QUALITY OF SERVICE UNICAST ROUTING IN MOBILE AD HOC NETWORK USING METAHEURISTIC APPROACHES: A SURVEY

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Abstract
Quality of Service (QoS) routing is very much challenging issue in Mobile ad hoc Networks (MANETs) compared to wired network due to mobility of nodes, multihop communication, decentralized coordination and contention for channel access. QoS guarantee is essential by many applications like multimedia, real time audio-video and military. QoS parameter varies according to type of applications. In last decades, many researchers have focused on this issue. This problem is a nonlinear combinatorial optimization (CO) problem, which is proved to be a NP-complete problem, at present; the problem can be easily solved by metaheuristic techniques. Previously many metaheuristics have been applied to solve CO problems with Ant Colony Optimization (ACO), Genetic Algorithm, Simulated Annealing and Tabu Search. Recently some of the authors have presented survey of routing protocol using these metaheuristics but not specific to quality of service routing. This paper presents the survey of routing protocol which support QoS with different metrics and shown strengths and weaknesses of protocols which allow us to identify the areas of future research.
Keywords: Quality of Service, metaheuristics, routing in ad hoc network,

I. INTRODUCTION

MANETs are becoming the important medium of present day communication due to their infrastructure-less, self-configuring and easily deployable nature. For the past decade, the field of mobile ad hoc networks [1] has been accepted as a justifiable area of research. Active research areas in MANETs are design of MAC protocol, resource management, power control, security and routing. Among these issues, routing has attracted more attention of researchers and many different routing protocols have been proposed in last few years. Routing protocols can be classified mainly in three categories: proactive, reactive and hybrid. Proactive protocols [10, 11, 12, 13] continuously learn the topology of the network by exchanging topological information among the network nodes. Thus, when there is a need for a route to a destination, such route information is available immediately. The reactive routing protocols [14, 15, 16, 17] are on demand means when route from source to destination is required then it starts route discovery. They do not need periodic transmission of topological information of the network between the nodes. Hybrid routing protocols [18, 19, 20] are mixture of both reactive and proactive by taking their advantages. Based on the method of delivery of data packets from the source to destination, classification of MANET routing protocols could also be done as unicast and multicast routing protocols. The unicast routing protocols that consider sending information packets to a single destination from a single source. Multicast routing protocols delivers information to a group of destinations simultaneously. Our focus is only on unicast routing protocols. In the beginning, MANET's researchers were focused mainly on designing distributed and dynamic communications protocols for shared channel and for route discovery. This offers best-effort protocols to ensure optimum network operation in an unpredictable wireless environment. They were not able to deliver some services, for which best-effort protocols are not adequate. This is because multimedia applications often have stringent delay and reliability sensitive service requirements. Subsequently, the research focus has shifted from best-effort services to the provision of better defined QoS in MANET.

II. QUALITY OF SERVICE ROUTING

QoS is defined as a set of service agreement between user application and network that needs to be met by the network while transporting data stream from source to destination. For example, an application may ask a particular QoS by specifying its requirements in terms of one or more metrics. It may require a guaranteed throughput of 125 Kb/s and a maximum packet delay of 25 ms. These metrics are calculated at particular layer [7].

- *Network layer metrics:* achievable bandwidth, end-to-end delay, delay jitter (variance), packet loss ratio, energy expended per packet, route life time
- *Link and MAC layer metrics:* MAC delay, link reliability, link stability, node relative mobility/stability
- *Physical layer metrics:* signal-to-interference ratio, bit error rate, node residual battery charge or cost.

The QoS metrics can be additive, multiplicative or concave. Bandwidth is concave means that end to end bandwidth is the minimum of all the links along the path from source to destination. Delay and jitter is additive where it is addition of hop to hop delay along the path. Probability of packet loss is multiplicative. To support QoS in mobile ad hoc network is challenging task due to its characteristics like dynamic topology, shared channel, limited resource availability, imprecise state information, insecure medium and lack of central coordination which imposes some difficulties [7].

