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Energy Efficient Adaptive Position Update For Geographic Routing in Mobile Ad Hoc Networks

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Abstract—**The nodes are required to regularly update the position information of their immediate neighbors in order to make forwarding decisions effective. One popular method to do so is to regularly broadcast beacon packets. However this method is not attractive from both update cost and routing performance point of view. We propose the Adaptive Position Update (APU) strategy which works on the frequency of position updates and the forwarding patterns of the nodes. Two simple principles : i) A node which is a regular updater of its node position provide difficulty in predicting it's movement ii) Those node which are nearest to forwarding paths are the regular updater of their positions.**

Our theoretical analysis, which is validated by NS2 simulations of a well-known geographic routing protocol, Greedy Perimeter Stateless Routing Protocol (GPSR),shows that APU can significantly reduce the update cost and improve the routing performance in terms of packet delivery ratio and average end-to-end delay in comparison with periodic beaconing and other recently proposed updating schemes. The benefits of APU are further confirmed by undertaking evaluations in realistic network scenarios, which account for localization error, realistic radio propagation, and sparse network.

Key Words — **Adaptive Position Update , Greedy Perimeter Stateless Routing Protocol, Mobility Prediction, On Demand Learning**

I. INTRODUCTION

The positioning devices like GPS have become quite popular and the geographic routing protocols have become an attractive choice [2], [3], [4].The basic routing principle is based on information about the geographically closest neighbor. The underlying principle used in these protocols involves selecting the next routing hop from amongst a node's neighbors, which is geographically closest to the destination. As forwarding is based on local knowledge there is a need to create and maintain routes for each destination. Hence position base protocols are highly adaptive and are robust to frequent changes in network topology As the forwarding decisions are done at any instant so the node always selects the optimal hop on the basis of the most current topology. Several studies [2], [5] have shown that these routing protocols offer significant performance improvements over topology-based routing protocols such as DSR [6] and AODV [7].In the protocols mentioned above the forwarding strategy needs the : (i) the position of the final destination of the packet and (ii) the position of a node's neighbors. The final destination can be obtained using a *location service* such as the Grid Location System (GLS) [8] or Quorum [9] and the neighbor node position can be obtained by exchanging its own location information using the GPS [1]) allowing each node to build a local map of the nodes within its vicinity often referred to as the *local topology*. However , in situations where nodes are mobile or switched off the topology hardly remains static thus necessitating the need to broadcast the location information by each node to all of its neighbor by packets called as beacons. In most geographic routing protocols (e.g. GPSR [2], [10], [11]), beacons are broadcast periodically for maintaining an accurate neighbor list at each node. These position updates turn out to be costly as they consume the node energy, wireless bandwidth for each update and increases the risk of packet collision at the medium access control (MAC) layer. Routing performance and accuracy is affected by collision and in such a scenario the lost packet is retransmitted where as(a lost beacon broadcast is not retransmitted). Instead of going for a static periodic update policy it make sense to frequently broadcast their updated position of a node which constantly changes its position. However for node which does not changes it position frequently periodic beacon update is not fruitful. In this paper, we propose a novel beaconing strategy for geographic routing protocols called *Adaptive Position Updates strategy (APU)* [12]. This scheme removes the drawbacks of periodic beaconing by adapting to the system variations. APU sets two rules for

initiating the beacon update process. The first rule, called as *Mobility Prediction (MP)*, uses mobility prediction scheme to estimate when a location information becomes inaccurate and the next beacon is broadcast only if the predicted error in the location estimate is greater than a certain threshold thus updating the frequency of the node's motion. The second rule, referred as *On-Demand Learning (ODL)*, aims at improving the accuracy of the topology along the routing paths between the communicating nodes. This ensures that nodes involved in forwarding data packets maintain a more up-to-date view of the local topology. The nodes which are not in the vicinity of the forwarding path do not broadcast beacon frequently. The APU has been modeled to measure the beacon overhead and the local topology accuracy. Our analytical results are proven by simulations.

