A Tutorial on the Implementation of Ad-hoc On Demand Distance Vector (AODV) Protocol in Network Simulator (NS-2)

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Abstract

The Network Simulator (NS-2) is a most widely used network simulator. It has the capabilities to simulate a range of networks including wired and wireless networks. In this tutorial, we present the implementation of Ad Hoc On-Demand Distance Vector (AODV) Protocol in NS-2. This tutorial is targeted to the novice user who wants to understand the implementation of AODV Protocol in NS-2.

1 Introduction

The Network Simulator (NS-2) [1] is a most widely used network simulator. This tutorial presents the implementation of Ad Hoc On-Demand Distance Vector (AODV) Protocol [2] in NS-2. The expected audience are students who want to understand the code of AODV and researchers who want to extend the AODV protocol or create new routing protocols in NS-2. The version considered is NS-2.32 and 2.33, but it might be useful to other versions as well. Throughout the rest of this tutorial, the under considered files are aodv.cc, aodv.h, aodv_logs.cc, aodv_packet.h, aodv_rqueue.cc, aodv_rqueue.h, aodv_rtable.cc, aodv_rtable.h which can be found in AODV folder in the NS-2 base directory.

2 File Dependency of AODV Protocol

Fig. 1 and 2 shows the file dependency of AODV Protocol [3]. As AODV is a routing protocol, so it is derived from the class Agent, see agent.h.

3 Flow of AODV

In this section, we describes the general flow of AODV protocol through a simple example:
1. In the TCL script, when the user configures AODV as a routing protocol by using the command,
\begin{verbatim}
$ns node-config -adhocRouting AODV
\end{verbatim}
the pointer moves to the “start” and this “start” moves the pointer to the
Command function of AODV protocol.

2. In the Command function, the user can find two timers in the “start”
\begin{verbatim}
* btimer.handle((Event*) 0);
* htimer.handle((Event*) 0);
\end{verbatim}

3. Let’s consider the case of htimer, the flow points to HelloTimer::handle(Event*)
function and the user can see the following lines:
\begin{verbatim}
agent -> sendHello();
double interval = MinHelloInterval + ((MaxHelloInterval - Min-
HelloInterval) * Random::uniform());
assert(interval -> = 0);
Scheduler::instance().schedule(this, &intr, interval);
\end{verbatim}
These lines are calling the sendHello() function by setting the appropriate
interval of Hello Packets.

4. Now, the pointer is in AODV::sendHello() function and the user can see
Scheduler::instance().schedule(target, p, 0.0) which will schedule the
packets.

5. In the destination node AODV::recv(Packet*p, Handler*) is called, but
actually this is done after the node is receiving a packet.
6. AODV::recv(Packet*p, Handler*) function then calls the recvAODV(p) function.

7. Hence, the flow goes to the AODV::recvAODV(Packet *p) function, which will check different packets types and call the respective function.

8. In this example, flow can go to
   case AODVTYPE HELLO:
     recvHello(p);
     break;

9. Finally, in the recvHello() function, the packet is received.

4 Trace Format of AODV

In NS-2, the general trace format is given as below:

s 0.0000000000 RTR — 0 AODV 44 [0 0 0 0] ——- [0:255 -1:255 1 0] [0x1 1 [0 2] 4.0000000] (HELLO)

s 10.000000000 RTR — 0 AODV 48 [0 0 0 0] ——- [0:255 -1:255 30 0] [0x2 1 1 [1 0] [0 4]] (REQUEST)

s 21.500000000 RTR — 0 AODV 48 [0 0 0 0] ——- [0:255 -1:255 30 0] [0x2 1 4 [1 0] [0 12]] (REQUEST)

r 21.501260809 RTR — 0 AODV 48 [0 ffffffff 0 800] ——- [0:255 -1:255 30 0] [0x2 1 4 [1 0] [0 12]] (REQUEST)

The interpretation of the following trace format is as follows:

r 21.501260809 RTR — 0 AODV 48 [0 ffffffff 0 800] ——- [0:255 -1:255 30 0] [0x2 1 4 [1 0] [0 12]] (REQUEST)

Node ID 2, receives a packet type REQUEST (AODV protocol), at layer RTR (routing), at time 21.501260809. This packet have sequence number 0.

