A Hybrid Optimization Framework for Optimal Routing in MANETs: Integrating Extended Foraging strategy with Cross Layering

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Abstract: Designed as a wireless network application for the battlefield, Mobile Ad hoc Networks (MANETs) establish multi-hop cooperation between power restricted mobile nodes to demonstrate technically feasible high speed inter-communication requirements of 6G applications. Creating network-aware adaptive protocols for self-tuning and self-forming 6G enabled MANETs is a challenging task. Protocols in 6G enabled MANETs demand adaptability, which is met by remarkably flexible bio-inspired principle and network parameters aware cross-layer interaction design approach. The discharge of the adaptive protocol is dependent on how accurately network conditions are calculated and acquired. An extended ant-based method for estimating network conditions is proposed in this paper. By utilizing network conditions such as density of nodes and intensity of traffic parameters, cross layer interactions allow for end-to-end delay management. According to a simulation study, adaptive protocol optimization in MANETs has improved performance even when numbers of nodes are more that too when data transmission speed is high.

Keywords: MANET, Routing, Medium Access, Ants, Foraging, Pheromone, Cross layer interaction, Adaptable protocols.

I. INTRODUCTION

The Ant Colony Optimization (ACO) technique, the Cross Layer Design (CLD) method, nature of Mobile Ad hoc Networks (MANETs), and the push for adaptation to create flexible protocols that could improve practical MANET application's performance are covered in this introduction section.

a. 6G enabled MANETs

A typical MANET shapes in various ways by connecting mobile routers (and its attached hosts) via wireless links. The architecture of the MANETs changes unexpectedly and quickly because MANET nodes are allowed to move in and out of transmission reach and can arrange themselves however they choose. MANETs can function as standalone systems or as a component of the wider Internet [1].

In excess of 50 plus billion wirelessly functional devices and at least one billion wireless portable handheld devices were seen to be in use for computing purposes in the information society by year 2020 [2]. MANETs, which are infrastructure-less, efficiently employ these massive numbers of devices in applications engaging mutual mobile data interchange, such as commercial networks and low-cost alternatives to expanding cell-based infrastructure. Wearable computing, community networks, teleconferencing, emergency disaster relief, and the military's need for IP-compliant data solutions can all boon from MANET's self-maintenance and spontaneous service introduction capabilities. MANETs enable "anytime," "anywhere," and "anyhow" communication for users by overcoming time and distance barriers. The benefits of MANETs are more evident in today's high-speed, real-time, Quality of Service (QoS) conscious 6G applications when following issues are properly addressed [3].

- The battery reliant node of MANETs presents a energy preserving demand as it cannot execute lengthy and complex algorithms due to need of frequently recharge.
- Unstable cartography results in breakage of well-established routing path. Re-route process results in increased protocol overhead.
- Signal fading, interference, and loss in routing path are issues that MANETs face because of their constrained bandwidth [4].

b. ACO Technique

The bottom-up method is used by Swarm Intelligence (SI), a branch of computational intelligence, to efficiently solve challenging combinatorial optimization problems. The ACO technique, a prominent and varied flavour of SI, uses probabilistic methods and leverages ant collective behavior and collateral characteristics to solve challenging combinatorial optimization problems. Every potential combination of variables and decision combinations is considered by the combinatorial optimization solution. Heuristic approaches of the ACO methods results in many benefits that reduce the time of analyzing all variables. ACO rules that rely on approximations to provide solutions are thought to be suitable in reasonable computational time and are actually important when developing adaptive protocols for dynamic topology based 6G enabled MANET applications. ACO's solution is incremental and employs various steps and iterative cycles. However, ACO's intrinsic flaws such as sluggish convergence speeds and local optimization values make it necessary to adopt multi-population strategy to improve performance in real world and same is illustrated by Multi-population and Co-evolution approach based ACO (MCACO), where routing protocol based on updated ACO technique [5]. Typically Forward Ant (FANT) and Backward Ant (BANT), artificial Ants in MANETs, provide the good estimate of the path (both probabilistically and deterministically). FANT investigates the route to the destination, and BANT returns via this path to update the table of routing kept at MANET nodes.

