Multi Objective Optimization on Clustered Mobile Networks: An ACO Based Approach

Sujoy Sett and Parag K. Guha Thakurta

Abstract Clustering technique transforms a physical network into a virtual one to obtain an improved Quality of service (QoS). Addressing this issue, a multi objective optimization (MOO) on QoS metrics for clustered mobile networks is proposed in this paper. A simultaneous optimization is done by minimizing the number of cluster heads (CHs) to reduce delay in routing call requests as well as maximizing the number of cluster members under a CH such that network coverage is improved. This is obtained through a proposed ant colony optimization (ACO) based routing algorithm followed by a checking procedure on network status to detect emergence of CHs and correctness of subsequent routing. The effectiveness of the proposed approach over existing one is shown with simulation studies.

Keywords Routing · Ant colony optimization · Cluster head selection · Clustering · Network coverage · Transmission delay

1 Introduction

Mobile networks comprise of different geographic areas known as cells. Each of these is served by a base station (BS), which are linked with neighbors in the network. The task of the BSs is to receive communication from mobile devices scattered in the area. A group of neighboring BSs is considered as a cluster to map the physical network onto a virtual one to reduce the communication overhead. For such reduction, a BS as a node within the cluster is selected as a cluster head (CH). The responsibility of CH is to aggregate communications from its members and act

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as sole representative for that cluster to establish communication with other clusters. Naturally an objective towards optimization of the number of CHs is required to reduce the transmission delay for a call request.

The reduction of transmission delay is associated with reduction of hop count, which can also lead to reduced energy consumption, provided communication is aggregated between CHs. Low-Energy Adaptive Clustering Hierarchy (LEACH) [1] is a cluster-based protocol using randomized rotation of CHs to achieve even distribution of energy dissipation throughout the network. Further, the HYENAS system [2] selects CHs using model-based processing. Here, the BS determines a node metric for each node in the cluster by considering residual energy and the total sum of squared intra-cluster distance.

The techniques discussed earlier are involved with determination of clusters beforehand and consequently determining the CH corresponding to each cluster. However, several combined model for addressing simultaneous routing and clustering have been studied in the area of dynamic networks [3]. A proposed GEDIR (geographic distance routing) algorithm [4] in this field uses the principle of forwarding the packet to one of its neighbors that are closest to the destination. An extension called Avoidance-GEDIR for clustered networks selects the second closest neighbor to destination for forwarding packets by addressing the higher energy consumption of CH nodes.

The clustering in mobile networks has been extensively studied using the concepts of Evolutionary algorithms. Using these algorithms, an objective function based on network parameters is defined for optimization. Under such scenario, an ant colony optimization (ACO) [5–7] based algorithm is preferably used for determining instantaneous routing over the other alternatives like genetic algorithm [8, 9], due to the reduced execution time of the former. Generally, ACO works upon selection of several initial routes analogous to ant trails. Every successive iteration, these routes are further optimized. For illustration, a chemical known as pheromone is left by ants on their trails which attract other ants. Therefore higher number of ants would travel on an optimal trail towards a food source and deposit more pheromones. Thus optimal routes get reinforced as more requests are being served by the ants. Pheromone slowly evaporates over time, simulating the concept that some routes are nearly abandoned in the long run.

In this paper, the dual objective of maximizing network coverage by CHs and simultaneously reducing the number of CHs in a network, is proposed for optimizing both energy consumption and routing delay. Here, an ACO based routing is developed, so that frequent trails get gradual reinforcement and subsequently CHs emerge naturally from the network. The idle trails loose popularity and are finally abandoned. The terminals corresponding to such reinforced routes are identified as the CHs for the network, the rest being the cluster members. For this trained network, requests are routed by following intermediate CHs thus satisfying the objectives mentioned earlier. Simulation studies highlight the fact that sufficient coverage can be achieved with minimal number of CHs by executing the proposed algorithm. In addition, the threshold value of pheromone above which a route would contribute CHs to the clustered network is identified.

The rest of the paper is organized as follows. Section 2 presents the system model and the problem is described in Sect. 3. Next, the proposed solution is presented in Sect. 4. The simulation results are shown in Sect. 5 followed by conclusions in Sect. 6.