The impact of varying the mobility dynamics and traffic load on the performance of APU is carried on first set of simulations[13]. The simulation results show that APU can adapt to mobility and traffic load well. In the second set of simulations, we evaluate the performance of APU under the consideration of several real-world effects such as a realistic radio propagation model and localization errors. The extensive simulation results confirm the superiority of our proposed scheme over other schemes. The main reason for all these improvements in APU is that beacons generated in APU are more concentrated along the routing paths, while the beacons in all other schemes are more scattered in the whole network

The rest of paper is organized as follows. In Section 2, we briefly discuss related work. A detailed description of the APU scheme is provided in Section 3, followed by a comprehensive theoretical analysis in Section 4. Section 5 presents a simulation-based evaluation highlighting the performance improvements achieved by APU in comparison with other schemes. Finally, Section 6 concludes the paper.

II. RELATED WORK

Forwarding decisions in geographic routing at each node are based on the locations of the node's one-hop neighbors and location of the packet destination as well. A forwarding nodes therefore needs to maintain these two types of locations. Many works, e.g. GLS [8], Quorum System [9], have been proposed to discover and maintain the location of destination. However, the maintenance of one-hop neighbors' location has been often neglected. Some geographic routing schemes, e.g. [14], [15], simply assume that a forwarding node knows the location of its neighbors. While others, e.g. [2], [10], [11], uses periodical beacon broadcasting to exchange neighbors' locations. In the periodic beaconing scheme, each node broadcasts a beacon with a fixed beacon interval. If a node does not hear any beacon from a neighbor for a certain time interval, called neighbor time-out interval, the node considers this neighbor has moved out of the radio range and removes the outdated neighbor from its neighbor list. The neighbor time-out interval often is multiple times of the beacon interval. Heissenbuttel et al. [13] have showed that periodic beaconing can cause the inaccurate local topologies in highly mobile ad-hoc networks, which leads to performances degradation, e.g. frequent packet loss and longer delay. In the distance-based beaconing, a node transmits a beacon when it has moved a given distance d. The node removes an outdated neighbor if the node does not hear any beacons from the neighbor while the node has moved more than k-times the distance d, or after a maximum time-out of 5s. This approach therefore is adaptive to the node mobility, e.g. a faster moving node sends beacons more frequently and vice versa. However, this approach has two problems. First, a slow node may have many outdated neighbors in its neighbor list. Second, when a fast moved node passes by a slow node, the fast node may not detect the slow node due the infrequent beaconing of the slow node, which reduces the perceived network connectivity.

In reactive beaconing, the beacon generation is triggered by data packet transmissions. When a node has a packet to transmit, the node first broadcasts a beacon request packet. The neighbors overhearing the request packet respond with beacons. Thus, the node can build an accurate local topology before the data transmission. However, this process is initiated prior to each data transmission, which can lead to excessive beacon broadcasts, particularly when the traffic load in the network is high.

The proposed strategy adjusts the beacon update intervals depending on the mobility dynamics and the forwarding pattern in the network. The beacons transmitted by the nodes contain their current position and speed. Nodes estimate their positions periodically by employing Using linear kinematic equations which work on the parameters specified by last beacons the nodes estimate there position periodically and if the predicted location is different from the actual location, a new beacon informing the neighbors about changes in the node's mobility characteristics is transmitted. Those nodes which are responsible for forwarding the packets need to have a very accurate information of the local topology. The proposed strategy thus increases the frequency of beacon updates at such nodes so as to update them with the local topology information .

Some other geographic routing protocols that do not need to maintain the neighbor list and therefore can avoid position updates, e.g., IGF [16], GeRaf [17], BLR [18], ALBA-R [19]. As they do not forward beacons they are called as beaconless routing protocols. These protocols use timers and each neighbor sets a timer for relaying the packets.The beaconless routing protocols can avoid excessive position updates and are particular suitable for networks where the topology is highly dynamic, e.g., in wireless sensor network where nodes periodically switch on and off (to save energy consumption) [20].

III. ADAPTIVE POSITION UPDATE

We begin by listing the assumptions made in our work:

1.Position and Velocity information of themselves is available to all nodes,
2. All links are bidirectional,
3. The current location and velocity of the nodes are updated in the beacon updates, and
4. All one-hop neighbors operate in the promiscuous mode and hence can overhear the data packets and data packets can piggyback position and velocity updates.

