Predictive Mobile IP for Rapid Mobility

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Abstract

Mobile computers require Mobile IP to preserve connectivity and properly route information while roaming over foreign networks. Registration, forwarding delay, and tunnel initialization diminishes the performance of mobility protocols during handoff . We propose a proactive rather than reactive solution to improve the performance of Mobile IP. We extend the current protocol with two new entities: ghost Mobile Host and ghost Foreign Agent. Our target is mobility scenarios in which mobile hosts are moving at a very high-speed. Our protocol extension uses the Kalman filter to determine the trajectory and speed of the mobile host and to proactively allocate resources for Mobile IP. Preliminary experiments conducted using the RAMON emulator show that the proposed predictive methods offer a promising range of 20-50% of performance improvement.

***Keywords**: mobile networking protocols, predictive algorithms, handoff, network emulation.*

1. Rapidly Moving Environments

The proliferation of wireless networks and high-speed internet access has led to massive deployment of IEEE 802.11b access points and embedded network cards in mobile devices. Wireless Local Area Networks provide connection speeds of 1-11Mbps [1] and 1-55Mbps [2] and represent a potential option for replacing or complimenting 3G cellular networks. Carriers are currently deploying solutions for future wireless subscribers offering bandwidths ranging from 40 to 140 Kbps (e.g. CDMA 2000) [3]; consequently higher deployment and licensing costs are expected, however IEEE 802.11b/a networks make use of the 2.4GHz free (unlicensed) spectrum and therefore significant growth will be expected in the years to come. In fact, many researchers and analysts around the world are debating the feasibility of 3G networks, especially when many carriers still have immense debts and the deployment of 2.5-3G networks has slowed down. Vehicular routes of trains and highways can benefit from Wireless LANs and supply end users with a communication scenario similar to existing office and home environments (without expenditures on extra equipment or technologies) at lower cost and enhanced user experience. High speed of mobility, however, represents a challenge to overcome in Wireless LAN. Registration-based solutions such as out of the box Mobile IP are not suitable for rapid mobility over Wireless LAN [4].

Indeed, registration delays represent a major obstacle for a wide deployment of Mobile IP wireless networks in vehicular applications for continuous connectivity. The IEEE 802.11a and IEEE 802.11b [5, 6] wireless LAN technologies offer micro-cell coverage, high throughput, and cheap deployment. The combination of these factors and the native characteristics of Mobile IP metrics, including network delay, handoff latency, and packet-forwarding give rise for the need to an alternative approach that would rely less on the costly registration mechanism. For instance, in an 802.11b network, cells range from 200m to 1000m for indoor and outdoor environments, providing throughputs of 1 to 11 Mbps [5]. Any authentication mechanism, network delay, or handoff initiated at the mobile host will diminish the performance and use of the cell significantly. For example, an 11 Mbps, 400m cell and a mobile unit traveling at 80 m/s generate a dwell time of 5 seconds. By assuming that the registration processing time is 20% of the dwell time, the mobility protocol in use (e.g. Mobile IP) could take up to one second to perform a handoff. This is obviously not acceptable; new architecture and mobility awareness are required to adapt to the changing conditions of mobility.

As a consequence of rapid mobility, the TCP stack is also affected by the unawareness of the user trajectory and continuous handoffs initiated by the MH. In a rapid mobility environment, mobile users roam around different networks at different cell sizes in a short period of time. As a result, adaptation of the TCP stack and context transfer among inter-domain and intra-domain handoffs are required to enhance the performance of TCP. Network awareness and integration of Layer-2 and Layer-3 protocols should therefore be considered in rapidly mobile protocols. Hence, speed of the mobile node and trajectory determination become important factors that should be considered in addition to the traditional factors described above.

2. Related Research

Trajectory prediction and predictive algorithms for mobility in wireless networks have been investigated in different cellular and micro-cellular infrastructures. Liang and Hass [6] provide a predictive-distance based location management algorithm. Their proposal replaces a random walk and group mobility models with a Gaussian-Markov state machine. User location is predicted given previous values of location and velocity. Similarly, Liu et al. [7] proposed a more complex predictive mechanism for mobility management in W-ATM (Wireless Asynchronous Transfer Mode) networks. Liu's algorithm uses a Kalman Filter and a Hierarchical Location Prediction algorithm (HLP). The algorithm combines location updating with location prediction for resource reservation and allocation in W-ATM networks.