2 System Model

The hexagonal cellular layout in mobile networks is transformed into a two dimensional coordinate system in this work as shown in Fig. 1. Every cell is represented as (x, y) in a 3 axes layout due to the angle 120° [10] covered by a BS in a cell. The next set of cells along axis 1 of the layout is determined by an increment or decrement of x-values. Similar cells along axis 2 are determined by change of y-values only, whereas that along axis 3 is done by changes in both the x and y values.

Based upon the layout described in Fig. 1, the neighborhood of every cell is categorized using the physical distance between them. Accordingly, the circles of neighbors around each cell are determined as Node Coordinate Interrelation (NCI) matrix, which is illustrated in Table 1. The model proposed in this work considers up to 5th circle considering the transmission range [11] of every BS.

Two cells (x1, y1) and (x2, y2) are determined as neighbors within transmission range of each other, if the following condition holds.

$$\text{Absolute}\,(x1 - y1 - x2 + y2) \leq 3 \tag{1}$$

The value obtained in (1) is used to determine the possible neighborhood of cells while calculating the possibility of forwarding of request through the layout. Thus the members of neighborhood for each cell are populated in this work as the NCI. On the other hand, NCI is populated with an arbitrary high value for the cells beyond

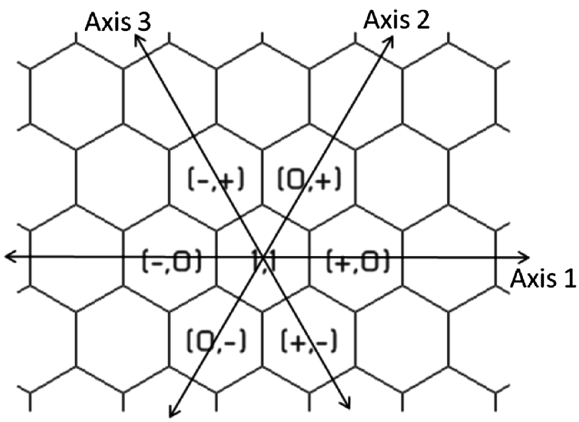

Fig. 1 Cellular layout represented as coordinate system

Table 1 Node coordinate interrelation (NCI) matrix

1st Circle	2nd Circle	3rd Circle	4th Circle	5th Circle
(x, y − 1)	(x − 1, y − 2)	(x, y − 2)	(x − 1, y − 3)	(x, y − 3)
(x − 1, y − 1)	(x − 2, y − 1)	(x − 2, y − 2)	(x − 2, y − 3)	(x − 3, y − 3)
(x − 1, y)	(x − 1, y + 1)	(x − 2, y)	(x − 3, y − 2)	(x − 3, y)
(x, y + 1)	(x + 1, y + 2)	(x, y + 2)	(x − 3, y − 1)	(x, y + 3)
(x + 1, y + 1)	(x + 2, y + 1)	(x + 2, y + 2)	(x − 2, y + 1)	(x + 3, y + 3)
(x + 1, y)	(x + 1, y − 1)	(x + 2, y)	(x − 1, y + 2)	(x + 3, y)
			(x + 1, y + 3)	
			(x + 2, y + 3)	
			(x + 3, y + 2)	
			(x + 3, y + 1)	
			(x + 2, y − 1)	
			(x + 1, y − 2)	

transmission range to inhibit direct communication between them. In addition, it is important to mention that $NCI_{source,destination}$ or NCI_{hop} is the notation commonly used in this work for removing ambiguity in representation. Identical approach in notation is followed for other essential parameters related with the network.

3 Problem Statement

The design of the clustered network in this work is associated with two objectives. The first one is involved with the minimization of the number of CHs such that any request can be routed through minimum number of hops, resulting in reduced delay. Another objective is to simultaneously address the placement of CHs so that maximum coverage can be achieved for the network. Thus the design addressed in this work can be presented by the following multi objective optimization (MOO).

$$\text{Objectives} = \begin{cases} \min(|\text{CH}|) \\ \max\ (\text{coverage}) \end{cases} \tag{2}$$

Subject to:

$$\begin{aligned} &\forall\, \text{route} \in \text{request} \\ &\forall\, \text{node} \in \text{route}, \\ &\text{NCI}_{\text{node,next node}} \leq \text{transmission range} \end{aligned} \tag{3}$$

In (3), the route selected corresponding to a request in the system gets transmitted using hops that are within the transmission range of each other.

