ACOLBR: ACO Based Load Balancing Routing in MANET

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Abstract
Real-time data transmission is one of the objectives of MANET (mobile ad-hoc network) to handle emergencies like a forest fire, flood, and earthquake. In this scenario, quick delivery of data is itself a challenging task for MANET and there is a possibility of load imbalance due to packet transmission in between source-destination pairs via the shortest path due to congestion or control overhead. In this paper, a novel routing protocol, called ACOLBR (ACO based load balancing routing), is designed to control the congestion and balancing the load among the multiple paths in between source to destination. The similarity between the environment of Ant Colony and the MANET inspires the authors to apply ACO (Ant colony optimization) technique during routing in MANET to control congestion and balance the load in the network. In our proposal, two colonies of ants (red/blue) carry their packets based on the network condition. A decision variable is designed to select red/blue ant for transferring packets based on different network parameters such as bandwidth, energy, mobility, and distance. The selection of red ant means the route where the concentration of red pheromone is maximum and reverse is true for blue ant. This protocol is also concerned about the link failure during packet transmission in a route. Simulation results using OMNET++ show that ACOLBR outperforms ARA, ANTHOCNET, FACO, AODV, DSDV, DSR, CA-ARTT, and MOAOVD in terms of load balancing efficiently in the route for data transmission in between source to destination.

Keywords ACOLBR · Load balance · ACO and MANET · Routing · Multi-agent

1 Introduction

Mobile Ad Hoc Network is a style of technology that is generating a new alternative way for mobile communication. In this type of network IoT (internet of things) devices construct a self-organizing and self-administering wireless network. All the nodes in this type of network are dynamic and real-time data transmission is one of the objectives to
handle the emergency where this type of infrastructure-less network is required. In this scenario, quick delivery of data is itself a challenging task. Thus, there is a possibility of load imbalance due to the non-uniformity of computing/processing power of the systems and as a result, a few nodes may be idle and a few may be overloaded. Multi-path routing can balance the load better than single path routing in such a scenario.

The objective of this article is to design a novel routing protocol for the quick delivery of packets between source and destination. For this purpose, the proposed protocol detects congestion-free and load balance routes between source and destination pair applying the ACO technique. Here, two colonies of ants (red/blue) are transferring packets through multipath to balance the load and control congestion. The proposed protocol is divided into four phases: (1) Route discovery, (2) Packet distribution, (3) Agent selection and (4) Final packet transmission. In the route discovery phase, all possible routes from source to destination are discovered and the routing table is designed to store the route information with its path cost. The packet distribution phase estimates the maximum load on each available route in the network to balance the load as well as minimize the routing cost. In the agent selection phase, this protocol designs a decision variable to generate Red/Blue agent depending on the different network parameters. This Red or Blue agent transmits the packets through different paths in the network from source to destination, to balance the load with congestion control overhead. At last in the final packet transmission phase packets are transmitted based on the probability of red and blue pheromone concentration in the network. Simulation results show that the proposed protocol enhances the performance of the network compared to other existing routing techniques in MANETs.

1.1 Contribution

The current works are showing the best performance contribution for ACO based multi-agent load balancing routing algorithm for MANET named as ACOLBR. In order to utilize load balancing into the existing multiple numbers of paths between source to destination after route discovery (Say R numbers of routes)

1. All the available packets are distributed among available all routes in the network to minimise the load in each route of the network.
2. Decision variable is computed here to select multiple red/blue agent for transferring packet through the routes where concentration of red/ blue pheromone is maximum.
3. Red/blue pheromone concentration for a route depends on different network parameters such as bandwidth, energy (for red ant) and mobility, distance (for blue ant). This way different colour agents select different routes and overall congestion will be minimised as well as resource utilisation will be optimised.
4. Route failure is also considered here. If route failure occurs the ant is returning back to the source node and the source node blocks that route and diverts the packet through another route.

The rest of the paper is organized as follows: Sect. 2 deals with the state of the art study, Sect. 3 proposes the design of a new protocol named as ACOLBR, Sect. 4 shows the complexity analysis of our proposed protocol, in Sect. 5 the simulation results and...
2 Literature Survey

The following sub-sections contain some discussions over related works on basic routing protocols and ant colony optimization routing protocol in MANETs.

2.1 Basic Routing Protocols in MANET

Routing protocols in MANET are divided into two parts: proactive and reactive. DSDV (Destination sequenced distance vector) is an example of a proactive routing protocol. It uses the Bellmen Ford algorithm during the path discovery phase but is not scalable. On the other hand, example of reactive routing protocol is AODV (Ad-hoc On-Demand Distance Vector Routing) where a stable path selection is done by determining a weight factor over multiple criteria with the modification of route request and route reply control messages [1].

The route discovery process is initiated only when a packet transmission is required between source and destination. It also reduces the memory requirement. In DSR (Dynamic Source Routing protocol) a reactive routing protocol that is used for multi-hop wireless ad hoc networks, has two phases route discovery and route maintenance. The mobile network is dynamic, so it leads to many problems like packet losses, delays in energy wastage, link failure due to congestion in the MANET [2].

Now a day’s bandwidth is highly demanding with the increase of mobile users to control the congestion in the network. This motivates the researchers to design Node Stability-based Routing (NSR) [3] to reduce congestion and increase the reliability of the link in the network. The authors of [4] proposed ARIMA model-based RTT estimation to reduce packet loss in the network.