Many authors have presented the survey on QoS routing for mobile ad hoc networks since last ten years. T. Bheemarjuna Reddy and C. Siva Ram Murthy [8] has presented a survey of QoS provisioning in MANET and given the layer-wise classification of the existing QoS solution in detail. Philipp Becker [9] has presented survey of existing QoS routing protocols and analyzed them based on robustness, scalability, whether suitable for ad hoc network (yes/limited), routing type (reactive/pre-active/hybrid), addressing (unicast/multicast), single Vs multi constraint and time complexity.

III. METAHEURISTIC APPROACHES

Many optimization problems consist of the search for a “best” formation of a set of variables to accomplish some goals. They can be divided into two categories: those where solutions are encoded with *real-valued* variables and those where solutions are encoded with *discrete* variables. Among the latter ones we find a class of problems called Combinatorial Optimization (CO) problems. Examples of CO problems are scheduling, Travelling Salesman Problem (TSP), Vehicle Routing problem and Assignment problem. To solve these problems, many algorithms have been investigated. These algorithms can be classified in *complete* and *approximate* algorithms. Complete algorithms are guaranteed to find the optimal solution in bound time but it has high computation time for practical purpose. While later algorithms can find good solution by scarifying optimal one but in reduced time compared to earlier algorithms. In the last 35 years, a new class of approximate algorithm has emerged which basically tries to combine basic heuristic methods in higher level frameworks aimed at efficiently and effectively exploring a search space. These methods are commonly called *metaheuristics.*

“A metaheuristic is formally defined as an iterative generation process which guides a subordinate heuristic by combining intelligently different concepts for exploring and exploiting the search space, learning strategies are used to structure information in order to find efficiently near-optimal solutions. [2]

A. *Classification of Metaheuristics*

They are classified based on different characteristics [3] among them which are shown in Fig. 1.

Nature Vs Non-nature inspired: Nature provides some of the efficient way to solve the difficult problems means algorithms imitates process from nature or inspired from nature.

Ant colony optimization (ACO) algorithms are derived from the behaviour of ant colony.

Population Vs Single point search: This characteristic specifies the number of solutions used at a time.

Dynamic Vs Static objective functions: Some algorithms keep objective function same throughout while others vary during the search process.

One Vs various neighbourhood structures: Some algorithms work on single neighbourhood structure means same fitness landscape topology while others may have set of neighbourhood structures.

Memory usage Vs memory-less methods: Most of the metaheuristic maintain the search record which means whether they uses memory or not.

Here we have chosen some of the metaheuristic algorithms which have been applied on QoS routing in MANETs so far. These are Ant Colony Optimization, Genetic Algorithms (GA), Simulated Annealing (SA) and Tabu Search (TS).

- Nature Vs Non-nature inspired
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Fig. 1. Classification of Metaheuristics

IV. ANT COLONY OPTIMIZATION

ACO has been formalized into a metaheuristic for combinatorial optimization problems by M. Dorigo [4, 5]. In the natural world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but to instead follow the trail, returning and reinforcing it if they eventually find food. Over time, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets walked over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones.

Ant colony optimization algorithms have been applied to many combinatorial optimization problems like scheduling, assignment, set covering and vehicle routing. The distributed nature of routing in ad hoc network is likely to match with ACO. This section presents the some of the quality of service routing protocol based on ACO which are proposed in the past.

A. *An Ant Based Multipath Quality of Service Routing(AMQR)*

Multi objective QoS on demand routing protocol [6] is proposed which finds the path from source to destination based on end to end delay, hop count and bandwidth. Every node running this algorithm contains three tables, namely, neighbor table which maintains the neighbor's pheromone value and available bandwidth that showing goodness of path through that neighbor, path preference table keeps the entry for each destination with list of neighbor nodes, and routing table maintains the best next hop for each destination to which source is about to send the data. Bandwidth of each outgoing link is calculated based on special type of packet called hello packet which in maintained in neighbor table of node. End to end delay is measured by RREQ_ANT message. Hop count is calculated based on RREP_ANT which is having stack of visited nodes.

