A Suitable Size Clustering Algorithm for Ad Hoc Wireless Networks*

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Abstract: Transmit power control is central technique for resource and interference management in Ad hoc wireless network. While power control has been traditionally considered as a means to counteract the harmful effect of channel fading, the more general emerging view is that it is a flexible mechanism to provide quality of service for individual users. In this paper, a novel adaptive clustering algorithm is presented in order to alleviate the dynamic characteristics of network topology and economize the power energy simultaneously. This proposal is a GPS based mechanism. By predicting the next location of mobile host with its historic trajectory, it adjusts its transmit power in advance. In order to maximize the throughput of network, it controls all clusters in suitable size adaptively. Experiments on GlomoSim have been conducted. The results show that clustering approach proposed in this paper is a practically valuable topology management mechanism for ad hoc wireless networks, especially for mobile networks composed of high-speed mobile hosts.

Key words: Ad hoc networks; mobility prediction; power control; clustering algorithm

Mobile hosts and wireless network hardware are becoming widely available, and extensive work has been conducted lately in integrating these elements into traditional networks such as the Internet. Oftentimes, however, mobile users wish to communicate in situations in which no fixed wired infrastructure available, either because it is not economically practical or physically possible to provide the necessary infrastructure or because the expediency of the situation does not permit its installation. For example, a class of students may need to interact during a lecture, friends or business associates may run into each other in an airport terminal and wish to share files, or a group of emergency rescue workers may need to be quickly deployed after an earthquake or flood. In such situations, a collection of mobile host with wireless network interfaces may form a temporary network without the aid of any established infrastructure or centralized administration. This temporary network is also called ad hoc network.

An ad hoc network is a collection of wireless mobile hosts forming a temporary network without the aid of any established infrastructure or centralized administration. In such a setting, it may be necessary for one mobile host to

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WANG Hong-bo was born in 1977. He is a Master student at the Tsinghua University. His research interests are routing and Qos control in wired networks and mobile ad hoc wireless networks. **ZHANG Yao-xue** was born in 1956. He is a professor and doctoral supervisor at the Tsinghua University. His current research areas are network interconnection, active network, program mining and services management. **WANG Xiao-hui** was born in 1972. He is a Ph.D. candidate at the Tsinghua University. His research interests are protocol design and performance evaluation for mobile ad hoc wireless networks. **GUO Guo-qiang** was born in 1964. He is an associate professor at the Changde Normal University. His current research areas are Qos control, and traffic engineering enlist the aid of other hosts in forwarding a packet to its destination, due to the limitation of each mobile host's wireless transmit range.

Numerous challenges[1] must be overcome to realize the practical benefits of ad hoc networking, for the network is highly dynamic and transmissions are susceptible to fading, interference, or collision from hidden/exposed stations. These challenges include effective routing, medium (or channel) access, mobility management, power management, security, and, of principal interest, quality of service (QoS) mainly pertaining to delay and bandwidth management.

Because nodes mobility can cause frequently unpredictable topological changes, the task of finding and maintaining routes in Ad hoc is non-trivial. Many protocols[2,8,9,11~13,19] have been proposed for ad hoc wireless network with the aim of achieving efficient routing.

In this paper, we concentrate on solving the problems caused by nodes moving with a relatively high velocity. For these fast-moving nodes, their location updates become obsolete by the time they reach the correspondent node. A reactive ad hoc routing protocol like[2] cannot be employed, because by the time a source route is established, the node has already moved to a new location, possibly a fair distance away from the previous one. This renders the source routing obsolete.

Mobility prediction based on an individual's movement history has been reported as an effective means to decreasing call-dropping probability and to shorten handover latency. To solve the above problem, a predictive geometric location-based ad hoc clustering algorithm has been developed. In our algorithm, we attempt to predict the future location of all hosts using geometric information from their previous location respectively, and adjust the topology before packet forwarding to avoid the active route disruption. The neighbor location updates are generated either periodically or by interrupt, caused by considerable change in the existing pattern of motion or velocity.

On the other side, power resource is limited for mobile facility. We must attach more attention to make power consumption economically possible. Furthermore, transmit power determines network topology and therefore has a direct impact on the performance of the clustering solution. A recent paper [3], based on a simple interference model (all nodes in an ad hoc network interfere in a omnidirectional fashion with a power decay law), derives a very interesting result. If there are N nodes in a bounded region attempting arbitrary point-to-point communication, the throughput per node decreases at $1/\sqrt{N}$. Obviously, it indicates that the congestion & collision control becomes more critical in larger scale cluster.

In order to bypass these problems discussed above and keep network in connectivity, we must make great efforts to search a novel mechanism. We found that maintaining the cluster at a moderate size can improve the total network throughput and avoid the complicate collision & congestion control.

Due to the constraint length of the paper, we only discuss mobility management assisted by power control to maintain an efficient and stable network supporting multimedia applications, which require quality of service guarantee, and to minimize the network management overhead and maximize the network throughput simultaneously. By predicting the mobile nodes' next position, the transmit power of relative mobile nodes is adjusted to control the cluster size and maintain the network connectivity.

The organization of the rest of this paper is as follows, Section 1 briefly reviews the related works on mobile management and power control. Section 2 presents network architecture. Based on this architecture, Section 3 introduces mobility prediction and power control to cluster the network. Section 4 shows the system performance. Section 6 concludes the paper and previews the future work.

1 Related Work

1.1 Clustering scheme

The clustering algorithm presents a logical topology to the routing algorithm, and it accepts feedback from routing algorithm in order to adjust that logical topology and make clustering decisions. So clustering algorithm plays a crucial role in ad hoc wireless networks for efficient routing.