QoS provisioning in MANET is a challenging task, due to its dynamic network topology, multi-hop routing, energy, bandwidth constraints, and security issues. Multi-constraints link stable multicast routing protocol in MANETs [5] is designed to overcome these issues. A QoS that aware metric introduces here to determine a stable link among all incoming links. It is based on Link Stability Factor [3]. In OBSUR [6], every node in the network regularly computes bandwidth availability, node and link stability, buffer availability, and stability factor between nodes. A node must check the stability of the neighbor node and QoS database for route establishment. It provides QoS satisfied, reliable and robust routes between communicating nodes.

2.2 Routing in MANET Using ACO

Ant Colony Optimisation (ACO) [7, 8] is a technique for optimization which was introduced in the early 1990s. This is best because of its robustness and efficiency of the collective behavior of insects’ societies. Nowadays they have become a source of inspiration for the designing of routing algorithms in dynamic networks. The main source of inspiration of ACO [9–11] is its foraging behavior of real ant colonies. Presently ACO
based intelligent routing protocol [12] is validate the coordinator nodes matrices through intermediate hops that reduce the network delays and link failure for MANET’s energy-efficient routing.

There are mainly two different types of agent base routing logic that are applied here, one is a single-agent and another one is a multi-agent system. In a single-agent system, only one agent is present for solving the problem. In contrast, several agents work simultaneously in a multi-agent system. The following section presents a categorized review of ant colony optimization-based routing protocols.

2.2.1 Single Agent Based ACO

In a single agent-based ACO, only one type of agent is transmitting packets from source to destination. This simplified ACO [13, 14] algorithm is applied for finding the shortest paths by using graphs and SACO (self-adaptive ant colony optimization) is one of the examples that were applied. Here, the shortest path is detected based on pheromone concentration. ANTNET (Ant-based routing in a network) [15] takes inspiration from SACO to solve combinatorial optimization problems and telephone network routing. It is a proactive routing algorithm but route establishment is more time consuming and is the basic disadvantage of ANTNET. ANTMANET [16] solves the problem of ANTNET using hybrid routing, which follows both reactive as well as the proactive routing protocol for MANET. To overcome the challenges of ANTNET [15], ANTMANET [16] hybridisation of ACO and heuristic approaches [17] are used by applying genetic algorithm in order to minimise the complexity through the vast scope of ACO parameters. ANTHOCNET [17] is also another hybrid algorithm, like ANTMANET [16] as well as this algorithm is reactive because it only gathers routing information about destinations that are involved in communication sessions. The drawback of ANTHOCNET [17] is that the huge number of routing messages needs to be sent in the network for establishing routes from source to destination that generates control overhead and also raise the issues of energy efficiency for the routing of MANET. The control overhead can reduces using broadcast network for MANET are proposed [18] by applying classical Kruskal’s and Dijkstra algorithm. Whereas, a new approach for mobile ad hoc networks combines the idea of Ant Colony Optimization (ACO) with multi-objective constraints applied energy efficient routing technique based on ant colony optimization in mobile Ad-hoc networks (MCER-ACO) are proposed [19]. The broader domain of AODV and its various parameters related to quality, energy, reliability and routing strategies [20] and comparison with ANT-AODV we can find. Another extended version of AODV is Multi-Objective Ad-hoc On Demand Vector (MOAODV) [21]. It is a unicast routing protocol that can optimize more than one routing parameter. During route discovery, it uses the multi-objective functions to minimize the link metrics (distance, cost, delay, and load) and maximize the reliability of the link that can leads to uninterrupted data transmission.

2.2.2 Multi Agent Based ACO

In, Multi-agent based ACO different types of agents transmit data from source to destination. It reduces the congestion and shares load in the network. A multi agent based hybrid algorithm supports multipath and is required to share the load efficiently. From [22] a designing methodology addresses the aforementioned problem and proposes a proactive ant based routing approach for MANETs inspired by the ACO
paradigm. Although, in most of the cases the high frequency links often decrease [23] the throughput rate of the network that again modified using Queuing Ant Colony System (QUACS) methodology a bio-inspired routing algorithm like AntHocNet and Ant Routing Algorithm (ARA). On the other hand, ARA [24] is the ACO based reactive routing protocol which detects cycle in the network. Route discovery in ARA is done by using Forward Ants (FANT) and Backward Ants (BANT) as in ANTNET. ARA is not able to perform better with high network load and multimedia data. A parallel ant colony optimization algorithm in MANET [25] focuses on demand routing using a metaheuristic search technique based on swarm intelligence. This algorithm finds all pair routing between nodes in the network besides the detecting cycle. The pheromone value gets updated by ants as they traverse the route. This algorithm also is not concerned about load and congestion in the network. A Novel Swarm Intelligence Based Routing Scheme for MANET using weighted pheromone proposed nonlinear weights for the deposited pheromone. In existing protocols total path delay is determined from hop count and processing delay (a fixed value for all nodes) only, which is far away from reality but is a reliable and survivable routing algorithm. In the case of path failure (due to mobility of the node, node battery depletion, etc.), the algorithm immediately uses the next available path. For better quality communication of ad-hoc network the stable and bandwidth aware dynamic routing (SBADR) [26] protocol proposed for all quality of service (QoS) data communication. On the other hand, in a dense network, the overhead of this protocol is a good impact on the above stated scenario. Similarly, Dynamic Source Routing (DSR) one of the popular reactive routing protocols for MANET uses route cache to store the intermediate nodes path information to provide support for next time paths selection in between source to destination, but all the information is not able to store due to limited cache. To select the optimal route in cache authors proposed an adaptive fuzzy inference system (ANFIS) algorithm [27] based on input parameters hop count, energy, and delay. Whereas, an enhancement multipath routing protocol CBMLB [28] proposed to reduce load among available alternative paths for increasing delivery ratio, reduces end to end delay, and communication overhead. Another ACO based multi-path routing is Application Research Based Ant Colony Optimization for MANET [29], which proposes an on-demand routing algorithm named ADAA for mobile ad hoc networks that combine many features of both AODV and DSR. To balance the load for routing in MANET, the multipath load balancing technique for congestion control (MLBCC) [30] proposed a mechanism that reduces congestion during data transmission and a routing protocol [31] designing technique according to the position of mobile nodes in MANET is also proposed. Multi-objective constraints with energy efficient routing technique based on ant colony optimization in mobile Ad-hoc networks (MCER-ACO) can have the ability to choose the next-hop node into a dynamic changing topology of MANET. On the other hand, from [32, 33] authors enlighten the QoS based routing algorithms consists of two phases namely path discovery phase and path maintenance phase is proposed. Multi agent Ant based Routing Algorithm for MANETs [20] balances the load of the network. It implements more than one colony of ants to search for the optimal path. Each colony of ants deposits a different type of pheromone of a different color. ARAMA [34] is one of the examples of a proactive routing algorithm. However, in ARAMA, the forward ant considers the hop count factor, as well as links local information such as the node’s battery power and queuing delay along the route. ARAMA is not performing well in high load. A routing protocol named LCRACO [35] has been designed to balance load and control congestion in the network. This
protocol applies more than one colony of ants to search for the optimal path. CLAR [36] is cluster based routing protocol that performs in high load in MANETs. In this algorithm two colonies of ants choose a different path for a particular destination after cluster formation and cluster head selection. It does not give better performance in high load.