As Table 1 illustrates, MANETs and ants share many common characteristics. Features of ACO techniques include distributed working, adaptive nature, adequate robustness, and traffic load balancing that happens automatically. The MCACO method effectively addresses the unique behavioral characteristics of MANETs, such as local interactions between nodes, the availability of several routes rather than only one, backup support for failure, rapid setup, and the requirement for strong adaptation precautions to changing traffic or topological conditions [6].

Table 1: Comparison between MANETS and Ants

Variables	MANETs	Ants Topology
Topology	Un-steadiness, disbursed and un-structured	Disbursed
Start of route	Sender sends RREQ message to know neighbor degree	Deposited pheromone select the new route
Multipath support	Provide one path or multipath to some extent	Multipath is generated
Goal	To conclude available shortest route	Define optimal path

c. CLD Approach

Layered design is assumed by a significant portion of the suggested protocols in MANETs. Because each layer-specific protocol design considers interaction with its neighboring layers, this design method is extremely tight and non-adaptive. Setting up meaningful interactions between different layers using the CLD approach is important in protocol design methods for MANETs to improve performance in 6G standard based applications. In order to be more advantageous in un-steadiness networks of MANETs, this CLD approach eliminates rigid layering and creates stack wide layer interdependencies. Using metrics like delay, energy utilization, the distance, security, throughput and overhead, cluster head is chosen in the routing protocol that uses CLD approach [7]. The CLD method in MANETs achieves protocol design flexibility by utilizing the current condition of the network stack. Cross-layer interaction between the physical, MAC, and routing layers is commonly used by CLD-based protocols for MANETs to reduce protocol overhead and prevent collisions of transmitted data in recent 6G applications of MANETs.

d. Adaptation Capability

In MANETs, the topology is impacted by two actions taken by mobile nodes: joining the network or leaving it. The term "node withdrawal" describes a node's functional termination, this could occur if a node fails, its power runs out, or it leaves the network. Node joining has to do with a node's functional beginning this occurs when a node recovers from a failure state or when a node is added to the network [8]. Multiple layers are impacted by the node's mobility: the physical layer is affected by changes in interference level and transmission errors; the link layer is affected by medium access and handoff policies; the network layer is affected by addressing and route initiation/maintenance; the transport layer is affected by congestion and flow control tasks; and the application layer is affected by QoS requirements. Appropriate protocol adaptation to build a disbursed network that creates a link to transfer data is always an inspiring problem in fault-tolerant, self-managed, self-organizing, and self-configuring MANETs. A good MANET protocol should successfully adapt to variables in the network, such as traffic intensity and network density, and gracefully incorporate an effective CLD approach [9].

II. RELATED WORK

Bio-inspired metaheuristic algorithms are superior to traditional computational methods for discussing MANET problems. The algorithms inspired by nature use essentially very basic rules and initial conditions, to describe and resolve complex relationships. These characteristics have led to their recent use as a source of inspiration for algorithm design in dynamic MANETs. The number of ants used for requests, the updating of pheromone value and frequency, and the computation of routing table probabilities are some of the ways that different ACO methods employ for routing in MANETs.

In [10, 11], the authors utilized ACO to identify all optimal paths for a specified source and destination pair. The performance metric is based on the delay experienced in packet delivery. These selected routes yield a globally optimal route. The finding of several routes between the selected sender and receiver pair mitigates communication failure, which may results from node or link failures. The ACO technique offers a satisfactory solution with significantly reduced computational demands.

ACO, which is based on multi-agent ants of the MARA protocol, establishes and sustains paths in the dynamic environment of MANETs [12]. Protocols that employ the ACO method demonstrate enhanced performance metrics in MANETs, such as reduced route discovery latency, improved packet delivery ratios, minimized end-to-end packet transmission delays.