Many clustering schemes[4~9] have been proposed out of special issue. References [4,5] are 1-hop clustering algorithms, in which every node can be reached with at most 2 hops from any other nodes in the same cluster, but there is no clusterhead. Kwon and Gerla in Ref.[4] propose a clustering proposal with power control, but it doesn't yield a practical method for power calculating. Other researchers in Ref.[6] aim at dealing with the problem of topology scalability

In order to reduce the communication overheads of migrating management information from old clusterheads to new clusterheads, proposal proposed in Ref.[7] tends to reelect existing clusterheads as cluster governors even when the network configuration changes. Chen in Ref.[8] views the connectivity as primary and lower ID as secondary criteria for selecting clusterhead. Mario in Ref.[9] uses simple geographic partition as clustering principle. Its advantage is that it does not require any measurement of radio propagation characteristics, whereas the radio propagation partition is more accurate than geographic partition for frequency reuse.

1.2 Proposed mobility model & mobility prediction

The mobility is an intrinsic characteristic of Ad hoc wireless network. Many researchers have presented their mobility models and proposals[2,10~14] to deal with this problem. These mobility models focus on the individual behavior in successive epochs, which are the smallest periods in a simulation, in which mobile hosts move in a constant direction at a constant speed. Reference [10] uses the random mobility model, in which mobile host moves in a constant direction at a constant speed. According to this model, the speed and direction of motion in a new time interval are independent from their histories, that is to say, this model can generate unrealistic mobile behavior such as sharp turning or sudden stopping. Some authors use modified versions of the random mobility. Jonson's Random Waypoint mobility model in Ref.[2] is also extension of random walk. This model breaks the entire movement of a mobile host into repeating pause and motion periods - a mobile host first stays at a location for a certain time then it moves to a new random-chosen destination at a speed uniformly distributed between [0, MaxSpeed].

Chiang's Markovian model[11] is another way to describe the random motion. States represent motion directions. The probability of maintaining the current state is specified in the transmit matrix. Once in motion the mobile host is more likely to keep on going in the current direction at the same speed. This model is more realistic than the random model. Similar to Chiang's Markovian model, other model[12] considers the relationship between a mobile host's previous motion behavior and the current movement in speed and direction. In particular, Haas[13] presents an incremental model in which speed and direction of current movement randomly diverge from the previous speed and direction after each time increases.

$$v(t+\Delta t)=\min[\max(v(t)+\Delta v,0),V_{\mathrm{MAX}}],\qquad \theta(t+\Delta t)=\theta(t)+\Delta\theta,$$

here Δv and $\Delta\theta$ are uniformly picked up from a reasonable data range of $[-A_{\max}\Delta t, A_{\max}\Delta t]$ and $[-\alpha\Delta t, \alpha\Delta t]$. $A_{\max}$ is the unit acceleration/deceleration and α is the maximal unit angular change.

Group motion model RPGM presented in Ref.[14] firstly organizes the mobile wireless network as several groups according to the logical relationship between mobile hosts; then, defines the motion of groups explicitly by giving a motion path for each group. The path that a group follows is given by defining a sequence of checkpoints along the path corresponding to given time intervals. As time goes by, a group moves from one checkpoint to the next on a continuing basis.

All above mobility models are proposed to generate the node motion for simulation, but none of them is incorporated into predicting the next location of mobile nodes adapting to topology change proactively.

William *et al* in Ref.[12], based on mobile node currently moving parameters (e.g., speed, direction, radio propagation range, etc), determine the duration of time when two neighbor hosts will remain connected, and a routing scheme is proposed based this value to achieve the stable route, but they only use this information for routing selection, not take any reaction to adapt the network for improving the network performance.

Chan *et al* in Ref.[15] have compared many kinds of mobility predication scheme, and concluded that the Direction Criterion has the best performance and that a high level of statistical randomness in users' movements may cause low prediction accuracy.

1.3 Power control mechanism

Power energy is a very scarce and expensive resource for mobile host, and configured power transmit range of host influences the total wireless network throughput[1]. Many researchers have studied in this area and proposed their schemes. The selection of optimal transmit range to maximize throughput is studied in Refs.[16,17]. However, they do not describe any techniques for actually controlling the power, nor do they concern themselves with connectivity.

Jie and Ming in Ref.[18] propose an algorithm of calculating connected dominating sets, taking nodes remainder energy into consideration, because nodes in the connected dominating set will consume more energy than those outside the set to transfer traffic for others. To prolong the life span of each node, and hence, it is necessary to balance the energy consumption by choosing nodes to form a connected dominating set alternately, but they didn't touch upon the concreted power transmit range adjustment scheme. Reference [19] is a routing algorithm, which takes power consumption as a cost metric, and weighs this problem in the other side.

The most related works have been done by Kwon[4] and by Ramanathan[20]. There are several important differences, which distinguish our work from theirs.

First, transmit power adjustment described in Refs.[4,20] takes reactively to maintain the quondam topology. For instance, while a mobile host moves out of the power range of its clusterhead and becomes an orphan node, it increases its transmit power to keep connection with other hosts, then neighbor nodes increase transmit power to keep symmetric connection. Reactive proposals of adjusting transmit power to maintain the ad hoc wireless network topology may induce the transient connection interrupt in QoS aware traffic and superfluous control overhead. We employ a proactive approach based on mobility prediction to adapt the topology change caused by host shift.

Second, Kwon in Ref.[4] does not provide a concrete approach for calculating the quantity of power adjustment. Ramanathan in Ref.[20] uses node density to calculate the number of nodes in its transmit range, but does not discuss how to choose the value of density, and because network changes dynamically, this approach will introduce larger difference from the desired topology state.