3 Design of ACOLBR

The state of the art scenario leads to that very few routing protocols are balancing load for achieving optimum throughput. Most of the on-demand routing protocols present in MANET act in such a way that load remains concentrated on a few number of nodes and links in the network which are not suitable for the applications of the emergency situations such as disaster management, forest fire management and defence as real time data transmission is mandatory in this situation. Load imbalance degrades the performance of the routing protocol by causing delay and power loss in the network. Multi-path routing can balance the load better than the single path routing in ad hoc networks. This is possible for the networks having a huge number of nodes between any source-destination pair.

A swarm intelligence algorithm called Ant Colony Optimization (ACO) [9] considers the ability of simple ants to solve complex problems by cooperation. In ACOLBR, two colonies of ants (red/blue) carry their packets on the basis of network condition. Pheromone tables are initialised on the basis of network metrics like Bandwidth, Distance, Mobility and Energy. At first ACOLBR estimates maximum load on each route among all available routes to minimise the routing cost which helps to distribute packets among all possible routes in cost optimized way for balancing load in the network. A decision variable is proposed here to select red/ blue agent for transferring packet on the basis of different network parameters such as bandwidth, energy, mobility and distance. This protocol also concerns on link failure during packet transmission through a route to the destination. Figure 1 depicts pictorial view of different modules of ACOLBR.

3.1 Energy Model

In MANET routing protocol focuses to maximize the utilization of the shortest paths that are exists in between source to destination. Efficient management of control overhead or congestion control in the routing path that are established before data transmission in MANET require an energy effectiveness of the nodes that act as an intermediate node for data communication. Designing an efficient MANET routing protocol is needed to control the network overhead and to retain the overall network energy. Here, considering the energy parameters with multiple constrain of MANET our propose ACOLBR routing protocol effects energy optimized multi-objective routing algorithm through load balancing by applying ACO. Below given energy model shows how its effect in MANET routing. The abbreviations used here are given in abbreviation Table 1.

3.1.1 Energy Model (Er)

The total energy consumption $E_{ri}$ for $i$th node can be calculated as the summation of energy required to receive data packets, process that data and transmit the processed data to the next hop node [37–39]. This can be described as
$E_{r,i} = E_T(x(k, d)) + E_R(x(k)) + E_P(x(k))$

$E_T(x(k, d))$ is the energy used to send k bits of data to the destination and can be computed as

$$E_T(x(k, d)) = kE_{elec} + k\epsilon_{fs}d^2, d < d_0$$

$$kE_{elec} + k\epsilon_{amp}d^2, d \geq d_0$$

where, $d$ is the distance between source and destination node, $E_{elec}$ is the energy used for transmitting/receiving a single bit data, $\epsilon_{fs}$ and $\epsilon_{amp}$ are the amplifier characteristic constants.
in the free-space propagation model and the two-ray ground reflection model respectively and \( d_0 = \sqrt{\frac{\varepsilon_{\text{at}}}{\varepsilon_{\text{amp}}}} \) is the distance [28] used to divide two kinds of path loss model. The energy consumed \( E_{\text{R}}(k) \) to receive a data packet for \( k \) bits of data can be calculated as

\[
E_{\text{R}}X(k) = k \times E_{\text{elec}}
\]

(3)

Processing energy: \( E_{\text{p}}(k) = \text{constant} \) Therefore the total energy consumption for \( K'h \) route containing \( n \) number of nodes can be computed as

\[
E_k = \sum_{i=1}^{n} E_{r,i}.
\]

(4)
3.2 Data Dictionary

The parameter and the related description are used in this paper and are shown in Table 1.

3.3 Definitions

The related terms are defined as follows:

(a) Energy ($E_k^{ij}$): It is defined as the residual energy on $k$th route to transmit the packets from source to destination from Eq. (5).

$$ E_k^{ij} = E_A - E_K $$  \hspace{1cm} (5)

$E_A$ is the total initial energy of all the nodes on $k$th route and $E_k$ is computed in Sect. 3.2.

