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A Swarm Based Hybrid Multipath Load Aware Routing Algorithm for WMN

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Abstract

Background: Wireless Mesh Networks is an emerging field and versatile network infrastructure constitutes the collaboration of heterogeneous mesh routers managed by different users to extend network coverage. The performance of WMNs depends on the designing of a routing protocol. While implementing the routing protocols, allocation of routing metrics are done to different paths for calculating best paths which represents a function for the prediction of the best routing path. **Methods:** To select best path in WMNs, tree based routing protocols and hop count based routing protocols are proposed earlier. However, Poor scalability and throughput, high overhead owing to control packet flooding are still exists as drawbacks. Moreover, factors namely high number of forwarding nodes and load balancing factor are not focused. A novel routing protocol based on A* path finding algorithm and hybrid BAT algorithm is proposed to solve these issues. There are three phases namely discovery, path selection and route maintenance. In path discovery, the shortest path between the gateway and other nodes is found using A* path finding algorithm where more than five routes have been discovered. In second phase, the best path is selected for data transmission by considering load balancing as an important factor using hybrid BAT algorithm based on path relinking algorithm. During the joining of new nodes or node failures or nodes that are moving continuously in route is maintained through the other two phases. **Results:** The results of the proposed algorithm is attaining a higher packet delivery ratio, lesser end to end delay and lesser routing overhead than the existing routing protocols such as PAWMNet, FKAWMNet, HBWMnet, and these were obtained from their simulation results. **Conclusion:** The performances of the proposed algorithm were compared with other existing algorithm using other standard performance metrics which gives best results. The results show that the proposed approach is efficient to determine the parameters which affect the network.

Keywords: A* Algorithm, Hybrid BAT Algorithm (HBA), Industrial Wireless Mesh Networks, Load Balancing Metrics, Multi-path Routing, Wireless Mesh Network (WMN)

1. Introduction

Wireless Mesh Networks (WMNs) includes mesh routers together with mesh clients in which all nodes have the adequate potential to operate at both as host as well as router. There are three categories in WMNs namely; Infrastructure backbone, client backbone and hybrid in accordance with the functionality of the nodes[1]. Mesh routers help in forming multi-hop and multi-path wireless relay backbone which can communicate effectively with clients and gateways. Mesh clients together can generate a self-organized ad-hoc networks having right to use services through relaying requests to wireless backbone network. The integration of infrastructure with client meshing is called hybrid mesh network architecture which is presumed to be suitable for the next generation WMNs. A typical WMN is visualized to constitute three level hierarchical structures. The primary hierarchy is been given to the IGW (internet gateway) or the gateway nodes having direct connection to the wired network. Next stage of hierarchy includes nodes similar to Access Points (APs)/ Mesh Routers (MRs) which could direct all traffic among themselves and also towards the IGW in muti-hop mode. In WMNs, MRs are static and stand

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as an important element[2]. The lowest level of hierarchy is been given to the Mobile Clients/Nodes (MNs) or the intended users which are having connection with MRs for the purpose of accessing the wired network services. Figure 1 illustrates the typical WMN. Multiple interfaces are employed to equip the MRs, so that each interface can be tuned to different non-overlapping channels for offering simultaneous process of both transmission and reception. This significant characteristic of WMN is concentrated to improve their working potential. In WMN, the approximated traffic capacity is presumed to be extremely high, so that there are chances of scalability and load balancing complication[3]. The WMNs necessitates high bandwidth broadband connections as it should provide some space for large number of users to access the internet for different application requirements.

