Modelling of AODV Routing Protocol using Timed Coloured Petri Nets

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Abstract –Due to the nondeterministic nature of concurrent systems it is very challenging to design and develop the system. The most feasible way to handle the unavoidable and undetected errors of constructing any concurrent system is to build a model of that system before its actual development. Among various modelling technique, Petri net model has been proved to be a best technique for modelling and validating concurrent systems. One major application area of Petri nets is modelling routing protocols which ensures that it is unambiguous and functionality correct. In this paper Timed CPN is used to model and validate the process of Ad hoc On-Demand Distance vector (AODV) routing protocol in the concurrent environment. AODV protocol is modelled in which an efficient packet transmission is done in the network with the node movement and frequent topology changes. Aimed to detect and maintain the routes in the dynamic environment and validate the key properties of AODV protocol.

Keywords – AODV Protocol, Wireless Network, Timed CPNs, End-to-End delay, Topology Introduction

NOMENCLATURE

AODV: Ad hoc on-demand vector routing protocol, is a dynamic routing protocol where the routes are established based on demand.
CPN: Colored Petri Nets is a modeling tool for concurrent and distributed systems.
TCPN: Timed Colored Petri Net is an extension of CPNs with time feature.
MANET: Mobile Ad Hoc Networks

I. INTRODUCTION

Mobile ad hoc network (MANET) is a framework with no previous foundation or incorporated organization. In MANET, any node can transmit data packets straightforwardly to a new node or can forward through multi-nodes. Network topology changes quickly because of subjective movements of nodes. MANETs are likewise portrayed by an irregular, dynamic and quickly evolving topology. This results in the routing algorithms to function ineffectively as these aren't sufficiently strong to suit such an evolving situations. Consequently, a topology estimation system, recognized as Ad-hoc On-demand Distance Vector (AODV) routing protocol, is utilized to show the mobility issues of a classic communication protocol by simulation [1]. AODV routing protocol [2] is a reactive routing protocol that means a route from an originator to a target node is made on the request premises.

The Ad hoc On-Demand Distance Vector (AODV) protocol empowers active, multi-hop, automatic routing for those movable nodes desire in establishing, maintaining routes in an evolving network. AODV authorizes movable nodes to gain routes rapidly for distinct targets, furthermore doesn't require determining routes between a source and a destination node, which are not in the active transmission mode. AODV permits any movable node to react to connection failures and progressions held beside the network topology periodically. The process for AODV is free of loops, and the fast concurrences issue is offered by avoiding the Bellman-Ford counts to "limitless" during node moves in a dynamic network. The point while connections break, AODV informed the affected located nodes that they have the ability with invaliding the routes utilizing the lost connection.

The most recognizing characteristic of AODV will be its utilization of the destination sequence number for every detected route. This destination sequence number is made toward those destination nodes which are to be considered in the route while transmitting any data by the requesting node. Utilizing the destination sequence numbers conforms loop flexibility also easy to program. Provided for the decision of choosing among routes to the destination, a requesting node will select the particular case having higher destination sequence number.

A Petri net is one of the mathematical and graphical modeling languages for the depiction of distributed and concurrent systems, developed by Dr. Carl Adam Petri in 1962. Petri net is the combination of graphical demonstration of the ad hoc performance of the systems with properly defined mathematical theory. The theoretical concepts of Petri net are used for the analysis and modeling of concurrent systems and the graphical representation is used to visualize the designed model. Petri net model has been proved to be a best formal technique for modeling and validating distributed and concurrent systems [1, 13].

One major application area of Petri nets is modeling routing protocols which ensure that it is unambiguous and functionally correct. Petri nets have been effectively demonstrated the correctness of various communication protocols.

Basic Petri nets are not completely sufficient for the analysis of performance of a concurrent system as the system had no assumptions during any of its activities. To enhance the performance of the systems, Petri net is extended with the time and color (multiple data type) feature, called as timed colored Petri net [14].

