EE360 Paper Review 2.0, Caleb Kemere, Spring 2001
Medium Access and Clustering with Power Control in Ad Hoc Networks

In modern *ad hoc* networks one of both the greatest advantages and impediments is the mobility of the users. Two papers are reviewed which deal with the latter issues using power control to increase capacity. The first paper describes a method of incorporating power control with the relatively simple, yet powerful, idea of clustering. The second paper describes a new multiple access scheme involving the integration of power control with a more traditional "busy tone" scheme. To someone who is less familiar with network systems than link designs, many of the ideas (clustering, busy tones) in the papers seemed quite novel. An effort is made to concentrate on the new contributions of the two papers, but because the basic ideas presented are quite interesting, it may seem that overmuch attention is given to them.

"Clustering with Power Control"

In mobile *ad hoc* networks (MANETs), one of the largest problems created by user mobility is the high rate at which network topology changes. One method used for reducing this complexity is to group the mobiles into smaller pseudo-cellular "clusters". A "2-hop" clustering scheme adheres to the following rules: one node, the "cluster head", can (given some adjustable maximum transmit power) communicate with all other nodes; all nodes within the cluster are at most 2 hops away; and no cluster head can communicate with any other cluster head. In addition to the cluster head, another user, the "gateway" also has a key role that is not clear from the previous explanation. To achieve a connected network, each cluster must be able to transmit to the other clusters. This is achieved through having nodes on the edge of the cluster – "gateways" – act as a member of (at least) two clusters with whose cluster heads they can communicate. Several algorithms over the past decade have been developed for segmenting a set of *ad hoc* users into 2-hop clusters.

When the mobile users are required to control their transmit power levels, the complexity of the system increases. In the scheme presented in (1), the cluster head uses a pilot signal to allow its member nodes to adjust their power to an appropriate level. Thus, it can also adjust the size of its cluster by increasing or decreasing the power of the pilot signal. If a node cannot detect a pilot signal, it will transmit its own, and attempt to form a cluster as a head. Otherwise, it adjusts its power based on the strength of the pilot (assuming transmit power information is embedded in the signal). Clearly, when mobility is added to the system, instability appears to be hard to prevent.

Given this basic construction, the two contributions of the paper are a power control algorithm and a model of user mobility. The power control/clustering algorithm is essentially a more finely tuned version of the outline above. After a cluster is formed (they refer to the least ID algorithm), the basic maintenance system will have to deal with two possibilities. First, a mobile may lose its cluster head (through moving out of the cluster, or having the cluster head move away). In their algorithm, the mobile first listens for pilot signals from other cluster heads, and, failing to detect one, becomes its own cluster head. The second maintenance possibility is a cluster head collision. In this case, the larger or higher degree cluster should be chosen as the "winner". The power control portion of the algorithm adds closed-loop functionality to the outline above. Thus, in addition to regulating the cluster size using the pilot signal power, the cluster head is also responsible for adjusting its data power so that the furthest user can receive and all users receive at an acceptable error rate (communicated through feedback), and regulating (through closed-loop control) the power it receives from each of its nodes.

The user mobility model, termed "natural random mobility", is very basic. User's movements are represented as the sum of two velocity vectors, one representing a gross trend, and one representing variation along that trend. Limits are put on the overall minimum and maximum node velocities, and also on the maximum change in velocity (acceleration). The benefit of this model is that it allows the simulation environment to only generate users once, and then simply randomly choose user-pairs for communications. This is clearly more realistic than the typical alternative, area-uniformly generating users each iteration of a simulation.

