Energy Performance Evaluation of Wireless Network using NS3

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***Abstract*— Wireless Mesh Network (WMN) is a form of ad-hoc network with flexible backhaul infrastructure and configuration, provides adaptive wireless internet connectivity to end users with high reliability. WMN is a wireless network consisting of mesh clients, mesh routers and gateways which are organized in a mesh topology with decentralized nature can consume more energy for data transmission. The networking performance of WMNs can be degraded due to the fact of high energy consumption for data transmission. Therefore, energy efficiency is the primary factor for attaining eminent performance. Organizing efficient routing and proper resource allocation can save huge amount of energy.**

The main goal of this thesis is to reduce the energy consumption in WMNs. To do this, a new energy efficient routing algorithm is suggested. Adaptive rates based on rate allocation strategy and end to end delay metric is used mainly for optimal path selection in routing, which may in turn reduces the resource utilization and energy consumption.

An energy efficient routing algorithm is implemented by using the Ad hoc On-Demand Distance Vector (AODV) routing protocol. The RREQ packet in AODV is modified by adding a new field known as delay parameter which measures end to end delay between nodes. Adaptive rates obtained from Rate allocation policy are considered in the routing process to reduce Energy consumption in the network. Energy measurement of the WMN and its performance is evaluated by measuring the metrics such as Throughput, End-to-End delay, Packet Delivery Ratio (PDR). For performing the simulation process, in this thesis, Network Simulator - 3 (NS-3) which is an open source discrete-event network simulator in which simulation models can be executed in C++ and Python is used. Using NetAnim-3.107 animator in NS-3-33, traffic flows between all the nodes are displayed.

The results are taken for existing algorithm and proposed algorithm for 25, 50, 75 and 100 nodes. Comparison of results shows that the total energy consumption is reduced for proposed algorithm for in all four scenarios.

Keywords*— *Energy consumption, End-to-End delay, Routing protocols, Network Simulator-3, Wireless Mesh Network.

I. INTRODUCTION

Wireless Mesh Networks (WMNs) are self-organizing ad-hoc networks that accommodates wireless internet access with mesh networking nature to mobile users, network operators etc. They are defined under wireless access technology set of IEEE 802.11s standards. IEEE 802.11s standards (subset of IEEE 802.11 standards) provide wireless mesh networking models for wireless network elements in order to form a WLAN mesh network. WMNs are deployed for dynamic connectivity over distributed geographical area and the networking framework is decentralized because each node in the network transmits data to the very next node. With increase in usage of WMNs, aiding a QoS over multi hop links is a challenging issue because transmission increases with increase in hop number.

Previous studies on WMNs based on 802.11 WLANs supports less QoS. Particularly, the multi hop wireless networks require high QoS for aiding real environment applications. Maintaining high QoS is a challenging issue for such networks because packet transmission delay is aggregated at every hop in a path. Meantime, scheduling schemes based on TDMA have been proposed for WMNs for maintaining low transmission delay. However, these schemes reduce the frame length and queuing delay which indeed maintains same packet transmission delay in WMNs.

Most popular type of wireless access network are WMNs, provides wireless connectivity through much cheaper and accessible back haul infrastructure compared to wired networks. In WMNs, all nodes are self-organized and are independent of pre-existing infrastructure. They create an adaptive topology and maintain continuous mesh connectivity between nodes in order to provide internet access to end-users. With vast increase of wireless technologies, usage for back hauling can substantially increase the energy consumption of the network, therefore efficient energy consumption reduction strategies should be implemented.

II BACK GROUND

A. *Wireless Mesh Networks*

Under IEEE 802.11, 802.15, 802.16 wireless access technologies it is observed that WMNs are extensively used, as they were able to provide a wide range of low cost-effective broadband access even to last-mile users in the network. WMRs provide connectivity to all end users with good performance, high client coverage and high output delivery. All the above factors mainly depend on the placement of the WMRs over a certain area. For example when mesh routers are placed at greater height, network connectivity is provided to enormous number of clients in that coverage area.