Initially , each node broadcasts a beacon informing its neighbors about its presence and its current location and velocity followed by this each node periodically broadcasts its current location information which is stored at each node. The local topology gets updated from the position updates received from its neighbors . Thus, the beacons play an important part in maintaining an accurate representation of the local topology. Instead of periodic beaconing, APU adapts the beacon update intervals to the mobility dynamics of the nodes and the amount of data being forwarded in the neighborhood of the nodes. APU employs two mutually exclusive beacon triggering rules, which are discussed in the following.

3.1 Mobility Prediction Rule

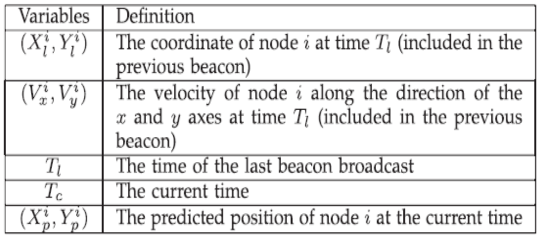
This rule adapts the beacon generation rate to the frequency with which the nodes change the characteristics that govern their motion (velocity and heading). The motion characteristics are included in the beacons broadcast to a node's neighbors. The neighbors can then track the node's motion using simple linear motion equations. Nodes that frequently change their motion need to frequently update their neighbors, since their locations are changing dynamically.

On the contrary, nodes which move slowly do not need to send frequent updates.

In our scheme, upon receiving a beacon update from a node i, based on linear kinematics each of the neighbor updates current position and velocity of node i. This update allow the nodes to check whether the node i is still within their transmission range. The goal of the MP rule is to send the next beacon update from node i when the error between the predicted location in the neighbors of i and node i's actual location is greater than an acceptable threshold.

As shown in Fig. 1, given the position of node i and its velocity along the x and y axes at time Tl, its neighbors can estimate the current position of i, by using the following equations:

$$X_p^i = X_l^i + (T_c - T_l) * V_x^i, \quad Y_p^i = Y_l^i + (T_c - T_l) * V_y^i. \qquad (1)$$



Variables	Definition
(X_l^i, Y_l^i)	The coordinate of node i at time T_l (included in the previous beacon)
(V_x^i, V_y^i)	The velocity of node i along the direction of the x and y axes at time T_l (included in the previous beacon)
T_l	The time of the last beacon broadcast
T_c	The current time
(X_p^i, Y_p^i)	The predicted position of node i at the current time

Table 1 Notations for Mobility Prediction

Note that, here (X_l^i, Y_l^i) and (V_x^i, V_y^i) refers to the location and velocity information that was broadcast in the previous beacon from node i. Node i uses the same prediction scheme to keep track of its predicted location among its neighbors. Let (Xa, Ya), denote the actual location of node i, obtained via GPS or other localization techniques. Node I then computes the deviation D^i_{devi} as follows:

$$D^i_{devi} = \sqrt{(X_a^i - X_p^i)^2 + (Y_a^i - Y_p^i)^2}. \qquad (2)$$

If the deviation is greater than a certain threshold, know as the Acceptable Error Range (AER), it acts as a trigger for node i to broadcast its current location and velocity as a new beacon.

The MP rule, thus, tries to maximizes the effective duration of each beacon.

3.2 On-Demand Learning Rule

The MP rule solely may not be sufficient for maintaining an accurate local topology. Consider the example illustrated in Fig. 2, where node A moves from P1 to P2 at a constant velocity. Now, assume that node A has just sent a beacon while at P1. Since node B did not receive this packet, it is unaware of the existence of node A. Further, assume that the AER is sufficiently large such that when node A moves from P1 to P2, the MP rule is never triggered. However, as seen in Fig. 2 node A is within the communication range of B for a significant portion of its motion. Even then, neither A nor B will be aware of each other. Now, in situations where neither of these nodes are transmitting data packets, this is perfectly fine since they are not within communicating range once A reaches P2. However, if either A or B was transmitting data packets, then their local topology will not be updated and they will exclude each other while selecting the next hop node. In the worst case, assuming no other nodes were in the vicinity, the data packets would not be transmitted at all. Hence, it is necessary to devise a mechanism, which will maintain a more accurate local topology in those regions of the network where significant data forwarding activities are on-going. In the On-Demand Learning rule a node broadcasts beacons on-demand, i.e., in response to data forwarding activities that occur in the vicinity of that node. Thus whenever a node overhears a data transmission from a new neighbor(one who is not in the neighbor list of this node), it broadcasts a beacon as a response. In reality, a node waits for a small random time interval before responding with the beacon to prevent collisions with other beacons. Recall that, we have assumed that the location updates are piggybacked on the data packets and that all nodes operate in the promiscuous mode, which allows them to overhear all data packets transmitted in their vicinity. In addition, since the data packet contains the location of the final destination, any node that overhears a data packet also checks its current location and determines if the destination is within its transmission range. If so, the destination node is added to the list of neighboring nodes, if it is not already present. Note that, this particular check incurs zero cost, i.e., no beacons need to be transmitted.