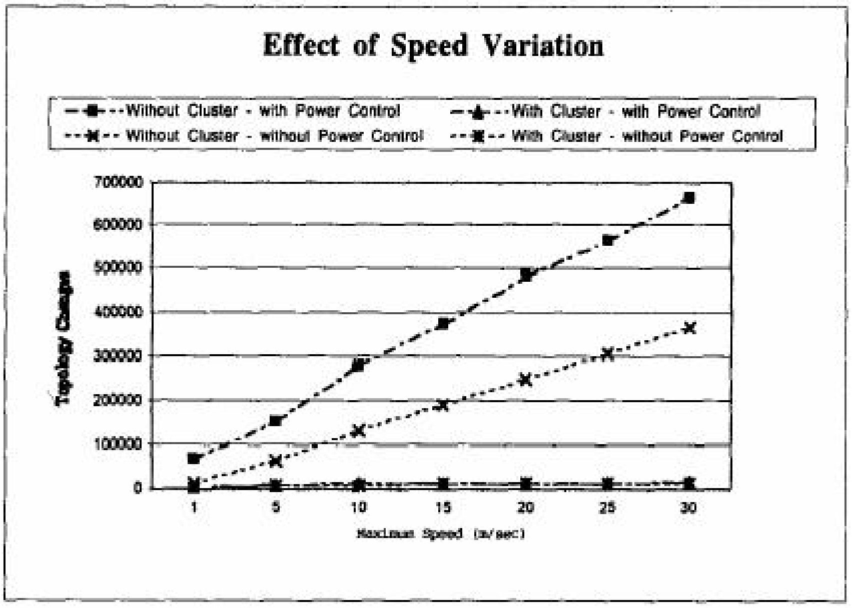

Figure 1: Topology Counts as the Maximum Velocity Increase

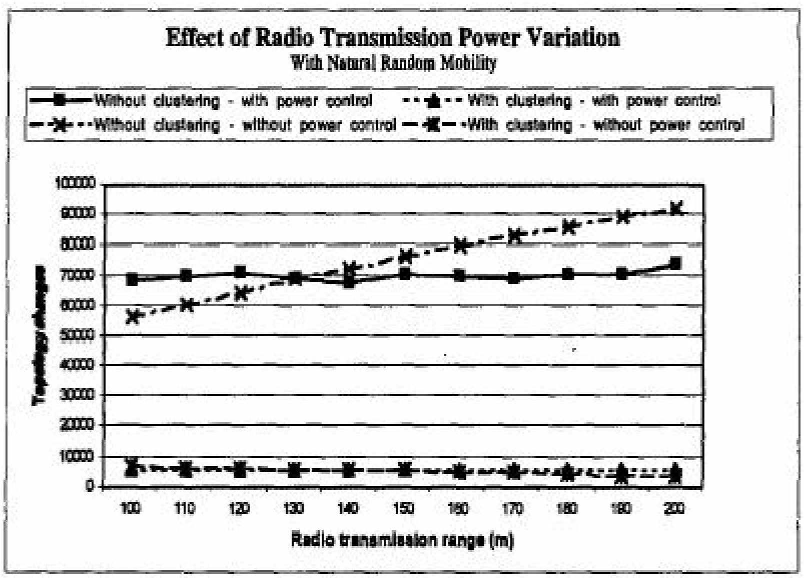

Figure 2: Topology Counts as Power Changes

The authors simulated a system in which 120 nodes were randomly located in a square, and given independent natural random mobility (as discussed above). The simulation assumed DSSS CDMA, without any channel variability. Limits were specified for the maximum size of a cluster (12) and the length of a pilot period (50 ms). The simulation ran for 10 (simulated) minutes at a time. To compare clustering and non-clustering algorithms, topology variation was measured in two different ways. In the first, a non-clustered topology change (which would lead to a "link failure") occurs whenever two previously connected nodes lose their connectivity. In the second a clustered topology change occurs only in the case in which a non-redundant gateway node loses its connectivity with one of its cluster heads. Figure 1 shows the (obvious) benefits of clustering under mobility conditions, but also the penalty (in topology changes) that power control causes to a system under certain conditions. Figure 2 shows that as the potential size of clusters increases (as represented by an increase in transmit power), power control becomes optimal without clustering. This makes sense, because as the maximum transmit distance increases, the effect of reducing interference through power control will become more pronounced. It is interesting to notice that, as would be expected, this advantage apparently goes away under clustering.