WMNs are connected usually based on two topologies i.e. full connected mesh topology and partially connected mesh topology. In full connected topology, all nodes are connected to each other in the network. During error conditions such as failure of one node in the network, instantly other alternative nodes which have a path to reach the destination are selected

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to continue the transmission process. This helps in increasing redundancy in the network. Coming to partially connected mesh topology, only a set of nodes are connected to all the nodes and some nodes are connected to the nearby two or more nodes. Usually partially connected networks are used in small scale connections. Using multi-hop routing capability schemes, coverage area of WMNs can be extended.

All wireless radio nodes are collaborated in a mesh topology to transmit data from source to destination. Internet service providers gain enormous advancements by adopting WMNs due to its low cost-effective internet connectivity and high network bandwidth nature. WMNs still have some issues like security, providing high reliability, scalability, high energy consumption etc. WMNs are multi hope networks; they use more number of intermediate nodes to transmit the data which allows all the nodes participating in the transmission to consume energy. This leads to more network energy consumption and resource consumption.

ARCHITECTURE

Traditional networks provide internet access to end users using wired connections in a small network coverage area where as WMNs provide wide range of network connections to last mile users in a large area of geographical network through wireless connections. WMNs consist of n nodes and (n-1) cablings. The n nodes can be WMRs and WMCs, and (n-1) cablings are the network connections between nodes. WMRs form multi hope network and provide broadband connectivity to all the WMCs, and the routers are connected to the internet, WI-FI, Wi Max etc. using bridging connection acts as gateways.

Routing protocols are used to route a packet from source to destination. Depending upon the operating nature of node, routing protocol changes its methods for transmission, for example we can consider three possible routes to transfer packets like WMC to WMC under same WMR, WMC to WMC under different WMRs in the same network, WMC to end user in the internet for all these routes, routing protocols efficiently allows routing for communications.

B. Energy Source

In NS-3, basic representation of any device or network element is node. Energy Source provides power supply to nodes using Energy Source modules. Each node in a network consists of network components like wifi radios, batteries etc. Energy Source will also provide power to these attached components. These components are maintained as list of Device Energy Model objects to Energy Source. In simulation process, Basic Energy Source as Energy Source is considered for energy consumption calculation.

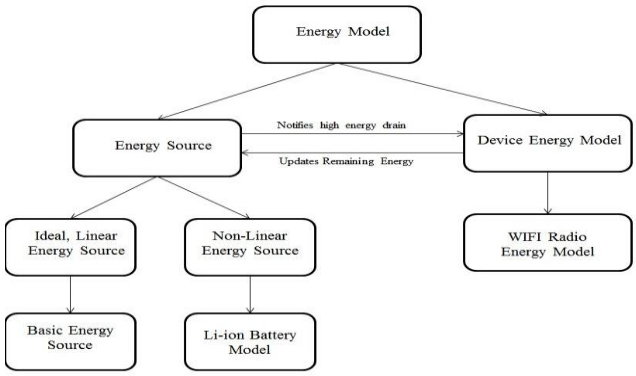

Figure 5 : Energy Model Hierarchy in NS-3

Operation: Basic Energy Source stores some initial energy value that is E_0 and k^{th} sample of total current draw (I_k) at the node with a time (t_k). When wifi radios change its operating state, Basic Energy Source is notified and new current value (I_{k+1})with in a time(t_{k+1})is

calculated by using Basic Energy Source objects such as calculate Total Current. Supply voltage V is taken. The total current is calculated as the sum of currents from all Device Energy Model components attached to the Energy Source.

Then energy consumption is calculated during (t_k, t_{k+1}),

$$E_{k+1} = E_k + V \times (t_{k+1} - t_k) \times I_k \qquad \text{Eq(1)}$$

In NS-3, initial energy is given by Get Initial Energy interface, after calculating the energy consumption, remaining energy is calculated by interface Get Remaining Energy and then gets updated to Basic Energy Source. Devices consume some energy in transmission process, after each transmission, Device Energy Model updates its residual energy to Basic Energy Source using Update Energy Source interface. In NS-3, Energy Source maintain Device Energy Model list and contain some interfaces. Each interface with their functionality is presented below.

