   /* schedule the next route update broadcast    */
   /* after a fixed delay of srip->updateInterval */
   newMsg = MESSAGE_Alloc(node, NETWORK_LAYER,
                ROUTING_PROTOCOL_SRIP, MSG_NETWORK_RTBroadcastAlarm);
   MESSAGE_Send(node, newMsg, srip->updateInterval);
 -----------------------------------------------------------------------
   /* Free old message after being processed */
   MESSAGE_Free(node, msg);
}
```

Ask IP to add header and send packet to MAC layer

Update local statistic

Schedule the next broadcast event

Free the old message

SRIP Packet Handling Function

- Called when a node receives a route advertisement

```
void SripHandleProtocolPacket(Node*       node,
                              Message*    msg,
                              NodeAddress sourceAddress)
{
   SripData* srip = (SripData*)
      NetworkIpGetRoutingProtocol(node, ROUTING_PROTOCOL_SRIP);
   int i, numEntries;
   char *pktPtr;
   SripTableEntry entry;

   pktPtr = msg->packet;
   memcpy(&numEntries, pktPtr, sizeof(unsigned int));
   pktPtr += sizeof(unsigned int);

   /* scan the entry list and update routing table only with entries with
    * shorter distance */
   for (i = 0; i < numEntries; i++)
   {
      memcpy(&entry, pktPtr, sizeof(SripTableEntry));
      entry.distance++;
      if (entry.distance < srip->routingTable[entry.destination].distance) {
         srip->routingTable[entry.destination].distance = entry.distance;
         srip->routingTable[entry.destination].nextHop  = sourceAddress;
      }
      pktPtr += sizeof(SripTableEntry);
   }

   MESSAGE_Free(node, msg);
}
```

Obtain pointer to local variable space

Packet format

#entries	1st entry	2nd entry	…

Free the message since this is its final destination

SRIP Router Function

- Called when IP layer receives a data packet from MAC or transport layer

```
void SripRouterFunction(Node*       node,
                        Message*    msg,
                        NodeAddress destAddr,
                        NodeAddress previousHopAddress,
                        BOOL*       packetWasRouted)
{
   IpHeaderType *ipHeader = (IpHeaderType *) msg->packet;

   /* Obtain a pointer to the local variable space */
   SripData* srip = (SripData*)
      NetworkIpGetRoutingProtocol(node, ROUTING_PROTOCOL_SRIP);
-------------------------------------------------------------------------
   /* do not route any SRIP packet, or any packets destined to myself */
   if (ipHeader->ip_p == IPPROTO_SRIP || ipHeader->ip_dst == node->nodeId)
      return;
-------------------------------------------------------------------------
   /* route the packet only when the destination is considered reachable */
   if (srip->routingTable[ipHeader->ip_dst].distance < SRIP_INFINITY)
   {
      *packetWasRouted = TRUE;
      NetworkIpSendPacketToMacLayer(
           node,
           msg,
           DEFAULT_INTERFACE,
           srip->routingTable[ipHeader->ip_dst].nextHop);
   }
}
```

Ignore SRIP packets and my own packets

Route the packet if the destination is reachable

SRIP Finalizing Function

- Called at each node when QualNet is terminating

```
void SripFinalize(Node *node)
{
   char buf[MAX_STRING_LENGTH];

   /* Obtain a pointer to the local variable space */
   SripData* srip = (SripData*)
      NetworkIpGetRoutingProtocol(node, ROUTING_PROTOCOL_SRIP);
-------------------------------------------------------------------------
   sprintf(buf, "Number of Route Updates Broadcast = %u",
      srip->numRouteUpdatesBroadcast);
   IO_PrintStat(node, "Network", "SRIP", ANY_DEST, -1, buf);
}
```

Report statistic

Make SRIP Recognized by QualNet

- Let QualNet know SRIP as a network layer protocol
  - In the file `include/network.h`

```
typedef
enum
{
    NETWORK_PROTOCOL_IP = 0,
    NETWORK_PROTOCOL_IPv6,
    NETWORK_PROTOCOL_MOBILE_IP,
    :
    :
    ROUTING_PROTOCOL_AODV6,
    ROUTING_PROTOCOL_DYMO,
    ROUTING_PROTOCOL_DYMO6,
    ROUTING_PROTOCOL_SRIP
}
NetworkRoutingProtocolType;
```


Make SRIP Recognized by QualNet

- Let IP module know SRIP as an IP protocol
  - In the file `libraries/developer/src/network_ip.h`

```
//
// IP protocol numbers for network- and transport-layer protocols.
//

// /**
// CONSTANT    :: IPPROTO_IP : 0
// DESCRIPTION :: IP protocol numbers.
// **/
#ifndef IPPROTO_IP
#define IPPROTO_IP  0
#endif
:
//StartIARP
#define IPPROTO_IARP    254
//EndIARP
//InsertPatch ROUTING_IPPROTO

#define IPPROTO_SRIP    211
:
```

Make SRIP Recognized by QualNet

- Have IP module recognize the five entry functions of SRIP
  - Have the file `libraries/developer/src/network_ip.cpp` include `routing_srip.h`

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
:
:
//InsertPatch HEADER_FILES

#include "routing_srip.h"
:
```