In [13], the authors applied the ACO framework to develop an intelligent version of Temporally Ordered Routing Algorithm (TORA), an energy-aware multipath routing algorithm. The parameters of protocol checked include network lifetime, packet loss, and average delay in packet transmission (end-to-end). The new updated TORA has resulted in an extended network lifetime, decreased packet loss, and a lower delay (average) in packet transmission. Additionally, TORA reduces the number of control packets, thereby achieving lower routing overhead.

A hybrid intelligent routing method that clubs ACO and Particle Swarm Optimization (PSO) has enhanced routing performance in MANETs [14]. The advantages of the ACO-PSO based approach, compared to the MARA protocol that relies solely on ACO techniques, include shorter distances, optimal bandwidth, reduced delays, lower power consumption, and balanced load across paths.

An energy-constrained honey comb routing procedure that focuses on cross layer variables aims to optimize energy across various layers by taking into account MAC queue usage, link expiry time, and probable transmission time [15].

In [16], the authors investigated Energy Efficiency (EE) method calculated in K bits per Joule for MANETs based on the CLD approach. The EE optimization challenge encompasses routing and traffic regulating along with power control in tune to the CLD method, researchers have formulated EE improving issue as a non-convex model which is NP-hard intrinsically.

Cross-layer communications between several layers, specifically PHY, MAC, and network, enhance power control by calculating the signal strength of receiver values, which subsequently identify a best path for the specified sender-receiver pair [17]. This cross-layer optimization framework enables the adjustment of sender’s power levels at the physical layer by utilizing RSS information pertaining to a node's one-hop neighbors. The modification of transmission power levels allows a node to adapt its propagation range, which is directly proportional to the transmission power. This information from the lowest layer is now communicated to the networking layer to determine best route in routing methods. A significant accomplishment of this CLD mechanism is its capability to facilitate information sharing from the lowest layers to the highest layers.

The CLD framework, designed to improve video transmission efficiency, prioritizes video packets and leverages information such as the signal to noise ratio at the MAC layer within the layer of application [18]. The CLD, which encompasses layers like application, network, and MAC, utilizes SNR value along the path from source to destination to strengthen the path re-construction process, thereby improving the working of MANETs.

An efficient data sending method employed in geographic routing techniques circumvents routing holes and establishes routes towards the destination. This hole-bypass mechanism enables the transmission of routing data to a node where the greedy relaying method can continue, offering additional benefits such as increased dynamism, higher packet delivery rates, and improved scalable factor [19].

The agility and scalable factor required in large-scale MANETs necessitate clustering [20]. The status of the groups includes bandwidth capacity link strength between clusters, and node membership, which are influenced by node mobility. A cluster based method that adapts effectively achieves coordination between the power utilization and node's workload. It ensures minimal overhead while promptly tracking changes accurately and timely.

In [21], a hybrid ant colony optimizer is introduced, which is designed for a 3D smooth path planning model for a group of unmanned aerial vehicles utilizing the said ball curve. Initially, the fundamental principles of various intelligent algorithms are applied to extend ACO into the continuous domain, accompanied by the development of three strategies. Following this, the adaptive foraging strategy is implemented to improve ACO's capability to balance exploration and exploitation phases, thereby enhancing its exploration efficiency within the search space.

III. PROPOSED ADAPTIVE PROTOCOLS METHODOLOGY:

Earlier, the advantages of foraging and CLD methods were merely utilized as add-on characteristic, rather than being integrated during the initial design section of MANET protocols. Analyzing the performance compromises among the various capabilities and alternatives of ACO and CLD methods reveals essential modifications needed in MANET's protocol to attain adaptability, which in turn enhances the execution of 6 G supportive MANET applications. Consequently, the adaptive protocols result in a reduction in the average delay experienced during packet transmission, a decrease in packet loss, and lower energy consumption.