C. Device Energy Model

Captures how energy is consumed by a network node. Device Energy Model accords the users to specify power consumption of the components for different operating states and then multiplied with time spent by a node in the perspective state. These models measure the energy consumption of the devices and update the Energy Source with new values. Here in this simulation scenario for energy consumption measurement of WMN devices, Wifi Radio Energy Model as Device Energy model is used. Device Energy Model is designed to be state based, with a current draw value associated with each of the states. In Wifi Radio Energy Model, each wifi radio contains four operating state IDLE, SLEEP, RX, TX. All these operating states contains some current draw value (in Ampere),Whenever the Wifi radio changes its state, the listener notifies the Wifi Radio Energy Model of the new state information of the Wifi radio and then notified to Energy Source. In NS-3, Device Energy Model provides five interfaces, each interface with their functionality is explained below.

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III. MODEL DESIGN AND IMPLEMENTATION

This sections explains the model considered for the experiment and the methods involved in Implementation. The following are the steps involved in the implementation process:

First step is to calculate adaptive rates based on rate allocation policy. Rate allocation policy mainly depends on distance parameter. These adaptive rates are given as an input to the AODV routing.

Second step is to modify AODV RREQ packet with delay parameter. Routing is performed between the source and destination through modified AODV routing protocol. Initially calculate the path estimation (i.e. distance measurement) through all of the nodes. Select the link path which has minimum distance of the intermediate nodes and minimum number of hops. Thereby overall minimum link path of intermediate nodes is chosen for transfer data between source and destination. Hence connectivity is maintained between source and destination for data transmission.

Third step is to obtain end to end delay between nodes with the modified algorithm.

Fourth step is to calculate the energy consumption of the total network using NS-3. Based on the modified algorithm, path with minimum number of nodes and minimum end to end delay is selected for data transmission.

Fifth step is to evaluate the performance of the modified algorithm by taking end-to-end delay, throughput, packet delivery ratio scenarios. All these scenario results are compared with existing algorithm for 25, 50, 75 and 100 nodes.

A Model Design

Data is to be transferred from source to destination over through the intermediate nodes. So dedicated path is maintained between source and destination as shown in below Figure6.UDP helper class is used for applications based on unicast delivery. The main purpose of modified AODV protocol is to provide good quality of experience with low energy consumption and to provide reliable amount of data through UDP connection. Node require some data to send onto intermediate node with the help of channel condition, by varying the distance in a large geographical area with minimum transmission range of 250m in wireless mesh network. Based on transmission opportunities with respect to channel condition, configure the network by splitting into nodes. Displacement between the two nodes is maintained with a gap of 10meters.Total displacement is considered as 40 meters and all the

Transmissions are performed for simulation time of 60 seconds.

B Components

Different components are used for message forwarding in grid network model. A WMN Model is designed based on the below mentioned grid topology with number of nodes as five. A list of specifications used in the Basic grid is shown in the following table.

Mesh Nodes, Destination Node	$M0, M1, M2, M3, M4$, DN
No of Nodes (N)	5
Total Displacement	40 meters
Displacement gap between Mesh nodes	10 meters
Simulation Time	60 Sec
Coverage Area	1.5 km
No. of grid Levels	5XN

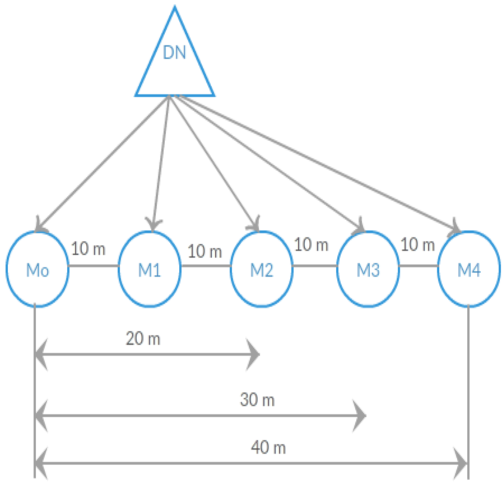

Figure 6: Basic Grid Model in Wireless Mesh Network

C General Mathematical Model for Proposing Rate Allocation Policy

Generally, UDP applications require low error rates. During the data transmission in wireless networks, data is compressed at the available bit rate where errors can ruin the data quality at the receiver. In order to uphold constant low error rate, the bit rate of the data stream must be adapted to the available bit rate which leads to low power consumption. This uses the physical layer channel information to be made available at MAC layer. The receiver calculates the signal strength of the transmission channel using channel model simulation at the physical layer. The parameter used for channel estimation at the receiver is termed as power indication Pr, which is calculated as:

