Clustering with Power Control

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Abstract – This paper proposes a stable, dynamic, distributed clustering for energy efficient networking. Via simulation, we evaluate the impacts of mobility and transmission power variation on network stability.

1. INTRODUCTION

As the portable computing technology emerges, the need to interconnect such portable devices using a wireless network is also gaining increasing importance. In the design of such wireless networks, it is essential to consider power economy, since most portables are powered by batteries with very limited weight and life. In conventional wireless telephony, where the cellular approach is prevalent, mobile units exercise power control to achieve not only longer battery life but also better communication quality [1].

The conventional cellular radio approach requires the presence of a fixed, wired infrastructure. If such an infrastructure is not available, ad hoc networking that is based on a fast deployable, self-organizing network offers an attractive alternative[2,5]. The ad hoc network strategy has been proposed for such scenarios as fast deployable, mobile LANs, emergency and disaster relief, and battlefield communications. The demands of the ad hoc network applications are scalability, mobility, and multimedia communication support.

One of the main obstacles to seamless communications in ad hoc networks is mobility. Most of the well-known complications in mobile radio indeed originate directly or indirectly from the topology instability caused by motion.

We propose to use clustering to overcome in part the problems related to mobility while at the same time addressing the issue of radio transmission power consumption.

PURPOSE AND ADVANTAGE OF CLUSTERING

The first advantage of clustering is stabilizing network topology. By judicious choice of the clusters, we can guarantee a relatively stable cluster topology. With clustering, only the cluster changes and a fraction of gateway changes will impact the network topology changes, and, as a result, routing and connectivity procedures. The second advantage is channel economy [2,9]. By assigning different channels/codes to different clusters, we can achieve spatial channel/code reuse. The third advantage is ease of location management. The Cluster heads can assist in locating mobile stations. Clustering is also known to be useful in improving the MAC resource management [9]. The last advantage of clustering is that it can provide a simple and feasible power control mechanism for an ad hoc network. By using 2-hop clustering, we can use the cellular system power control scheme with minor modifications.

NECESSITY OF POWER CONTROL.

Cellular communication devices are generally equipped with low power chips, and they are also exercising power control to achieve transmission power economy [4]. Power control is not only for saving power. It is also a necessity for CDMA in order to reduce the interference. By using only the strictly necessary power, channel interference can be minimized. With power control, we can also expect better channel utilization. For densely populated areas, available resources are easily exhausted if we use a uniform cluster or cell size. Indeed, we can provide better service if we control the number of nodes in a cluster by increasing/decreasing pilot transmission power of the cluster head and thus the physical cluster size.

RESEARCH OBJECTIVES.

Previous works have proved the benefits of clustering in the management of MAC level resources in a wireless multi-hop network [2,9]. However, those works were based on relatively simple radio assumptions - most notably, no power control.

In this research, we apply power control to clustering in order to improve the performance and the power economy, yet retaining stability and ease of operation. Of course, power control introduces a number of complications. Firstly, and most importantly, it creates asymmetric links. For example, one station can
transmit data to another, but the latter cannot respond directly to the first one. Secondly, power control tends to create several clusters of smaller sizes. This can be a major trigger of cluster instability since the mobility remains the same. Finally, there is a cost issue: each mobile station must be equipped with power measuring/adjusting circuitry. We will address and provide possible solutions for the problems listed above, and propose a new clustering which is suitable for the power controlled MAC layers. Our major goal in this research is to reduce the impact of node mobility and variable radio transmission power on the performance of ad hoc networks by using clustering. The stability improvement of the clustering in mobile environments will be demonstrated by simulation results.

2. BACKGROUND

2-HOP CLUSTERING

The definition of clustering is grouping network nodes into manageable set. “k-hop” clustering refers to a clustering such that every node in a cluster can be reached with at most k hops from any other node in the cluster. 2-hop clustering is a special case of k-hop clustering with the following properties.

- There is a Cluster Head (CH) on the center of cluster and CH can communicate with any node in the cluster with a single hop.
- No CHs are directly linked.
- Any two nodes in a cluster are at most 2-hops away.

2-hop clustering ends up with a clustering which is similar to the cellular system. There are CHs on the center of clusters. Nodes belonged to more than one cluster are Gateways (GW). The rest of nodes are mobile stations. (or ordinary nodes)

STABLE CLUSTERING

A number of 2-hop clustering algorithms have been proposed in the literature; Lowest ID (LID) Algorithm [9], Highest Connectivity Algorithm [9], and Least Clusterhead Change (LCC) Algorithm [8]. The LCC algorithm is developed to minimize the clusterhead changes and is known to be the most stable 2-hop clustering algorithm.

POWER CONTROL MECHANISM IN CELLULAR NETWORK

In CDMA (IS95), a mobile station monitors the received power level of a pilot signal from the base station by which it is currently serviced. Since the received power level is inversely proportional to the n-th power of distance where n is in the range of 2 to 5, a mobile station must determine the adequate power level to transmit the signal to its base station. The procedure is referred to as open loop power control [4]. The base station (BS) can also control (via feed back) the power level of a mobile station. This power control initiated by a BS, which is known as closed loop power control, is based on the difference between the power level measured with an open loop control and the reference power level.

