An Intelligent Hybrid Protocol for Effective Load Balancing and Energy Efficient Routing for MANETs

C. Kalaiselvi and S. Palaniammal

***Abstract* — MANET (Mobile ad hoc network) is an autonomous decentralised network. And it is a collection of wireless mobile nodes that dynamically form a temporary network without the reliance of any infrastructure or central administration. Routing is a challenging task in manet. When the size and complexity increases the important challenge in manet is to avoid congestion with effective load balancing and improve energy, QoS parameters inside the network. In this work we propose a new hybrid protocol by combining ACO and Predator prey (LV) model which known as ACRRCC (Ant colony based rate regulating congestion control) method, which works efficiently in two phases. The efficient and optimal routing strategy is done by phase I using ant colony optimization. In phase II the congestion is majorly controlled by employing a mathematical model named predator-prey model which regulates the rate of the traffic flow in the network path. Performance of our proposed hybrid model ACRRCC yields good results under simulation study when compared with simple ACO.**

***Index Terms*—ACO, Cogestion, Manets, Routing.**

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I. Introduction

Mobile adhoc network is a decentralized and infrastructure-less network where all nodes interact with one another by hop-by-hop manner through intermediate nodes within the transmission range under a wireless medium. Since, the topology in Manet is ever changing, efficient routing and congestion control is a challenging task, and which seriously affects the required QoS in the network. To ensure the required Qos in manets enormous routing algorithms is proposed by many authors which can be categorized as proactive, reactive and hybrid protocols. In the proactive method, always a route will be maintained in the network whether it is needed or not, but in reactive or on demand method a route is explored when there a need of route to send data, whereas in hybrid routing method combines both methods which will give the complete information about the routing table and overcome disadvantages. The reactive method is very much useful where the route is used in uneven intervals.

ACO (Ant Colony Optimization) is a metahuristic approach which works efficiently for finding the optimal path. Many authors have discussed the ACO based routing protocols for MANETS [1]-[2] which are more reliable in nature. In ACO algorithm several ants starts to traverse from its nest in a random manner in the network to find the food source. While traversing the ants lay a chemical substance called pheromone. This pheromone value is used to find the optimal path. If the pheromone value is more in a path, the probability of use of that path increases. In such a way ACO exhibits various interesting properties for MANETS and works in a distributed manner.

Congestion control is the major problem in mobile ad hoc networks which is related to controlling the traffic entering into a telecommunication network. Since manets works in a smaller transmission range, if there is link failure or a queue overflow then congestion may arise. Due to this congestion there will a packet loss, increased overhead, delay in sending packets, low bandwidth, which all in a core seriously effects the required QoS in the network. Severe throughput degradation and massive fairness problems are some of the identified congestion related problems. These problems are incurred from MAC, routing and transport layers. To avoid congestive collapse or link capabilities of the intermediate nodes and networks and to reduce the rate of sending packets congestion control is used extensively. End system flow control, network congestion control, network based congestion avoidance, and resource allocation includes the basic techniques for congestion control.

The rest of this paper is structured as follows. Section II deals the review of the works related to routing problems in manets. In Section III, the proposed method is explained and, in Section IV, the mathematical model is presented. In Section V, the evaluation if the proposed model is done under simulation setup. Finally, the conclusion of the work is presented in Section VI.

II. Related Works

Several researchers have contributed their extreme efforts to improve the multi-constrained QoS in wireless ad-hoc networks. The Qos in manets totally rely on three major key functionalities such as, optimal routing, scheduling of packets and congestion control in the network. The overall network throughput can be increased by the above mentioned aspects. The end-to-end delay and the cost can be reduced by proper routing process. Appropriate scheduling algorithm helps in

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effective bandwidth allocation. Congestion control measures are used to overcome the congestion in the network. Many related works for the above mentioned constraints are briefly discussed in the following.

Enormous works have been established by the authors for the efficient routing process in networks based on various constraints such as reliable route selection, power aware routing, maximum battery life routing, routing with minimum contention time, load balancing ,maximum network life time, pre-emptive multipath routing etc., In the research work [3] the authors made a survey on existing routing protocols.