Most of the traffic in WMNs is meant as the more traffic on certain routes (most importantly in the direction of the IGW). At the same time as the IGWs are important for forwarding the entire network traffic, also they are considered as a main limitation in case of WMNs. The elevated traffic more traffic in the place of a gateway causes saturation which will subsequently result in packet drops because of excess buffer overflows. As there will be a consumption of various available network resources during the routing from source till the IGW, in the mean time the packet drops are considered undesirable and inefficient in IGW. Hence, in order to keep away from the threat of congestion, it is sensible to stabilize the traffic load over several

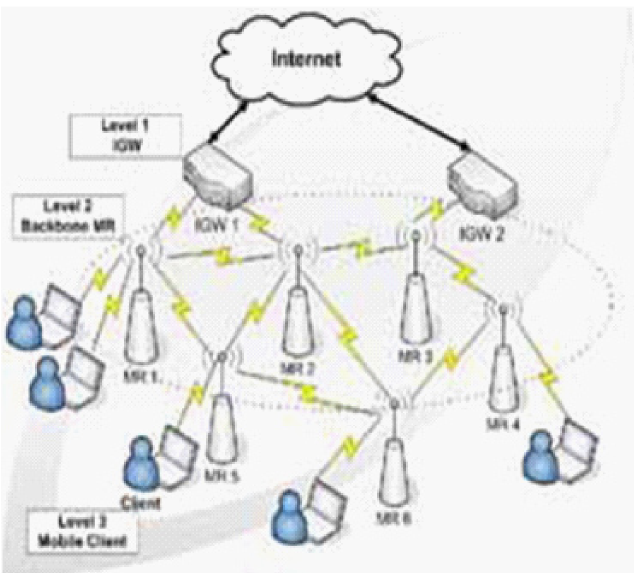

Figure 1. Simple Mesh networking Scenario.

IGWs and moreover possibly in the routes pursued by the packets enroute to the IGW. The key point triggered and motivated to propose a scheme having the ability to share the load between multiple gateways, with the intention of enhancing the overall performance of the network.

The present work considers load balancing in WMN with stationary nodes. Wireless Mesh[4] and Community networks namely the Self-Organizing Neighborhood Wireless Mesh Networks are also been included in the study. The following objectives are framed to provide experimental algorithm in order to provide load balancing in WMN: (a) increase network throughput by means of admissibly best possible distribution of the network traffic across the wireless links, (b) make sure the method is safe, and (c) guarantee fairness to the entire nodes in the network for bandwidth allocation. The motivation for singling out these novel networks over other conventional wireless networks for designing load balancing heuristic algorithms has been driven from the following literature as given below.

2. Related Works

Nandiraju, Santhanam, Nandiraju and Agrawal[5] illustrated the flow performance degradation in a WMN on account of congestion at an IGW. The well-designed load balancing mechanism is hence proposed so as to distribute the traffic load in the midst of multiple gateways by means of converting the spot of attachment in the primary nodes for active generation of high traffic. The primary goal is to make use of the entire available gateways for the purpose of balancing the traffic load and to lessen the congestion at only certain gateways. The simulation helps in a better way to demonstrate that the proposed scheme can stabilize the load to a large extent.

Virendra, Duan, Upadhyaya and Anand[1] proposed heuristic approaches for the purpose of load balancing and highest throughput scheduling in WMNs with stationary nodes. The objectives such as (a) improving the network throughput by means of admissibly best possible distribution of the network traffic although the wireless links, (b) ensuring secureness of the scheme and (c) ensuring fairness to the entire nodes in the network for the purpose of bandwidth allocation had been considered. However, the important aim is to route non-local traffic among the nodes and the target by means of multiple Internet gateways. The proposed scheme enables splitting of an individual node's traffic to the internet easily reached across multiple gateways. Simulation results showed that the approach showed marked increase in average network throughput both in moderate as well as heavy traffic scenarios. In the present work, the difficulty of the algorithm in case of an adversary to obstruct a small part of a node's accessible paths is been proved, making it exceptionally hard to negotiate the entire traffic from a node. The simulation results ensured the fairness of the scheme in bandwidth distribution even to nodes with lengthiest paths to the particular gateway nodes.