A. Extended ACO Technique for Adaptable Protocols

1. The route set G^{FANT} is established from the sender node S to the receiver node D after the source node S generates FANT at the beginning of node deployment in MANETs.

$$G^{FANT} = \{G_{s,d}^{FANT} \mid \forall s \in S, \forall d \in D\} \qquad (1)$$

   a. A connected graph with n = $|V|$ nodes or vertices and a set E of lines or edges is represented by the equation G = (V, E). Between nodes S and D on graph G, the ACO method calculates the shortest path length which is determined by the count of nodes along the path that satisfies the traffic inflow essentials.

   b. Each edge $e\ (i,\ j) \in$ E of the graph connecting the nodes n_i and n_j has a (artificial pheromone) variable ς_{ij} which is incremented as the FANTs move from node *ni* to *nj*, they update this in accordance with the regional updating rule. The application of this edge affects the pheromone concentration ς_{ij}. Over time, the artificial pheromone concentration decreases, suggesting that the pheromone value on the edges is rapidly convergent.

2. Each FANT present in node n_i uses pheromone ς_{ij} of n_j for choosing the next hop node to collect data of node and is proportional to probability of traffic arrival, which is described using the following mentioned state transition rule.

$$\varsigma_{i,j}(t+1)=(1-y)\varsigma_{i,j}(t)+y\varsigma_0 \qquad (2)$$

Here, y $(0<y<1)$ is the regional pheromone decay variable and ς_0 is the starting pheromone value.

3. The node's traffic rate is modified relative to node's distance and the approximated traffic inflow probability.

Algorithm:
{
Input: Size of Packet: 512 bytes
Count of nodes: 50 to 250 in steps of 50
Reach of Transmission: 250 meters
Allowed Bandwidth: 2 mbps

Output: Optimal path
Reduced Energy utilization and overhead
Re-calculated Traffic rate
Method
{
for i=1 to n do
Calculate the value: Node's traffic inflow value
Estimate distance from sender to remaining all nodes of network
Vary the node's traffic rate for other nodes with respect to distance

if (traffic rate)<= (calculated traffic inflow approximation)
Prepare FANT to identify next transmission node
else
Drop the FANT
end if
end for
}

4. Using the approximated path, the Network Adjacency Matrix (NAM), degree of node (calculated using NAM) and the node neighbor set N_j are calculated.

a. The network adjacency matrix, also known as the matrix of connection, is depicted as a matrix with records and fields labelled by the network nodes. In this matrix, a 1 or 0 is placed in position (i, j) based on condition that if nodes *ni* and *nj* are adjacent. The diagonal members of this matrix are all zero, as edges from a vertex to itself are not permitted. By examining the matrix of network adjacency, we can determine (From R to L) all the connects to a node *ni* by reviewing the i^{th} row, and one can identify remaining connects from a node *nj* by analyzing the j^{th} column.

b. The node degree: Is defined as the count of edges linked to that node. In the circumstances of the matrix of adjacency A, the node's degree is indexed by i in an un-directed MANETs graph is represented as:

$$k_i=\sum a_{ij}, \text{ (for all j)}$$

Where, the summation is over all nodes that are connected.

c. Estimating the neighbor set Nj: Each mobile node assesses the received power at a specific time by utilizing statistical prediction techniques, enabling every node to more precisely find the nearest neighbor.

5. The above steps from step1to step 4 are continued until FANT forms route set G^{FANT}.
6. When FANT acquires G^{FANT} from S and D, the function of path evaluation $F_{G^{FANT}}$ is assessed based on the metrics of packet loss ratio, end-to-end delay, queue length, and average energy consumption.
7. The highest value of the path evaluation function $F_{G^{FANT}}$ and the global best route set G_{best}^{FANT} are calculated.
8. Following the global pheromone density increasing rule, the density of pheromone of the link is modified by $\Delta_{i,j}(t)$, the excess of the intensity of pheromone of link {i, j}.
9. If the termination condition (Ic> Imax) is met, the algorithm concludes. If not, the aforementioned process is reiterated.

Here, Ic represents the count of iterations and Imax denotes the highest count of iterations.

This calculated Network Density (ND) {ς} and Traffic Intensity (TI) {$G_{i,j}^{FANT}(t)$ } information, derived from the updated ACO technique, is subsequently relayed to the relevant MANET protocol(s) to ensure adaptability. Figure 1 depicts the flowchart depicting the operation of the ACO method in estimating network parameters.