In the research work [4] the authors compared three protocols AODV (Ad-Hoc On Demand Distance vector), DSR (Dynamic source routing) and DSDV (Destination-Sequenced Distance-Vector Routing) protocol by considering the performance measures such as energy consumption, average delay, average throughput, average end-to-end delay, and packet delivery ratio beneath wavering node movements. In the DSR protocol the average throughput of the network is increased by increasing the number of nodes with a node speed 15m/sec. The protocol AODV becomes more static and outlines a stable path from source to destination for the same no of nodes and speed. Whereas the performance of DSDV is not so better when compared the above two protocols. In DSDV when the node count is increased the result is dropped because of the link failure in the network. The authors in [5] have compared and concluded that the protocols DSR and AODV consumes more when compared with DSDV which is a table driven one. And also in the same work they have exposed that DSR works good compared to AODV.

In the paper [6] the authors have explored a Neighbour Coverage based Probabilistic rebroadcast protocol (NCPR). This model is a combination of probabilistic method with neighbour knowledge method. In this protocol a novel rebroadcast delay system is designed to determine the rebroadcast order by which they obtain a more accurate additional coverage ratio. The additional coverage ratio is the ratio of the number of nodes that should be covered by a single broadcast to the total number of neighbours. The network connectivity is tracked frequently by a metric called connectivity factor. The connectivity factor reveals the information about the network connectivity and the number of neighbour nodes of a particular node and also it decides the number of neighbours should receive the Route Request (RREQ) packet. Then the additional coverage ratio and the connectivity factor are merged to find the rebroadcast probability which is used to reduce the number of rebroadcasts of the RREQ packets and helps in improving the routing performance. Additionally NCPR works well for the broadcast storm problem and helps in decreasing the routing overhead.

Vast number of evolutionary and optimizing algorithms have been analysed by many researchers which includes genetic algorithm (GA) [7], Particle Swarm optimization [8], Bee colony optimization [9], Bird flight technique [10] and etc. ACO and GA are some of the prominent algorithms used for efficient routing and to attain expected QOS in manets. The routing requirements of manets coincide with ACO technique because of its foraging and self-configured nature. In the research work [11] the authors examined a new hybrid routing algorithm for ad-hoc networks named Ant-Hoc-Net which works for link failure problem by both reactive and proactive methods. In paper [12] a new protocol named Ant-based On-demand Energy Routing (AOER) is analysed where three different factors like, energy resolved in each node, the cost accounts for the path and number of hops used in the network are considered.

The authors Genhang Ding et al., [13] have acquainted with an algorithm called Improved Ant-Colony Algorithm (IACA) in which the QoS routing problems are fingered by multiple strategies, by revamping the pheromone update rule. In the route selection process the piecewise function Q(t) is substituted for the probability constant and in this work two sets of metrics are considered. One set consists of cost, delay, delay- jitter with packet loss and another set includes bandwidth instead of packet loss. The algorithm allows a large search space and also it utilizes the existing current information for searching the ranges to get the best fitness ant, which leads to an optimal solution.

In the work [14] the authors proposed a Multi-objective ACO (MOACO) algorithm. In this work they have innovated a new encoding and decoding scheme. The encoding method converts the solution space to the search space. The author suggested a bit-string encoding method which deals with the binary numbers 0 and 1. Depending on these binary values the cluster heads are chosen in which 1 means the node is chosen as a cluster head and 0 means the node is not and the pheromone values are associated with the nodes in the network. This pheromone value indicates the probability of a node to be chosen as a cluster head. Whereas the decoding scheme is a reverse process of encoding scheme which changes the search space back to the solution space. In this scheme the nodes which are tagged as a binary number 0 is chosen as a cluster heads as well as the cluster members. The main drawback of decoding method is, in a particular transmission range we have one cluster head and the remaining cluster members miss the opportunity to be chosen as cluster head which may also leads to a good solution.

In the paper [15] the authors have investigated an ant-based multi-objective QoS routing protocol (AMQR) which satisfies the various QoS requirements in manets for time varying topology. This algorithm mainly deals with two phases such as route discovery and route conservation. Each node in this algorithm maintains three different tables namely neighbour table, path preference table and routing table. The job of neighbour table is it highlights the virtue of the outgoing links in various paths to destination using the pheromone substance and it indicates the available bandwidth of the outgoing link from that neighbour. In the path preference table has a probability value for every node associated with the list of neighbour nodes which is used to choose the best next hop in the desired path. The higher path preference value of a neighbour node is used in the routing table to reach the desired destination.