In summary, no research has yield a operable approach for assigning different transmit power to different nodes to meet a finely integrated performance, such as a stable and connected network with maximal throughput, and none of them has studied an implementation in the context of a prototype of multi-hop wireless network.

In this paper, we employed a practical physical method to predict future position of nodes. Based on this result, we can get a precise value for adjusting transmission power of related nodes to optimize the network architecture.

2 Network Model

In a wireless network, each node has a transceiver for communication. The neighbors of a node, which a node can directly communicate with, is not fixed but depends on the power used by its radio transmitter. When the power of the radio transmitter is increased, a node can directly communicate with a larger set of nodes (i.e., It has a larger number of neighbors).

The propagation function is represented as R:: $L \times L \rightarrow Z$, where L is a set of location coordinates in the space. Function $\Re(l_i, l_j)$ gives the loss in dB due to propagation at location $l_j \in L$, when a packet is originated from location $l_i \in L$. The successful reception of a transmitted signal depends,

$$p - \Re(l_i, l_j) \geq S \tag{1}$$

along with the propagation function R, on the transmit power p of sender and the receiving sensitivity S of receiver. The receiving sensitivity is the threshold signal strength need for reception and is assumed to be a previously known constant, same for all nodes. In particular, for successful reception, we assume that R, is a monotonically increasing function of the geographical distance $d(l_i, l_j)$ between l_i and l_j. This is generally true for free space propagation or when environmental clutter causes the same amount of signal degradation in all directions. We can then combine S and R, into one function as fellows,

$$\lambda(d) = \Re(d(l_i, l_j)) + S \tag{2}$$

Clearly, p must be at least $\lambda(d)$ for successful reception.

So given an Ad hoc network $M=(N,L)$, a transmit power function p, and a least-power function λ, we can represent the induced graph as $G=(V,E)$, where V is a set of vertices corresponding to nodes in N, and E is a set of undirected edges so that $(u,v)\in E$ if and only if $p(u)\geq\lambda\ (d(u,v))$, and $p(v)\geq\lambda\ (d(u,v))$. Then, we can think of the links as being symmetric and the resulting graph as undirected. Furthermore, we assume that there exists a medium access scheduler so that each node can transmit at a certain bit rate without interference.

3 Clustering Algorithm

The assignment of mobile nodes to clusters must be a dynamic process; wherein, the nodes are self-organizing and adaptable with respect to node mobility. Consequently, it is necessary to design an algorithm, which dynamically implements the self-organizing procedures in addition to defining the criteria for building cluster.

3.1 Mobility prediction

The mobility of node should be natural and realistic even in a simulation. In this section, we introduce a new mobility model, which can simulate natural and realistic mobility for various applications. Most of the existing mobility models allow pure random movements, such as the sudden stop, turn back, and sharp turn, etc., which are physically impossible in the real world for mobile nodes. With those unusual movements, it will induce movement that is hard to move to the distance with the expected speed of the node in the period. The distance of physical displacement has been underestimated from the reason and this will lessen the impact of mobility to the applications, which adopt those mobility models.

As it showing in Ref.[15] that a high level of statistical randomness in users' movements may cause this low prediction accuracy and enlightened by Haas, if we pay more attention to analyze the recent trajectory of a mobile node and do some delicate conjectures about the future location based on actual experience, we can get a realistic mobility model. Without breaking this scheme, it is also possible to imitate almost all-existing mobility models. Our mobility model is especially designing for high-speed move environment, in which the move trend is continuous because of the inertia. The advantages of our model are natural, realistic motion, simple positioning update, and ease of implementation. In the low speed move scenario, random and bursty are the primary characteristics of mobility. For this application, mobility prediction algorithm need be reconsider.

By interacting with Global Position System (GPS), any host gets its location (x,y,z). In a very short period, because of the inertia effect, we can assume the force acting on the host moving with high speed is constant, and this force can be decomposed in three dimensions, so we can also assume that the velocity variance is constant in three directions separately.

As all know the principle motion law

$$s = v*t + \tfrac{1}{2}a*t^2 = \bar{v}*t \tag{3}$$

and

$$V = v + a*t, \tag{4}$$

here S is the displacement in the period t, v is the initial velocity and α is acceleration same direction of v. we employ V denoting the final velocity after period t.

Figure 1 shows the trajectory of a mobile node. Now we employ v_x', v_x to denote the node average motion velocity in the segment from (x'',y'',z'') to (x',y',z') and the segment from (x',y',z') to (x,y,z) in the X-axis(same mean as v_y, v_z), and T to denote location sampling cycle, then we can get (5) from (3),

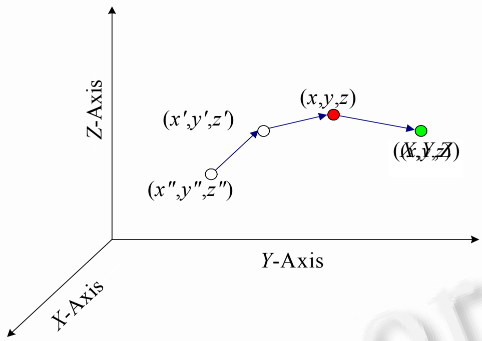


Fig.1 Illustrating node motion trajectory, where (x'',y'',z'') and (x',y',z') are the history location. Current node locates $L(x,y,z)$. we predict it will be (X,Y,Z) in the next hits.