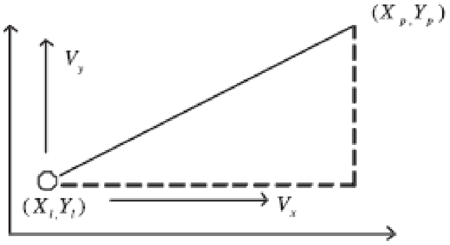


Figure 1 Mobility prediction ,an example

The ODL rule allows active nodes that are involved in data forwarding to enrich their local topology beyond this basic set. Active nodes have rich neighbor list where as the inactive nodes maintain the basic neighbor list. By maintaining a rich neighbor list along the forwarding path, ODL ensures that in situations where the nodes involved in data forwarding are highly mobile, alternate routes can be easily established without incurring additional delays.

IV. ANALYSIS OF ADAPTIVE POSITION UPDATE

APU can be analyzed by focusing on two key performance measures:

1) update cost and 2) local topology accuracy.

While the update cost is measured as the total number of beacon broadcast packets transmitted in the network. The local topology accuracy is collectively measured by the following two metrics:

a) ***Unknown neighbor ratio***: This is defined as the ratio of the new neighbors a node is not aware of, within the communicating radio range of the node to the total number of neighbors.

b) ***False neighbor ratio*:** This is defined as the ratio of obsolete neighbors that are in the neighbor list of a node, but have moved to the total number of neighbors.

The unknown neighbors of a node are the new neighbors that have moved in to the radio range of this node but have not yet been discovered and are hence absent from the node's neighbor table.

For mathematical tractability, we make the following simplifying assumptions:

a) Nodes move according to the Random Direction Mobility (RDM) model used in the analysis and simulations of wireless ad hoc networks. This mobility model maintains a uniform distribution of nodes in the target region over the entire time interval under consideration [21].

b) Each node has the same radio range R, and the radio coverage of each node is a circular area of radius R.

c) The network is sufficiently dense such that the greedy routing always succeeds in finding a next hop node. In other words, we assume that a forwarding node can always find a one-hop neighbor that is closer to the destination than itself.

d) The data packet arrival rate at the source nodes and the intermediate forwarding nodes is constant.

4.1 Analysis of the Beacon Overhead

The two rules employed in APU are mutually exclusive. Thus, the beacons generated due to each rule can be summed up to obtain the total beacon overhead. Let the beacons triggered by the MP rule and the ODL rule over the network operating period be represented by O_{MP} and O_{ODL}, respectively. The total beacon overhead of APU, O_{APU}, is given by

$$O_{APU} = O_{MP} + O_{ODL}. \qquad (3)$$

4.2 Analysis of the Local Topology Accuracy

We have defined two metrics that collectively represent the neighbor table accuracy:

1) unknown neighbor ratio and

2) false neighbor ratio.

The neighbor table maintained by a node is only referenced when the node has to forward a packet. Consequently, it only makes sense to calculate the neighbor table accuracy at the time instants when the node is forwarding a data packet. We first analyze the unknown neighbor ratio. For the average number of beacons triggered by each packet Forwarding operation (γ) , we have shown that, according to the ODL rule, the average number of new neighbors that enter the radio range of a node between two successive forwarding operations (i.e., the interval $1/\lambda$) is given by γ. The node will only become aware of these new neighbors when it forwards the next packet, since theseneighbors will broadcast beacons announcing their presence in response to the packet transmission. On an average $\rho\pi R^2\delta(1/\lambda)$ new neighbors enter the radio range of a forwarding node during the interval $1/\lambda$. The number of actual neighbors is the total number of nodes within the radio range of the forwarding node, which is $\rho\pi R^2$ on average. Therefore, the unknown neighbor ratio, represented by Λ^{m}_{APU}, can be computed as follows:

$$\Lambda^{m}_{APU} = \frac{\rho\pi R^2 \cdot \delta\left(\frac{1}{\lambda}\right)}{\rho\pi R^2} = \delta\left(\frac{1}{\lambda}\right). \qquad \text{---- (4)}$$