In the research paper [16] the authors have used the Lotka Volterra (LV) [17]-[18] competition model to design a scalable and self-adaptable congestion control approach for autonomous decentralized networks. By employing this LV based rate regulating congestion control method and by using effective parameter values the system achieves high packet delivery ratio and less end-to-end delay. The same authors in the research work [19] used the stable equilibrium condition [20]-[21] of the general LV model and proved that there is a positive and stable equilibrium point when the interspecific competition is weaker than the intra-specific competition.

III. Proposed System

The proposed algorithm ACRRCC, is an efficient routing algorithm for manets which works in two phases such as route exploration process and route maintenance process to obtain the desired QoS. In the proposed algorithm ant colony optimization technique is used to find the optimal path from source to destination. In the theory of ACO the foraging behaviour of the ants is studied [1]. The structure of ACO is very much similar to manets i.e., in ACO the artificial ants wander randomly to find their food whereas in manets the nodes will move in a random nature and they search for their neighbour nodes to transmit data packets to the destination nodes. In the route finding process the ants lay a chemical substance called pheromone. More pheromone on the path increases probability of path being followed. The pheromone trail starts to evaporate in an unused path and the pheromone are reinforced in the mostly used path. In such a way ACO algorithm is used for optimization problems. In our problem pheromone of each edge is found and then the global pheromone value is calculated and it is used to find the optimal path. In transmission of data from SN (source node) to DN (destination node) congestion is a major problem which arises when demand exceeds the available buffer of the neighbour nodes. If a SN initiate a traffic flow to its NN (neighbour node), and in case this NN receives data packets from some other SN then, there will be a congestion if the incoming bytes of data is more than the available buffer of the NN. To overcome the congestion and effective load balancing, the rate at which a SN can initiate a traffic flow is regulated using a Predator prey (Lokta Volterra competition model) biological model. In this biological model a natural ecosystem is studied, which comprises of species of same kind and different kind which are called intra-specific and inter-specific species respectively. This model exhibits the behaviour of manets i.e., in ecosystem the species compete with one another for the available resources, where as in manets the data flows compete with themselves for available buffer of the NN.

IV. Mathematical Model

MANET is considered to be analogous to an ecosystem. An ecosystem comprises of multiple species that live together and interact with each other as well as the non-living parts of their surroundings (i.e. resources) to meet their needs for survival and coexist. Similarly, a Mobile ad hoc network involves a number of cooperative nodes. Each node has a buffer in order to store packets, a communication channel of a certain (dynamic) capacity, and is able to initiate a traffic flow. Traffic flows can be seen as species that compete with each other for available network resources (buffer space communication channel capacity) while traversing a set of intermediate nodes forming a multi-hop path leading to the sink. The population size of each species corresponds to the rate of each traffic flow. In analogy with ecosystems, the goal is the coexistence of traffic flows.

A. Route Exploration

To explore a path from SN to the DN, the SN first find all its NN and send a route request to all its available neighbour. Now the neighbour nodes send a route request to their NN the process is continued until the route request reaches the DN. The DN gives a route reply to nodes from whom it got a route request and it continues until the rout reply reaches the SN. By using this method a general structure of all possible paths are found. Once after getting the information about the available paths the SN search for the neighbour nodes based on the pheromone value. From the available neighbours the SN will choose a NN with highest pheromone value and sends the data. If a SN have more than one NN with the same highest pheromone value each of it selected one by one and SN starts to send the data till the destination and every route is stored in the routing table. The pheromone value of each link is calculated by considering the bandwidth , energy and the distance between the nodes i and j which is given by the following equation

$$Pheromone(ij) = \frac{Q * \left(\frac{banwidth\ of\ neighbour\ 'j'}{banwidth\ threshold}\right)}{distance(ij)} * \frac{\left(\frac{energy of\ neighbour\ 'j'}{energy threshold}\right) *}{traffic flow} \tag{1}$$

where Q is the size of the queued packets, *traffic flow* of each node is regulated using the predator prey model which is briefly explained in the next section.