Timed Petri net is proposed by assigning the firing time to the nodes of the designed Petri net model. It provides a convenient framework for precisely and devotedly describing the concurrent systems. Timed Petri nets have well-structured properties that define the behavior of every net correctly. The presence of such properties makes it feasible to implement simulators in timed Petri nets. An automatic simulation and analysis of nets are provided software like CPN tools.

The expansion of time to the low-level Petri net model brought about a great deal of new and intriguing technologies to analyze the dynamic phenomena of a system. Rather than accepting deterministic action terms, an endeavor is made to catch the quintessence of a system by probabilistic assumptions. These probabilistic assumptions mostly result in the distribution of the delays in the net. The strategies utilized for the examination of the dynamic performance of a system demonstrated by timed colored Petri nets suffers from computational issues. Thus, timed colored Petri nets are broadly used for the analysis of the nets with highly complex dynamic systems.

The successful usage of timed Colored Petri nets in the field of concurrent systems makes it easier in the analysis and verification of the ad hoc networks. Here, by using the concepts of timed Colored Petri net our proposed AODV protocol have been modelled and successfully validated all its dynamic properties with the help of simulation.

The organization of the paper is made by narrating the related work done so far in the field of AODV routing protocol and its comparison with contemporary protocols using coloured petri nets in section II. Section III explains the working of AODV protocol in details followed by section IV that describes the Petri Nets modelling of the AODV routing protocol in details. Finally, section V concludes the paper.

II. RELATED WORK

The correctness of communication protocols have been successfully verified by the employ of colored Petri nets in this field including MANETs. Modelling and verification of numerous ad hoc routing protocols have been correctly done using colored perti nets such as DSDV, AODV, TORA, DYMO, DSR etc.

In [2] Ad hoc on demand distance vector (AODV) routing protocol has been modelled and verified by color petri nets. A topology approximation (TA) mechanism have been suggested by the authors to address the issues related to the mobility in MANET and model this mechanism using CPN tools. The assumption made for this is that the neighbor relationship between nodes is symmetric, means each node has same transmission range. Another assumption made is every node has a similar number of neighbors and the number of neighbors for each node should be provided by the designer during simulation.

In [3] Destination sequence distance vector (DSDV) routing protocol has been shown. In network topology, the way the model gets the dynamic variations has been outlined. Here few intriguing mistakes were revealed. The first mistake was even if one node gets a broadcast message from a different node it fails to update the broken link to that node. The second one was the route entry of a node can be updated by exchanging its metrics value of hop count of zeros with the value of infinity and diverting the packets assigned to itself to another node. Additionally to eradicate these errors they recommend few modifications.

In [4] Dynamic MANET on Demand (DYMO) protocol has been demonstrated by a CPN model which modelled primary route establishment methodology. The establishment and processing of various routes and routing massages have been analyzed by state-space analysis report produced by the CPN simulator. A hierarchy CPN model is modelled with numbers of modules that minimize the complexity of total model.

In [5] Edge Router Discovery Protocol (ERDP) has been designed by applying color Petri net tools. The simulation and state space analysis have been performed to observe the behavior of the protocol and to identify different designing errors. The model demonstrates and analyses the connection of gateways to edge routers in a fixed MANETs. Here the CPN model considers the static network topology of MANETs by ignoring its dynamic behavior.

In [6] a CPN model for neighbor detection protocol utilized to assists mobile nodes to locate their direct neighbors in the ad hoc network is proposed. In ad hoc network a mechanism is provided to discover the single-hop neighbors of the movable node by the author. This Model is verified by the simulation of CPN tools and various properties has been analyzed.

In [7] one general updating strategy, called as distance updating strategy has been proposed using timed Petri net model. Furthermore, a technique for evaluating the time expected to update the database of moving objects has been demonstrated using time Petri net, utilizing the theory of minimum cycle time. Here the time feature is used as major criteria to study the overhead communication cost of the moving object database. Here the moving objects are modeled without any specific DBMS architecture by using a single distance updating policy.

In [8] Session Initiation Protocol (SIP) has been built up by utilizing timed colored Petri nets (TCPN). Here some extensive feature of SIP like the timer and other time associated problems has been modeled and analyzed by the usage of time attribute of TCPN. This model hadn't considered the communication over the unreliable medium.