"Intelligent Medium Access for Mobile *Ad Hoc* Networks with Busy Tones and Power Control"

The second paper in this review, (2), centers once again on a modifying an existing concept through the addition of power control. Again, the existing concept is an intriguing one. In the semi-classic multiple access protocol known as "dual busy tone multiple access" (DBTMA), in addition to having RTS/CTS signals – which reserve a channel for a period of time (the *ad hoc* analogue of packet reservation), the transmitter and receiver both transmit tones ("busy tones") on an associated narrow band adjacent to the transmission. This allows for a system similar to ethernet, in which potential transmitters are able to sense nearby users and prevent themselves from becoming interferers. This is, in fact, the situations for which these types of multiple access schemes are designed. In a classical *ad hoc* system, when a node is transmitting, it is (relatively) simple for nearby nodes to detect its presence. However, when a node is receiving, a large proportion of potential near-by transmitters will be able to interfere with its reception, but will not be able to detect the transmitted signal.

To combat this, in the typical DBTMA system, a calling node transmits the RTS (request to send) signal only if it cannot detect a receive busy signal (BT_r), and the callee node replies with the CTS (clear to send) signal only if it cannot detect a transmit busy signal (BT_t). Furthermore, the calling node asserts the transmit busy signal when it begins to transmit, and the callee node asserts the receive busy signal as soon as it has acknowledged the beginning of a transfer. Thus, all nearby nodes will have the information they need to ensure that their transmissions are not causing interference to others. (This is also quite similar to (3), except that symmetric duplex channels are assumed there (removing the necessity for busy tones), whereas here, the channel is uni-directional.)

One of the key assumptions of the paper is a simple exponential path loss model. Combined with a fixed caller transmit power, this assumption allows the callee to adjust the power of its receive busy signal so that it is just large enough that the caller (and any potential interferers the same or lesser distance away) will detect it. Thus, the performance gains that will be discussed next arise essentially only from limiting the power of the receive busy signal! Using a geometric approach, the authors derive expressions comparing the probability of two nearby pairs interfering with each other under DBTMA and their modified protocol, and also for the amount of channel usage (measured as time transmitting data divided by time (successfully and unsuccessfully) transmitting handshaking signals plus time not transmitting at all). Finally, they present a proof for the assertion that in the case of discretely adjustable power levels, the optimal step is a linear (i.e., an even division of the range) one.

The authors simulated their protocol in a similar environment to that of the previous paper. 600 mobile nodes are generated inside a 64 km square area. Data packets were generated to a random pair of nodes (within the maximum transmission distance, which varied from 0.5 – 2.0 km) with a Poisson distribution. The impact of user mobility was tested by assigning a constant velocity of 125 km/h to the users in one simulation set. Figure 3 shows the channel utilization versus traffic. Clearly, the power control algorithm results in a large improvement. Figure 4 shows that, just as in the previous case, mobility decreases the channel utilization significantly.

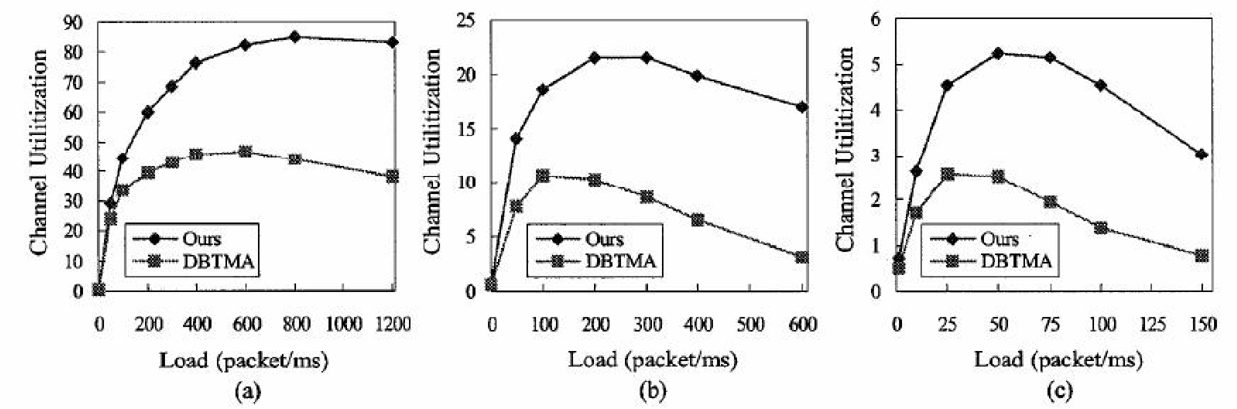

Figure 3: Channel utilization versus traffic load when (a) r_{max} = 0.5 km, (b) r_{max} = 1.0 km, and (c) r_{max} = 2.0 km.