$$P_r = \frac{P_t G_t G_r H_t H_r \lambda^2}{(4\Pi d)2L} \qquad \text{Eq (2)}$$

Here,
Pt and Pr are signal power at transmitter and receiver.
Gt and Gr are gain for a signal to a node from the transmitter and receiver.
Ht and Hr are height of the transmitter and receiver
λ is wavelength
d is distance between the transmitter and receiver
L is system loss.

Based on Eq (2), receiver estimates the signal strength. This received signal strength is mapped to a transmission data rate at the MAC layer. The receiver sends the calculated bit rate to the sender. Based on the current rate from the receiver, the physical layer at the sender updates its transmission rate consequently. Other nearby nodes that receives the packet will update the information in their network allocation vector and waits for their transmission until existing transmission is ended.

D Background for Rate Allocation Policy

In the following mathematical program, the design behind the rate allocation policy to minimize the power consumption in the wireless networks is described. The generalized resource allocation and scheduling scheme over the time T according to Shannon capacity bound(Appendix) can be expressed as follows:

$$R = B \log_2 \left(1 + \frac{hp}{N_0 B}\right) \quad \text{Eq (3)}$$

Where,

B is Bandwidth
R is data rate
h is Channel gain
p is the transmitted power
N_0 is Noise power

Here, M users are considered for transmission, user m requires an information message of W^m bits and b_t^m is the total bandwidth assigned to the user.

$$\text{Minimize} \quad \sum_{m=1}^{M}\sum_{t=1}^{T} P_t^m \quad \text{Eq (4)}$$

$$\text{subject to} \quad \sum_{m=1}^{M} p_t^m \leq P_{max} \ \forall\, t \quad \text{Eq (5)}$$

$$\sum_{t=1}^{T} b_m^t \log_2\left(1 + \frac{h_t^m p_t^m}{N_0 b_t^m}\right) = W^m \ \forall\, m \quad \text{Eq (6)}$$

$$\sum_{m=1}^{M} b_t^m \leq B \ \forall\, t \quad \text{Eq (7)}$$

$$p_t^m \geq 0 \ \forall\, t, m \quad \text{Eq (8)}$$

$$b_t^m \geq 0 \ \forall\, t, m \quad \text{Eq (9)}$$

Constraints of Eq (5) guarantee that the power allocated to all users at each time interval is below the ceiling value P_{ma} . Constraints of Eq (6) guarantee that the information message will be delivered to each user within the pre-defined time horizon of T seconds and Eq (7) limits the bandwidth assigned per user at each time slot to the system bandwidth. Inequalities Eq (8) and Eq (9) define the continues variables of the problem. Note that the non-linearities are found in the constraints of the problem. It is easy to show that this problem can be transformed into a nominal convex non-linear optimization problem by linearizing the constraints as follows,

$$\text{Minimize} \quad \sum_{m=1}^{M}\sum_{t=1}^{T} \frac{N_o b_t^m}{h_t^m}\left(2^{r_t^m/b_t^m} - 1\right) \quad \text{Eq(10)}$$

$$\text{subject to} \quad \sum_{m=1}^{M} r_t^m \leq W^m \ \forall\, m \quad \text{Eq(11)}$$

$$\sum_{t=1}^{T} r_t^m = W^m \ \forall\, m \quad \text{Eq(12)}$$

$$r_t^m \geq 0, b_t^m \geq 0 \ \forall\, t, m \quad \text{Eq (13)}$$

This gives the optimum data rate allocation in order to achieve minimum power consumption within the message delivery delays. However, energy savings could be achieved by deviating 28from that target when there are favorable channel gains allowing for increased transmission rates at a given power level.

