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ABSTRACT

Node movement can be exploited to reduce the energy consumption of wireless network communication. The strategy consists in delaying communication until a mobile node moves close to its *target* peer node, within an application-imposed deadline. We evaluate the performance of various heuristics that, based on the movement history of the mobile node, estimate an optimal time (in the sense of least energy use) of communication subject to the delay constraint. We evaluate the impact of node movement model, length of movement history maintained, allowable delay, single hop versus multiple hop communication, and size of data transfer on the energy consumption. We also present measurement results on an iPAQ pocket PC that quantify energy consumption in executing the prediction algorithms. Our results show that, with relatively simple and hence efficient prediction heuristics, energy savings in communication can significantly outweigh the energy expenses in executing the prediction algorithms.

Categories and Subject Descriptors

c.4 [**Performance of Systems**]: Design Studies

General Terms

Design, Experimentation, Measurement, Performance

Keywords

Ad hoc network, energy efficiency, wireless communication, movement prediction

1. INTRODUCTION

Network communication in the case of handheld devices is one of the major battery power consumers. This paper evaluates some heuristics that try to exploit the movement of mobile nodes in an ad hoc network to reduce energy consumption in network communication.

Our strategy is based on the observation that reduction in distance between two communicating parties in a wireless network will result in reduced energy use for the communication. We consider the situation where a set of mobile nodes in an ad hoc network is communicating with a fixed node, henceforth mentioned as the *target*. Then, if we can predict when a mobile node will move closer to the target, we can postpone our communication until a future time. This assumes that we can afford some amount of delay subject to an application imposed deadline. Our heuristics predict when a mobile node will move closer to the target based on the location history of the mobile node. This paper presents two highly effective heuristics drawing analogy with the secretary problem. We also present simulation results to evaluate the performance of the heuristics in a realistic scenario. Our simulation results show that considerable energy savings can be achieved.

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2. SYSTEM MODEL

We divide the entire network into virtual grids. We assume that each node knows its position using GPS and consequently can associate itself with a grid. We assume slotted time and that a node remembers its movement *history* as the grid IDs visited in the previous n time slots. We also assume that all nodes know the position y of the target. For the experiments in this paper, we use the random waypoint mobility model which is widely used in many ad hoc networking experiments.

3. TERMINOLOGY

There are mainly two parameters used in our prediction strategy: the history length n, and maximum allowable delay k for which a communication can be postponed. $S_h = \{x_1, x_2, ..., x_n\}$ is the sequence of n previous grid positions visited by the mobile node h, where x_i is the ith grid ID. x_n is the most recent grid ID visited in the sequence. We also define $d(i, j)$ as the Euclidean distance between two grid positions i and j.

4. POWER SAVING STRATEGY

Our power saving strategy consists of calculating the likelihood that a mobile node will move closer to the target and then postponing the communication if it is fairly likely. Then we choose a good time in the next k time units when the mobile node is close to the target and perform the communication at that time. In case the node does not move closer within the next $k-1$ time units, we communicate at the kth time unit. In this case we might pay a misprediction penalty.

Our strategy saves power on the assumption that reduction in distance between two communicating parties in a wireless network will result in reduced energy consumption of communication. This is obvious in the case of single hop communication where we can directly use transmission power control. However, in the case of multihop communication, it will depend on the network state and node density.

5. APPLYING THE SECRETARY PROBLEM

The problem of deciding when in the next k time units to communicate is analogous to the well known secretary problem [1]. It is a well studied problem and we use the 37% rule

[1], single threshold selection strategy [3], one-bounce rule [4], Quine and Law's algorithm [7] in designing our heuristics with suitable modifications. We present two of our most effective heuristics in this section.

5.1 Average distance (AD) heuristic

The AD heuristic is based on the weighted average distance between a mobile node and the target over all periods of length k in the mobile node's movement history. We calculate the average as follows:

$$average = \left(\frac{1}{\sum_{l=1}^{n-k+1} w_l}\right) \sum_{j=1}^{n-k+1} w_j \frac{1}{k} \sum_{i=j}^{j+k-1} d(x_i, y),$$

where w_j is the weight associated with time period j to $j+k-1$ ($1 \le j \le n-k+1$). If the current distance between the mobile node and the target is greater than *average*, then the mobile node decides to postpone the communication, or else it communicates immediately. If it decides to wait, then in the next $k-1$ time units, whenever the current distance becomes not greater than *average*, communication is performed.

5.2 Least Distance (LD) heuristic

The LD heuristic is the simplest and most effective heuristic presented in this paper. This heuristic is based on the 37% rule. We first find the least distance d_{min} between a mobile node and the target in the history of that node:

$$d_{min} = Min_{\forall x \in S_k} d(x, y)$$

Then, in each of the next k time slots we check if the current distance d is less than or equal to d_{min}. At any time slot, if we find $d \le d_{min}$, we communicate immediately, else we communicate at the kth time unit.

6. SIMULATIONS

To evaluate the performance of our heuristics, we use the ns-2 simulator [5] with ad-hoc routing extensions contributed by CMU [2]. We use the standard *two-ray-ground* model as the propagation model. We use 10 nodes that move in a 1500m by 1500m area with movement speeds uniformly distributed between 0 and 10 m/s and one node (the target) always fixed at the center. The transmission and reception energy values are chosen to reflect the values of a standard waveLAN network card.

6.1 Experimental results

Figures 1 and 2 show the percentage energy saving with the AD and LD heuristics, respectively, for different values of k for both single hop and multi-hop transmissions. As we increase the value of k, a mobile node can save more energy since it now has more opportunities (i.e., a longer time) to move closer to the destination. From the figures, we can see that the percentage energy saving increases rapidly as we increase k initially. However, after some point it tends to stabilize. We also observe that the percentage saving in energy is much more in the case of single hop communication.

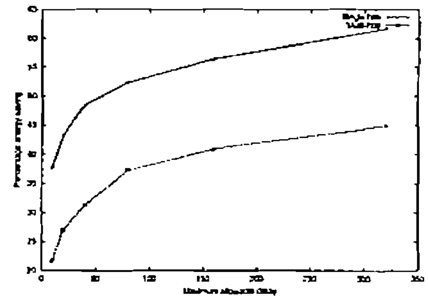

Figure 1: Percentage energy saving as a function of k for AD heuristic.

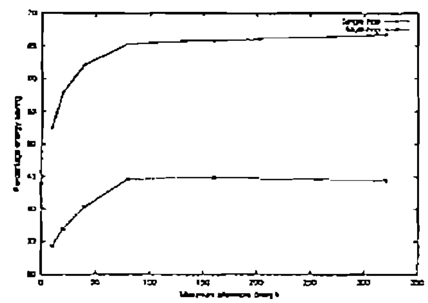

Figure 2: Percentage energy saving as a function of k for LD heuristic.

7. CPU PROCESSING COST

The prediction algorithms run on the mobile nodes. The required CPU processing incurs an energy cost. Our prediction strategy will effectively reduce energy consumption of the mobile device only if the computational cost, in terms of energy, is less than the energy saving in network communication. Our measurements on a Compaq's iPAQ 3650 running Linux shows that the energy consumptions due to CPU processing of AD and LD heuristics are 1.209 and 0.134 Joules. These values (of the order $10J$) are clearly negligible compared to the energy saving in network communication (of the order $10^3 J$).

8. CONCLUSION

Limited battery life is an important issue in ad hoc networking. Our strategy presented in this paper can conserve energy of the mobile nodes up to 50%, thus increasing the network lifetime. Currently, we are looking into the problem where both the communicating peers are mobile.

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