In [9] An Interval Timed Coloured Petri Net (ITCPN) model has been demonstrated that models the dynamic behavior of complex and large systems with proper formal analysis. To analyze the temporal behavior of the net a new analysis technique called as Modified Transition System Reduction Technique (MTSRT) has been proposed. This technique shows that delays are described by an interval through a reduced reachability graph.

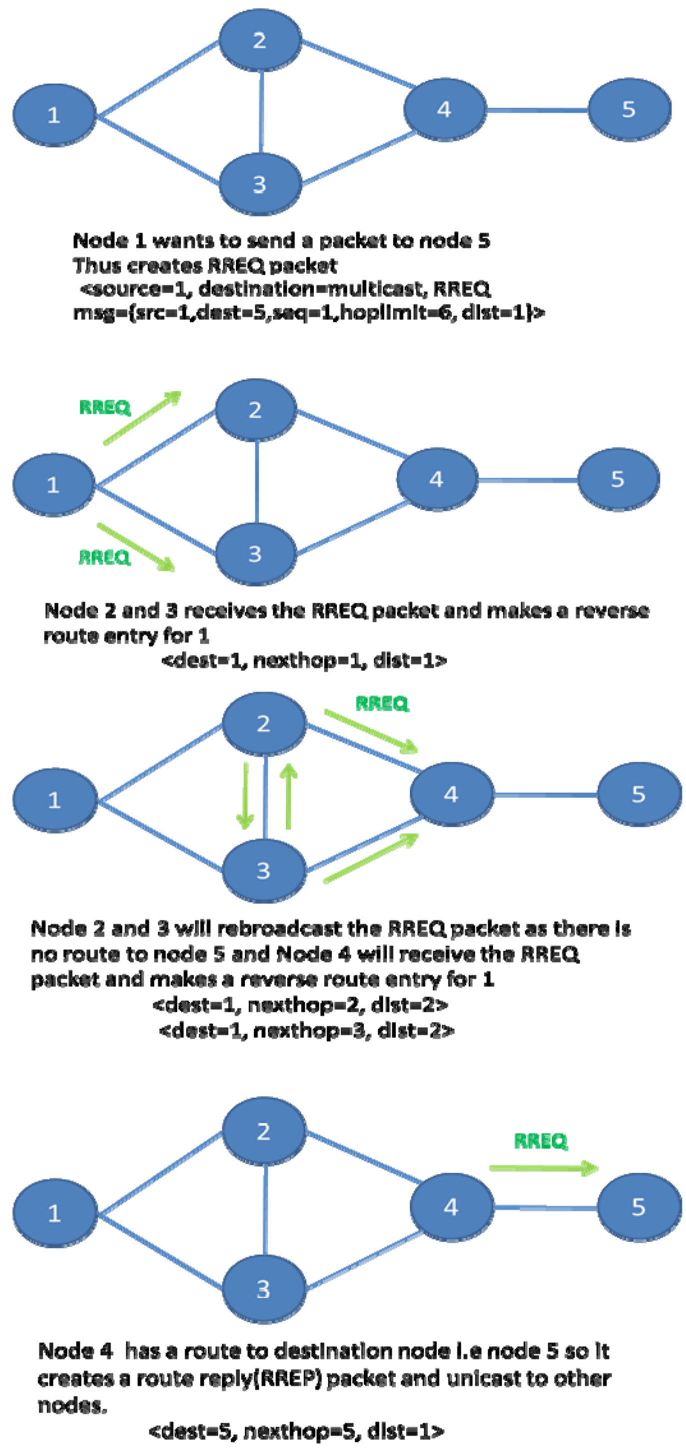
In [10] Precision Time Protocol (PTP) has been modeled using Timed Colored Petri Nets. PTP is a clock synchronization protocol that is utilized in computer network environment. It is a standout amongst the most generally utilized check synchronization convention in the areas where the high level of accuracy is required. A lot of works have been accomplished for check and re-enactment of the protocol. There are still absences of formal model portrayals of the PTP in transient association's perspectives. This paper proposes to utilize Timed Colored Petri Nets (TCPN) to demonstrate PTP and formally speak to with worldly measurement. We will check the model by methods for reproduction strategies.