The difficulty in placement of load balancing gateway has been studied by Feng and Zhigang[6] based on which a greedy scheme GA-LBC was formulated. It works in order to partition the WMN into load-balance and disjointed clusters, where all cluster meets QoS constraints. In accordance with the basis of GA-LBC scheme and of GA, a hybrid algorithm HA-LBPG is proposed in this work to obtain the near-optimal solution. The results showed that the amount of gateways produced by HA-LBPG is just about to the effect from supplementary gateway assignment approaches. In case of load balancing along the gateways, HA-LBPG seemed to be performing much better than the other algorithm.

Mohammad, Misagh and Mohmood[7] also addressed the complication of load balancing in WMNs. In that work, Cluster dependent Wireless Mesh Architecture was implemented, here the WMN is partitioned into several clusters. This could help minimizing the updating overhead while there exists change in topology as a result of mobility of the mesh nodes or congestion of load on a cluster. Each cluster contains a gateway having comprehensive understanding regarding group memberships and also regarding link state details in the cluster. Mostly the gateway is been opted for the cluster configuration process. The load of gateways is usually considered which has to be reduced. Hence, it is usual that when a gateway undertakes to be an interface for connecting nodes of a wireless mesh network to other networks or internet, there would be some problems such as congestion and bottleneck. This motivated to propose a new paradigm for overcoming these problems. For solving the limitation, clustering is employed to reduce load of gateways followed by division of cluster for preventing from bottleneck on gateways. The method of detecting congestion on a gateway and reduction of loads for preventing from bottleneck on gateway are been studied in the present work and therefore to increase throughput of network to encountering many loads.

Choi and Han[8] formulated a new load balancing routing approach for WMNs together with numerous gateways, specifically, sink routers. Since the largest part of traffic taking place in case of WMNs is transmitted to these gateways by means of wireless connections in a multi-hop manner, moreover the sink routers are overloaded without any difficulty. In this scenario, if a user begins a communication session and the consequent route in the direction of the sink router will not offer the necessary range of operations, the session is declined. The major aim is just attain load balancing routing that diminishes these kinds of refusals. In this circumstance, a scheme called adaptive partitioning is employed; this scheme heuristically partitions the whole network into divisions and executes load balancing in between separations and within separations.

A coding- aware opportunistic routing scheme is a combination of hop-by-hop opportunistic forwarding and confined inter-flow network coding for the purpose of enhancing throughput performance of WMN[9]. It was proposed by the author all the way through the use of opportunistic forwarding, CORE permits the next-hop node with the maximum coding gain to prolong the process of packet forwarding. CORE tries to increase the quantity of packets through localized coding network packets that can be passed in a single transmission.

3. Materials and Methods

Hops, bandwidth, and link quality estimation being the key components of wireless mesh networks are used for selecting the best path by calculating the link weight between the nodes during the path discovery and path selection. The neighboring node information can be collected and stored as in the neighbor table during the initial period of a network. The Sample Wireless Mesh Network is shown in Figure 2.

3.1 Path Discovery using A^* Search Algorithm

In this phase, an industrial WMN is indicated as an uncomplicated connected graph, $G = (V_G, E_G)$ in which V_G and E_G represent the collection of vertices and edges, correspondingly. The weight can be considered as distance among the nodes. In this research work, parameters such as distance, bandwidth estimation and energy consumption helps in finding the path between the gateway and

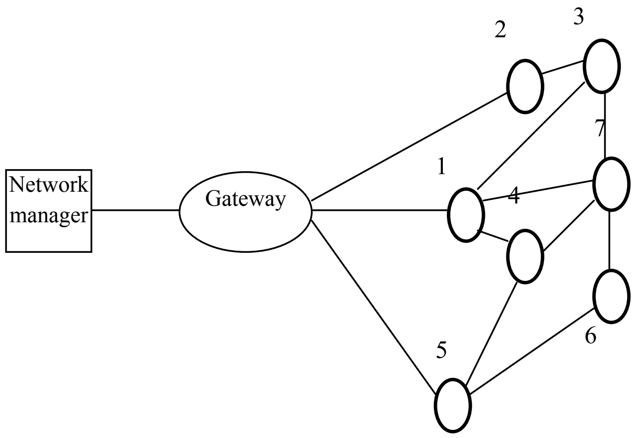

Figure 2. Sample Wireless Mesh Network.