$$\begin{aligned} v_x' &= \frac{x'-x''}{T}, v_x = \frac{x-x'}{T} \\ v_y' &= \frac{y'-y''}{T}, v_y = \frac{y-y'}{T}, \\ v_z' &= \frac{z'-z''}{T}, v_z = \frac{z-z'}{T} \end{aligned} \tag{5}$$

(6) From (4)

$$\begin{aligned} v_x &= a_x*T + v_x' \\ v_y &= a_y*T + v_y' \\ v_z &= a_z*T + v_z' \end{aligned} \quad . \tag{6}$$

Additional, in very short slice T, we assume that the acceleration is the same as the last slice, so the next most probable location can be predicted as,

$$\begin{aligned} X &= x + (v_x + a_x * T) * T \\ Y &= y + (v_y + a_y * T) * T \\ Z &= z + (v_z + a_z * T) * T \end{aligned} . \tag{7}$$

Replace *v*, *a*, and *T* in (7) with (5), (6), we get a simpler expression (8).

$$\begin{aligned} X &= 3 * x - 3 * x' + x'' \\ Y &= 3 * y - 3 * y' + y'' \\ Z &= 3 * z - 3 * z' + z'' \end{aligned} . \tag{8}$$

3.2 Clustering with power control

Power control is a necessity in multi-hop networks, both to save power and to optimize spatial reuse. In this context, we are looking for an optimal clustering scheme allowing all participating nodes to adjust their power to a power efficient and/or bandwidth efficient way. Power control is required for CDMA in order to reduce the interference, but is applicable also to non-CDMA networks if each node can adjust its transmission power.

The power changes are done in shuffle periodic, that is, the time between power changes is randomized around a mean. This is done in order to eliminate lock-step execution and interference between packets.

As mentioned in Section 3.1, each node deploys a geolocation method to find its physical location. Now, we derive the formula employed in SSCA to adjust the power. It is based on a well-known generic model for propagation[21] by which the propagation loss function varies as some ε power of distance. The value of ε is usually between 2 and 5, depending on the environment, specifically, if R is the loss in dB, then

$R(d)= R(d_{thr})$, if $d<d_{thr}$

$R(d)= R(d_{thr})+10*\varepsilon*\log_{10}(d/d_{thr})$ if $d\ge d_{thr}$

where d is the distance, and d_{thr} is a threshold distance below which the propagation loss is a constant; all logarithms in the remainder of this section are base on 10.

Let s_c, p_c, respectively, denote the current cluster size and current clusterhead transmit power. We need an expression for new transmit power p_d, so that the cluster has the desired size s_d.

Let cd_i^j, ed_i^j, respectively, denote the current distance and expected next distance from i to its neighbor j, and p_e denotes adjustment targeted power, $[d_{\min}, d_{\max}]$ is the range of adjustable power transmit distance,

$$\begin{aligned} cd_i^j &= \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \\ ed_i^j &= \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2 + (Z_i - Z_j)^2} \end{aligned} \tag{9}$$

$$cd = \max\{cd_i^j\},\ j \in N_i \tag{10}$$

$$ed = \min\{d_{\max}, \max\{ed_i^j\}\},\ j \in N_i \tag{11}$$

As noted before, S is the receiving sensitivity for all nodes. Then as $cd > d_{thr}$ & $ed > d_{thr}$, the following hold

$$p_c - \left(\Re(d_{thr}) + 10 * \varepsilon * \log\left(\frac{cd}{d_{thr}}\right)\right) = S \tag{12}$$

$$p_d - \left(\Re(d_{thr}) + 10 * \varepsilon * \log\left(\frac{ed}{d_{thr}}\right)\right) = S \tag{13}$$

From (12) and (13), we get a simpler equation

$$p_d = p_c - 10 * \varepsilon * \log\left(\frac{ed}{cd}\right) \tag{14}$$

In our system, we employed $\varepsilon = 4$, but ε can also be configured depending upon the environment. Equation (14) can thus be used to calculate the new power periodically. We note that the formula applies for both power increasing and decreasing to bring the cluster size close to s_d.

3.3 Suitable size clustering algorithm (SSCA)

The definition of clustering is to group network nodes into manageable sets, "*d*-hop" clustering refers to a clustering that every node can reaches its clusterhead with at most *d* hops.

The cluster algorithm presents a logical topology to the routing algorithm, and it accepts feedback from routing algorithm in order to adjust logical topology and make cluster decisions. The rapidly changing topology may break an active route and cause subsequent route search.

In this section, we present a distributed heuristics for topology control, named Suitable Size Clustering Algorithm (SSCA). SSCA controls the cluster at a suitable size for maximizing the overall throughput and "spatial reuse". Unlike LID or the highest degree algorithm, we do not strictly abide to the clustering construction rule after initialization, while maintaining cluster in face of mobility, i.e., we do not keep the lowest ID or the highest degree rules all the time.

We note that while SSCA do not explicitly introduce control overhead, the adjustment of transmit power may cause link up/downs. In many routing protocols, this causes routing update. An excessive number of updates induced by such topology control may actually eat up network bandwidth and decrease the effective throughput. In order to minimize this, SSCA is incremental, in which it calculates new transmit power not from scratch, but being based on the currently used values.

Initially, all nodes start with the maximum possible power. With 1-CONID[8] clustering Algorithm, this results in a maximally connected network, which enables successful propagation of updates and the initialization of a network topology database at each node. After this initialization, the SSCA is activated, as right.

Λ is system configurable value is related to the power adjustment capability.