B. CLD approach for adaptable protocols

The CLD method employed for developing adaptable MANET protocols in 6G scenario facilitates data transmission through the exchange of information across the physical layer, MAC layer, network layer, and transport layer. Figure 2 identifies process of information exchange within the protocol suite of adaptive MANET protocols enabled CLD method. A common database is established to allow layers to communicate information, despite each layer executing distinct functions. Two numbers of interfaces are established between pairs of layers to support up and down flow of information. When designing cross-layer interactions for adaptable MANET protocols, efforts are to reduce conflicting and unintended interactions that may lead to stability issues and performance decline because of routing overhead.

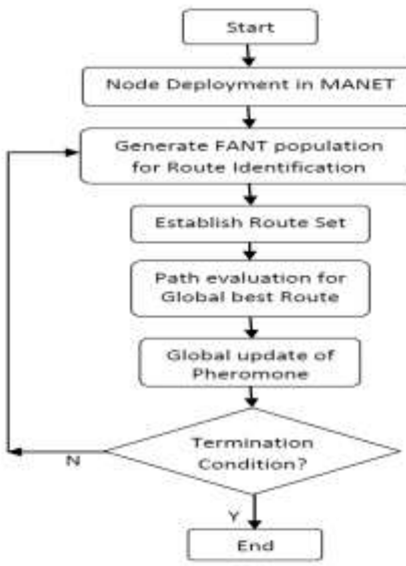

Figure 1: Flowchart showing method of extended ACO method

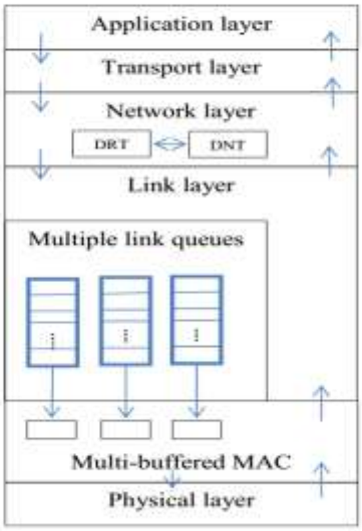

Figure 2: Protocol structure of adaptive MANET protocols that shares information

IV. SIMULATION AND RESULT ANALYSIS

a. Model of Simulation

In view of high cost and impracticality of field simulation testing, a simulator is employed to conclude the effectiveness of MANET protocols. The Network Simulator Version 2 (NS-2), which has been effective in examining the dynamic characteristics of MANETs, is used to simulate the proposed ACO and CLD employed protocols for MANETs [22]. This event driven simulation tool, NS-2, generates a TCL file that outlines the scenario, including the count of nodes and the type of agent operating on those nodes, among other details. NS-2 is developed using Object-Oriented Programming (OOP) principles in C++, with OTCL (TCL) serving as the scripting language. TCL functions as the front end while C++ operates in the backend. By executing the .tcl file, the simulation is conducted, and Awk is employed to analyze the results of the simulation.

b. Parameters of simulation

In the simulation, 50 mobile nodes are configured to traverse a 1300 meter by 1300 meter area for a duration of 50 seconds. Each node possesses an identical transmission range of 250 meters, and the traffic being simulated follows a Constant Bit Rate (CBR) model. A summary of the simulation settings and parameters can be found in Table 2.

Table 2: Simulation settings

Count of nodes	From 20 to 100 in bunches of 20
Antenna mode	Omni/Dir Antenna
MAC protocol	IEEE 802.11
Transmission reach	250m
Simulation time set	50 sec
Traffic source	CBR
Network area size	1.3 KM X 1.3KM
Size of packet	512
Packet sending rate	50,100,150,200 and 250kb
Propagation scheme	Two Ray Ground
Architectures	Grid, Linear and Non-Linear
Number of directions	4
Modulation	BPSK

c. Discussion of Results

The effectiveness of the proposed ACO and CLD employed Adaptable MANET Protocol (ACAMP) is assessed by contrasting it with the standard routing protocols DRP [22] and MCACO based routing protocol [5].