other nodes using A^* search algorithm[11]. A^* algorithm creates a two list for selecting the best path. Moreover, the first one creates a list of paths leading to destination known as OPEN list and then it creates a list of shortest path between gateway and nodes called as Close list.

Step 1: Generate a search graph G, consisting only the start node as a gateway node.

Step 2: Select the node 'n1' from path 1 and node 'a1' from path 2 on OPEN list and calculate the energy of the selected node using the formula

$$E_{ini} = \text{Voltage} * \text{Current} * \text{duration} \tag{1}$$

Compare it with the predefined threshold.

Step 3: if the energy is high, then it is removed from the OPEN list then it moved to the CLOSE list along with energy value.

Step 4: calculate the bandwidth between the start node and selected nodes.

The bandwidth between the two nodes is estimated as a

$$b(L) = (L-1) \times \frac{S}{\Delta(L)} \tag{2}$$

Where, b(L) is the bandwidth estimate, L is the length of the packet train, S is the size of each packet, and Δ(L) is the difference in time between (dispersion) the first packet and the final packet of the train.

Step 5: The same process is continued until it finds the shortest path for the destination from gateway node.

3.2 Route Selection using Hybrid Bat Algorithm

The detailed mechanism of the best path selection was clearly discussed in this chapter. Hybrid BAT algorithm based on key components such as bandwidth, channel diversity, energy, and packet transmission rate helps to find out the best path. The bat algorithm[10] is a combination of Path relinking strategy and constructing the elite set (ES) for efficient selection of path. Each and every node in the pathsis considered as initial population i.e., bat in the algorithm. The shortest paths discovered in the previous phase from gateway to other nodes are given as an input to the algorithm along with the energy and bandwidth. For each and every input path the components of the routing metrics is calculated and used as an input parameters in the proposed algorithm[12].

An objective function of the algorithm is Bandwidth. Based on the bandwidth the input paths are sorted from best to worst and store it in KEEPBAT. Link quality measurement and energy consumption of the path are the key parameters in validating the path. Here the link quality measurement and energy consumption is considered as a velocity and position of the bat.

3.2.1 Link Quality Measurement

The gateway transmits series of the packet with predetermined size and length to move into each and every node exist in the network in time interval t. The packet delivery ratio (pdr) is found using the following formula,

$$pdr_i^j = (1-\mu)\frac{P_s}{P_T} \tag{3}$$

Where, μ indicates smoothing constant, P_s represents an amount of packet received and P_T denotes a total amount of packets transmitted.

The link qualities among the nodes are computed by means of link cost and link capacity measurement. Initially, the link cost is described as the converse of the packet delivery ratio (pdr) among the nodes. The cost of the link node i → node j is computed using,

$$c = \frac{1}{pdr_r^j} \tag{4}$$

The link capacity is estimated with the help of the packet delivery ratio among the node i and node j, and it is given as follows,

$$LC_{ij} = \frac{1}{pdr_i^j pdr_j^i} \tag{5}$$

Both the link cost and link capacity among the nodes ij are employed to compute the link quality among nodes i and j.