By using the pheromone values, all the available paths in networks are found. From these possible path we have to find the efficient and shortest path from the source to destination which is found using the global pheromone value given by the formula (2). After finding the global pheromone value of each path, the path with highest global pheromone value is selected as the efficient path and it is saved in the routing table and the SN starts to send the data packets.

$$\left.\begin{matrix} Global\ pheromone\ value \\ of\ a\ path \end{matrix}\right\} = Sum\ of\ all\ the\ pheromone\ values\ in\ the\ path\ from\ i\ to\ j. \tag{2}$$

B. Rate regulating System using predator prey model

In the predator prey model the whole ecosystem is divided into smaller sub-ecosystems involves all nodes that send traffic to a particular one-hop-away node (neighbour node). The traffic flows initiated by each node play the role of competing species and the buffer (queue) capacity of the parent node is considered as the limiting resource within the sub-ecosystem.

Within a virtual ecosystem, participant nodes may perform different roles. In particular, each node is able to either initiate a traffic flow i.e. is a source node(SN), or serve as a neighbour node (NN) to forward packets of multiple flows passing through it, or perform both roles being a source-neighbour node (SNN).

The general form of a n-species LV [19] system is expressed as below

$$\frac{dx_i}{dt} = x_i\left[r_i - \left(\frac{\psi_i x_i}{B_i}\right) - \frac{r_i}{B_i}\left(\sum_{j=i\ i\neq j}^{n}\phi_{ij}x_j\right)\right] \quad for \quad i = 1,2,3........,n \tag{3}$$

where $x_i(t)$ is the population size of species i at time t ($x_i(0) > 0$). Parameter Φ_{ij} measures the intensity at which the packets of same traffic flow interact with each other, whereas parameter Ψ_i measures the intensity at which the packets of different traffic flows interact with each other and the parameter 'r' corresponds to the speed (how quickly) each traffic flow's rate increases. Also B_i the carrying capacity of species and also it represents the maximum number of individuals of a species that can be sustained in the ecosystem in the absence of all other species competing for the same resource when $\Psi_i = 1$. Finally, parameter B is the buffer's capacity on each node (the shared resource) otherwise, the maximum population size of species i can reach B_i/Ψ_i. If only one resource exists and all species (having the same carrying capacity B_i) compete for it, then B_i can be seen as the resource's capacity. The LVCC [19] approach is developed on the basis of the n-species LV model, assuming that the n species have the same characteristics: $r_i = r$, $B_i = B$, $\Psi_i = \Psi$ and $\Phi_{ij} = \Phi$ for every i and j. Therefore the above equation becomes

$$\frac{dx_i}{dt} = rx_i\left[1 - \left(\frac{\psi}{B}\right)x_i - \left(\frac{\phi}{B}\right)K_i\right] \quad for \ \ i = 1,2,\ldots,n \tag{4}$$

where $K_i = \sum_{j=i\ i\neq j}^{n} x_j$

$x_i(t)$ is the number of bytes sent by node i corresponds to the rate of each traffic flow at time t. Here, the terms flows and species are interchanged. Model involves four parameters: r, Φ, Ψ and B. In order to solve for a single node i, it is necessary to be aware of the aggregated number of bytes sent from all other nodes which compete for the same resource and it is denoted by K_i

C. Calculation of Traffcic flow rate of SN

Pure source nodes are end-nodes which are attached to the rest of the network through a downstream node e.g. a neighbour node (NN), or a source-neighbour node (SNN) located closer to the sink. Each SN is expected to initiate a traffic flow when triggered by a specific event. By using (2) we can identify traffic rate. In manet architectures, the assumption of K_i-awareness is quite unrealistic. However, each SN can indirectly obtain this information through a small periodic backpressure signal sent from its downstream SNN/NN (parent node) containing the total number of bytes sent from all parent's children, denoted by BS. Each node can evaluate its neighbour's contribution C_i by subtracting its own contribution x_i from the total contribution BS and the transmission rate x_i for SN/SNN is given below which is obtained by integrating (2)

$$x_i(t) = \frac{wx_i(0)}{\psi x_i(0) + [w - \psi x_i(0)]e^{-\left(\frac{wrt}{B}\right)}}$$

where $w = B - \phi K_i$ (5)