III. OVERVIEW OF AODV PROTOCOL

It is a classical routing protocol for MANETs which utilizes a distributed procedure i.e. it keeps the record of the neighbor nodes only and it does not set a series of routes to arrive at the destination. It uses two mechanisms, i.e. route discovery and route maintenance [11].

During ***Route Discovery*** phase, the source node that wants to send a packet to a receiver checks whether any direct route is present to the intended receiver or not. If direct route is not present then the source node broadcast message to its neighboring nodes a typical control packet called ***route request (RREQ)*** message. During the process, two type of pointers such as a forward pointers and backward pointers are used during route discovery. When a node gets RREQ packet it immediately verifies if it has received that same request earlier or not. If it has already received then it discards that packet, else a reverse route entry is created for that node. For this purpose two entries are made for forward route reverse route entry. Finally, when the route request message is received by the destination node, it unicasts the ***Route Reply*** (RREP) message towards the source node through the intermediary nodes which are traced by the reverse route entry. The main feature of AODV is that it uses the sequence number to verify the recent path to the destination.

Due to the mobility of the nodes in MANET, the connection between the nodes may break hampering in packet transmission. Therefore ***Route Maintenance*** phase is required to maintain the connectivity among the nodes by sending HELLO messages periodically. When a HELLO message is not received by a neighbor node, it creates Route error (RRER) message to indicate an invalid node in the route and broadcasts the link failure to all nodes. To check the valid and efficient route, the sequence number is managed by each node and that value is updated every time a new RREQ packet is generated by the source and this information is propagated to every node in the packet transmission process. The nodes in the route with higher sequence number are preferred as it indicates its freshness. Fig. 1 describes the stage wise working of route discovery and maintenance phase.



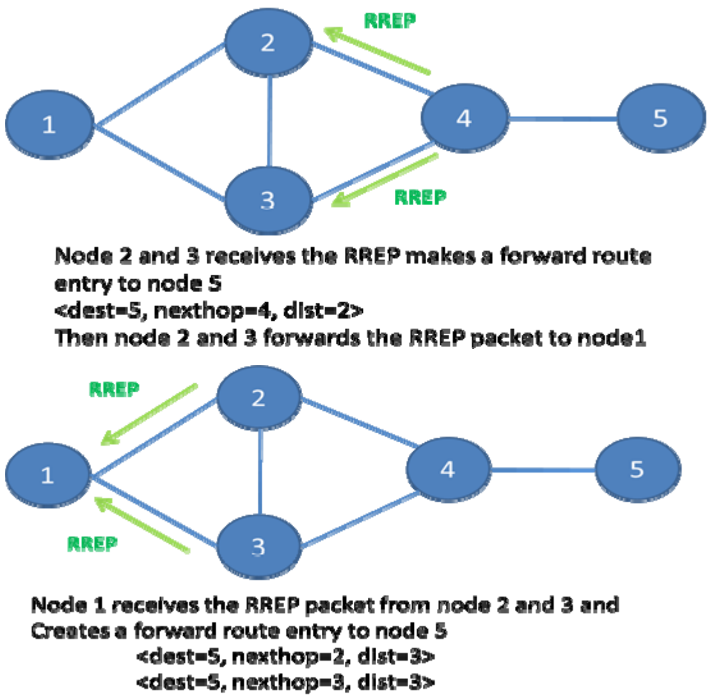


Fig. 1: Different stages of the Route Discovery and maintenance

IV. TIMED CPN MODEL OF AODV PROTOCOL

Our Timed CPN model is modelled with different hierarchical modules. All the required features of the designed AODV protocol like topology generation and updation, RREQ packet generation followed by RREP replies packets to discover the route etc. has been modelled for verification and validation.

A. Topology Modelling of the Network

The topology of the network is determined using the coordinates of the position of the nodes. Two nodes are considered to be within transmission range of each other, if the Euclidean distance between them is less than their transmission range.