3.2.2 Energy Consumption

Following to the estimation of link quality, the energy consumption for the link among the node i and node j is computed. As a result, the total power consumption of a node can be given as follows,

$$E_i = \alpha^{ecb} \sum_{k \in N_{in}(i)} \tau_{ki} + \sum_{j \in N_{out}(i)} \alpha_{ij}^t \tau_{ij} + \mu \tag{6}$$

$$E_i = \alpha^{ecb} \sum_{k \in N_{in}(i)} \tau_{ki} + \sum_{j \in N_{out}(i)} \frac{\tau_{ij} N_0}{RG\left(2^{R/\eta W} - 1\right)} + \mu$$

Where, α^{ecb} indicates the energy utilization of the receiver for receiving one bit data. The energy per bit can be given as,

$$\alpha^t = \frac{N_0}{RG}\left(2^{R/\eta W} - 1\right) \tag{7}$$

Where, R indicates the transmission rate, W denotes the bandwidth estimated, G represents channel gain,N_0 indicates the noise power and $\eta \in (0,1)$ denotes the probability that information can be consistently sent at a specified transmission rate. The transmission rate can be computed as a $R = \eta C$, where, C indicates the Shannon capacity. The channel gain can be computed with the help of the formula $G = G_0\left(d/d_0\right)$, where d represents the distance among nodes.

3.2.3 Load Balancing Factor

The formulated routing metric for computing the load depends on two factors; they are inter flow interference and intra flow interference in mesh networks. This category of routing metric discovers paths with very low congestion, low packet drop ratio, small level of interference and high data rate.

Inter-flow interference

The inter-flow interference takes place at the time of neighboring nodes contend with each other for obtaining channel bandwidth during they send on the same channel. The extent of interference is in accordance with the quantity of load produced through the interfering node and not on the amount of interfering nodes. With the aim of obtaining the interflow interference, the following formula is used,

$$Ie_c = \begin{cases} ETT_{Gn}(C) \times N_{Gn}(C) K_{Gn} \neq 0 \\ ETT_{Gn}(C) K_{Gn} \neq 0 \end{cases} \tag{8}$$

Where, Ie_C indicates the interflow interference for channel C, $ETT_{Gn}(C)$ indicates the anticipated transmission time among the gateway node and node n(n = 1, 2, 3, …), $N_{Gn}(C)$ denotes a average load of the neighbors among the gateway node and node n(n = 1, 2, 3, …), and K_{ab} indicates the number of intermediate nodes among gateway node and node n(n = 1, 2, 3, …).

$$N_{Gn}(C) = \frac{L_{K_{Gn}}}{K_{Gn}} \tag{9}$$

Intra-flow interference

Involving two paths that comprise similar interference weight, the nodes that make use of dissimilar channels to send the data have a lesser amount of intra-flow interference than the path that constantly exploits the same channel. Formula for computing the intra flow interference is given as,

$$Ia_C = \begin{cases} Iw_1 CH(prev(G)) \neq CH(G) \\ Iw_2\ CH(prev(G)) = CH(G) \end{cases} \tag{10}$$

Relating to,

$$0 \leq Iw_1 \leq Iw_2 \tag{11}$$

Suppose a gateway node that is furnished by means of several radios and constructed to various channels. With the intention of removing intra-flow interference, gateway node is supposed to send to subsequent hop by means of a channel different from the channel it employed to obtain the data from prev(G), specifically, previous hop of gateway node. CH(G) indicates the channel that gateway node utilizes to send to its subsequent hop and CH(prev(G) the channel utilized through the preceding hop of gateway node. When gateway node utilizes similar channel to obtain the data from preceding hop and send to subsequent hop, maximum weight is allocated, explicitly, Iw_2. As an alternative, when the gateway node utilizes two dissimilar channels for the purpose of reception and sending a lower weight of Iw_1 is allocated in order ranges from $0 \leq IW_1 \leq IW_2$.

Overall load balancing factor for a specific path is given as follows,

$$LB_p = \mu \times \sum Ie_C + \sum Ia_C \quad (12)$$

Where, μ indicates scaling factor among the inter flow and intra flow interference.