(b) Bandwidth (B) [40]: Bandwidth is defined as the net bit rate, channel capacity or maximum throughput of a logical or physical communication system. The bandwidth $B_k^{ij}$ between two nodes i and j can be defined as

$$ B_k^{ij} = B_M - B_C $$  \hspace{1cm} (6)

where $B_M$: maximum available bandwidth; $B_C$: consumed bandwidth

$$ B_C = \frac{S_k^{ij}}{D_k^{ij}} $$  \hspace{1cm} (7)

S_k^{ij}$: size of transmitted packets from source i to destination j for $K$th route; $D_k^{ij}$: packet delay is the amount of extra time required for the router to push a packet calculated from Eq. [8].

$$ D_k^{ij} = T_i^k - T_e^k $$  \hspace{1cm} (8)

$T_i^k$: total time required for the router to push a packet. $T_e^k$: estimated time for the router to push a packet.

(c) Distance $d_k^{ij}$: distance covered by a packet from source i to destination j for $k$th route having m no of nodes, calculated using Eq. [9].

$$ d_k^{ij} = \sum_{i=1}^{n} \frac{1}{d_ij} $$  \hspace{1cm} (9)

$d_ij$: The Euclidean distance between the two nodes i and j is computed applying Eq. [10]

$$ d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} $$  \hspace{1cm} (10)

(d) Mobility $Mob_k^i$ : Mobility models represent the movement of mobile users, and how their location, velocity and acceleration are changing over time. Proposed protocol...
applies Random Waypoint Model (RWP) consists of 3-tuple \((V_{max}, T_p, V_i)\). whereas, \(V_{max}\): maximum velocity of a node and the velocity is uniformly distributed from 0 to \(V_{max}\). \(T_p\): Pause time. In RWP [41], a node randomly chooses a destination, called waypoint, and moves towards it in a straight line with constant velocity, which is selected randomly from 0 to \(V_{max}\). After reaching the waypoint, the node pauses for some time and then repeats the same procedure. The next waypoint for the node at \((x, y)\) can be given as: \(d(x, y) = d(x - 1, y - 1) + V_i\) The mobility \(Mob_i^k\) of \(i\)th node on \(k\)th route can be calculated as:

\[
Mob_i^k = \frac{d(x, y)}{T_p}
\]  

(11)

The stability \(Stab_{ij}^k\) of \(k\)th route consisting of \(m\) nodes can be defined as

\[
Stab_{ij}^k = \sum_{i=1}^{m} \frac{1}{Mob_i^k}
\]  

(12)

(e) CostTable [35]: It consists of the cost required for packet transmission from source to destination node. The format is: \(S_{id}, N_{id}, C_k\) where \(S_{id}\) is the source node IP Address, \(N_{id}\) is the neighbourhood IP Address, and \(C_k\) is the cost on the \(k\)th path measured in terms of the average time required for sending HELLO message and receiving an ACK message and number of hops between \(i\) and \(j\). Cost is computed applying Eq. (13).

\[
C_k = \Upsilon[(T_r^k) - (T_s^k)] * H_{ij}^k
\]  

(13)

\(C_k\) = Cost of \(k\)th route from source node \(i\) to destination node \(j\). \(T_s^k\) = Time at which the “Hello” message is sent through \(k\)th route from source to destination. \(T_r^k\) = Time at which “ACK” message is received through \(k\)th route from destination to source. \(H_{ij}^k\) = Hop count from source node \(i\) to destination node \(j\) in \(k\)th route. \(\Upsilon\) = Constant.

(f) Routing table: It consists of information about the source node, next hop node on the path to particular destination node. Thus, the routing table vector is \(S_{id}, N_{id}, D_{id}, H_{ij}^k, C_k\).

### 3.4 Modular Description of Propose Algorithm

ACOLBR is divided into following modules such as:

- A. Route discovery
- B. Packet distribution
- C. Agent selection
- D. Final packet transmission
- E. Route maintenance

#### 3.4.1 Route Discovery

In this phase source node detects all available \(R\) number of routes from source to destination. For this purpose, the source node in the network broadcasts “HELLO” message and waits for acknowledgement (“ACK” message) from the destination node. The content
of “HELLO” message is: [Seq-no, N_id, D_id, H_{ij}^k], where, initially, H_{ij}^k=0, N_id=0. Next hop nodes again broadcast this packet to their neighbours and increment the hop-count value by 1. The id of those nodes is added in the id field of their neighbour node N_id. In this way “HELLO” messages are reached to the destination from source node. Destination node replies back the “ACK” message through the same routes to source node. The content of “ACK” message is: [Seq-no, D_id, N_id, S_id, H_{ij}^k]. The delay time is computed by source node for transmitting the Hello message and receiving the ACK message for each individual route. This delay time with hop count is assigned as the cost on each individual route. The cost function is defined in Eq. (13).

### 3.4.2 Packet Distribution

This phase estimates packet distribution among all possible available routes. The objective of this phase is to divide packets among different routes in such a way that not only load of the network will be reduced but also the overall route cost of the network will be minimised. Let there are N number of total packets and R number of available routes. Two cases of distributing N packets among R routes to minimize route cost are described as follows

**Case 1:** All possible ways to distribute N packets among R available routes are:

$$n = \binom{N+R-1}{R-1}$$

(14)

In this case, there are one possible way where all packets are transmitted through minimum cost route among all available routes. It gives the best result among all possible combinations. But packet distribution is unfair here. It does not balance load in the network. This is not applicable in ACOLBR.