Case-1(Grid):

In our initial experiment (Grid topology), we adjust the rate to 50, 100, 150, 200, and 250 Kb for CBR traffic. Figures 3 and 4 illustrate the results regarding delay and throughput as the rate varies from 50Kb to 250Kb for CBR traffic across the ACMAP, MCACO, and DRP protocols. Upon comparing the performance of these three protocols, we conclude that ACMAP surpasses MCACO and DRP by 43-56% in delay and 84-89% in throughput.

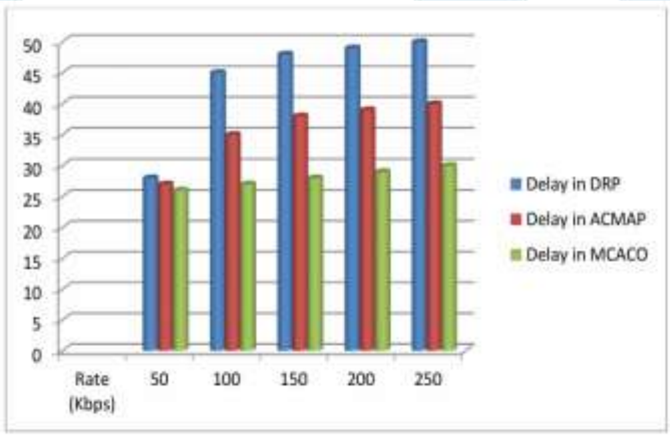

Figure 3: Grid topology- Rate (Kbps) Vs Delay (in Sec)

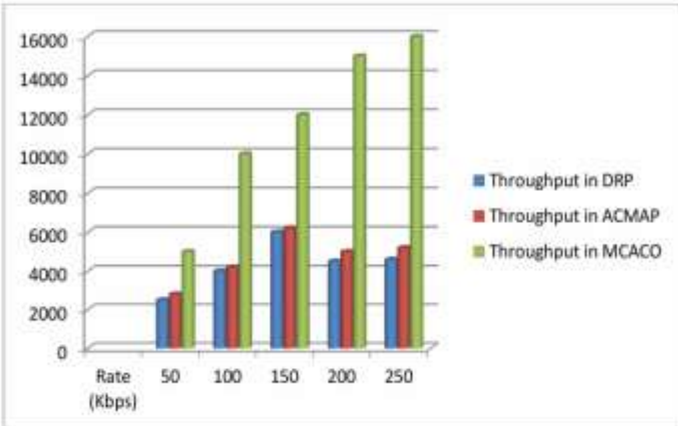

Figure 4: Grid topology- Rate (Kbps) Vs Throughput (in Mbps)

Case-2 (Non-Linear)

i. Based on Nodes: In the second experiment (Non-linear topology), we modify the count of nodes ranging between 20 to 100.

Figures 5 and 6 present the results for delivery ratio and throughput as the count of nodes varied from 20 to 100 for CBR traffic in ACMAP, MCACO, and DRP protocols. In comparing the performance of these three protocols, we find that ACMAP exceeds MCACO and DRP by 28-48% in delivery ratio and 52-69% in throughput.