$s_c < s_d$:
  $ed = \max\{ed + \mathrm{rand}(\Lambda), d_{\max}\}$
  recalculate p_e with (14)
$s_c > s_d$:
  $ed = ed_i^{S_d}$, where $ed_i^1 < ed_i^2 < ed_i^3 < \cdots < ed_i^{S_c}$
  $ed = \min\{ed, d_{\min}\}$
  recalculate p_e with (14)
adjust transmit power to p_e

The SSCA tries to maintain the cluster size suitable around the configure value S_d. It is triggered whenever an event driven or periodic link-state update arrives. Its purpose is to override the high threshold bounds and to adjust the power if the topology change is indicated by the routing update results in undesirable connectivity. The main challenge here is to coordinate such power change with other nodes, since we do not want all nodes to react to the topology.

A clusterhead also conducts power control to maintain proper size of cluster by adjusting its pilot signal level. If the cluster has too many nodes including ordinary nodes (mobile stations) and gateways, the clusterhead reduces its pliot signal to make the area of the cluster shrink. If a cluster is suffering from isolation or has too little connectivity, its clusterhead increases pilot power. Since both parties (clusterhead and mobile station) can control transmission power, a pilot signal should embed its transmission power level. Otherwise, the open loop power control would be impossible because the open loop control assumes a predefined power level of pilot signals.

When the heuristic terminates, a node either becomes a clusterhead, or is at most d hops away from its clusterhead. A Gateway node is that it can reach two or more clusterheads at most of d-hop. The value d is a parameter of the heuristic. The heuristic can be run either at regular intervals, or whenever the network configuration changes.

After the network is established, each node knows the low level (one level) topology about node connectivity within its cluster and the high level topology about cluster connectivity of the whole network. A packet is forwarded by specifying the hierarchical address (cluster ID and node ID) of a destination node in the packet header.

The global state update manner resembles as fisheye routing[22]. All nodes update its d-hops neighbors in a short slot periodically, and a longer periods for updating peripheral node states. Different from fisheye routing of all nodes participating in peripheral state update, Only Clusterhead and Gateway nodes participate in inter-cluster state updating in SSCA.

4 Simulation and Performance Evaluation

4.1 Performance Metrics

To evaluate the algorithm's performance, here, we define several metrics related to clustering. Link status change (up/down) caused by the motion of nodes reflects the network stability, and then reacts to network clustering procedure. We use Link Up/Down per node (LUD)

$$\text{LUD} = \frac{\text{Total up or down links}}{\text{Total number of node}}.$$

And ClusterHead Change (CHC)

$$\text{CHC} = \frac{\text{Total number of clusterhead change}}{\text{Total number of node}}.$$

For evaluating the network stability while node density and node mobile speed are greatly varied.

For the characteristics of high dynamic and propagation broadcast in Ad hoc wireless network, throughput is specially important. Because our clustering algorithm is not a routing algorithm, it is not easy to get the actual network throughput. We use the average packet collisions per node as alternative metric for measuring throughput.

$$\text{Collisions} = \frac{\text{Total number of collisions}}{\text{Total number of Node}}.$$

More collisions indicate that more packets must wait to be retransmitted; the actual transport capability is scarcer. Power consumption is another important factor in ad hoc wireless network. The power energy of portable battery is very limit and expensive. Much energy consumption will constrain the applicability of network organization mechanism. Since the receiving power consumption is constant in the specified circumstance, we only take the transmit power consumption into account. We use transmit power usage ratio (txPur) to measure the degree of power saving.

$$\text{txPur} = \frac{\text{CTP}}{\text{CMTP}} \times \frac{\text{CTD}}{\text{TTD}},$$

where CTP is current transmit power, CMTP is configured maximum transmit power, CTD is current transmit duration and TTD is total transmit duration per node.

Finally, we use the average inter cluster update times and control overhead (ControlOH) to estimate the algorithm overhead. It is necessary specially to claim that this control overhead is a part of routing status update, and the actual communication overhead in our clustering algorithm is zero.

4.2 Simulation environment and parameter configuration

The simulator is implemented within the Global Mobile Simulation (GloMoSim) library[23]. The GloMoSim library is a scalable simulation environment for wireless network system by using the parallel discrete event simulation capability provided by PARSEC[24]. Our simulation models a network varying mobile hosts from 50 to 150 placed uniformly within a 1000m×1000m area. Radio propagation range for each node is configured from 110 to 190 meters and channel capacity is 2Mbps. Each node simulation execute for 600 seconds of simulation time. Multiple runs with different seed numbers are conducted for each scenario and collected data are averaged over those runs.

The mobility model we used is a revised version of random waypoint mobility model[2]. The original one selects the next destination randomly, and the move step and movement interval in it are constant in one moving period. In the paper, because our mobility prediction is based on constant sample time slice, we configure the moving interval as constant equal to neighbor update time interval, and vary the movement steps in the revised random waypoint mobility model.

HIDEAKI and LEONARD have derived the optimal transmission range for randomly distributed terminals are just covering about 7 nearest neighbors in Ref.[16], so we configure the cluster size as 8. And the simulation result testifies in the next part. Other default parameters are configured as