**Case 2:** All the possible way to distribute N packets among R routes such that at least one packet must be sent through each route in the network are:

$$n = \binom{N-1}{R-1}$$

(15)

In this case, there are no possible way where all packets are transmitted through minimum cost route and rest of the routes are idle. The distribution is still unfair as it can distribute one packet on each available routes excluding lowest cost route and rest of the packets are distributed on lowest cost route. The distribution is modified in ACOLBR to remove aforementioned problem in the following way:

N packets are divided among R number of routes such that,

$$N = X_1 + X_2 + X_3 + \cdots + X_R$$

The combination matrix, cost matrix and output matrix are: M[i][j] with order $n \times R$ stores all $n$ possible ways to distribute $N$ packets among $R$ number of routes. C[j] with order $n \times 1$ is a cost matrix which stores cost of all possible routes. O[j] with order $n \times 1$ is a output matrix which stores the cost of each possible way of packet distribution among $R$ number of available routes.

$$O[j] = M[i][j] \times C[j]$$

(16)

where
In \( O[j] \), each row depicts cost of packet transmission of each combination of packet distribution among \( R \) number of routes. \( O[j] \) consists of combination of five minimum packet distribution cost. All packets are distributed through these five combinations in \( O[j] \).

### 3.4.3 Generation of Red/Blue Ant

The objective of ACOLBR is to balance the load and control the congestion in the network. Previous section (B) estimates maximum number of packets on each available route to minimise the cost in the network. In this phase, source node generates sequence of red/blue ant for sending the \( N \) number of packets. A decision variable is designed to decide when red/blue agent will be selected for transmitting packet between source and destination. Two colours of ants build/set their pheromone tables on the basis of different network parameters. The route selection parameters for both the ant are as follows:

1. **Blue ant:** This colour ant elects their routes on the basis of bandwidth \( B \) and distance \( d \) between nodes in the network.
2. **Red ant:** This type of ant elects their routes on the basis of energy \( E \) and stability \( M \) of the nodes in the network.

This agent selection depends on the requirement of the network which helps to balance the resources in the network. Decision variable \( X^p_{ij} \) depends on network matrices (Energy, Bandwidth, Stability and Distance), where weight factor \( W1 = 2 \) and \( W2 = 1 \). The decision variable can be computed in the following way

\[
X^p_{ij} = \sum_{k=1}^{R} \left( \frac{W1E^k_{ij} + W2Stab^k_{ij}}{y(W1B^k_{ij} + W2d^k_{ij})} \right) \geq 1; \text{Redantselected} \nonumber \]

\[
X^p_{ij} < 1; \text{otherwise Blueantselected} \nonumber \]

If \( X^p_{ij} \geq 1 \), Red ant is selected for transmitting packet \( p \) between node \( i \) and \( j \). Otherwise, Blue ant is elected. Decision variable selects red/blue ant according to network demand to detect route. This protocol represents Red ant by +1 and Blue ant by −1.
3.4.4 Final Packet Transmission

Finally packets should be transmitted in the network through selected routes from source to destination. In this phase red/blue ant detects routes for transmitting packet. Source node checks whether packet distribution in any route crosses the estimated threshold value or not, where threshold value is decided in combination matrix $O_{Select}$ [m] [p] (calculated in section B). If the number of packets in any route crosses this value, that route will be blocked.

When red ant is generated, the route is selected based on maximum probability value of red pheromone concentration applying Eq. (19).

$$P_{r_{ij}}^{k}(t) = \frac{\delta r_{ij}(t)}{\sum_{x\in nk(t)} \{\delta r_{ij}(t) + \delta b_{ij}(t)\}}$$

(20)

When sequence value is -1, blue ant is generated and it selects the route where probability of blue pheromone is maximum applying Eq. (20).

$$P_{b_{ij}}^{k}(t) = \frac{\delta b_{ij}(t)}{\sum_{x\in nk(t)} \{\delta r_{ij}(t) + \delta b_{ij}(t)\}}$$

(21)

where $t$ = Time index. $P_{r_{ij}}^{k}(t)$ = The probability that a Red ant at time t selects $k$th route for transmitting packet. $P_{b_{ij}}^{k}(t)$ = The probability that a Blue ant at time t selects $k$th route for transmitting packet. $\delta b_{ij}(t)$ = The blue pheromone level on route $k$ at time $t$. $\delta r_{ij}(t)$ = The red pheromone level on route $k$ at time $t$. $nk(t)$ = The set of feasible paths from source node i to destination node j at time $t$.

When red/blue ant selects the route for transmitting the packet red/blue pheromone table is updated which is inversely proportional to the cost on the route. Updating of the pheromone table for the ant of red/blue colony is done applying the Eqs. (21) and (22).

$$Pr_{ij}^{k}(t) = \delta r_{ij}(t) + \frac{1}{q}$$

(22)

$$Pb_{ij}^{k}(t) = \delta n_{ij}(t) + \frac{1}{q}$$

(23)

After the certain time interval pheromone is evaporated and this is proportional to the cost on the route.

Evaporation of pheromone is done using Eqs. 23 and 24 for red and blue ant:

$$Pr_{ij}^{k}(t) = \delta r_{ij}(t) - \mu \times c_{ij}(t)$$

(24)

$$Pb_{ij}^{k}(t) = \delta n_{ij}(t) - \mu \times c_{ij}(t).$$

(25)

3.4.5 Route Maintenance

If anywhere link failure is occurred, the ant is returning back to the source node. The source node will block that route and divert the packet through another route. In such case, the path preference probability will automatically decrease and hence alternate routes will
be determined by calling route discovery phase. The alternate routes are also periodically checked for their validity even though they are not currently used. If anywhere link failure is occurred, the ant is returning back to the source node. The source node will block that route and divert the packet through another route. In such case, the path preference probability will automatically decrease and hence alternate routes will be determined by calling route discovery phase. The alternate routes are also periodically checked for their validity even though they are not currently used.