Make SRIP Recognized by QualNet

- Have IP initialize SRIP if specified in the configuration file
  - In the file `network_ip.cpp`, function `NetworkIpInit()`

```
void NetworkIpInit(Node *node, const NodeInput *nodeInput)
{
    NetworkDataIp *ip = (NetworkDataIp *) node->networkData.networkVar;
        :
        if (NetworkIpGetInterfaceType(node, i) == NETWORK_IPV4) {
            IO_ReadString(
              node->nodeId,
              NetworkIpGetInterfaceAddress(node, i),
              nodeInput,
              "ROUTING-PROTOCOL",
              &retVal,
              protocolString);
        }
            :
        if (retVal)
        {
            :
            //InsertPatch NETWORK_INIT_CODE
            else
            if (strcmp(protocolString, "SRIP") == 0) {
                NetworkIpAddUnicastRoutingProtocolType(node, ROUTING_PROTOCOL_SRIP, i);
                if (!NetworkIpGetRoutingProtocol(node, ROUTING_PROTOCOL_SRIP)) {
                    SripInit(node,
                             SripData **) &ip->interfaceInfo[i]->routingProtocol,
                             nodeInput, i);
                }
                else {
                    NetworkIpUpdateUnicastRoutingProtocolAndRouterFunction(
                       node, ROUTING_PROTOCOL_SRIP, i);
                }
            }
            :
```

Make SRIP Recognized by QualNet

- When the network layer receives an event for SRIP, dispatch it to SRIP's event handling function
  - In the file `network_ip.cpp`, function `NetworkIpLayer()`

```
void
NetworkIpLayer(Node *node, Message *msg)
{
    switch (msg->protocolType)
    {
        :
        case ROUTING_PROTOCOL_ALL:
        {
            ERROR_Assert(FALSE, "IP event error");
            //HandleSpecialMacLayerStatusEvents(node, msg);
            break;
        }
//InsertPatch NETWORK_IP_LAYER
        case ROUTING_PROTOCOL_SRIP:
        {
            SripHandleProtocolEvent(node, msg);
            break;
        }
        :
```


Make SRIP Recognized by QualNet

- When IP receives an SRIP route advertisement packet, dispatch it to SRIP's packet handling function
  - In the file `network_ip.cpp`, function `DeliverPacket()`

```
static void //inline//
DeliverPacket(Node *node, Message *msg,
              int interfaceIndex, NodeAddress previousHopAddress)
{
    :
    ipHeader = (IpHeaderType *) msg->packet;
    ipProtocolNumber = ipHeader->ip_p;
    :
    switch (ipProtocolNumber)
    {
        :
//InsertPatch NETWORK_HANDLE_PACKET
        case IPPROTO_SRIP:
        {
            SripHandleProtocolPacket(
                node,
                msg,
                sourceAddress);

            break;
        }
        :
```

Make SRIP Recognized by QualNet

- Call SRIP's finalizing function when IP is terminating
  - In the file `network_ip.cpp`, function `NetworkIpFinalize()`

```
void
NetworkIpFinalize(Node *node)
{
    NetworkDataIp *ip = (NetworkDataIp *) node->networkData.networkVar;
    :
    for (i = 0; i < node->numberInterfaces; i++)
    {
        switch (NetworkIpGetUnicastRoutingProtocolType(node, i))
        {
            case MULTICAST_PROTOCOL_STATIC:
            {
                RoutingMulticastStaticFinalize(node);
                break;
            }
            :
//InsertPatch FINALIZE_FUNCTION
            case ROUTING_PROTOCOL_SRIP:
            {
                SripFinalize(node);
                break;
            }
            :
```


Compiling QualNet with SRIP

- Put SRIP source files (`routing_srip.h/cpp`) into the directory `libraries/developer/src/`
- Edit `libraries/developer/Makefile-common`
  - Add `routing_srip.cpp` to DEVELOPER_SRCS macro as the following

```
      :
# common sources
#
DEVELOPER_SRCS = \
$(DEVELOPER_SRCDIR)/adaptation_aal5.cpp \
$(DEVELOPER_SRCDIR)/adaptation.cpp \
      :
$(DEVELOPER_SRCDIR)/routing_ripng.cpp \
$(DEVELOPER_SRCDIR)/routing_srip.cpp \
$(DEVELOPER_SRCDIR)/routing_static.cpp \
      :
```

Compiling QualNet with SRIP

- Rebuild header dependencies:

```
cd $QUALNET_HOME/main
make depend
```

- Rebuild QualNet executable:

```
make
```


Creating a configuration file for SRIP

- In `$QUALNET_HOME/bin` directory, copy `default.config` into `srip.config`, then modify/add the following parameters:

```
EXPERIMENT-NAME srip
:
ROUTING-PROTOCOL SRIP
SRIP-UPDATE-INTERVAL 10S
:
```

Testing the Protocol

- In `$QUALNET_HOME/bin` directory, run qualnet on the SRIP configuration file:

```
cd $QUALNET_HOME/bin
./qualnet srip.config
```

- Check `srip.stat` file to find SRIP's statistics
- For complete codes and instructions, refer to http://degas.cis.udel.edu/QualNet/Chapter4/

Programming Tips

- `MESSAGE_Free()` must be called only once per message
- Filling data into a packet or a packet header can be tricky
  - A field may span across a word boundary, causing '*bus error*' in some systems
  - Use `memcpy()` instead of an assignment operation (i.e., `=`)
- Use message's info field to carry extra information internally (within the same node)
- Add constants to the end of lists in header files (but before the "placeholder")
- A good way to learn QualNet is to study the provided code of another simple/similar protocols