Route discovery: When source node has data to send and if path is not available in routing table then it starts route discovery. Source node broadcast the packet called RREQ_ANT which contains starting time, available bandwidth and stack of nodes visited. When intermediate nodes receive the RREQ_ANT message then they check the bandwidth of previously visited link. If the value is lower than the available bandwidth field of message then replace it with this value. The node also set the reverse path and adds this node as visited in stack of nodes in message. When RREQ_ANT is received by destination then it calculates the delay based on arrival time of it and starting time of RREQ_ANT and prepare RREP_ANT message. RREP_ANT message contains hop count, delay and available bandwidth and stack of nodes visited by RREQ_ANT. Destination now forwards the reply message to the last visited node. Whenever RREP_ANT is received by intermediate nodes and source node, they update the path preference table and routing table.

Route maintenance: Each node maintains updated view of neighbors by periodically sending hello message. When node cannot sense this message from any of the neighbor in predefined time then its entry is removed from all the tables. If data transmission is going on through that failed link then alternate route with next best path preference probability will be selected to resume transmission.

Performance: AMQR is compared with AntHocNet [21] and AODV. AMQR has less delay compared to both in case of increased flow counts (25) and also with increased mobility. Routing overhead is more than AODV and AntHocNet while increasing node mobility and pause time.

The bandwidth estimation technique is not that much accurate so, one can replace/modify it and many other QoS metrics can be combined as future work.

B. An Ant Based Multipath Routing with Quality of Service for MANETs

The multipath routing [22] for QoS sensitive multimedia services is proposed which can establish effective multi paths to enhance the network reliability. The most significant feature of the proposed approach is its adaptability to current traffic conditions. The network load is balanced by distributing the traffic adaptively on different discovered paths with maintaining the QoS requirements.

They have used bandwidth and delay as QoS metrics to select the best path from source to destination. Each ant selects the next link based on pheromone value but author has defined communication adaptability of link based on distance and queue length at next node. Distance between two nodes reflects energy dissipation rate, the closer the next node, the more attractive for routing due to the less communication cost. The queue length decides whether packet overflow occurs or not. Once all paths are discovered, most adaptable path is selected and then from remaining nodes, next adaptable paths are also chosen for load balancing. Traffic from source to destination is distributed among these paths using routing packet distribution.

Performance: Simulation result shows that performance of proposed algorithm is better than AMPR [22] and CMPR [23]. Nodes' remaining energy ratio and packet delivery ratio are higher than both schemes when offered load is increased. The lifetime of node is longer if remaining energy is higher. Packet loss probability and energy balance in path is also better than both when offered traffic is increases. Energy balance represents the maximum difference of the minimum remaining energy nodes in the established multiple paths.

C. A Biologically Inspired QoS Routing Algorithm for MANETs (EARA QoS)

Improved version of swarm intelligence inspired on demand routing algorithm is presented which proposes a light weight QoS scheme to provide service-classified traffic control [25]. Traffic is divided into predefined set of service classes that are defined by their relative delay bounds, such as delay sensitive (real-time) and insensitive traffic. Each node maintains two tables: probabilistic routing table and pheromone table. This algorithm integrates positive feedback which originates from destination nodes to support existing pheromone on good path, and negative feedback for exponential pheromone decay.

This algorithm uses cross layer optimization by taking three parameters from lower layers: average MAC layer utilization, queue length and average MAC delay. The routing probability value is calculated based on pheromone value, queue length and link delay. By considering queue length and link delay it poses the property of congestion avoidance. Data traffic is distributed according to probability for each neighbor in routing table which also show the load balancing behavior.

Algorithm consists of several components in addition to route discovery like route reinforcement to push more data traffic through good path by sending reinforcement signal packets whenever destination detects new good paths, local foraging ants to locally search for new routes whenever all the pheromone trails of node towards destination drop below specified threshold value, local connectivity management to maintain local connectivity information of neighbors and QoS provision to classify flows into a predefined set of service classes by their relative delay bounds.

Performance: simulation result shows that packet delivery ratio, average end-to-end delay, average delay jitter and path optimality is better than AODV.

D. *Ant Colony Based Routing for MANETs Towards Improved QoSs*

Pro active ACO based Optimized Link State Routing (OLSR) is proposed [26] to identify multiple stable paths between source and destination nodes. OLSR protocol is enhanced version of pure link state routing protocol which is used in wired network. The main idea in OLSR protocol is selection of multipoint relay (MPR) among one hop neighbors which cover all the two hop neighbors. Each node maintains topology information about the network which is done by topology control message. Node also maintain routing table created from topology information.