4 Complexity Analysis of ACOLBR

Time complexity of ACOLBR is depends on route discovery, packet distribution into the network, agent selection, packet selection and finally with the route maintenance. According to the above notation table the complexity of ACOLBR is define below.

4.1 Route Discovery

Initially for Route Discovery the control packet is transmitted through all the paths/routes that are exists into the network on that time instance and the packet should be transmitted via intermediate neighbour nodes that are in their transmission range. In order to broadcast the control message generated from the source node initially transmitted though their neighbour nodes and so on. According to MANET we know there can be two types of paths/routes exist, one directly link with the neighbour mentioned here single link \((R_s)\) and second type is path/route shared by two adjacent neighbour means common link \((R_c)\).

| Notation | Description |
|----------|-------------|
| \(R\)    | Number of total path exist in the network |
| \(R_c\)  | Number of common path exists in the network |
| \(R_s = R - R_c\) | Number of single path exist |
| \(B_T\)  | Total number of message broadcast into the network |
| \(O[j]\) | With order \(n \times 1\) is an output matrix which stores the cost of each possible way of packet distribution among \(R\) number of available routes |
| \(M[i][j]\) | The combination matrix, \(M[i][j]\) with order \(n \times R\) stores all \(n\) possible ways to distribute \(N\) packets among \(R\) number of routes |
| \(C[j]\) | With order \(n \times 1\) is a cost matrix which stores cost of all possible routes |
| \(X_{j}^{P}\) | Decision variable that depends on network matrices (energy, bandwidth, stability and distance) |
| \(R_f\)  | Number of root failure occurs |
| \(R_c^F\) | Number of common root failure occurs |
| \(R_s^F\) | After failure route discovery occur |
| \(M_C\) | Complexity of ACOLBR |
So, during route discovery the control messages [18] should be transmitted through all the paths broadcasted by the individual nodes and if that can be done through common link shared by adjacent node both will broadcast the control message, hence, in that case using this link two numbers of time control message will be transmitted otherwise single broadcast will occur (Table 2).

Let, as per notation table consider total numbers of link for a particular instance of time is

\[ R = R_S + R_C \]

As well as we can say control message broadcast occur via common link is \( 2 \times R_C \) and via single link is \( R_S \)

So, we can say total numbers of control message broadcasting \( (B_T) \) can be done for route discovery is,

\[ B_T = (R_S + (2 \times R_C)) \]

For, very large \( R_S \) or \( R_C \) we can consider \( \approx R \).

So,

\[ B_T = (R + (2 \times RR)) = 3R \]

Hence, total complexity for route discovery that depends on the number control message broadcasting depends on the numbers of routes \( R \) i.e, \( O(R) \)

### 4.1.1 Packet Distribution

For packet distribution time complexity depends of our proposed ACOLBR algorithm works in such a way that \( N \) packets are divided among \( R \) no of routes such that,

\[ N = X_1 + X_2 + X_3 + \ldots + X_R \]

and complexity depends on the combination matrix \( (M[i][j]) \), cost matrix \( (C[j]) \) and output matrix \( (O[j]) \) as stated above from the previous section we can say,

\[ O[j] = M[i][j] \times C[j] \]

where we know \( M[i][j] \) with order \( n \times R \) stores all \( n \) possible ways to distribute \( N \) packets among \( R \) number of routes requires \( (N \times \log R) \) way of distribution. \( C[j] \) with order \( n \times 1 \) is a cost matrix which stores cost of all possible Routes \( (R) \) can be distributed as \( (R \times 1) \). \( O[j] \) with order \( n \times 1 \) is an output matrix which stores the cost of each possible route way of packet distribution among \( R \) number of available routes can be express as

\[ O[j] = (N \times \log R) \times R \times 1 = N \times R(\log R) \]

as, \( N \) is a constant variable so for packet distribution the complexity depends on the numbers of routes i.e., \( O(R\log R) \).

### 4.1.2 Agent Selection

After Packet distribution in case of agent selection in our ACOLBR Red/Blue agent selection is occurred and as stated above agent selection can be done using Decision variable
depends on network matrices (Energy, Bandwidth, Stability and Distance) shown in Eqn. 19 and selection required a constant $C_1$ amount of time,

Hence,

$$X^p_{ij} = C_1$$

lies between $< 1$ or $>= 1$

So, we can say time complexity for agent selection required $O(1)$ is constant say, $C$.

4.1.3 Final Packet Selection

In Final packet selection using ACOLBR, Source node checks whether packet distribution in any route crosses the estimated threshold value or not and pheromone table update that inversely proportional to the route cost where the threshold value is decided in combination matrix is,

$$O_{Select}[m][p] \text{ can be express as } M[i][j] \text{ where } M[i][j] = N \times R$$

and pheromone table update that inversely proportional to the route cost is, $C_2/(C[j]) = C_2$ a constant

Hence, complexity required, $(N \times R + C_2)$

$= O(R)$ for large $R$ where, $N$ and $C_2$ are constant variable.

4.1.4 Route Maintenance

Finally according to our ACOLBR the Route Maintenance required route discovery once again but here route discovery should be done among those link that are till exists into the network without any failure.