We now proceed to evaluate the false neighbor ratio. As per the MP rule, a node periodically estimates the current locations of its neighbors using (1). Let ω denote the periodicity of this operation. At the beginning of each period, the node updates its neighbor list by removing all the false neighbors (i.e., those nodes that are estimated to have moved out of its radio range). Since, data packets arrive at the forwarding node at random during the interval ω, the average time of arrival of a packet is given by $\omega/2$. The number of false neighbors at time $\omega/2$ is the number of neighbors that have moved out of the radio range during $\omega/2$. Therefore, the false neighbor ratio, denoted by Λ^{f}_{APU} is given by

$$\Lambda^{f}_{APU} = \frac{\rho\pi R^2 \cdot \delta\left(\frac{\omega}{2}\right)}{\rho\pi R^2} = \delta\left(\frac{\omega}{2}\right). \qquad (5)$$

V. SIMULATION

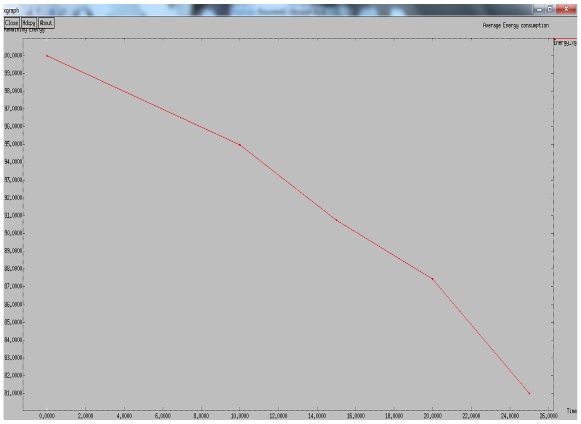


Figure 2 Energy Graph

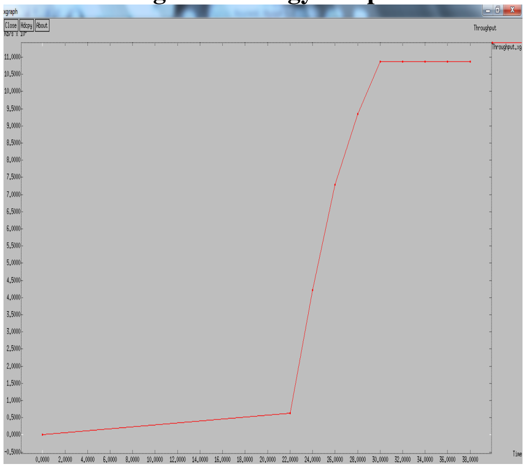


Figure 3 Throughput graph

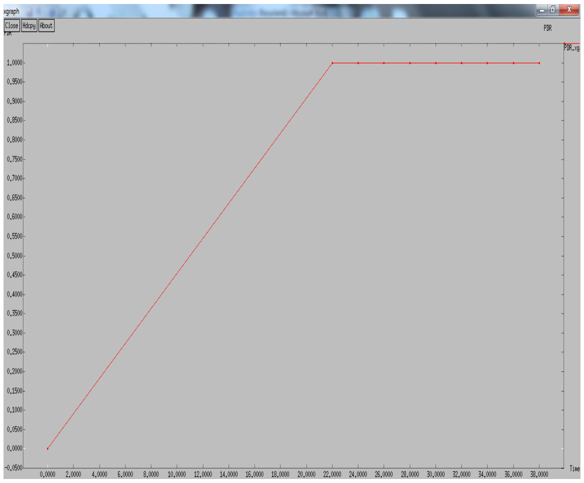


Figure 4 PDR Graph

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