In Eq (3), R is the data rate allocation at time instance t. For different distances and channel gains between the nodes, adaptive rates are obtained based on rate allocation policy. Effectively, it provides an optimal trade-off between the transmission rate during bad channel conditions (which might be required to ensure smooth playback) and increased transmission rate at good channel locations.

IV Proposed Algorithm

The Proposed algorithm is referred as the energy efficient algorithm. This Algorithm depends on previously proposed rate allocation policy by implementing the adaptive rates. The main purpose of using this algorithm is to balance energy at each node (i.e. increasing the no of nodes) so that high data rate is transferred from one node to node. Usually this algorithm work in two steps with help of AODV protocol.

The first step is grid based approach studied under three cases which indirectly depends on the number of nodes used. The second step involves adaptive rate measurement in mesh network after satisfying the first step. Therefore, the obtained adaptive rates are given as input.

CASE 1: when no of nodes=25 with the mesh size N=5 condition.

CASE 2: when no of nodes=50 with the mesh size N=10 condition.

CASE 3: when no of nodes=75 with the mesh size N=15 condition.

Procedure followed from these cases.

A Steps for Implemented Algorithm

Input: Received Adaptive Rates

Step 1: Initially, routing between packets is performed based on stable routing algorithm. When any node needs to send data, it generates the Route Request (RREQ) packet and broadcast it to its neighbor with initial common transmission range of 250m.

Step 2: The route reply messages from the intermediate nodes contain two fields' locX and locY that stores the information about the location of the node sending the route reply.

Step 3: In AODV, the path is established for the first RREP received. But in our modified AODV routing, each

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node waits for a time (T_wait) till it receives all the RREP messages destined for the node.

Step 4: The source node then calculates the distances between the nodes from where the RREP message is received and itself. This is done using own location and the locations of the intermediates nodes.

Step 5: Now, the node with minimum distance is selected calculated in step 4 and its location is also updated in the routing table as two entries n_hopX and n_hopY.

Step 6: Destination node in a routing path will calculates the packet delivery time by using below equation. If route contain 'n' nodes, there will be (n-1) links. The packet delivery time can be calculated as follows

"Packet delivery time = packet processing delay due to (n-1) links+ packet process

time in(n-2) links "

Step 7: Depends upon the above calculated minimum distance and minimum packet delivery time, the route between source and destination is maintained for data transfer.

Step 8: If the route is broken, repeat from step 1.

