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Stable Clusterhead Selection Algorithm for Ad Hoc Networks

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Abstract

This paper provides a clusterhead review of clusterhead selection algorithm in Mobile Ad Hoc Networks (MANETs) and proposes a Stable Clusterhead Selection Algorithm for ad hoc networks (SCSA). The algorithm constructs a stable clusterhead with the help of reducing the number of clusterhead reconstruction. It selects the nodes which have the stability to be the clusterheaders. The results of simulation show that, with the proposed SCSA clusterhead selection algorithm, the average number of clusterheads, the frequency of clusterhead changes, the frequency of cluster member changes, and cluster lifetime can be improved in most of cases. It is an available approach to clusterhead decision.

Keywords: *MANET; clusterhead; mobility; Algorithm*

1. Introduction

A mobile ad hoc network (MANET) is a collection of distributed mobile nodes without any fixed infrastructure (such as access points and base stations) or any form of centralized administration. Such a network can be effectively used in military battlefields, emergency disaster relief, and other emerging applications including dynamic mobile ad hoc networks. One of the most distinguished characteristics is that each node plays a router for multihop routing. Due to limited energy and bandwidth, there exist many challenging issues in wireless communication in MANETs [1-12]. For this reason, many routing protocols have been developed, trying to accomplish this task efficiently. For example, in some routing algorithms, where each node maintains a global routing table, in order to deal with the topology changes due to the movements of nodes, the routing table in each node must be updated [5-9].

In spite of these constraints, MANETs are designed such that they are able to dynamically adapt themselves with the changing network configurations. One of the ways to handle the topology changes and to maintain a connected network can be brought about by entrusting certain nodes with more responsibility [7-14]. Serving as the basic technology of large-scale networks, clustering structure also brings convince to hierarchical network management [4-10]. A cluster structure divides a network into groups called clusters, each of which consists of one clusterhead and some ordinary nodes. In each cluster, the clusterhead controls the communications in intra-cluster and inter-clusters. To reduce unnecessary communication and to keep providing stable service for external application using the cluster structure, stable cluster structure is necessary. The paper consider a realistic mobility model, called Random Waypoint Group mobility model (RWG) where nodes move in groups. This type of mobility can be seen in event sites and stations. In such a situation, if each group forms a cluster, the cluster structure may be kept unchanged for a long time. This is an important issue since frequent clusterhead changes adversely affect the performance of algorithms such as the stability of clusters, speed of mobile nodes, local topology, and battery power. Choosing clusterhead algorithm is an NP-hard problem [4-10].

In this paper, the authors focus on providing stable cluster structures, specifically for highly wireless networks such as MANETs. Due to node movement and unstable radio channel, the network topology may change frequently. These changes will cost bandwidth to transmit a great amount of control messages to update the routing table in every clusterhead. Thus, the stability of available wireless communication connections is one of the most important concerns in this scenario. The clustering scheme proposed in this paper refers to Stable Clusterhead Selection Algorithm for ad hoc networks (SCSA), which is suitable for highly mobile ad hoc networks where moving direction and speed of nodes are not directly available or easily obtained. The proposed method discovers such mobility groups in a distributed manner and elects a clusterhead based on the stability and the movement vector of each mobility group, including an adaptive clustering routing transition protocol (ACRT) [8], type-based cluster-forming algorithm (TCA) [10] and the proposed method by simulation experiments. The paper consider one parameters for the determination of the clusterheads — mobility of the nodes. More specifically, our contributions are the following.

First, the paper demonstrate the motivation behind using cluster lifetime for capturing relative information.

Next, the paper calculate the stability for node parameters — the cluster lifetime.

Through simulation experiments, the paper demonstrate the performance of proposed scheme in terms of the average number of clusterheads, the frequency of clusterhead changes, the frequency of cluster member changes, and the cluster lifetime.

The rest of the paper is organized as follows. In Section 2, the paper briefly review the clusterhead selection algorithm for ad hoc networks. Section 3 presents proposed Stable Clusterhead Selection Algorithm for ad hoc networks (SCSA). Some simulating results are provided in Section 4. Finally, the paper concludes in Section 5.

2. Related work

Several clustering methods for MANETs focusing on node mobility and power consumption have been proposed. Many existing solutions have been taken into account various parameters of clusterhead suitability.