A generalized explanation of trace format would be as follows:
| Column Number | What Happened? | Values for instance... |
|---------------|----------------|------------------------|
| 1             | It shows the occurred event | 's SEND, 'r' RECEIVED, 'D' DROPPED |
| 2             | Time at which the event occurred? | 10.000000000 |
| 3             | Node at which the event occurred? | Node id like 0 |
| 4             | Layer at which the event occurred? | 'AGT' application layer, 'RTR' routing layer, 'LL' link layer, 'IFQ' Interface queue, 'MAC' mac layer, 'PHY' physical layer |
| 5             | show flags | — |
| 6             | shows the sequence number of packets | 0 |
| 7             | shows the packet type | 'cbr' CBR packet, 'DSR' DSR packet, 'RTS' RTS packet generated by MAC layer, 'ARP' link layer ARP packet |
| 8             | shows size of the packet | Packet size increases when a packet moves from an upper layer to a lower layer and decreases when a packet moves from a lower layer to an upper layer |
| 9             | [...] | It shows information about packet duration, mac address of destination, the mac address of source, and the mac type of the packet body. |
| 10            | show flags | — |
| 11            | [...] | It shows information about source node ip : port number, destination node ip (-1 means broadcast) : port number, ip header ttl, and ip of next hop (0 means node 0 or broadcast). |

5 Main Implementation Files aodv.cc and aodv.h

5.1 How to Enable Hello Packets

By default HELLO packets are disabled in the aodv protocol. To enable broadcasting of Hello packets, comment the following two lines present in aodv.cc
```c
#ifndef AODV_LINK_LAYER_DETECTION
#endif LINK LAYER DETECTION
```
and recompile ns2 by using the following commands on the terminal:
makemake
sudo make install

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5.2 Timers Used

In ns2, timers are used to delay actions or can also be used for the repetition of a particular action like broadcasting of Hello packets after fixed time interval. Following are the timers that are used in AODV protocol implementation:

- **Broadcast Timer**: This timer is responsible for purging the ID’s of Nodes and schedule after every BCAST_ID_SAVE.

- **Hello Timer**: It is responsible for sending of Hello Packets with a delay value equal to interval, where
  \[
  \text{double interval} = \text{MinHelloInterval} + (\text{MaxHelloInterval} - \text{MinHelloInterval}) * \text{Random::uniform}() ;
  \]

- **Neighbor Timer**: Purges all timed-out neighbor entries and schedule after every HELLO_INTERVAL.

- **RouteCache Timer**: This timer is responsible for purging the route from the routing table and schedule after every FREQUENCY.

- **Local Repair Timer**: This timer is responsible for repairing the routes.

5.3 Functions

5.3.1 General Functions

- **void recv(Packet *p, Handler *)**: At the network layer, the Packet is first received at the recv() function, sended by the MAC layer in up direction. The recv() function will check the packet type. If the packet type is AODV type, it will decrease the TTL and call the recvAODV() function. If the node itself generating the packet then add the IP header to handle broadcasting, otherwise check the routing loop, if routing loop is present then drop the packet, otherwise forward the packet.

- **int command(int, const char *const *)**: Every object created in NS-2 establishes an instance procedure, cmd{} as a hook to executing methods through the compiled shadow object. This procedure cmd invokes the method command() of the shadow object automatically, passes the arguments to cmd{} as an argument vector to the command() method.
5.3.2 Functions for Routing Table Management

- void rt_resolve(Packet *p): This function first set the transmit failure callback and then forward the packet if the route is up else check if I am the source of the packet and then do a Route Request, else if the local repair is in progress then buffer the packet.

If this function founds that it has to forward a packet for someone else to which it does not have a route then drop the packet and send error upstream. Now after this, the route errors are broadcasted to the upstream neighbors.