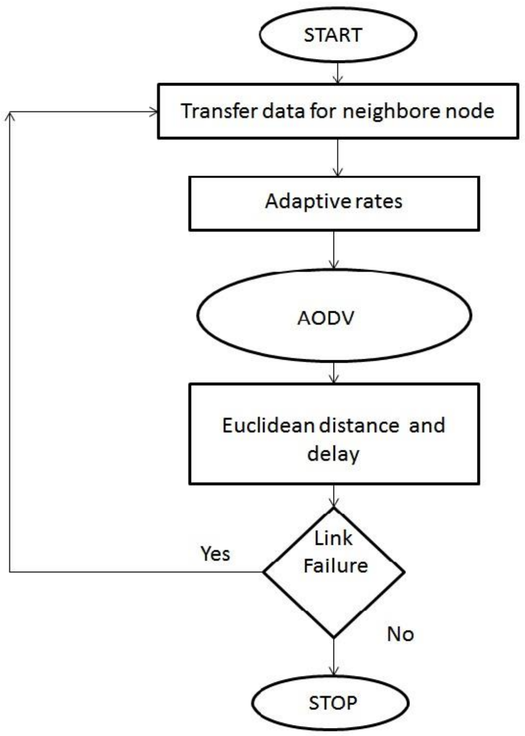


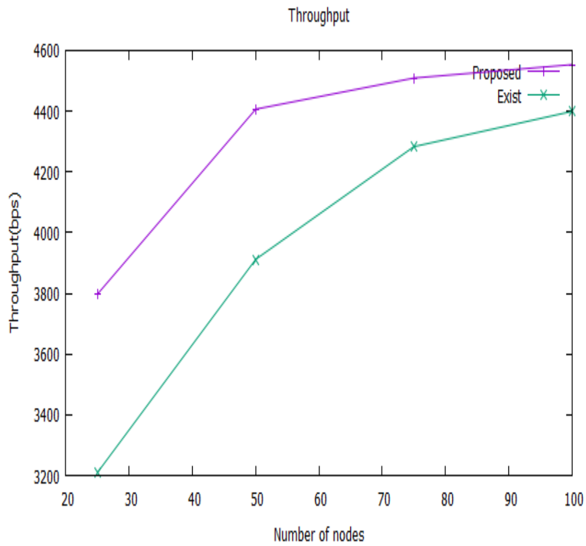
Figure 7: Flow chart for proposed algorithm

Figure 7 shows the flow for the implemented algorithm to balance energy at each mobile node. This Process can be achieved by distribution of adaptive data rates from one node to neighbor node with the Euclidean distance and lesser delay.

V RESULTS AND ANALYSIS

In this section we are describing about proposed model performance by considering various scenarios. In this experiment, we are evaluating the above mentioned proposed system Performance by comparing the results with an existing AODV approach. We have considered Energy consumption, end-to-end delay, and throughput and packet delivery ratio scenarios. Here we have computed all these scenarios for 25, 50, 75 and 100 nodes. All the results are simulated using NS-3.33, and comparison results are tabulated and plotted. Using Net Anim 3.107 animator available in NS-3.33, topology of WMN and packet flows between nodes is displayed.

A Results



Number of nodes (N)	Proposed (bps)	Existing (bps)
25	3797.58	3210
50	4406.4	3912
75	4508.83	4283
100	4552.99	4399

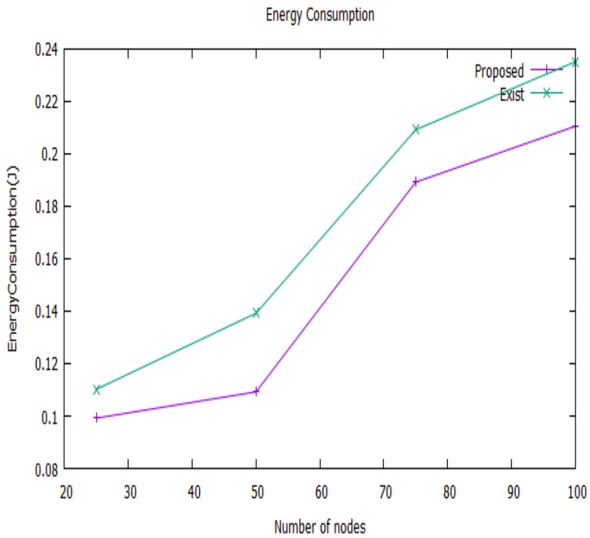
Number of nodes	Propod(J)	Existing (J)
25	0.0992	0.1102
50	0.1092	0.1392
75	0.1892	0.2092
100	0.2105	0.2351

Analysis:

The above Figure 8 presents average throughput comparison for existing and proposed algorithm based on number of nodes. Considering x-axis as number of nodes and y-axis as average throughput(bps). As the number of nodes increases, many different paths are available for a node to transmit the data to the destination. This leads to increase in throughput with respect to the number of nodes in both the cases. For the proposed model, data transmission is performed based on less delay and minimum number of nodes path. Due to less delay, more number of bits are transmitted in less time. For the existing model, data transmission is based mainly on minimum number of nodes, due to this consideration, packets wait time at all nodes is increased which leads to delay. Therefore, throughput rate is down for existing work due to more retransmission process. According to the simulation results, the throughput rate of proposed model is higher than existing one with 15 to 18% of rate variation. Hence, the performance of proposed algorithm has higher throughput and it shown better performance results.

B Energy Consumption

Energy consumption is the measure of total energy consumed by a network.