The topology of the network is modeled in the manner such that every node possesses an adjacency list of nodes. If the two nodes are in transmission range then they are considered as link node of other node and then stored in a list. Initially, a counter is set to 1 considering there is at least one link exists between any two nodes. Each time a node is not in the transmission range of other then counter is updated. A Boolean place (bol1) holds true value for every enabled link node (Node1) transition. The counter value (cn) gives the number of disconnected nodes and from that value connect nodes can be calculated using the formula

TN = (TN-1-cn); where TN=total Nodes

If the number of connected nodes is equivalent to the number of nodes present within the link list then the transition (adjacency list) is enabled and the topology of that node is updated with its link nodes as shown in Fig. 2.

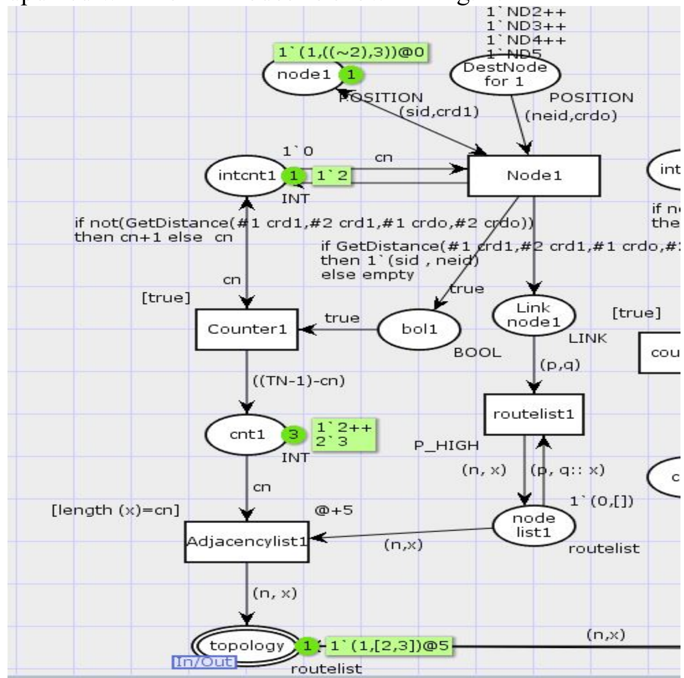


Fig. 2: Topology Modelling.

B. Topology Mobility

As the nodes in the network topology move frequently, there may be disconnection of links. So the protocol constantly checks whether any link exists between any nodes or not. If link is not found, then the new topology is updated and the old link is removed and the same is updated in the routing table by SetBrokenRoute() function. The RRER packet is created for the node using CreateRRER() function. Fig. 3 explains the execution of transitions for udating of the paces.

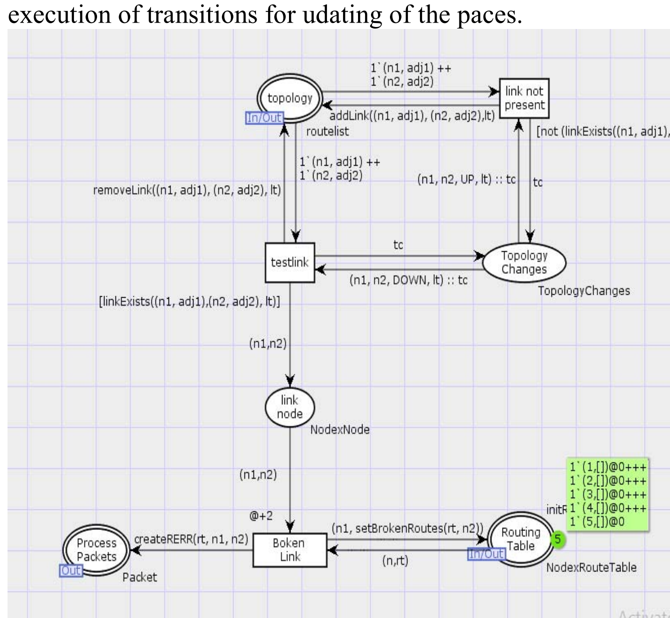


Fig. 3. Topology Mobility module.