Clustering technology is particularly promising and has received much attention in the research community. In a hierarchical network, the data gathered by the ad hoc nodes is transmitted to clusterhead. The sensed data from nodes within one cluster usually exhibit high correlation. Therefore, a clusterhead can aggregate data to remove redundancy and only to send one packet to the sink.

A node is selected to be the clusterhead when it has the minimum weighted sum of four indices: the number of potential members; the sum of the distances to other nodes in its radio distance; the node’s average moving speed (where less movement is desired); and time of it being a clusterhead. When a node moved out of its cluster, it will firstly check whether it can be a member of other clusters. If such a cluster exists, it will detach from current cluster and attach itself to that one. The process of joining a new cluster is known as reaffiliation. If the reaffiliation fails, the whole network will recall the clusterhead election routine.

The mobility-based d-hop clustering algorithm (MobDHop), which forms variable-diameter clusters based on node mobility, is proposed in Ref. [4]. This algorithm introduces a new metric that measures the variation of distance between nodes over time to estimate the relative mobility of two nodes. Tian *et al.*, [5] proposes a novel chain-cluster based routing protocol (ECR). ECR takes advantages of both LEACH and PEGASIS, so the network lifetime of ECR is longer than that of LEACH or PEGASIS. Because ECR uses chain to send data, the delay is as long as that of PEGASIS. And ECR needs sink perform concentrically control. So, the scalability of ECR is not good. Huang *et al*., [6] presents a cluster-based load balancing multi-path routing protocol (CLBM), which obtains better load-balancing and longer network lifetime than PEGASIS does. However, the clustering method of CLBM is the same as that of LEACH. Ni *et al*., [7] proposes a scheme, Doppler shifts associated with received signal are used to estimate the relative speed between cluster head and cluster members. So, the distribution of clusterheads is not satisfactory. To solve the expansibility problem of traditional flat routing protocols in ad hoc networks, Xu *et al*., [8] proposes an adaptive clustering routing transition protocol (ACRT). ACRT creates clusters adaptively by real-time apperceiving network scale which can solve the conflict between the expansibility of flat routing protocols and clustering overhead of clustering routing protocols. Wei *et al*., proposes [9] a distributed clustering algorithm, Energy-efficient Clustering (EC), that determines suitable cluster sizes depending on the hop distance to the data sink, while achieving approximate equalization of node lifetimes and reduced energy consumption levels. In order to reduce the update frequency of cluster-heads, Wu *et al*., [10] proposes a type-based cluster-forming algorithm (TCA) for employment in emergency MANETs, where the nodes tend to move in a concerted action as a group. They propose a method assigning a larger weight to a node with fewer changes in its relative position. However, this method does not consider any realistic node mobility.

Xu *et al*., [11] propose a Density-based Energy-efficient Clustering Algorithm (DECA). The DECA define the density of each node and regard it as an important evaluation metric. Together with nodes' residual energy under consideration, each cluster head is selected based on the density of nodes. Kawai *et al*., [12] proposed a stable clustering scheme, which uses the average speed to estimate the time that a cluster member may stay in a cluster. The scheme is based on the assumption that every node knows its absolute Cartesian coordinates in the deploying area. Wang *et al*., [13] proposed coverage-aware clustering protocol, the paper define a cost metric that favors those nodes being more energy-redundantly covered as better candidates for cluster heads and select active nodes in a way that tries to emulate the most efficient tessellation for area coverage.

3. Stable clusterhead selection algorithm (SCSA)

In the clustering algorithm, each node is granted a priority, reflecting how the node is suitable to be the clusterhead. While determining the priorities, the following factors are considered: the speed of the node is taken as one of the factors because the slower the speed is, the higher the priority is; clusterheads need more stable.

3.1. Network model

The network consists of N uniformly distributed mobile nodes in an area of $l \times l$ square meters. The communication range is r meters for every node. In the moving phase, the node chooses a random direction from $[0, 2\pi]$ and a random speed from $[v_{\min}, v_{\max}]$. The direction and the speed are both uniformly distributed random variables. The paper denote the longest membership time as the random variable T_m. The paper assume that link existence is solely determined by the distance between nodes, and ignore the link disruptions due to wireless signal interferences and obstructions. A cluster is constructed by determining the clusterhead and its affiliated clustermembers. A clustermember is always connected directly to its clusterhead. Two clusters are neighbors if there exists at least one link that connects two nodes from the two clusters respectively.