4 Proposed Model

The model proposed in this work begins with the initialization of the network as discussed earlier. This involves pre-calculation of NCI for the network, along with the resident energy ($energy_{node}$) for BSs and initial pheromone values corresponding to every possible elementary hop ($pheromone_{hop}$ or $pheromone_{source,destination}$). Next, routing for the incoming set of call requests is attempted by following proposed ACO based algorithm. In addition, the network status is checked after successive intervals of routing to detect emergence of CHs and correctness of subsequent routing by utilizing them.

4.1 Proposed ACO Based Algorithm

It is important to introduce the following key terminologies used in the system before presenting the algorithms. Two modulating factors, α and β has been introduced to normalize the control factors guiding the algorithm discussed later. Another factor λ is applied upon the transmission range for consumption of residual energy at a node. Further, ACO algorithms are characterized by two other factors, pheromone deposit rate (Q) and pheromone evaporation rate (ρ). By natural observation, value of Q is selected to be significantly higher than the value of ρ. The algorithm in this work for determining the routes between the source and destination corresponding to a request while simultaneously using the CHs as intermediate hops is proposed by the following rules.

Rule1
The neighbors of a current node residing in the direction of the destination are considered as possible next hop. Among the alternatives, the hop with a higher pheromone value has a greater chance for getting selected. Further, such a hop gradually reinforces the neighbor, which can subsequently emerge as a CH.

Rule2
The amount of residual energy of the current node determines the possibility of selecting the next hop as a distant or a near one. Here, if the BSs of a region in the network become low in residual energy, CH density of such regions tends to be higher than the rest of the network. Accordingly transmission delay gets prolonged in such regions.

A request queue is maintained locally at every node, having requests originating from it as well as other neighboring nodes. The queue is derived from the call requests for the entire network, which is characterized by parameters like source node, destination node, call duration and priority of the request. The delay encountered by a request at a specific node depends upon the queue length of that node, having priority equal to or greater than the current request. The selection of the next node to forward the request is determined by the rules introduced earlier.

For all the alternatives lying in the direction of the destination node, a weighted product called 'taueta' is derived by obeying the two rules. This ensures that both the factors have sufficient control upon the selection procedure. A roulette wheel selection [12] mechanism upon the cumulative sum of all taueta values determines the next hop. This procedure is described by the following algorithm.

Algorithm 1. determine next hop (current node, destination node)

```
∀ node ∈ transmission range of current node
        if node ∈ direction(destination)
                nodes possible hop = nodes possible hop ∪ {node};
                taueta node = ((energy source/NCI source, node)^ β)*(pheromone source, node ^α);
        end if
end for
taueta cumulative = cumulative sum (taueta);
next node = roulette wheel selection (nodes possible hop, taueta cumulative);
trail source, destination = trail source, destination ∪ hop current node, next node;
```

Based on Algorithm 1, once a call has been successfully routed from the source to destination, subsequently the residual energy of the initial and intermediate forwarders are reduced by a factor depending on the distance of the transmission hop to the next node. Besides, the pheromone values of the hops used in the current trail is increased, whereas the same for all other possible hops is reduced. This is illustrated by Algorithm 2.

Algorithm 2. adjust parameter values (trail)

```
∀ hop  ∈ trail source, destination
        decrease = (1-ρ) * pheromone hop ;
        increase = Q / length(trail);
        pheromone hop = decrease + increase;
        energy hop-source = energy hop-source – λ * length(hop);
end for
```

4.2 Evaluation of CH Selection and Network Coverage

The proposed methodology for determining the number of CHs and network coverage is based on the pheromone value of the hops obtained in Algorithm 2. This procedure is executed alongside the routing described in Algorithm 1 to check the emergence of CHs and accuracy of subsequent routing. The pheromone values are initialized to a small fraction uniformly for all the hops. While routing, the pheromone values are updated according to the number occurrence of the hops in the trails. Thus, an important hop has significantly higher probability of getting selected for future routing. The terminals of such a hop can be treated as CHs, and transmissions are more probable to converge on such a node on later stage as compared to other members. The threshold pheromone for a hop, beyond which CHs emerge, is determined in this phase.