POWER CONTROL IN AD HOC NETWORK.

A cluster head also controls a mobile station’s transmission power with a closed loop power control packet. Of course, we have no fixed base station nor the cell structures in ad hoc network. However, we can construct clusters and let the cluster heads act as a base stations. A cluster head sends out a pilot signal and the mobile stations try to detect such pilot signals. If mobile stations can not receive a pilot signal from any cluster head, they can claim to be new cluster heads by broadcasting initialization pilots. To form a new cluster, orphan mobile stations which are away from the clustered area, send out initialization pilot signals so they can compete to be a new cluster head. This initializing pilot signal should be differentiated from normal pilot signal because the pilot signal does not come from a functional cluster head. If a mobile node detects pilot signals, it measures the reception power level of each pilot, tries to be a member of one or more clusters and becomes a mobile station (ordinary node) or a gateway. Then, the clustered station adjusts its transmission power based on the received pilot signals. A cluster head 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 cluster head reduces its pilot signal to make the area of the cluster shrink. If a cluster is suffering from isolation or has too little connectivity, its cluster head increases pilot power. Since both parties (cluster head 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 power control assumes a predefined power level of pilot signals.

3. CLUSTERING WITH POWER CONTROL

In this section, we describe a new algorithm for building and maintaining stable 2-hop clusters with power control. The stability of the algorithm stems from not enforcing the clustering discipline all the time. LCC [8] is the first 2-hop clustering algorithm which introduces the concept. Unlike LID or 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 highest degree rules all the time. The Following is a sketch of the algorithm.
ASAP Algorithm – Asymmetric link avoidance
(Added Structure for Applying Power control)
2-types of pilot: (normal) pilot, initialization pilot
Pilot carries additional information: ID, power level.

a. Initial clustering:
   a.1. Collecting neighbor information: all the nodes
       send out their initialization pilot signals (packets)
       with the maximum pilot power to acquire their
       neighbor information (ID and distance).
   a.2. Initial clustering: Use the LID algorithm to form
       an initial clustering.

b. Cluster Maintenance
   b.1. MS goes out of the clustered area: Claim to be
       a CH (send out initialization pilot and try to
       become a CH.)
   b.2. CH collision – CH goes into a different cluster
       area: Only one cluster head survives. (Larger
       cluster wins or higher degree cluster wins.)
   b.3. CH dies or MS goes out of its cluster: Try to
       find accessible CH by monitoring pilot. If no CH
       is available, follow b.1.

POWER CONTROL PROCEDURES
With the following power control procedures, mobile
nodes can exercise power control. We can also
eliminate the asymmetric link problems between CH
and any nodes in the cluster.

c. CH power control
   c.1. CH pilot power control: CH adjusts the pilot
       signal level when it needs to change the size of
       the cluster in order to keep a proper number of
       active MS in the cluster.
   c.2. CH data power control: Adjusting CH’s data
       transmission powers so the furthest node (or the
       destination) can receive the transmission.
   c.3. CH closed loop power control: If a node in the
       cluster reports unusual error rates, increase the
       data transmission power level. (From d.3.)
   c.4. If CH experiences unusual weak/strong signal
       from a node, send a closed loop power control
       signal to the node.

d. MS/GW power control
   d.1. Open loop power control: By monitoring pilot
       signals, an MS or GW can determine an adequate
       transmission power level. Use the measured
       transmission power level when they transmit data
       to the CH.
   d.2. Closed loop power control: If the CH initiates a
       closed loop power control (from c.4), follow the
       direction.
   d.3. Report CH if the node experiences unusual
       reception error rate.

4. MOBILITY IMPLEMENTATION
One of the major objectives of this research is to
achieve ad hoc network stability in spite of motion.
The mobility of nodes should be natural and realistic
even in a simulation. In this section, we introduce a
new mobility framework which can simulate natural
and realistic mobility for various applications. Most of
the existing mobility models allow pure random
movements, so the sudden stop, turn back, sharp turn,
and etc., which are physically impossible in the real
world for mobile nodes, happen in the models. With
those unusual movements, it is hard to move a mobile
station to the distance that can be expected from the
speed of the node. The distance of physical
displacement has been underestimated from the reason
and this will lessen the impact of mobility to the
applications of those mobility models. By storing
the current mobility information of a node and by allowing
only partial change of current mobility, we can achieve
a better mobility model. Without breaking this scheme,
it is also possible to imitate almost all-existing
mobility models. The advantages of this model are
natural, realistic motion, simple positioning update,
ease of implementation, and we can even correctly
predict mobility in some cases.