Each node may work as one of the four following roles: clusterhead, gateway, compound gateway and cluster member. As shown in Figure 1, node 1 is the clusterhead of cluster A, node 2 is the gateway between cluster A and cluster B, node 3 and node 4 construct a compound gateway connecting cluster A and cluster C.

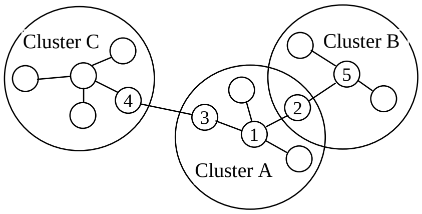

Figure 1. Cluster architecture

3.2. Cluster lifetime

The longest cluster lifetime is achieved when the clusterhead undertakes its role without interruption until its entire affiliated cluster members have moved away. Xu *et al.*, [14] has defined a cluster lifetime, more detailed definition sees literature [14].

The relative speed V_R is representative of the relative speed between a node and its neighbour nodes. A lower value of V_R indicates a lower relative speed with respect to a neighbour node, thus a low-speed node is more suitable for election as a clusterhead. The paper illustrate the movements inside and the relative speed in Figure 2.

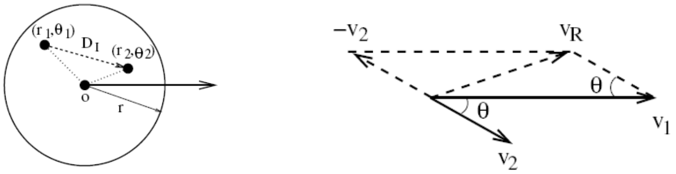

Figure 2. The movements inside and the relative speed V_R

1) Cluster Membership Time: The longest membership time takes place when clustermembers stay affiliated to its clusterhead all the time until they move to *r* meters apart. This is measured by their neighboring time.

In the Figure 2, both nodes are moving initially. With probability P_I, they stop within each other's transmission area. Denoting the time to one node stopping as T, We have $E(T) = \tau_{2,I} = E(D_I/V_R) = E(D_I)E(1/V_R)$, where $\tau_{2,I}$ denotes the mean time of two nodes moving inside each other's transmission area, D_I is the random travel distance inside the transmission area, and V_R is their relative speed. $E(D_I)$ is determined by

$$\begin{aligned} E(D_I) &= \frac{1}{(\pi r^2)^2}\int_0^{2\pi}\int_0^{r}\int_0^{2\pi}\int_0^{r} d(r_1,\theta_1,r_2,\theta_2) r_1 dr_1 d\theta_1 r_2 dr_2 d\theta_2 \\ &\approx \frac{1}{(\pi r^2)^2}\sum_{\{r_1,\theta_1,r_2,\theta_2\}} d(r_1,\theta_1,r_2,\theta_2) r_1 (\frac{r}{k})(\frac{2\pi}{k}) r_2 (\frac{r}{k})(\frac{2\pi}{k}) \\ &= \frac{4}{k^4 r^2}\sum_{\{r_1,\theta_1,r_2,\theta_2\}} d(r_1,\theta_1,r_2,\theta_2) r_1 r_2 \end{aligned} \tag{1}$$

where $d(r_1,\theta_1,r_2,\theta_2) = \sqrt{(r_1\cos\theta_1 - r_2\cos\theta_2)^2 + (r_1\sin\theta_1 - r_2\sin\theta_2)^2}$