The authors [19] have studied an ecosystem based network of flows compete for the available resources in which the rate of flow is regulated using the formula given in (3) and they proved that the system is in an stable equilibrium position when Ψ> Φ and Ψ,Φ>0. Using this equilibrium condition the values generated by SN's that converges to a coexistence solution is given by (4) refer [19] for detailed proof.

$$x_i^* = \frac{B}{\phi[n-1]+\psi} \qquad i = 1,2,.....,n \tag{6}$$

To avoid buffer overflows, it should be ensured that when a system of n active nodes converges to the coexistence solution the bytes send by each node is less than or equal to B/n i.e.,

$$x_i^* \le \frac{B}{n} \tag{7}$$

Hence equation (4) is satisfied when

$$\phi[n-1]+\psi \ge n \quad o \quad \psi - \phi \ge n(1-\phi).$$

If we set Φ ≥ 1 and we need Ψ > Φ (as given by the equilibrium stability condition in [19]), then the above-mentioned inequality is always satisfied. Therefore, to confirm both convergence and no buffer overflows the following two conditions must be satisfied:

$$\Psi > \Phi\,, \quad \Phi > 1$$

The calculated transmission rate of each node $x_i(t)$ converges to the stable coexistence solution, x_i^* within time period Tcn. The convergence time, (Tcn) of a traffic flow is calculated by $x_i(Tc) = x^*$, using (4), and it is observed that it is proportional to parameter Φ and inversely proportional to parameter r. This practically implies that there is fast convergence of time when Φ is small or r value is large

Using (4), a series of values corresponds number of bytes sent every period T is evaluated. In (4), when we set the initial value of the transmission rate $x_i(0)$ at time t=0, we can directly obtain the transmission rate $x_i(t)$ for any time t. The transmission rate can be calculated iteratively using the following formula.

$$x_i((k+1)T) = \frac{w(kT)x_i(kT)}{\psi x_i(kT) + [w(kT) - \psi x_i(kT)]e^{-\left(\frac{w(kT)r}{B}\right)*T}} \tag{8}$$

D. Calculation of Traffic flow rate of NN

Pure neighbour nodes are entities which do not initiate any packets, but forward packets belonging to several flows traversing themselves which compete for their resources. The main function of a NN is to combine (or multiplex) all incoming flows into a super flow and relay it to the dedicated downstream node (SNN or NN). Each NN allocates resources for its active upstream nodes based on a slightly modified expression (6) which is given below.

$$x_{NN}((k+1)T) = \frac{w(kT)H(kT)}{\psi x_i(kT) + [w(kT) - \psi x_i(kT)]e^{-\left(\frac{w(kT)r}{B}\right)*T}}$$

$$H(kT) = \frac{1}{m} x_{NN}(kT) \qquad and \qquad w(kT) = B - \phi \tag{9}$$

where 'm' is the total number of active sender nodes which belong to the tree having NN as root. Each NN can calculate the number of its active sender nodes m by scrutinizing the source id field of each packet traversing itself. K*NN(kT) reflects the total number of bytes sent (BS) to the receiver node from all its competing children nodes, subtracting the contribution of a single flow belonging to the superflow, given by

$$K^*_{NN}(kT) = BS - \frac{1}{m} x_{NN}(kT) \tag{10}$$

E. Source node as neighbour nodes (SNNs)

A source-neighbour node acts as both source and neighbour node, having both functions concurrently operated as described above. The development of the LVCC protocol on the basis of the Lotka Voltera population model that governs the coexistence of species competing for limited resources.

V. Simulation Results

The proposed ACRRCC routing protocol is tested under the certain simulation setup which is given in Table I.

TABLE I
Simulation Parameters

Property	Values
set val(chan)	Channel/WirelessChannel
set val(prop)	Propagation/TwoRayGround
set val(netif)	Phy/WirelessPhy
set val(mac)	Mac/802_11
set val(ifq)	Queue/DropTail/PriQueue
set val(ll)	LL
set val(ant)	Antenna/OmniAntenna
set val(ifqlen)	100
set val(nn)	50
set val(rp)	ACRRCC
set val(x)	1000
set val(y)	1000
set val(stop)	200s
set val(chan)	Channel/WirelessChannel

A. Energy

Energy consumption in a network is a very important aspect. The energy consumption of the proposed congestion control routing protocol works very effectively for various speeds of the node when compared to simple ACO routing. In the Fig. 1 the performance of the proposed ACCRRC protocol is compared with simple ACO and it indicates that the energy used by the proposed one is less.