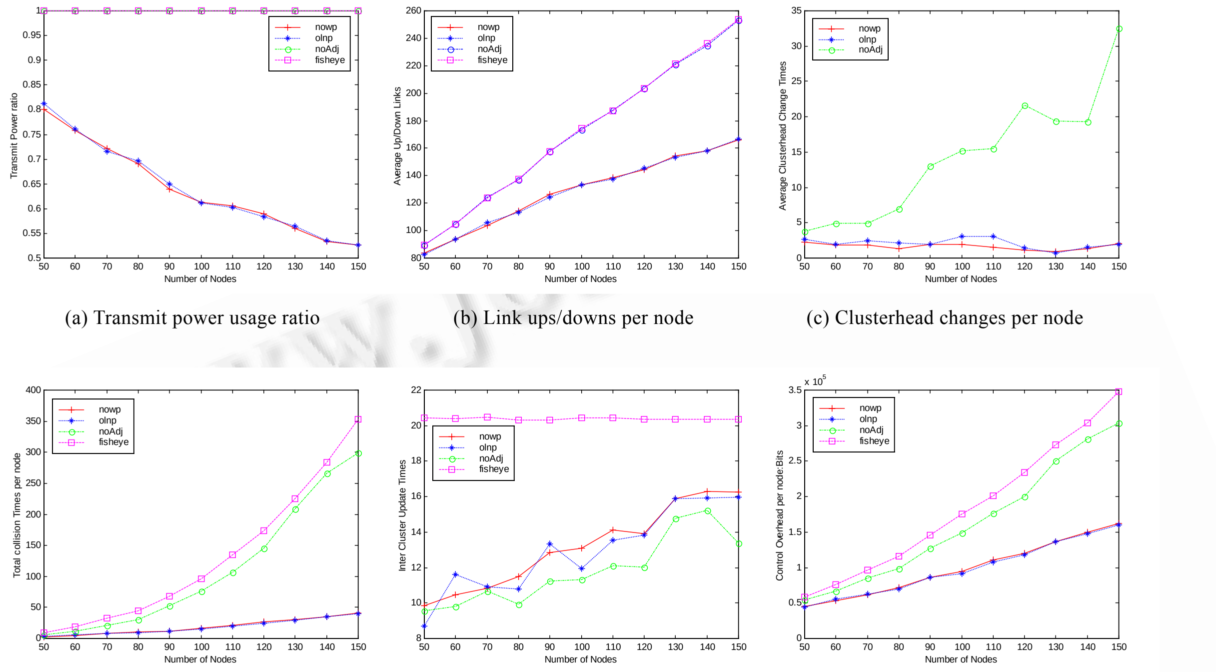
Suitable size $S_d = 8$	Mobility interval = 5s
Number of node = 100	Inter-Cluster update interval = 15s
Maximum speed = 10 m/s	Direct neighbor update interval = 5s
Minimum speed = 5 m/s	Maximum transmit power range =150m

To validating the effectiveness of mobility prediction, we compare the performances of our clustering algorithm in two cases. One is calculating the next transmit power range only based on the prediction distance (Abbr. as **olnp**), and the other based on the maximum of current distance and prediction distance (Abbr. as **nowp**). In order to test the advantage of power control, we have simulated the version of no power control (**noAdj**), which is 1-CONID proposed in Ref.[8]. In addition, we also simulate **fisheye** routing proposed in Ref.[22] for performance comparison. We will show how node density, mobility speed, transmit power range and cluster size impact the network performance in the next part.

4.3 Simulation results

Figures 2~5 show the impacts of node density, mobility speed, transmit power range and desired cluster size respectively.

We can see how node density impacts the network performance from Fig.2. With the number of nodes increasing, the node density increases because the terrain is constrained in 1000m×1000m, which means average distance between two nodes is shortening. In this situation, if we also use the previous transmit power, any node will cover more neighbor nodes, and more links will bring forth more link up/down, shown in Fig.2(b); other result of frequent link status change is clustehead changes frequently, shown in Fig.2(c). On the other side, we can see from Fig.2(d) that collisions of **onAdj** and that of **fisheye** increase rapidly as the node density increasing due to the node propagation broadcast of wireless network. By the cause of employing 802.11 as MAC protocol, the collision nodes will wait a time of binary countdown exponential function. More collisions show there are more nodes must be in the state of passive waiting, so the throughput decreases a function of the number of average collision. In this paper, we use packet collision per node as a metric to reflect the network throughput change indirectly. In the future work, we will quantify the impact of the network throughput.



(a) Transmit power usage ratio (b) Link ups/downs per node (c) Clusterhead changes per node

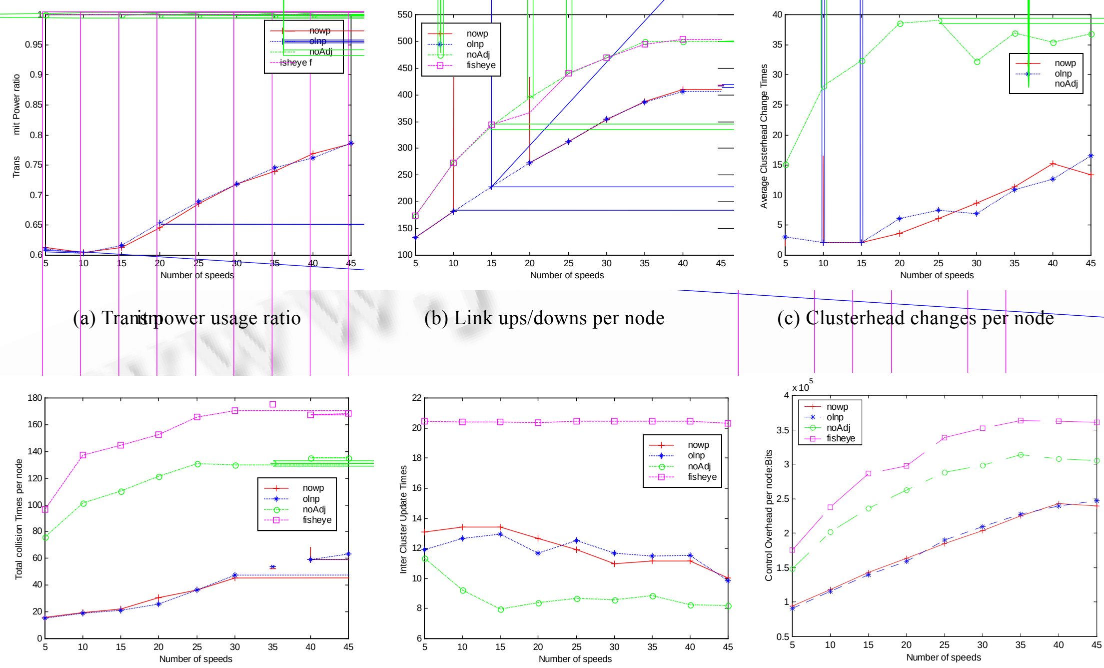
(d) Packet collisions per node (e) Inter-Cluster updates per node (f) Control overhead per node