Coverage of the network is defined as the percentage of nodes that finds at least one CH among its neighbors, which undoubtedly, would increase upon decreasing the threshold pheromone. However, decreasing this threshold has the effect of unnecessary increase of CHs in the entire network, which would result in increased delay in subsequent requests. Hence an optimal balance between these two is necessary, which is heuristically determined in this step. The entire procedure is described by Algorithm 3.

Algorithm 3. Evaluation of coverage and optimal CH count

```
∀ threshold ∈ {1:0.1 step (-0.05)}
        hops_prominent = {hop | pheromone_hop > threshold} ;
        ∀ hop ∈ hops_prominent
                CH = CH ∪ {source_hop} ∪ {destination_hop} ;
        end for
        ∀ node ∈ network
                If ∃ neighbor_node such that neighbor_node ∈ CH
                        count_coverage = count_coverage +1;
                end if
        end for
        if count_coverage / count (node ∈ network) == 1
                threshold_coverage = threshold ;
                break;
        end if
end for
```

5 Simulation Studies

The experimental results for the proposed model have been obtained by simulating a network grid of size 100 × 100, and simulating random requests between the nodes. The various system parameters are highlighted in Table 2.

For a randomly generated set of requests, the threshold is varied from 1 to 0.1 with different values of Q and ρ. Higher values of ρ imply more decrease in pheromone value. The increase effect is produced by adding a proportion of the current ant's total trail length, where the proportion is determined by Q. Higher values of Q increase the amount of deposited pheromone. Simulation studies show that a high value of Q leads to identification of high number of CH and total coverage in network. With a low value of Q (=2) we can still achieve total coverage at a low value of threshold. Keeping Q fixed, next ρ is varied. With reasonably low value of ρ, total coverage is achieved, which is illustrated in Figs. 2 and 3.

Table 2 Simulation parameters

Network grid size	100 × 100
Allowable diversion	Maximum 5 nodes
Objective modulator (α)	3
Objective modulator (β)	2
Pheromone evaporation rate (ρ)	0.1
Pheromone deposit rate (Q)	2.0
Interval for threshold calculation	100 Requests
Energy depletion factor (λ)	0.05

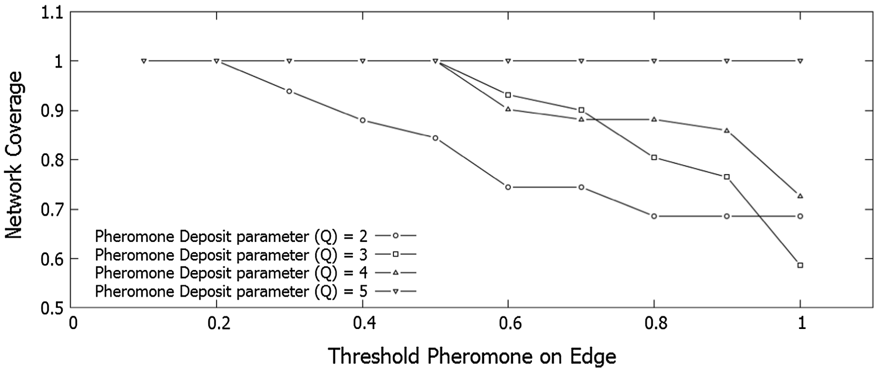

Fig. 2 Node coverage versus threshold pheromone for different values of Q

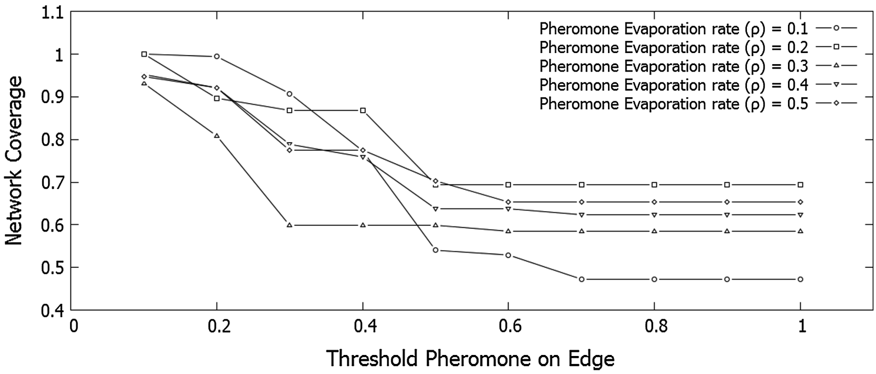

Fig. 3 Node coverage versus threshold pheromone for different values of ρ

Once total coverage in the network is achieved, another objective to minimize the number of CHs is attempted. As we interpret from Fig. 4, a high percentage of CHs (nearly 30 %) can achieve 100 % coverage, whereas only a third of that, i.e. nearly