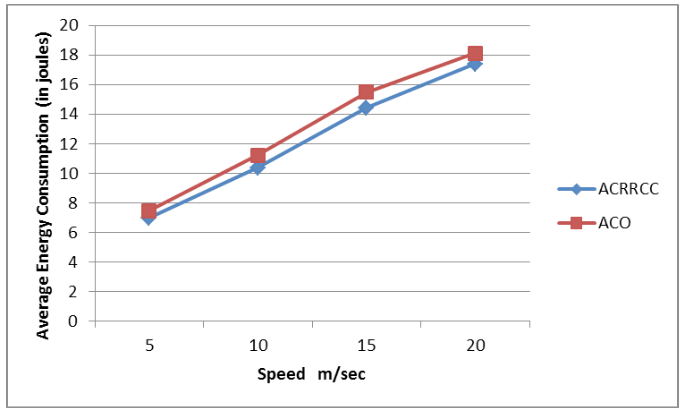

Fig 1. Speed vs Energy.

B. Throughput

Fig. 2 shows that the overall throughput of ACRRCC is high when compared with simple ACO, because in simple ACO the routing part alone is done but in ACRRCC the routing is done along with the effective load balancing due to congestion control mechanism.

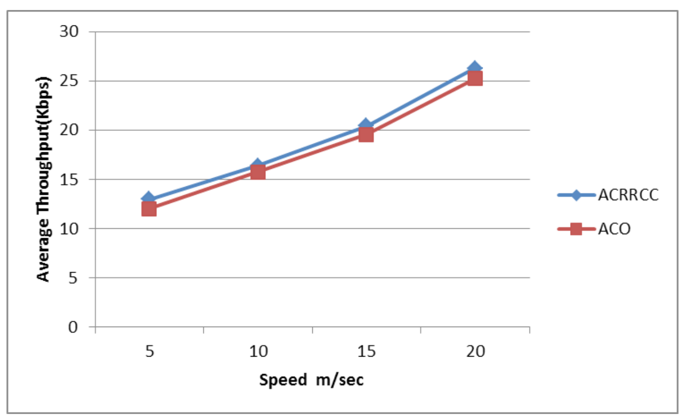

Fig. 2. Speed vs Throughput.

C. Packet delivery Ratio

Packet delivery ratio may decrease in the network due to path disconnections and congestion. The proposed ACRRCC protocol works well in finding an efficient path and controlling the congestion which leads to increase in percentage of packet delivery ratio when compared with simple ACO which is presented in Fig. 3.

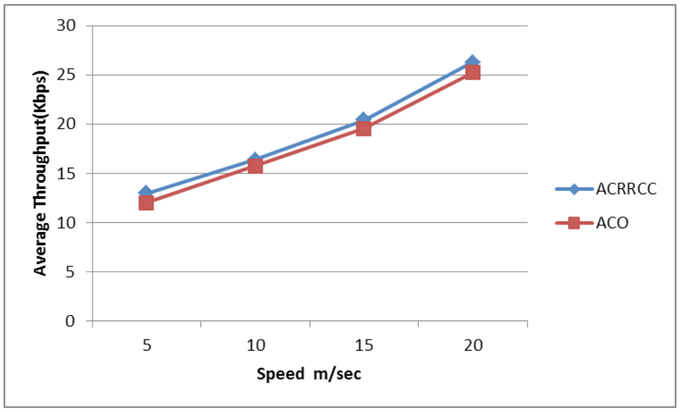

Fig. 3. Speed vs Packet delivery ratio.

D. Routing overhead

The routing overhead of the proposed model is decreased when compared with simple ACO which is shown in Fig. 4.