3.3 Proposed Algorithm for Path Selection

Initialize the generation counter t = 1; intialize the population as path and node. Define loudness as packet delivery ratio, velocity as link quality measurement, and pulse rate as energy consumption evaluate the each and every bat ie., node in the population using the objective function bandwidth

$$pdr_i^j = (1-\mu)\frac{P_s}{P_T} \quad (13)$$

If cardinality of (ES) $\neq$ ps // population size then

$$Elite_{set(x)} \leftarrow ES\bigcup\{x\} \quad (14)$$

while $t \leq t_{max}$ do

Compute the link capacity also between two bats i and j using equation

$$LC_{ij} = \frac{1}{pdr_i^j pdr_j^i}$$

if $LC(x_{ij}) < LC(x_{1k})$ then

$Select_{Elite_{set(ES)}} \leftarrow$ remove the worstnodes

$ES_* \leftarrow Select_{Elite_{set(ES)}}$

for i = 1 to N do

$x \leftarrow path_{relinking(ES_*, x)}$

End

Evaluate the fitness value of each individual again

$ES \leftarrow Elite_{set(x)}$

Compute loudness i.e., the energy consumption using the equation

$LD_i \leftarrow E_i$

if $LD(x_{ij}) < LD(x_{ik})$ then

$Select_{Elite_{set(ES)}} \leftarrow$ remove the worstnodes

$ES_* \leftarrow Select_{Elite_{set(ES)}}$

for i = 1 to N do

$x \leftarrow path_{relinking(ES_*, x)}$

End

Evaluate the fitness value of each individual again

$ES \leftarrow Elite_{set(x)}$

$t = t + 1$

end

Store the best path

Path relinking

$x_s \leftarrow x;$

$x_t \leftarrow ES_*$

$f(x_t) \leftarrow f(Es_*)$

$\Delta \leftarrow difference(x_s, x_t)$

For i = 1 to n do

$j \leftarrow Find_{Position}(x_s, x_t, \Delta_i)$

$x_i \leftarrow Replace(x_s, \Delta_i, j)$

$x_i \leftarrow Replace(x_s, x_t, \Delta_i)$

$iff(x_i) < f(x_t)$

$x_* \leftarrow x_i$

$f(x_t) \leftarrow f(x_t)$

The above mentioned algorithm is used for selecting the best path for data transmission.

"Keep-alive" message

All the nodes share its information to its neighbors using "keep-alive" messages with the help of wire mesh form. The real intention is just to explore quiescent links, find out latest neighbors, and preserve time synchronization. "Keep-alive" notifications are supposed to be transmitted just once per minute for the avoidance of power consumption and network flooding by recurrent messages. This message plays an essential part during route maintenance phase. In case of the route exploration phase, when a node acquires fresh details of paths to the gateway, the node transmits "keep-alive" notifications to its corresponding neighbors. The moment in time gap of the broadcast of these messages has to be in excess of 1 s. Every notification contains details regarding five routes and carries it to the gateway at most. Since this phase terminates, the characteristics of "keep-alive" notification are reorganized to their default arrangement.

3.4 Route Maintenance for Topological Changes

In case of industrial fields certain topological changes take place because of the defective nodes or imminent exterior circumstantial aspects. Some transformation of network topology, like linking of fresh nodes, shifting of nodes, and breakdown of node, might induce routing control. The network administrator can make consequent progressions in accordance with different topological transformations to adapt the changes that occur.

3.4.1 Joining of New Nodes

In case if a node satisfies the conditions of a network then the node is ready to join the network. The newly joined node launches links together with extra nodes when the distance among them is inside the network limit. The node is supposed to send or receive probe packets as soon as the connection is established. Based on the initial energy the several path is formed for transmitting the data using A^* path finding algorithm. Then the path is evaluated using the parameters of the proposed route selection algorithm.

3.4.2 Nodes Moving

The network manager informs "keep-alive" notifications to inform the neighbor nodes of the travelling node like that the existing nodes move on. The network administrator makes a decision whether or not to initiate route examination in accordance with the specific conditions. There is no transformation of the hops among nodes if the nodes move for a short distance. The network supervisor revises the pdr of the routes in accordance with the travelling node instead of route exploration. This is for the reason that the distance among the node and its neighbors has transformed. On contrary, when the routes along this travelling node are stopped, subsequently the network supervisor route discovery and route selection phase again.