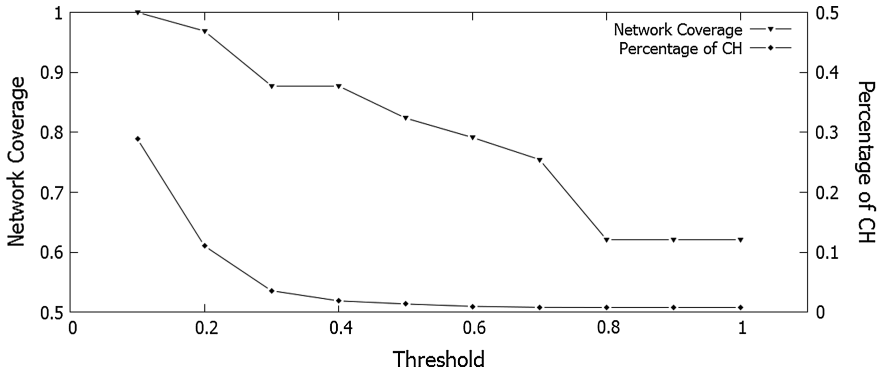

Fig. 4 Node coverage and CH probability versus threshold pheromone

10 % CHs is able to achieve over 95 % coverage in the network. For optimal results, we can target less than 100 % coverage in the network at a reasonably reduced number of CHs, resulting in reduced transmission delay in the network.

Further, a comparison with the iterative approach of CH selection, as attempted in traditional approaches [1, 13–15], is performed. These perform a randomized CH election, based upon the fact that a CH that has been earlier elected has reduced chance of getting elected again. However, the algorithm proposed in current work illustrates a reverse concept, nodes that are elected as CH has higher chance of getting elected in next rounds. The former approaches attempt uniform energy depletion in the network, ignoring the concept of coverage. As seen from Fig. 5, the proposed algorithm selects CHs with stable coverage upon the entire network, which is higher than the average coverage gained by traditional models.

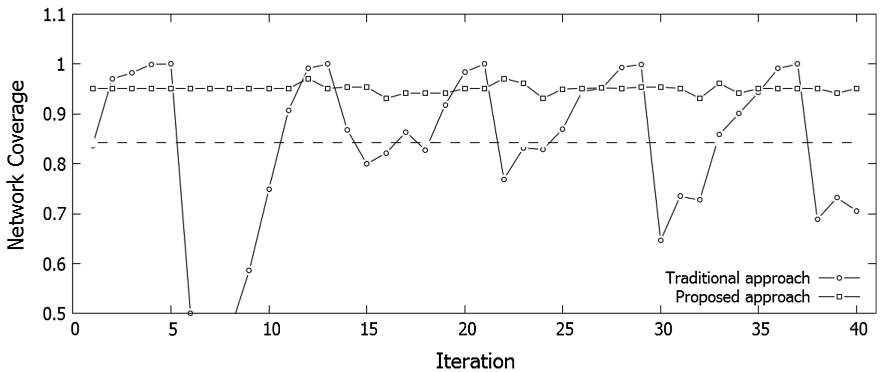

Fig. 5 Comparison of network coverage of the proposed algorithm and traditional approach

6 Conclusions

In this work, an ACO based routing algorithm that plays the dual objective of minimizing CHs in the network and increasing coverage is proposed. These objectives are modeled with an attempt to address the granular requirement of reducing the transmission delay and energy consumption in mobile networks. The proposed algorithm is implemented to cluster the routes for call requests in a network. Simulation studies derive the threshold upon the parameters, using which we can achieve maximum network coverage for a minimum assignment of CHs. Improvement by the proposed model over the traditional one is highlighted. Further, subsequent improvements in different network scenarios through similar evolutionary algorithmic approaches are under current investigation.

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