MOBILITY VECTOR
A mobility of a node is expressed by a Mobility Vector
\( \overrightarrow{M} = (x_v, y_v) \) which represents the 2-dimensional
motion speed and the direction at the same time. A 3-
dimensional extension is intuitive and simple by
adding one more element to the vector. The scalar
value (norm) of a Mobility Vector is the distance
between the current position of a node and the next
position after a unit time that can be easily translated to
the velocity of the node or vise versa. Each mobile
node keeps its own Mobility Vector so the node can
record its current mobility status. The mobility vector
itself is not a new concept, but this Mobility Vector has
2 major sub vectors and additional properties. There is
no limiting factor for having only 2 sub vectors per an
implementation. For more complex mobility models,
we can subdivide a mobility vector further. One of the
2 sub vectors is a Base Vector, \( \overrightarrow{B} = (bx_v, by_v) \) or
\( (r_b, \theta_b) \) and the other is a Variable Vector,
\( \overrightarrow{V} = (vx_v, vy_v) \) or \( (r_v, \theta_v) \). A Mobility Vector is
calculated by the vector sum of two sub vectors.
\( \overrightarrow{M} = (x_v, y_v) = \overrightarrow{B} + \overrightarrow{V} = (bx_v + vx_v, by_v + vy_v) \)

A Base Vector can define the major direction and
speed of a node, which is very useful when
implementing a group mobility and geography dependent mobility. A Variable Vector stores the mobility deviation from the base vector. We also define 3 properties of Mobility Vector. The first two are the Minimum/Maximum Speed of a node, so the normalized scalar value of a mobility vector lies in between Min/Max value. We can also separate those Min/Max values for x, y directions. And the last one is an Acceleration factor, which defines the proportion of speed (or scalar value of a mobility vector) that can be changed at a time. By adjusting the Acceleration factor, we can limit the acceleration or deceleration of a node within the node's mobility capability. The acceleration factor can eliminate chances for a node to have unrealistic motion while the node is conducting a given mobility. This is the unique idea of the new Mobility Vector model. If we are using radian, we can define the Min/Max angle, and the steering factor which can limit the directional change more naturally. By randomizing the vector variation within the product of an acceleration factor and a maximum speed, we can simulate smooth trajectory of motion. We named this mobility model to Natural Random Mobility.

Mobility vector model can improve the simulation efficiency because additions will generate the next position in a simulation. On every positioning update, conventional probability based jumping models require at least 2 random function calls in 2-dimensional implementation. On the other hand, the mobility vector model requires 2 additions to calculate the next coordinate. Random functions are called only when there is a mobility vector update. Because realistic mobility preserves the current mobility pattern, we do not need to update the mobility vector as frequent as the position (coordinate) update.

5. SIMULATION RESULTS

We developed ASAP simulator with the following assumptions. Perfect, omni-directional radio, and DSSS CDMA. All the nodes are capable of being a base station and a mobile station. Forwarding channel and reverse channel are interchangeable. A Unique identification is assigned to each node. The simulated area is 1 Km². Perfect reflections upon the borders are assumed. The pilot period is 50 milliseconds. 120 nodes are randomly placed in the square, and all of them are independently assigned natural random mobility (acceleration factor was .20.) The simulation time is 10 minutes. We allow a maximum of 12 nodes in a cluster, which implies 12 is the maximum capacity that a cluster head can handle at a time. The power control step is set to 30 meters in transmission range.

We measured the topology change at two levels. The first level is without clustering. All the participating nodes are vertices in the topology; all the possible radio links between adjacent nodes are edges in the first level topology. A topology change due to the mobility can be interpreted as a link failure. The cluster level topology is an abstracted topology with clustered level. All the cluster heads are the vertices in the topology, and all the GWs are the edges in the topology. At the cluster level of topology, there might be multiple edges between two vertices. Note that only a portion of the GW changes will trigger topology changes in the cluster level. The topology change in the cluster level can be interpreted as a CH connectivity failure in the clustered ad hoc network due to mobility.

If we use a distance vector routing scheme, and the distance vector consists of the list of CHs, then the routing stability will be increased by the amount of topology stability gained by clustering.

The first simulation results (Fig.1) compare the effects of velocity on the network stability. Maximum radio radius is set to 120 meters and the power controls are conducted in the step of 30 meters. In the simulation, as the maximum speed of a mobile station increases, the network topology changes also increase in the case of without clustering. Power control indeed exacerbates the topology changes. As we can see in the two lower curves in the Fig 1., clustering does provide a robust infrastructure even with power control.

Fig. 2 shows the effect of radio transmission range on network topology stability with and without power control. Clustering reduces the topology changes by one order of magnitude. We report in Fig 3 the average radio range as a function of maximum range value for the adaptive power control case. We notice that adaptive power control keeps the average transmission range below 70 meters, thus leading to substantial energy savings without compromising topology stability.

![Effect of Speed Variation](image)

Fig. 1 Topology Counts as the Maximum Velocity Increase
6. Summary

We proposed a clustering algorithm and a transmission power control mechanism for an ad hoc network. This clustering is an effective way to achieve transmission power efficiency at the same time the higher channel utilization. The clustering algorithm also prevents asymmetric links problems between mobile stations and their cluster heads. One of the focus of this research was to reduce the impacts of mobility and adaptive transmission power on the performance of ad hoc network. Simulation results demonstrates the improvements of network stability by using clustering. In the simulation, we developed and used a new realistic mobility model.

References


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