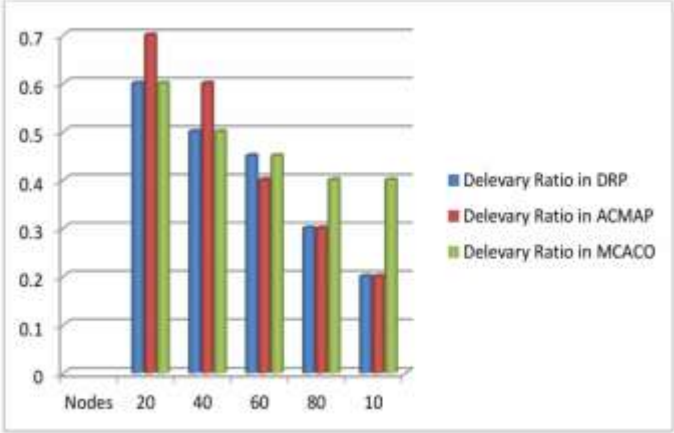

Figure 5: Non-linear topology- Nodes Vs Delivery Ratio

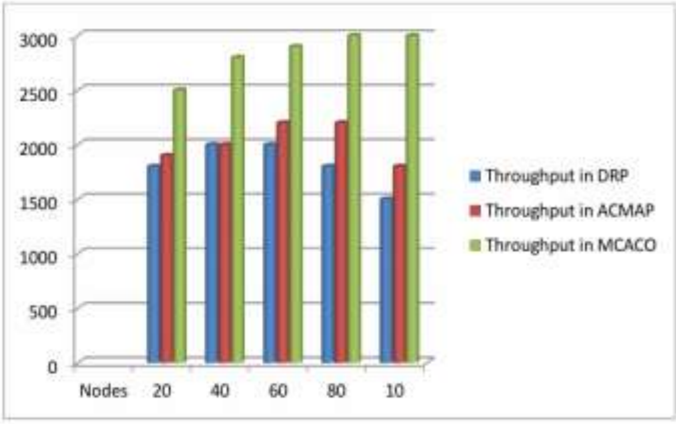

Figure 6: Non-linear topology- Nodes Vs Throughput (in Mbps)

ii. Based on Rate: In our second experiment (Non-linear topology), we alter the transmission rate to 50, 100, 150, 200, and 250Kb.

Figure 7 displays the throughput results as the rate varies from 50Kb to 250Kb for CBR traffic in ACMAP, MCACO, and DRP protocols. When comparing the performance of these two protocols, we determine that ACMAP outperforms MCACO and DRP by 49-64% in throughput.

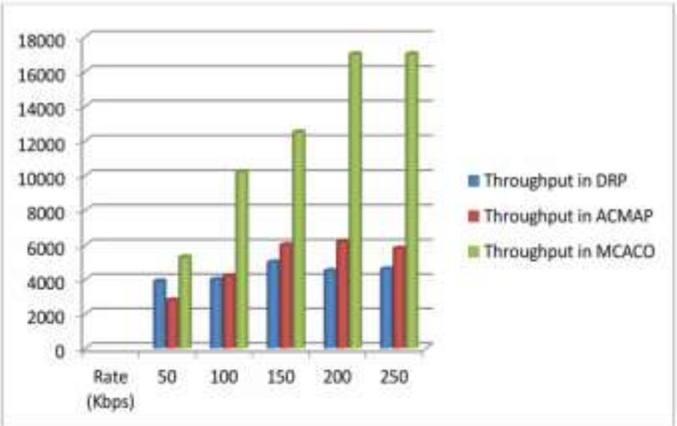

Figure 7: Non-linear topology- Rate (Kbps) Vs Throughput (in Mbps)

CONCLUSION

Critical network resources are kept from being wasted by adapting MANET's protocols to the current network conditions, such as traffic intensity and network density. One benefit of estimating network conditions using the updated ACO metaheuristic approach rather than more conventional techniques is that it takes less time to compute the best solution. By establishing cross-layer interactions between the physical, MAC, network, and transport layers, a number of design issues with 6G enabled MANET applications, including security, energy concerns, user mobility pattern, restricted link capacity, and topology control are successfully resolved. When cross-layer interactions and extended bio-inspired algorithms are added to protocols of MANET applications, they become robust and adaptive. Simulation results demonstrate that the use of suggested techniques in developing 6G supportive applications based MANET protocols improves throughput by 39–59 percent, increases the delivery ratio by 22–39 percent, and reduces delay by 33–46 percent.

FUTURE WORK

In order to improve real-time data transfer capability, future work will concentrate on implementing ACO and CLD methods in issue based MANET applications. The goal is to adjust the pheromone concentration in various ways and investigate ways to examine how the pheromone value is maintained, which affects the QoS requirements of 6G supportive applications of MANETs such as energy usage for multimedia packets and high network loads.

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