3.4.3 Node Failure

A node receives an "unconnected message" from its neighbor or the neighbor node doesn't exchange the message exceeding the "Time keep-alive interval," then the node presumes to send the command "Alarm graph route failed" to the network manager. Then the other nodes were informed about the route of the failure node by the network manager, such that these nodes can keep track of this topological transformation and the network manager could restart route exploration for this node.

4. Experimental Results

The model experimentation was performed by Ns2 simulator to estimate the performance of the proposed algorithm. The simulation experimentation were performed with nodes randomly selected within the range 100, 200, 300, and 400 nodes in a square area with area distance end to end of 10 units. Data transmission communication among two nodes based on their distance values were performed and found that the values may be less than or equal to $\sqrt{2}$ units. The following parameters are mostly used to analysis the results of the algorithm in WMN are given below.

1. The delay time taken by the source to destination during data transmission communication path was measured by End-to-end delay.
2. Pdr is characterized as amount of packets which is effectively obtained at the target without loss of any packets or failure, if the packet delivered ratio of the system is high it becomes more secure and highly efficient
3. Overhead in number of packets is characterized as the association among the amount of packets controlled throughout data transmission communication and the totally delivered packets at the receiver side.

These three metrics are used to analysis the results by comparing the various methods. The performances comparison results of the end to end delay between the methods such as PAWMNet, FKAWMNet, HBWMnet and proposed LBWMnet is illustrated in Figure 3a, it shows that the proposed LBWMnet has less end-to-end delay when compared against the other schemes such as PAWMNet, FKAWMNet, HBWMnet.

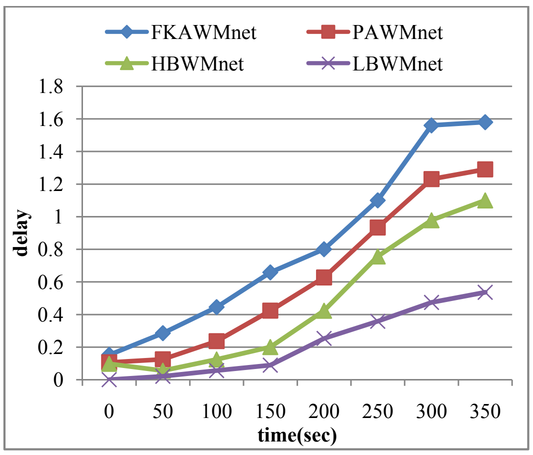

Figure 3 (a). Average End To End Delay.

The proposed LBWMnet has high packet delivery ratio when compared with existing approaches PAWMNet, FKAWMNet, HBWMnet. The evaluation of the pdr of the proposed LBWMnet and existing PAWMNet, FKAWMNet, HBWMnet results are shown in Figure 3b.

Proposed LBWMnet and existing PAWMNet, FKAWMNet, HBWMnetresults of the overhead in number of packets are illustrated in Figure 3c. The proposed LBWMnet has less overhead in number of packets when compared to existing approaches PAWMNet, FKAWMNet, HBWMNet.

Comparison ofLBWMnet and existing PAWMNet, FKAWMNet, HBWMnetresults are illustrated in Figure 3d by the obtained graphical outputs. It clearly reveals that