Say, $R^S_F =$ numbers of single link failure occurs after certain amount of time

So, now single route exists into the network

$= R - (R^S_F)$

As well as, consider common link failure occur is $R^C_F$

So, common link or path exists into the network is

$= R_C - (R^C_F)$

Hence, now route discovery should be done after failure $R^I_F$ is,

$$R^I_F = ((R - (R^S_F)) + 2 (R_C - (R^C_F)))$$

| Table 3 | Simulation parameters |
|---------|-----------------------|
| Parameter used for simulation | Value |
| Channel | Wireless |
| Propagation | Two way |
| Network interface type | Wireless |
| Antenna | Omni antenna |
| No. of nodes | 40 |
| MAC | IEEE 802.11 |
| Simulation area | 600 $\times$ 600 m$^2$ |
| Pause time | 1–25 s |
| Simulation time | 100–500 s |
| Node speed | 10–50 s |
| Mobility model | Random way point |
≈ R for large numbers of Link exists into the network. Hence complexity for route maintenance depends on $O(R)$

Finally we can say,

**Total Complexity of ACOLBR** $M_C = O(R) + O(R \log R) + C + O(R) + O(R)$

≈ $3 O(R) + O(R \log R) + C$

≈ $O(R) + O(R \log R)$.

### 5 Performance Analysis and Simulation Results

This protocol is simulated by the OMNET++ simulator. IEEE 802.11 is used for wireless LAN as MAC layer. The channel capacity of mobile node is 2 Mbps. In our simulation mobile nodes move in a $600 \times 600$ m$^2$ region for 100–500 s simulation time. Mobility model is considered here as random way point. It is assumed that each node moves independently with the speed 10–50 m/s and pause time is 0–25 s. No path loss is
considered. The network size is 40 nodes. The simulated traffic is constant bit rate (CBR). Table 3 shows the simulation parameters of the network environment. The performance of ACOLBR is compared with two category of existing routing protocols

1. Basic Routing Protocols in MANET
2. Ant colony optimization based routing protocols in MANET

5.1 Performance Comparison ACOLBR with Basic MANET Routing Protocols

In this section ACOLBR is compared with basic routing protocols AODV, DSDV, CAARTT, MOAODV, MMRP and DSR with respect to pause time (0 s, 5 s, 10 s, 15 s, 20 s and 25 s), simulation time (100 s, 200 s, 300 s, 400 s and 500 s) and mobility (10, 20, 30, 40 and 50)m/s of nodes.

5.1.1 Packet Delivery Ratio Versus Simulation Time

In Fig. 2 performance metrics used to evaluate our proposed scheme is delivery rate and simulation time. We can observe that the packet delivery ratio of the proposed protocol is better than all other basic routing protocols due to congestion free route selection of ACOLBR in the network. On the other hand, AODV [1], DSDV [42] and DSR [2] don’t follow any strategy to balance load and control congestion in the network. In ACOLBR, packet distribution phase and agent selection module assist the source node to transmit the packet in such a way that load in the network is balanced. Thus packet delivery ratio of ACOLBR is stable compared to other existing routing protocols in the network.

5.1.2 Packet Delivery Ratio Versus Node Speed

In Fig. 3 performance metrics used to evaluate our proposed scheme are packet delivery ratio and node speed. It is observed that initially the packet delivery ratio of ACOLBR is better than AODV [1], DSDV [42], DSR [2], MMRP [5] and OBSUR [6] due to balance
load in the network during packet transmission. At node speed (40 m/sec) the performance of DSDV [42] and ACOLBR are degrading due to high speed. In high mobility of nodes ACOLBR requires more time for agent selection and path set up, which leads to decrease in performance with the increase in mobility. It is also observed that the overall performance evaluation of ACOLBR gives better result compared to AODV [1], DSDV [42], DSR [2], MMRP [5] and OBSVR [6], as ACOLBR considers mobility of a node as a parameter during path selection.

5.1.3 Average End to End Delay Versus Simulation Time

In Fig. 4 performance matrices used are End to End Delay and Simulation Time. It is observed that initially the end to end delay of ACOLBR is similar to AODV [1], DSDV [42] and DSR [2]. At simulation time 200s end to end delay of AODV [1] and DSR [2] is highly increased with compare to ACOLBR as it balance load in the network during packet transmission. The result also shows after simulation time 300s the end to end delay of
AODV and DSR are abruptly decreasing. It shows that overall performance of ACOLBR is stable throughout the simulation period compared to AODV, DSDV and DSR.

5.1.4 Packet Delivery Ratio Versus Pause Time

In Fig. 5, the considered performance matrices are Packet Delivery Ratio and Pause Time. It is observed that initially the performance of ACOLBR is better than all. When the pause time is 16sec performance of ACOLBR is degrading. After 22sec the performance of ACOLBR is enhanced. Overall performance of ACOLBR is better than AODV [1], DSDV [42] and DSR [2].

5.1.5 End to End Delay Versus Pause Time

In Fig. 6 performance metrics are End to End Delay and Pause Time. Initially the performance of ACOLBR is slightly degraded compared to AODV [1], DSDV [42] and DSR [2] due to agent selection and path set up. End to end delay of AODV [1] and
DSR [2] are again highly increased after pause time 15 second while the performance of ACOLBR is stable compared to others. It shows that overall performance of ACOLBR is better throughout the simulation period compared to AODV [1], DSDV [42] and DSR [2] due to selection of optimised sequence of red and blue ant during packet transmission.

5.1.6 End to End Delay Versus Node Speed

In Fig. 7 performance metrics used to evaluate our proposed scheme are Average End to End Delay and Node Speed. End to End delay of ACOLBR is increasing with the increase of node speed. The reason behind this ACOLBR requires some times for path setup and agent selection. After node speed 20m/second end to end delay of ACOLBR is decreasing and after node speed 30m/second end to end delay of AODV [1], DSDV [42] and DSR [2] are increasing abruptly compared to ACOLBR.
5.1.7 Throughput Versus Simulation Time

This section from Fig. 8 compares proposed protocol with DSDV, DSR, CA-ARTT and AODV with respect to throughput and simulation time. The throughput of AODV [1], DSDV [42] and DSR [2] is reduced after simulation time (200sec) due to congestion in the network. On the other hand, CA-ARTT [4] is a congestion avoidance algorithm which differentiates the cause of packet losses, which reduces the packet losses and increases the throughput. ACOLBR shows better performance compared to all these protocols due to the sequence of red and blue ant generation for balancing load in the network.