The algorithm has two phases: route discovery and route maintenance. The QoS metrics used in the proposed work are bandwidth, link expiration time and end-to-end delay. When an ant searches for a path, it chooses the next node probabilistically [27] among its neighbor's nodes that are not yet visited. Whenever node has moved, it causes the link failure and automatically path preference probability will decrease on that path and alternate path can be used which was found during route discovery phase. The authors have not compared the performance with any existing routing algorithm so, it cannot show the efficiency of proposed work. The future work can be applied to multicasting routing protocol with same quantitative parameters of proposed work.

E. *Bandwidth Constrained Routing of Multimedia Traffic over Hybrid MANETs using ACO (HMQAnt)*

For Hybrid MANETs, multipath QoS ACO based ad hoc routing protocol is proposed [33] which mainly concerned to optimize bandwidth as key to find paths for multimedia traffic. QoS requirements are given in terms of bandwidth or delay. Whenever the source node sends forward ants, it specifies the bandwidth requirement of data transmission. Upon receiving these forward ants, intermediate nodes check the required bandwidth against their own. If it is less than that it replaces the bandwidth in forward ants before broadcasting it. When destination node receives the forward ants, it copies the bandwidth value in backward ants. Source node compares the bandwidth in backward ants with required bandwidth. If bandwidth requirement is satisfied then data transmission can start otherwise source node initiates route discovery process again. This protocol is pro-active which shares topology information with its neighbor nodes regularly.

Author has proposed the modification of AntHocNet [34] algorithm which minimizes the number of control messages flooded in the network and hence suitable for large and dense networks. At each node, an ant selects the next hop among its neighbors with probability which depends on pheromone value, queue length and average delay. Link availability between nodes is provided by periodic transmission of HELLO message. They have also done queuing analysis which is very important for computer networking because it can forecast the length of time a computer will need to wait for the data which it has requested.

Implementation result shows that number of packet drop count is increased due to bandwidth constraint path compared to without bandwidth constraint. Where delay for data transmission is decreased in bandwidth constraint compared to without bandwidth constraint. Bandwidth is assumed at each node before simulation starts. There is not any detail about how delay is calculated as well. So, one can apply some better techniques to estimate the bandwidth in this protocol as a further research work.

F. *Quality of Service Enabled Ant Colnoy based Multi path Routing for MANETs (QAMR)*

The authors proposed [35] a quality of service enabled ant colony based multipath routing (QAMR) algorithm based on the foraging behaviour of ant colony for selecting path and transmitting data. QoS parameters are bandwidth, delay and hop count along with the stability of node, number of hops and path preference probability factors. Next hop availability [NHA] is a considered to choose the path which is based on node probability and link probability. Link probability is mobility factor and node' remaining battery life time is energy factor.

During route discovery phase, FANTs are forwarded by only those nodes which are trusted neighbors. Trusted neighbors are decided based on NHA ($NHA > NHA_{thr}$). During path searching for the destination the FANT will collect transmission delay of each link, processing delay at each node, the available capacity of each link and the number of hops visited. When FANT reaches to destination node then node calculate the path preference probability for that path and also wait for some interval to arrive other FANTs. Finally BANT is unicasted to source node by stacking the nodes visited by FANT. BANT contains path preference probability calculated at destination which can be used to update routing pheromone table at intermediate and at source node. Source node may receive more than one BANT then there will be multiple paths for the destination and which ever has higher pheromone is selected for data transmission. Hello message are broadcasted periodically to know the existence of neighbors. Pheromone value is initialized when node receives hello message, updated by intermediate on receiving of FANT. If there is not any data transmission on any node then pheromone is decayed by some factor.

The simulation result shows that QoS success ratio is higher compared to AODV and ARMAN which indicates the number of paths which satisfies the user requirements among all paths explored. Routing overhead is slightly higher than AODV and ARMAN because more control packets are required and also periodic update of path explored. Packet delivery ratio is higher compared to both because if routing path is broken and source node can also know the link break notification but other best QoS path are available in routing table to keep data transmission active.