C. RREQ Packet Creation

The route discovery starts with a request from the source node to the destination node; this request is accepted and processed with initial RREQ count as 0. The value of n is bound to the source node number i.e. 1. The "Create RREQ" transition checks the route between the requested and the destination node does available or not into the routing table if not then CreateRREQ() function created RREQ packets and sends to the nodes present in its adjacency list and those packets are bound to "np" as shown in Fig. 4.

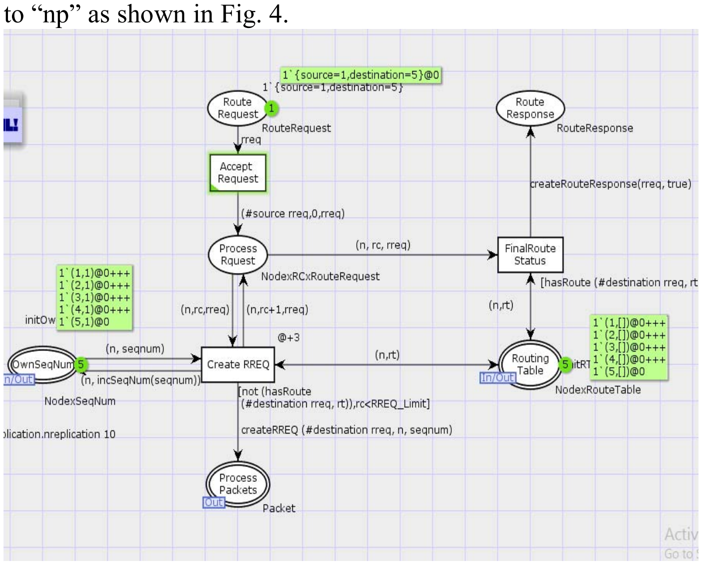


Fig. 4. RREQ Packet Generation.

D. Transmission of Packets

The RREQ packet is transmitted to all its adjacency nodes using transmit() function as shown in Fig. 5. Node 1 transmits RREQ packet to node 2 and 3. Then the packets are verified whether the route it has to follows New route, Old route, Super route, Loop route, Sub route or not or it is the message of its own.

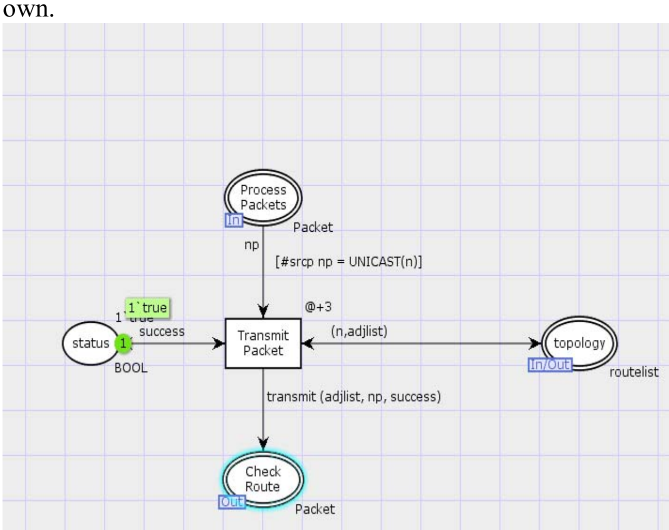


Fig. 5. Packet Transmission.

E. RREQ Packet and its transmission

The packets received by the "incoming message" are check by "target RREQ" transition continuously whether the node is destination-node and the message is RREQ type or not. If the node is not destination node and the message is RREQ type then the packet is forwarded to the adjacency nodes by "forwardRREQ()" where source node then to the nodes in the adjacency list. The packets are created and available to transmit the RREQ packet further. If that node is the destination node then "CreateRREP()" function creates RREP packets for the destination node and increases the sequence number it.