- void rt_update(aodv_rt_entry *rt, uint32_t seqnum, uint16_t metric, nsaddr_t nexthop, double expire_time): This function is responsible for updating the route.

- void rt_down(aodv_rt_entry *rt): This function first confirms that the route should not be down more than once and after that down the route.

- void local_rt_repair(aodv_rt_entry *rt, Packet *p): This function first buffer the packet and mark the route as under repair and send a RREQ packet by calling the sendRequest() function.

- void rt_link_failed(Packet *p): Basically this function is invoked whenever the link layer reports a route failure. This function drops the packet if link layer is not detected. Otherwise, if link layer is detected, drop the non-data packets and broadcast packets. If this function founds that the broken link is closer to the destination than source then It will try to attempt a local repair, else brings down the route.

- void handle_link_failure(nsaddr_t id): This function is responsible for handling the link failure. It first checks the DestCount, if It is equal to 0 then remove the lost neighbor. Otherwise, if DestCount > 0 then send the error by calling sendError() function, else frees the packet up.

- void rt_purge(void): This function is responsible for purging the routing table entries from the routing table. For each route, this function will check whether the route has expired or not. If It founds that the valid route is expired, It will purge all the packets from send buffer and invalidate the route, by dropping the packets and tracing DROP_RTR_NO_ROUTE "NRTE" in the trace file. If It founds that the valid route is not expired and there are packets in the sendbuffer waiting, It will forward them. Finally, if It founds that the route is down and if there is a packet for this destination waiting in the sendbuffer, It will call sendRequest() function.
• void enqueue(aodv rt entry *rt, Packet *p): Use to enqueue the packet.

• Packet* dequeue(aodv rt entry *rt): Use to dequeue the packet.

5.3.3 Functions for Neighbors Management

• void nb insert(nsaddr_t id): This function is used to insert the neighbor.

• AODV Neighbor* nb lookup(nsaddr_t id): This function is used to lookup the neighbor.

• void nb delete(nsaddr_t id): This function is used to delete the neighbor and it is called when a neighbor is no longer reachable.

• void nb purge(void): This function purges all timed-out neighbor entries and it runs every \texttt{HELLO INTERVAL} * 1.5 seconds.

5.3.4 Functions for Broadcast ID Management

• void id insert(nsaddr_t id, uint32_t bid): This function is used to insert the broadcast ID of the node.

• bool id lookup(nsaddr_t id, uint32_t bid): This function is used to lookup the broadcast ID.

• void id purge(void): This function is used to purge the broadcast ID.

5.3.5 Functions for Packet Transmission Management

• void forward(aodv rt entry *rt, Packet *p, double delay): This function is used to forward the packets.

• void sendHello(void): This function is responsible for sending the Hello messages in a broadcast fashion.

• void sendRequest(nsaddr_t dst): This function is used to send Request messages.

• void sendReply(nsaddr_t ipdst, uint32_t hop_count, nsaddr_t rpdst, uint32_t rpseq, uint32_t lifetime, double timestamp): This function is used to send Reply messages.
5.3.6 Functions for Packet Reception Management

- **void sendError(Packet *p, bool jitter = true):** This function is used to send Error messages.

- **AODV::recvAODV(Packet *p):** This function classify the incoming AODV packets. If the incoming packet is of type RREQ, RREP, RERR, HELLO, It will call recvRequest(p), recvReply(p), recvError(p), and recvHello(p) functions respectively.

- **AODV::recvRequest(Packet *p):** When a node receives a packet of type REQUEST, it calls this function.

- **AODV::recvReply(Packet *p):** When a node receives a packet of type REPLY, it calls this function.

- **AODV::recvError(Packet *p):** This function is called when a node receives an ERROR message.