Fig.2

Adopting power control adaptive clustering algorithm, first, we can save more power energy to prolong the life of total network. For a special ad hoc wireless network composed of 100 nodes in the specified area, we can save about 36% transmit power energy. Secondly, since we control the cluster at a suitable size, and maintain the total active links of the network at about a constant, the clusterhead change frequency and per node collisions do not change notably with the increasing of node density.

Longer transmit power range reduces to larger cluster size. In other word, SSCA may create more cluster than **noAdj**, but the update packets of SSCA are less than that of **noAdj.** These are show in Figs.2(e) and 2(f). Because **fisheye** updates far way links status periodically, its "inter-cluster" update times is constant. The cause of **noAdj**'s control overhead per node less than that of **fisheye** is that every node participate in update far away links status, but in **noAdj** only clusterhead and gateway nodes participate in.

Figure 3 shows the impacts of node mobility speed. With the node's moving speed increasing, links up/down becomes more frequent. But the average link change per node of SSCA is only about 70% of that of **noAdj** or **fisheye,** and the number of average clusterhead change is milder and keeps at a lower value than that of **noAdj**. This benefits from adopting mobility prediction and power adjustment. Because current transmit power range is less than the configured maximum transmit power range at most time, when some neighbors move away from their clusterhead, clusterhead can increase its transmit power range according to predicted neighbors' next position and its own next position. But when adopting **noAdj** mechanism**,** there are more neighbors in edge of area covered by power range of clusterhead. Every time when these neighbors move in or out of these areas is produced a link up or down, so average clusterhead change of **noAdj** is more frequent than that of SSCA.



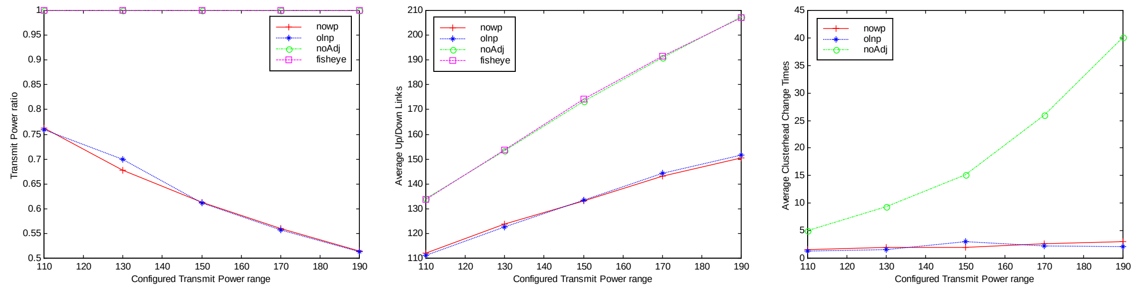
(a) Transmit power usage ratio (b) Link ups/downs per node (c) Clusterhead changes per node

(d) Packet collisions per node (e) Inter-Cluster updates per node (f) Control overhead per node

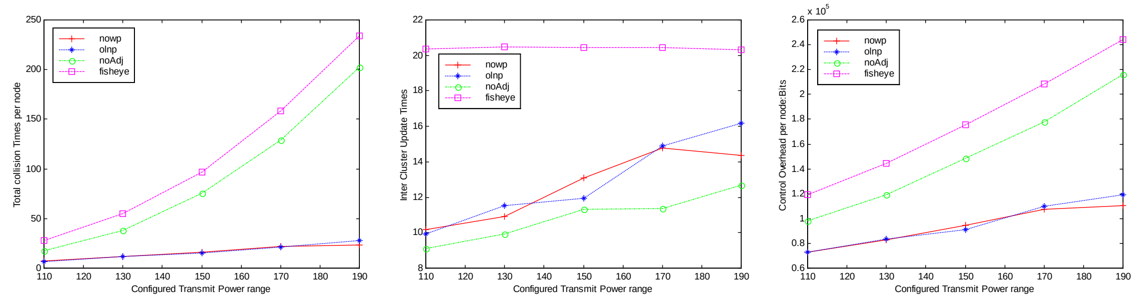
Fig.3

The cause of transmit power range usage ratio increasing as the node moving speed increasing is that higher motion speed increases the probability of current active neighbor moving away the cluster head. For maintaining the connection, the clusterhead must increase its transmit power, then the dominated neighbor increases its own transmit power so that it keeps connected with clusterhead. With the transmit power range increasing, more node will enter cluster head covered area, so the average collision time increases. The cause of inter-cluster update and control overhead increasing is the same as explanation for node density.