Because no closed-form solution exists for the integral in (1), the paper approximate it by the numerical computation that divides the domain of each variable into k subsets and sums up the approximate integration result in each subset combination. The speed V_R is uniformly distributed and compute $E(1/V_R)$ as

$$E(\frac{1}{V_R})=\frac{1}{\pi(v_{\max}-v_{\min})^2}\int_{v_{\min}}^{v_{\max}}\int_{v_{\min}}^{v_{\max}}\int_0^{\pi}\frac{1}{V_R}d\theta dv_1 dv_2 \approx \frac{1}{k^3}\sum_{\{\theta,v_1,v_2\}}\frac{1}{V_R} \tag{2}$$

where $V_R=\sqrt{v_1^2+v_2^2-2v_1v_2\cos\theta}$

2) Cluster Lifetime: Let T_h denote the longest cluster lifetime. The paper assume clustermembers come and leave in Poisson processes. Transitions take place when nodes join and leave. λ is determined as follows. Denoting N_m and N_h as the total number of clustermembers and clusterheads in the network respectively,

$$\lambda=(\frac{N_m}{E(T_m)}+\frac{N_h}{E(T_h)})\cdot\frac{\pi r^2}{l^2}\cdot\beta_1\cdot\beta_2 \tag{3}$$

where $N_m/E(T_m)+N_h/E(T_h)$ accounts for the network wide arrival rate of nodes seeking a cluster to join, $\pi r^2/l^2$ is the geographical factor considering the percentage that takes place in the clusterhead's transmission area, β_1 is the mobility factor, and β_2 is the clusterhead selection factor.

3.2. Clusterhead election process

In SCSA, a clusterhead is selected based on the node's mobility, and a node with larger weight is more likely to be selected as a clusterhead. SCSA guarantees self-stabilization and robustness even when the network topology changes. The main motive of clusterhead election process is to select minimal mobility of nodes that dominate the whole network only by using 1-hop neighborhood information. If node *i*'s priority is higher than all of its 1-hop neighbors', then node *i* sets itself as the clusterhead. Since the nodes use the same information and run the same algorithm, so if *i* determines itself as the clusterhead, it means that its 1-hop neighbor works out the same result; otherwise, node *i* elects one of its 1-hop neighbors with the highest priority as the clusterhead. In the clusterhead election process, node *i* sets the states of all of its 1-hop neighbors as FALSE, meaning they are not yet dealt with by node *i*.

4. Simulation Experiments

4.1. Simulation model

To effectively evaluate SCSA's performance, the paper compare it with other famous clusterhead protocols ACRT [8] and TCA [10] for the average number of clusterheads. The number of clusterhead updates per unit time, and the number of nodes changes events per unit time. To conduct the simulation studies, the paper have used randomly generated networks on which the algorithms were executed [15]. This ensures that the simulation results are independent of the characteristics of any particular network topology.

The paper use network simulator (NS-2) [16] to simulate our proposed algorithm. In our simulation, 50 mobile nodes move in a 1000 m × 1000 m rectangular region for 600 seconds simulation time. All nodes have the same transmission range of 250 m. The mobility model is the Random Waypoint Group Mobility Model (RWG) [17] with the displacement varying uniformly from 0 to a maximum value per unit time. The RWG shows the highest hops count. This is because all the data packets can potentially need several forwarding nodes. On the other hand, those scenarios using any of the group mobility model have a mixture of intra-group data packets and intergroup data packets, thus the average hops count decreases with respect to the RWG case. Each node has a pause time of two seconds to simulate a high mobility environment. In the RWG, a group mobility model imbedded with partition function is used as the basis to evaluate our SCSA algorithm. The traffic type is CBR with a 512-byte data packet. The application agent is sending at a rate of 10 packets per second whenever a connection is made. The maximum data rate is set at 2 Mbps, and the IEEE 802.11 distributed coordination function (DCF) is used as the MAC layer protocol. Table 1 lists the simulation parameters which are used as default values unless otherwise specified. The paper conduct the simulation experiments 100 times and show the average results.

To measure the performance of our proposed stable clusterhead selection algorithm, the paper identify four metrics:

1) The average number of clusterheads: The average number of clusters shows the quality of clustering.

2) The frequency of clusterhead changes: The frequency of clusterhead changes counts the number of output state changes (from an ordinary node to a clusterhead and from a clusterhead to an ordinary node) for all nodes per step.

3) The frequency of cluster member changes: The frequency of cluster member changes counts the number that ordinary nodes move from one cluster to another per step.

4) Range of communication: This is the radius of cluster head’s coverage area.