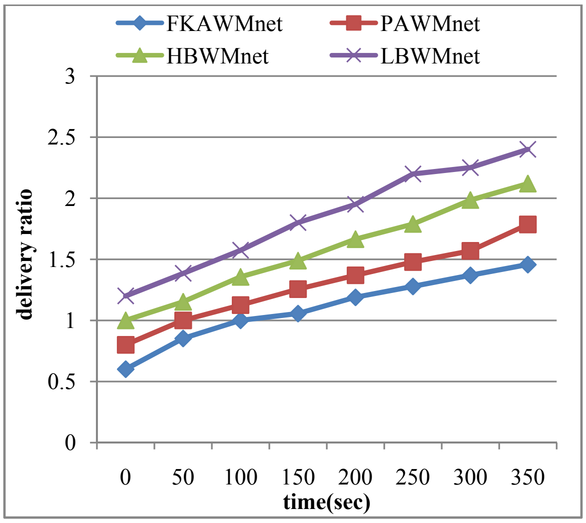

Figure 3 (b). Packet Delivery Ratio.

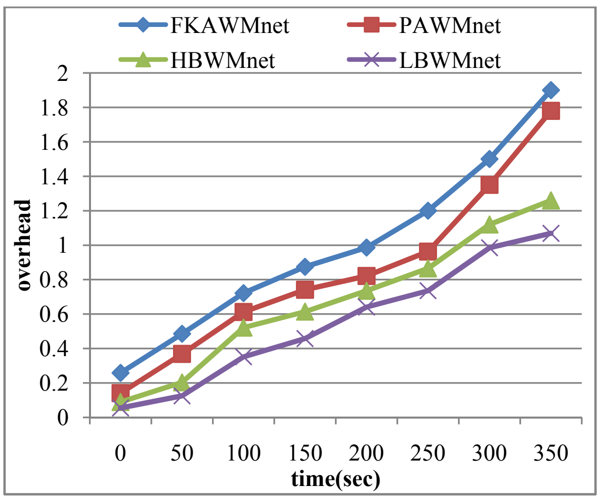

Figure 3 (c). Overhead In Number Of Packets.

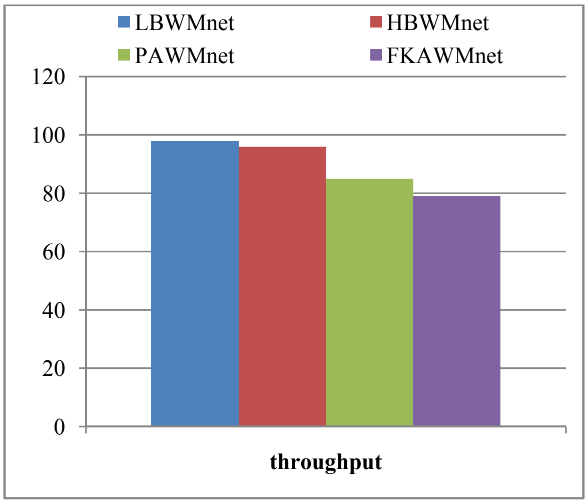

Figure 3 (d). Comparison Of Throughput.

the proposed LBWMnet has maximum throughput when compared with existing approaches PAWMNet, FKAWMNet, HBWMnet.

5. Conclusion

The successful development of a hybrid multipath load aware routing algorithm for WMN was clearly investigated in this paper. The Mesh connection between nodes helps in making WMN more consistent and achieving less cost estimation of on-demand path discovery results over multiple links in WMN. The energy and load aware metrics for each and every path assess the worth of WMN. There are two steps in the proposed work one is multipath route routing based on A* path finding and the other one is path selection based on the Hybrid BAT algorithm for best route selection based and further development in the maintenance also. By removing redundant routes the route examination results has been enhance and further enriching both HBWM net and HBA to achieve better score. The consideration of link quality, energy consumption and load balancing metrics helps in selecting the efficient path selection which provides higher data transmission. The major achievement of the proposed algorithm is attaining a higher pdr, lesser end to end delay and lesser routing overhead than the existing routing protocols such as PAWMNet, FKAWMNet, HBWMnet, and these achievements were obtained from their simulation results. Highly reliable communication, assurance of load balancing and easily applicable to topological changes without node failure were achieved from the proposed LBWMnet.

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