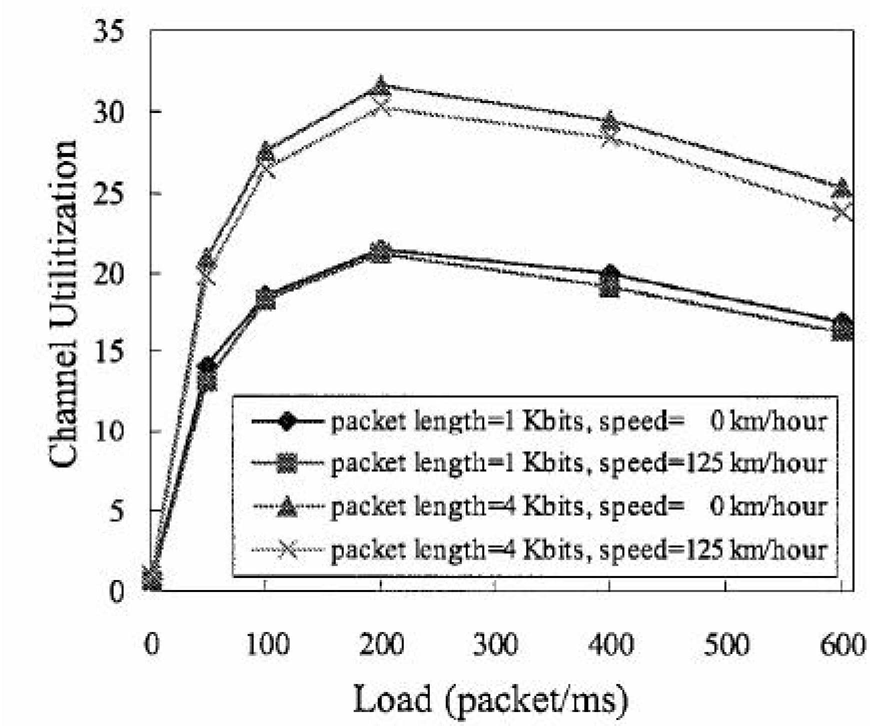

Figure 4: Channel utilization versus traffic load when hosts have no mobility and when hosts move at 125 km/h. The transmission distance r_{max} = 1.0 km.

Conclusion

Both papers presented are not groundbreaking in their approach to the problem of networking mobile *ad hoc* users. However, once again, it is clear that controlling the power transmitted not only benefits the user in the area of increased battery life, but also adds system capacity and robustness. Another result found in both papers is that mobility adversely impacts system capacity (with or without power control). It is interesting to compare the reasoning presented with that in (4), in which the authors make a claim to the opposite.

One key shortcoming in all these models is that they either ignore, or pay little attention to shadowing and fading. Clearly, in any high-speed wireless environment, but especially those in places in which one would expect mobile users to group in numbers large enough to form an *ad hoc* network (e.g., urban areas, indoors, etc.), these channel factors will significantly change the network topology. It seems important to consider that distance is not perfectly correlated with signal strength in such situations, and that channels can vary very quickly. These two issues may adversely impact the algorithms presented, especially in (1), but also somewhat (2).

In general, it appears clear that a good system design will have to incorporate elements from the link layer, all the way to the multiple access layer, as seen in these two papers. Perhaps the next interesting area of research will be the gray area of transmission/multiple access schemes (such as OFDMA or MC-CDMA) in which the multiple access method is intricately tied into the link, but with which little research has been done for distributed dynamic methods for resource allocation.

Bibliography

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