5.1.8 Throughput Versus Pause Time

In Fig. 9 performance metrics used to evaluate our proposed scheme are Throughput Load vs. Pause time. This section compares proposed protocol with AODV [1], DSDV [42] and DSR [2] with respect to throughput and pause time. The throughput of AODV [1], DSDV [42] and DSR [2] are varying with different values of pause time. Throughput of ACOLBR is approximately stable and maximum than all other protocols. Main objective of these protocols is to increase the throughput of the network by sharing the load. Load balancing strategy of ACOLBR increases throughput in the network.

5.1.9 Throughput Versus Node Speed

In Fig. 10 performance metrics are throughput and node speed. The throughput of AODV [1], DSDV [42], MOAODV [21] and DSR [2] are reduced after node speed (20m/s) because of congestion in the network. The throughput of MOAODV [21] is constant throughout the simulation. On the other hand overall performance of ACOLBR is better compared to AODV [1], DSDV [42], MOAODV [21] and DSR [2] due to the sequence of red and blue ant generation for balancing load in the network.

![Fig. 11 Throughput versus simulation time](image-url)
5.2 Performance Comparison of ACOLBR with Ant Colony Optimisation Based Routing Protocols

In this section ACOLBR is compared with Ant Colony Optimisation based routing protocols ARA [24], ANTNET [15], ANTHOCNET [16], FACO [43], ANTAODV [20], MOAODV [21] and CLAR [36] with respect to Pause time (100s, 150s, 200s, 250s, 300s, 350s, 400s, 450s, 500s, 550s and 600s), simulation time (100s, 150s, 200s, 250s, 300s, 350s, 400s, 450s and 500s), mobility (10, 20, 30, 40 and 50) m/s of nodes, packet delivery ratio, end to end delay and throughput.

5.2.1 Throughput Versus Simulation Time

In Fig. 11 ACOLBR is compared with CLAR [36] and ANTNET [15] with respect to Throughput and Simulation Time. CLAR is the ant colony optimisation based routing protocol to balance load in the network. In CLAR [36] red and blue ant are selected alternatively. This protocol does not have any packet distribution phase and agent generation.
5.2.2 End to End Delay Versus Pause Time

In Fig. 12 ACOLBR is compared with ant colony optimisation based routing protocols like ARA [24], FACO [43], ANTAODV [20] and ANTHOCNET [17]. In ARA, two types of ants (FANT and BANT) are applied during path discovery phase. It does not implement any strategy to share the load among all the available routes in the network. This causes performance degradation of ARA compared to ACOLBR. ANTAODV [20] gives better performance than ARA, but it does not follow load balancing strategy. Thus ACOLBR
gives better performance compared to ARA [24], ANTAODV [20], ANTHOCNET [17] and FACO [43].

5.2.3 Packet Delivery Ratio Versus Pause Time

In Fig. 13 performance metrics used to evaluate our proposed scheme are packet delivery ratio and pause time. ACOLBR is compared with ARA [24], FACO [43], ANT-AODV [20], CLAR [36] and ANTHOCNET [17]. ARA [24] and ANT-AODV [20] do not share the load among all the available routes in the network. This degrades the performance of ARA [24] compared to ACOLBR. FACO [43] gives better performance than ARA [24], ANTHOCNET [17] and ANT-AODV [20]. A pause time 300s the performance of all the routing protocols are improved but still, they are not better than ACOLBR, as they did not follow load balancing strategy. Thus ACOLBR gives better performance compared to ARA [24], ANT-AODV [20], CLAR [36], ANTHOCNET [17] and FACO [43].

5.2.4 End to End Delay Versus Node Speed

In Fig. 14 performance metrics used to evaluate our proposed schemes are end-to-end delay and node speed. ACOLBR is compared with ANTHOCNET [17]. It does not share the load among all the available routes in the network. Initially, the performance of both the protocols degraded, and after node speed, the 20s the performance of protocols are improved. The overall performance of ACOLBR is better than the ANTHOCNET [17].

5.2.5 Packet Delivery Ratio Versus Node Speed

In Fig. 15 performance metrics used to evaluate our proposed schemes are packet delivery ratio and node speed. ACOLBR is compared with ANT-HOC-NET [17] and MOAOVD [21]. The performance of these protocols is degrading continuously. They are Ant colony optimization routing protocol but do not share the load among all the available routes in the network. This leads to better performance for ACOLBR compared to MOAOVD [21] and ANT-HOC-NET [17].

6 Conclusion

ACOLBR is playing an inevitable role in an emergency system for faster communication and quick decision making. A brief review of the well-known methodologies in this area shows that very little attention has been provided by the researchers towards balancing load and controlling congestion in MANET. This paper proposes a new multi-agent-based routing methodology based on the theory of ant colony optimization. The performance of ACOLBR shows that it balances load efficiently compared to other existing routing protocols in MANET. Besides, this proposed protocol can detect congested links, take necessary action to avoid them, and send data through alternative links in the network. The load balancing and congestion control technique of ACOLBR
provides real-time data delivery. Simulation results show that ACOLBR performs better than other existing routing protocols like AODV, DSDV, DSR, RMOAODV, MMRP, OBSVR, CA-ARTT.

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