Analysis:

Using rate allocation policy, all the nodes in the network are allocated with sufficient amount of rates. Due to adaptive rates, wastage of resource utilization of the nodes is decreased which leads energy consumption reduction. Proper infrastructure with sufficient resource utilization is maintained. Therefore, energy consumption in proposed algorithm is reduced. Considering x-axis as number of nodes and y-axis as energy consumption (J). For the proposed model, packets are transmitted based mainly on less delay and minimum distance path. Due to these considerations, packets are not queued at nodes which lead to less resource utilization and less energy consumption.

For the existing model, packet transmission is based mainly on minimum number of nodes, due to this consideration, packets wait time at all nodes is increased which leads to delay. Due to this delay, packets form queue at nodes which leads to more resource utilization. Therefore, energy consumption is more for existing work due to more usage of resources. From above Figure10, energy consumption is set to 3J when there is no displacement between base station and user launched on the mesh. As the displacement increased to 10 meters' power across the base station decreased to 0.006J. From above tabulated values, approximately 11.08% of energy consumption is saved using proposed model.

C Display of Traffic flow between 25 nodes

Below figure displays the traffic flow between 25 nodes at simulation time of 6.459 sec. Here node 0 is the source node and node 24 is the destination node, traffic flow between these nodes is displayed below. All these nodes are placed at a coverage area of 1.5kms. In NS-3, ns3: Animation Interface class is used to trace the packet flow between nodes. Animation Interface creates a XML file, in which all the information about infrastructure and traffic flow is stored. Using tx and rx trace hooks, all the events of transmission and reception are recorded. Generated XML file is loaded in NetAnim animator and corresponding traffic flow is displayed. Here we are using XML trace file generated for 25 nodes WMN proposed algorithm. Using command "./NetAnim", animator is launched. Each node is assigned with specific IP address and MAC address. AODV protocol is implemented between these nodes, intially an RREQ packet is generated by source node and is sent to all the intermediate nodes. Now, these nodes will send RREP packets to source node. Based on coordinated packet data, source node sends data to particular destination node.

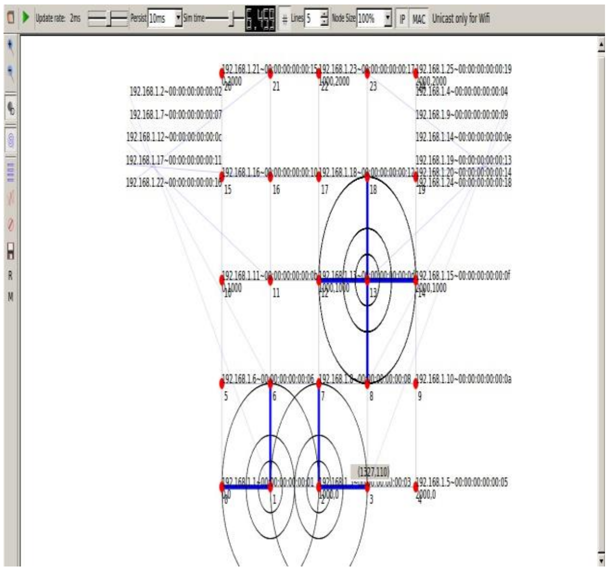


Figure 12 : Traffic flow between 25 nodes

D Display of traffic flow between 50 nodes

Below figure displays the traffic flow between 50 nodes at simulation time of 6.011 sec. Here node 0 is the source node and node 49 is the destination node, traffic flow between these nodes is displayed. Generation and distribution of RREQ and RREP packets from all the nodes are displayed in Figure 13.