5) Cluster lifetime: The longest cluster lifetime is achieved when the clusterhead undertakes its role without interruption until all of its affiliated clustermembers have moved away. Since it is determined by the time when the last clustermember leaves, the paper investigate a clustermember’s membership time first.

Table 1. Simulation parameters

Number of nodes	100	Map Size	1000 m×1000 m
Transmission range	250 m	Simulation time	600 seconds
Node’s mobility speed	2-20 m/s	Mobility model	Reference point group
Communication model	Constant bit rate (CBR)	Connection Rate	10 pkts/seconds
Node pause time	2 seconds	Examined routing protocol	ACRT [8], TCA [10]

4.2. Simulation results

Figure 3 shows that the average number of clusterheads varies as a function of the maximum node speed. The paper can observe that as speed increases because of links break the average number of clusterheads varies increase in SCSA, ACRT and TCA. This is because, in higher speeds, more frequent link breakage may occur and consequently a packet loss fraction is increased. At lower speeds, the difference between the four methods is negligible. However, at high speed like 20 m/s of SCSA, it does much better while the performance of ACRT and TCA. Our SCSA exhibits a lower sensitivity to the node speed than the ACRT and TCA. The improved resilience against node speed fluctuations is attributed to the quantitative consideration of the relative node-mobility and long-term node-stability measures. In the SCSA, the paper limited the size of each cluster, and therefore the number of clusterheads was relative stable, when the maximum speed is varied.

The frequency of clusterhead changes is related to the maximum node speed, as shown in Figure 4. Figure 4 shows the success delivery ratio for SCSA, ACRT and TCA. It illustrates that our proposed SCSA outperforms ACRT and TCA at any mobility speed ranging from 2 to 20 meters/second.

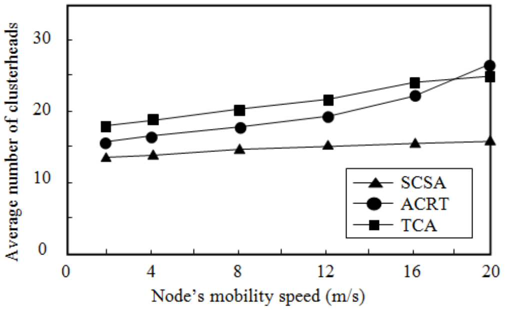

Figure 3. Average number of clusterheads vs node's mobility speed

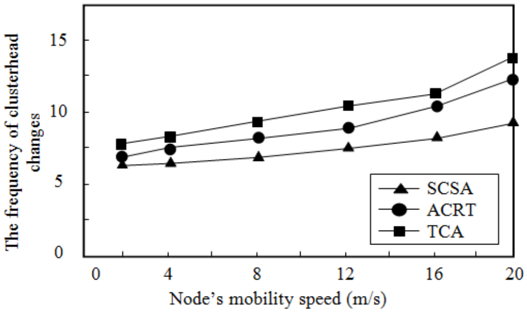

Figure 4. The frequency of clusterhead changes vs node's mobility speed

Figure 5 demonstrates the frequency of cluster member changes at different level of node mobility, respectively. SCSA achieves a lower frequency of cluster member changes compared to ACRT and TCA.

The increment of movement speed induces more frequent topology change and thus the probability of broken links grows. Broken links may cause additional clusterhead recovery process and clusterhead discovery process. As the node speed is increased, the nodes roam more often outside the coverage range of their clusterhead, and hence the cluster structure becomes more unstable. Similarly, the number of clusterhead updates and the cluster-change events become increasingly more frequent. The paper observe in Figure 5 and Figure 6 that propose SCSA significantly improves the stability of the cluster structure, and accordingly reducing the frequency of clusterhead update events, as the node mobility increased.

The average cluster lifetime as obtained through the simulations is shown in Figure 6. In Figure 6, the average cluster lifetime of SCSA is at most 10-20% larger than that of ACRT and TCA and the corresponding improvement curve shows that the advantage of SCSA in extending cluster lifetime is becoming more and more obvious with the increasing number of nodes. In Figure 6, the cluster lifetime of the ACRT and TCA is significantly shorter than that of SCSA.