Figure 4 shows the impacts of the configured maximum transmit power range. Increasing the maximum transmit power range means that there are more capability of power adjustment. In the special instance when some move far away its clusterhead, if the configured maximum transmit power is less than this distance, the link connecting this node to its clusterhead must be broken. Otherwise, if we configure larger value for transmit power range, this link may keep connected in the next time slot with adjusting the transmit power just above its distance. We can see from Fig.4(a) that the transmit power usage ratio is decreasing its function of configuring maximum transmit power range but not a rigid verse inverse proportion function. This is also the cause of average up/down link of SSCA increasing with the configured maximum value of transmit power range. And we can see from figure 4(b) the average link change times and from Fig.4(c) the average clusterhead changes of SSCA increase more moderately than that of **onAdj** or **fisheye** respectively. As known the average transmit power range increasing with configured maximum value increased, it is easy to understand why the simulation result is as show of Figs.4(d), 4(e) and 4(f).



(a) Transmit power usage ratio (b) Link ups/downs per node (c) Clusterhead changes per node



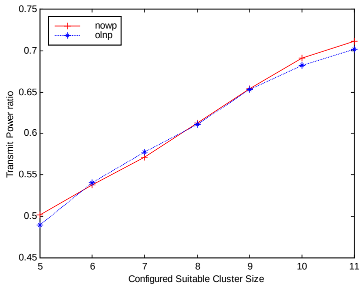
(d) Packet collisions per node (e) Inter-Cluster updates per node (f) Control overhead per node

Fig.4

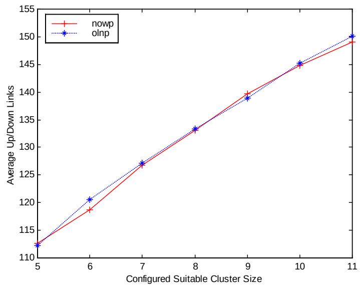
Figure 5 shows the impacts of desired cluster size. In order to cover more nodes, a clusterhead must increase its transmit power range, this is why transmit power usage ratio increases when desired cluster size increasing as showing in Fig.5(a). Transmit usage ratio increasing leads to average link up/down (in Fig.5(b)), average collision times (in Fig.5(c)) and clustehead changes (in Fig.5(d)) increase directly. And we can see cluster -head changes when desired cluster size is 7 almost equals to that of desired cluster size at 8. This result is consistent with the theory analysis result of Ref.[16].

The cause of inter-cluster update time decreasing shown in Fig.5(e) is that the number of clusterhead is decreased. Because there are more nodes in cluster, the update packet size is larger than before. Average total control overhead increases as shown in Fig.5(f).

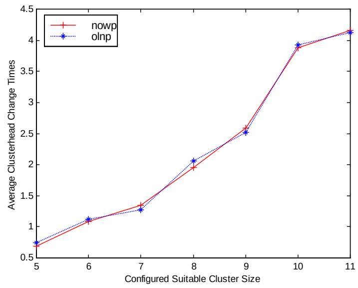
From all simulation results, we can see the performances of **onlp** are almost the same as that of **nowp**, which shows our prediction mechanism is valid and precise.



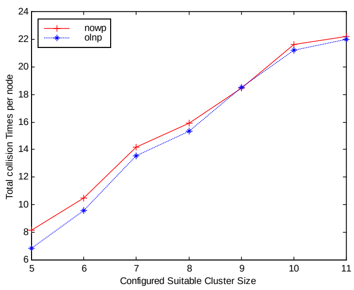
(a) Transmit power usage ratio



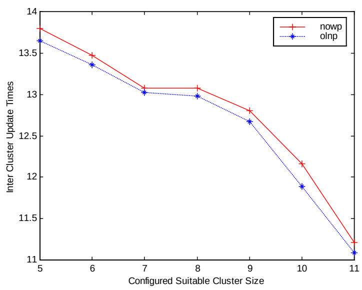
(b) Link ups/downs per node



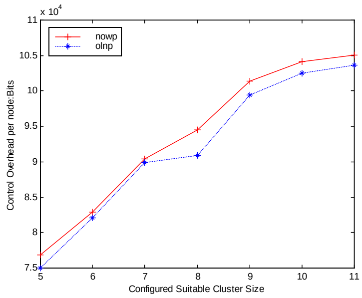
(c) Clusterhead changes per node



(d) Packet collisions per node



(e) Inter-Cluster updates per node



(f) Control overhead per node

Fig.5

5 Conclusions

In this paper, first, we have proposed a new and more realistic prediction method, then provided a concrete power adjustment method based on this prediction information, finally proposed a novel adaptive clustering algorithm, called Suitable Size Clustering Algorithm (SSCA). And we have implemented this clustering algorithm in GlomoSim. The simulation result shows that the suitable size clustering with mobility prediction and power control is a practically valuable mechanism for ad hoc wireless network, especially for that in high-speed motion environment. We will study how to implement Qos guarantee routing based on this work.

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无线自组网中基于移动预测与功率调整的适应性分簇算法

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摘要: 传送功率控制是无线自组网中资源管理和控制干扰的中心技术.传统上功率控制只是用作消除信道消隐负作用的一种手段,当前观点一般认为功率控制是一种可以为单个用户提供服务质量的灵活机制.提出一种分簇算法以达到减轻网络拓扑的动态变化的同时节省电能.此提案是基于全球定位系统的(GPS).根据移动主机的历史轨迹预测它下一个最可能处在的位置,预先调整传送功率.为了最大化网络的吞吐量,算法自适应性的控制每个簇在合适的大小.在 GlomoSim 模拟器上仿真了提出的算法.仿真结果表明,它是无线自组网中有效的拓扑管理机制,对由高速运动主机组成的网络特别有效.

关键词: 无线自组网;移动预测;功率控制;分簇算法

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