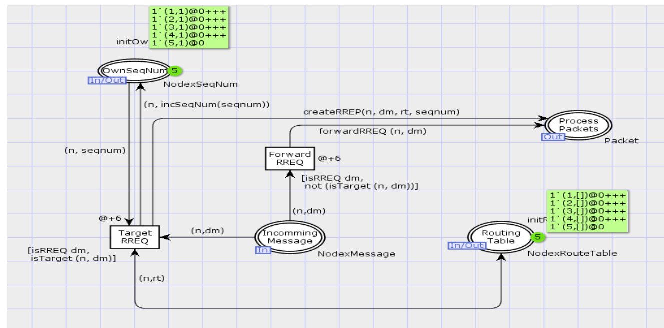


Fig. 6. RREQ Packet processing.

F. RREP Packet

The RREP packet is transmitted to neighbor nodes by the "transmit message" transition and valid RREP packets are received by "incoming message". If the target node is the source node then the packet is successfully delivered to the source node, if not then the node creates RREP packets and sends to its neighbor node from the routing table. Once the RREP packet is arrived at the source node then the end to end delay between source and destination is calculated by the designed timed Colored Petri net model. The time feature of TCPNs enabled the designed model to add various delay values to transitions so that the end to end delay value for each packet can be calculated including the processing, transmission and queueing delay value. For example here "forward RREP" transition takes 6 time unit which is mentioned as "@+" indicating a time value in the net, to forward a RREP packet to its neighbour node. "calETEDelay()" function takes two input i.e. the total delay value includes all delays and number of hopes in the route from source to destination and calculates the end to end delay for a packet to transmit from source to destination point.

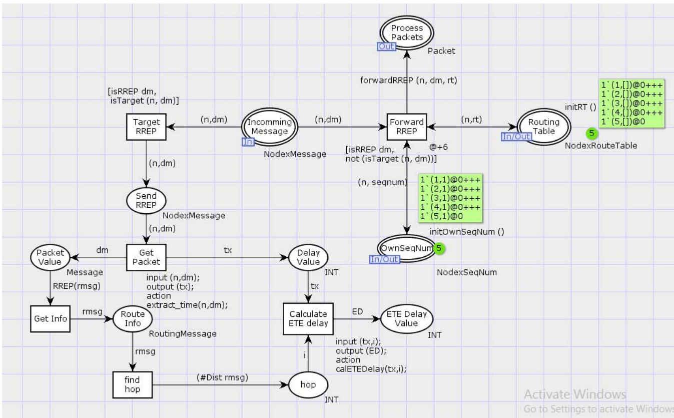


Fig. 7. RREP Packet processing.

G. RRER Packet

If a route breaks from a node then there is no other node reachable from the current node then "modifyRRERMessage()" function creates a RRER packet and forward to its neighbour nodes. When broken route found the "SetRoutesBroken()" function updates the routing table and sets the node is unreachable.

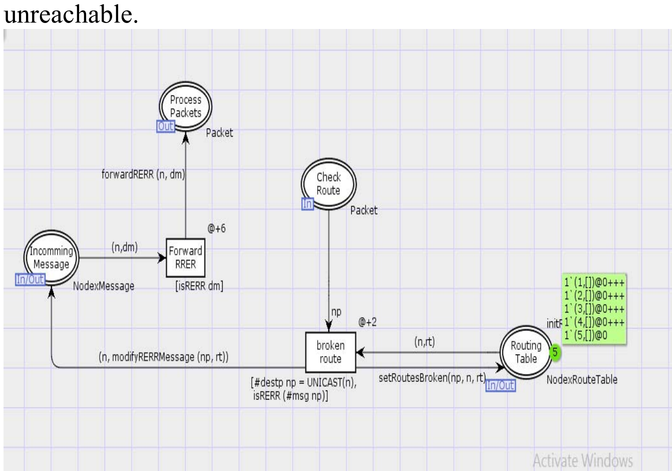


Fig. 8. RRER Packet processing.

VI. CONCLUSION

Here, the operation of AODV protocol is modelled stage wise using Timed CPNS. The transmission of packets from source to destination is modelled successfully. The state space analysis of the model is verified and various properties like liveness, Boundedness, dead markings etc. are analyzed. The future work of may contain the comparison existing NS2 simulation results. The comparison of various performance measures like packet delay, packet delivery ratio, throughput, queue length etc. with the NS2 can validate the current work.

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