V. GENETIC ALGORITHMS

GA is a search heuristic or metaheuristic that takes off the process of natural selection. This metaheuristic is routinely used to generate useful solutions to optimization and search problems [28]. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. GA has been effectively applied to several combinatorial problems. Like shortest path routing problem [29], the multicasting routing problem [30], the dynamic channel allocation problem [31], the dynamic routing problem [32]. This section presents some of the existing protocols which have applied GA as optimization.

This section presents the solution of QoS routing in MANETs.

A. *Multiobjective GA based QoS routing for MANETs*

The author proposed [36] GA based QoS routing to find feasible path from source to destination by satisfying multiple objectives. QoS parameters are bandwidth, end to end delay, MAC delay and nci (node connectivity index). Node connectivity index describes quality of connectivity between pair of adjacent nodes.

During route discover phase, it uses NDMRD (Non Disjoint Multiple Route Discovery) protocol to explore the paths which are not required to be disjoint. These paths are generated using RREQ messages same as in DSR. Source node collects all the information like end to end delay, MAC delay, bandwidth available at nodes and nci matrix.

Chromosome Encoding: chromosome is made of positive integer in which each locus represents the order or position of node in a route. Length of chromosome is variable, but not exceed than total number of nodes in network.

Population: initial population is generated either randomly or based on result of NDMRD protocol.

Fitness function: each objective function is assigned a weight. These weights are combined into single objective function:

$F = F_1 * a + F_2 * b + F_3 * c$. Where F_1, F_2, F_3 are bandwidth, delay and nci metric respectively. Weights a, b and c are relative importance of one objective compared to other.

Crossover operation: the two chromosomes chosen for crossover should have at least one common gene, except for source and destination nodes. A set of pairs of nodes which are commonly included in the two chosen chromosomes but without positional consistency being first determined. Such pairs are called potential cross sites. Four selection methods are considered, namely the roulette wheel selection (RWS), tournament selection (TS), stochastic universal selection (SUS) and elitism (ET) technique.

Mutation operation: it is used to change randomly the value of a number of the genes within the candidate chromosomes. It generates an alternative chromosome from a selected chromosome.

Simulation was carried out by author to show the behavior of GA based solution by varying a CBR sources. The performance is affected by number of routes, number of CBR sources and the respective data rate. Average packet delivery ratio and average packet delay metrics are measured to verify the proposed solution but comparison is not made with any existing solution. The work shows that proposed solution to QoS routing using GA is feasible.

VI. SIMULATED ANNEALING

SA is a generic probabilistic metaheuristic for the global optimization problem of locating a good approximation to the global optimum of a given function in a large search space. It is often used when the search space is discrete (e.g., TSP). For certain problems, simulated annealing may be more efficient than exhaustive enumeration, provided that the goal is just to find an acceptably good solution in a fixed amount of time, rather than the best possible solution.

The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects, both are attributes of the material that depend on its thermodynamic free energy. Heating and cooling the material affects both the temperature and the thermodynamic free energy. While the same amount of cooling brings the same amount of decrease in temperature it will bring a bigger or smaller decrease in the thermodynamic free energy depending on the rate that it occurs, with a slower rate producing a bigger decrease.

VII. TABU SEARCH

TS is a metaheuristic local search algorithm [37] that can be used for solving combinatorial optimization problems. It uses a local or neighborhood search procedure to iteratively move from one potential solution to the neighborhood of each solution as the search progresses.

TS uses a local or neighborhood search procedure to iteratively move from one potential solution X to an improved solution X' in the neighborhood of X, until some stopping criterion has been satisfied. Local search procedures often become stuck in poor-scoring areas or areas where scores plateau. In order to avoid these pitfalls and explore regions of the search space that would be left unexplored by other local search procedures, tabu search carefully explores the neighborhood of each solution as the search progresses. The solutions admitted to the new neighborhood, $N^*(X)$, are determined through the use of memory structures. Using these memory structures, the search progresses by iteratively moving from the current solution X to an improved solution in $N^*(X)$.

VIII. CONCLUSION

In this paper, we have presented the survey of mainly four metaheuristic techniques to solve the QoS routing problem: ant colony optimization, genetic algorithms, simulated annealing and tabu search. Some of the metaheurstics are yet not applied for routing in MANETs like cuckoo search, firefly algorithm and bat algorithm, which are the scope for further work.

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