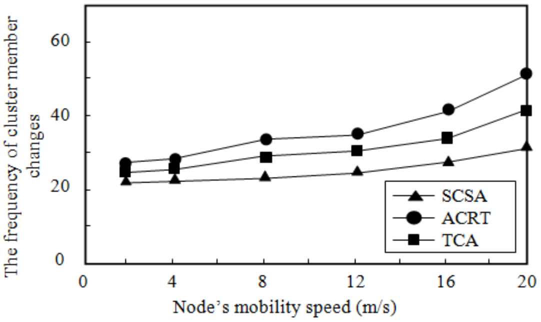

Figure 5. The frequency of cluster member changes vs node's mobility speed

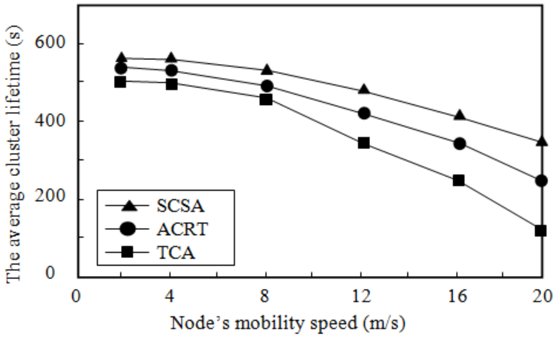

Figure 6. The average cluster lifetime vs node's mobility speed

To simulate and investigate the effect of communication range, another set of simulations have been done. As shown in Figure 7. ACRT shows much more dependence on the communication range to form stable clusters. SCSA outperforms the other two and provides a balanced performance as it more accurately estimates the link duration in addition to handling the predictable connection loss. Similarly, Figure 8 shows the effect of communication rage on the average cluster lifetime. The figure also reveals that SCSA produces stable clusters compared with the other two schemes.

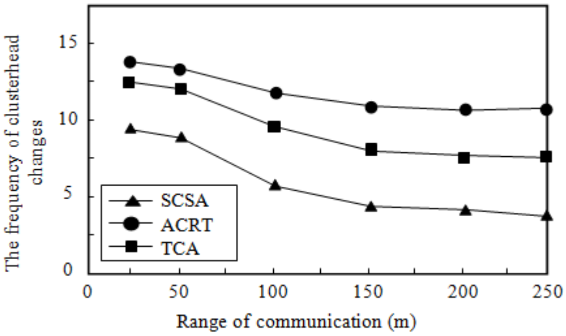

Figure 7. The frequency of clusterhead changes vs node's range of communication

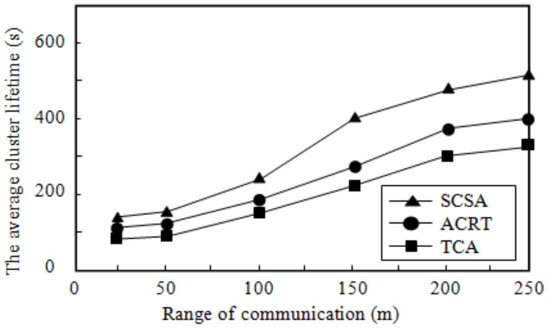

Figure 8. The average cluster lifetime vs node's range of communication

5. Conclusion

In this paper, the authors propose Stable Clusterhead Selection Algorithm for ad hoc networks (SCSA). The algorithm constructs a stable clusterhead with the help of reducing the number of clusterhead reconstruction. It selects the nodes which have the stability to be the cluster headers. Compared to the adaptive clustering routing transition protocol (ACRT) and type-based cluster-forming algorithm (TCA), SCSA assigns the construction of clusterhead selection it algorithmically simple, resulting in the improved performance of the average number of clusterheads, the number of clusterhead updates per unit time and the number of nodes change events per unit time incurred at intermediate nodes. The simulation experiments showed that the considered SCSA algorithm is able to cope with this type of dynamic networks, in particular its ability to improves the system performance which has been reflected in the model, since it reduced both the number of clusterhead update events and cluster change events. Hence its quality-of-service may be deemed higher. In the future, we would explore a more realistic joint system to improve the cluster-forming and update with the aid of the fuzzy controller.

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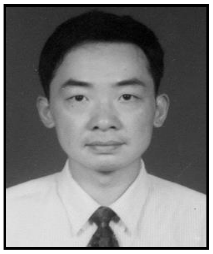

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