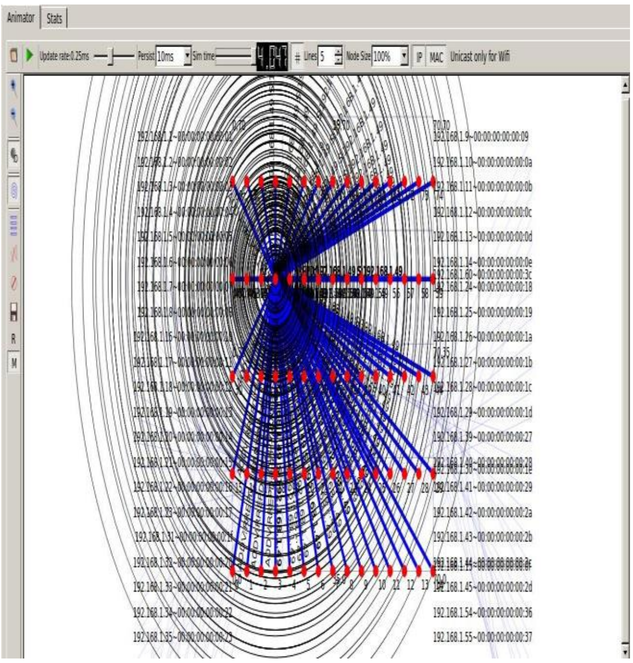


Figure 13: Traffic flow between 50 nodes

E Display of Traffic flow between 75 nodes

Below figure displays the traffic flow between 75 nodes at simulation time of 4.047 sec. Here node 0 is the source node and node 74 is the destination node, traffic flow between these nodes and each node RREQ, RREP packet generation is clearly shown in below Figure 14.

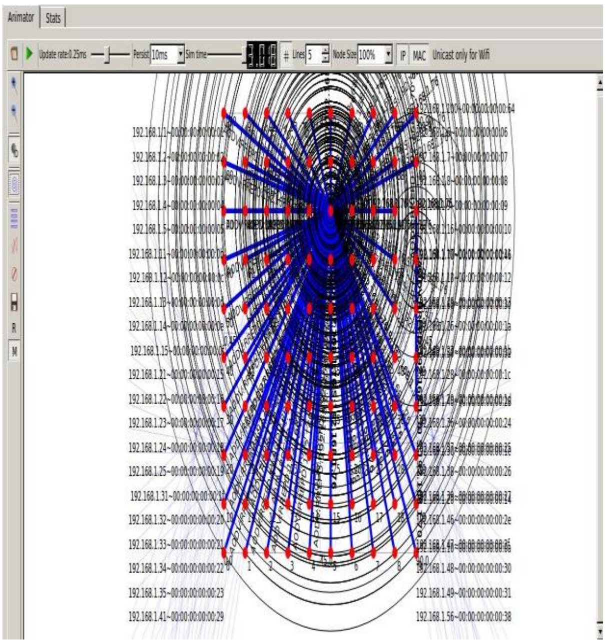


Figure 14 : Traffic flow between 75 nodes

F Display of Traffic flow between 100 nodes

Below figure displays the traffic flow between 100 nodes at simulation time of 3.018 sec. Here node 0 is the source node and node 99 is the destination node, traffic flow between these nodes and each node AODV RREQ, RREP packet generation is displayed in below Figure 15.

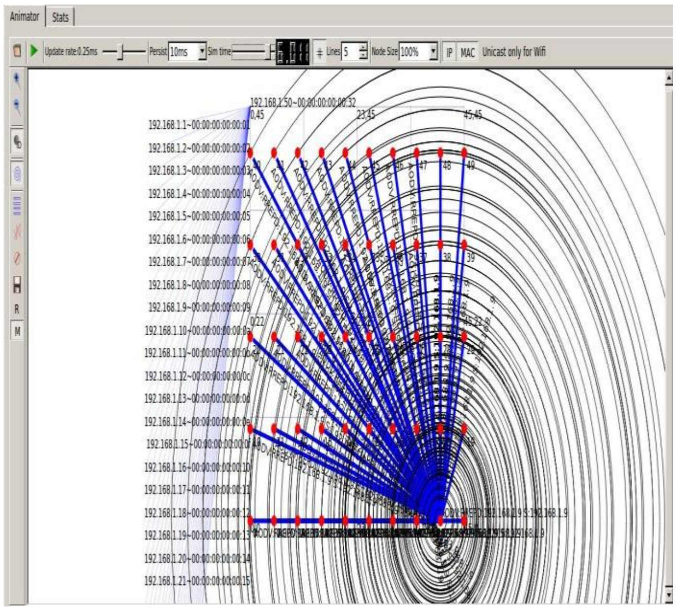


Figure 15 : Traffic flow between 100 nodes

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