- **AODV::recvHello(Packet *p):** This function receives the HELLO packets and look into the neighbor list, if the node is not present in the neighbor list, It inserts the neighbor, otherwise if the neighbor is present in the neighbor list, set its expiry time to: \( \text{CURRENT\_TIME} + (1.5 \times \text{ALLOWED\_HELLO\_LOSS} \times \text{HELLO\_INTERVAL}) \), where \( \text{ALLOWED\_HELLO\_LOSS} = 3 \) packets and \( \text{HELLO\_INTERVAL} = 1000 \text{ ms.} \)

**References**

[1] [Online]. Available: http://www.isi.edu/nsnam/ns/

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[3] [Online]. Available: http://www-rp.lip6.fr/ns-doc/ns226-doc/html/aodv_8cc-source.htm

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6 Appendix: A Simple TCL Script to Run the AODV Protocol

# wireless-aodv.tcl
# A 3 nodes example for ad hoc simulation with AODV
# Define options
set val(chan) Channel/WirelessChannel;# channel type
set val(prop) Propagation/TwoRayGround;# radio-propagation model
set val(netif) Phy/WirelessPhy ;# network interface type
set val(mac) Mac/802_11 ;# MAC type
set val(ifq) Queue/DropTail/PriQueue ;# interface queue type
set val(ll) LL ;# link layer type
set val(ant) Antenna/OmniAntenna ;# antenna model
set val(ifqlen) 50 ;# max packet in ifq
set val(nn) 3 ;# number of mobilenodes
set val(rp) AODV ;# routing protocol
set val(x) 500 ;# X dimension of topography
set val(y) 400 ;# Y dimension of topography
set val(stop) 150 ;# time of simulation end
set ns [new Simulator]
set tracefd [open simple.tr w]
set namtrace [open simwrls.nam w]
$ns trace-all $tracefd
$ns namtrace-all-wireless $namtrace $val(x) $val(y)
# set up topography object
set topo [new Topography]
$topo load flatgrid $val(x) $val(y)
create-god $val(nn)
# Create nn mobilenodes [$val(nn)] and attach them to the channel.
set chan 1 [new $val(chan)]
# configure the nodes
$ns node-config -adhocRouting $val(rp) \
-liType $val(ll) \
-macType $val(mac) \
-channel $chan \
-ifqType $val(ifq) \
-ifqLen $val(ifqlen) \
-antType $val(ant) \
-propType $val(prop) \
-phyType $val(netif) \
-topoInstance $topo \
-agentTrace ON \
-routerTrace ON \
-macTrace OFF
-movementTrace ON \ 

    for {set i 0} {i <$val(nn) } { incr i } {
set node_($i) [$ns node] 
}

    # Provide initial location of mobilenodes
$node_0 set X 5.0
$node_0 set Y 5.0
$node_0 set Z 0.0
$node_1 set X 490.0
$node_1 set Y 285.0
$node_1 set Z 0.0
$node_2 set X 150.0
$node_2 set Y 240.0
$node_2 set Z 0.0

    # Generation of movements
$ns at 10.0 "$node_0 setdest 250.0 250.0 3.0"
$ns at 15.0 "$node_1 setdest 45.0 285.0 5.0"
$ns at 110.0 "$node_0 setdest 480.0 300.0 5.0"

    # Set a TCP connection between node_0 and node_1
set tcp [new Agent/TCP/Newreno]
$tcp set class 2
set sink [new Agent/TCPSink]
$ns attach-agent $node_0 $tcp
$ns attach-agent $node_1 $sink
$ns connect $tcp $sink
set ftp [new Application/FTP]
$ftp attach-agent $tcp
$ns at 10.0 "$ftp start"

    # Define node initial position in nam
for {set i 0} {i <$val(nn) } { incr i } {
    # 30 defines the node size for nam
$ns initial_node_pos $node_($i) 30
}

    # Telling nodes when the simulation ends
for {set i 0} {i <$val(nn) } { incr i } {
$ns at $val(stop) "$node_($i) reset";
}

    # ending nam and the simulation
$ns at $val(stop) "$ns nam-end-wireless $val(stop)"
$ns \text{ at } $val(stop) "stop"
$ns \text{ at } 150.01 "\text{puts } \text{"end simulation" } ; \text{\$ns halt}\"
proc stop {} {
   global ns tracefd namtrace
   $ns \text{ flush-trace }
   close $tracefd
   close $namtrace
}
   
   $ns \text{ run}