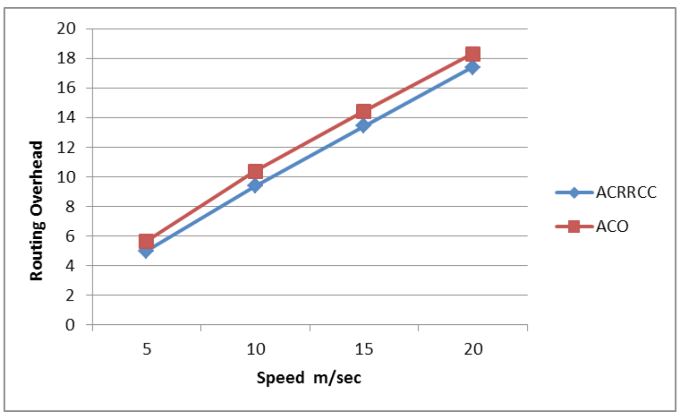

Fig. 4. Speed vs routing overhead.

E. Packet Loss Ratio

In the networks there will be packet loss when there a queue overflow or improper routing information. Both the above mentioned difficulties is taken into account and the packet loss is decreased in the proposed ACRRCC routing protocol is less than the ACO.

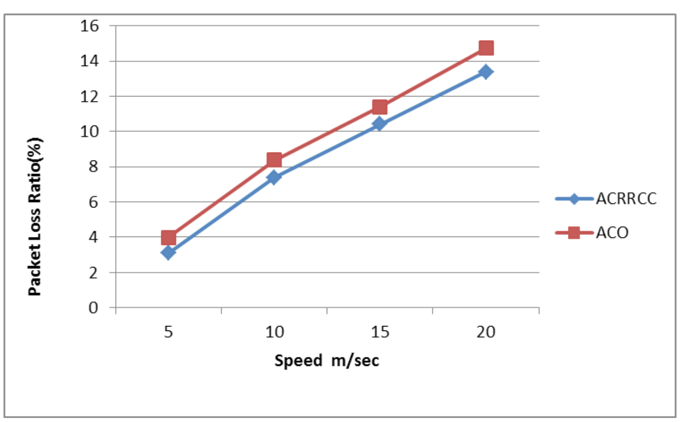

Fig. 5. Speed vs Packet loss ratio.

F. Delay

Fig. 6 shows the end-to-end delay of the ACRRCC model is reduced than the simple ACO because the traffic flow rate is adjusted according to the available buffer of the next hop neighbor.

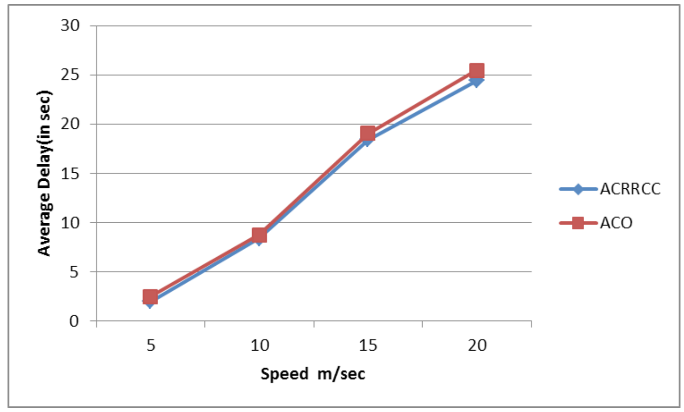

Fig. 6. Speed vs Average Delay.

VI. Conclusion

In this is research work a hybrid protocol for effective load balancing and energy efficient routing using ACRRCC protocol is proposed. Energy efficient routing is done by ACO technique and effective load balancing is handled by employing a bio-inspired mathematical model named LVCC [19] in which the traffic flow rate is regulated according to the receiver node's buffer capacity. In routing process the efficient path is selected using ACO technique by considering the global pheromone values of all the selected paths. By regulating the traffic flow rate of each node there will be no buffer overflow and congestion. Thus our proposed ACRRCC hybrid model works effectively and simultaneously in routing and congestion control. As a result of the proposed work the average end-to-end delay, energy consumption in the network, packet loss ratio, and the routing overhead are decreased, and the network throughput, packet delivery ratio are increased when ACRRCC is compared with simple ACO and which all in a core improves the QoS in the network.

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