Predictable models could also involve dynamic programming and stochastic control [8]. In order to cope with mobility we followed an approach similar to Levine's shadow clusters [9]. In Levine's, surrounding cells to a mobile node become its shadow where packets are forwarded to depending upon network and mobility conditions. Although our approach is similar, we combine the mobile node's shadow as well as foreign agents.

Dynamic programming and Kalman Filters showed good simulative results but lacked of a real implementation. Our work focuses on a real implementation using Linux as an operating system, Kalman Filters, and Mobile IP.

Our proposed protocol determines speed and trajectories using GPS (Geographical Positioning System). GPS information is also investigated in Ad-hoc networks [10] where GPS information is used to improve the performance of Distance Vector protocols. Similarly, Location Aided routing (LAR) [11] assumes that GPS information is available at the mobile node and is used for routing in ad-hoc networks. The combination of Mobile IP and GPS [12] showed great improvements during handoff and registration and henceforth its utilization is highly recommended.

Position information and speed are highly correlated. The effect of speed and mobile protocols has been researched mostly as part of ad-hoc networks. Handoff rate is generally used as an equivalent to speed. Speed has a negative effect on mobility, especially the performance of ad-hoc and infrastructure networking protocols. Holland et al. [13] simulated several ad-hoc scenarios and showed that the average throughput decreases at higher speeds. The results corresponded to a simulation performed in *ns* network simulator [14] focusing only on the performance of ad-hoc networks. The same effects on throughput due to speed were measured by Gerla [14], while experimenting with tree multicast strategies in ad-hoc networks at speeds up to 100 km/hr.

Given the negative effects of speed and the reactive mechanisms found in the majority of mobility protocols, we proposed a Predictable Mobile IP extensions targeted to improve the effects of speed in rapidly moving vehicles.

3. Predictable Mobile IP (Ghost Mobile IP)

The majority of mobile networking protocols requires registration to keep the home network aware of mobility. The Home Location Register (HLR) and the home agent structure used in Mobile IP [15] are well known examples of mobile protocols. The hierarchical implementations of Mobile IP [16] used in our research is the Dynamic Mobile IP implementation from Helsinki University of Technology (HUT). This implementation requires less initialization time and provides a well documented source code. The predictable mobility protocol was tested using RAMON [17]. RAMON is a rapid mobility network emulation platform developed at the University of Florida where mobile protocols could be tested and emulated.

All experiments were conducted using an agent advertisement time of 1 sec, with no agent solicitation messages, handoff required approximately 2 to 10 seconds depending upon the speed of the mobile host.
In a rapid mobility, non-assisted and reactive handoff mechanisms, handoff time (5 sec) is closed in magnitude to the dwell time in the cell at certain speeds (60 m/s). In order to minimize the effect of speed, the mobile protocol should be able to be preemptive and predict the position of the MH, and handoff to take

place faster while maintaining connectivity even at high speed. In general, Mobile IP present acceptable performance for scenarios where a cell size ranges between 500 to 1000m. and the mobile unit travels at a speed of 80 m/s, the T_{dwell} time would be between 6 to 12 seconds, therefore any significant reduction on the handoff time and the forwarding delays associated with the reactive approach taken by Mobile IP protocol will allow a better utilization time of the cell.

Mobile IP reactive mechanism for handoff is not suitable for rapid-mobility. In order to cope with speed, we need to add two additional entities. These entities speed up handoff and improve the performance of the hierarchical and non-hierarchical implementations of Mobile IP. These entities are:

- Ghost Mobile-Node (g-MN) moves with the MN along the different cells and follows a determined trajectory. The g-MN is a "virtual" repeater capable of registering and allocating resources in a predictive matter. The g-MN speeds up handoff and augments the performance of Mobile IP. The g-MN is capable of replicating the registration request, handling the creation of the tunnel, and replicating Authentication and Authorization information from the MN and acts on behalf of the MN before is in the range of the new FA.

- Ghost Foreign Agent (g-FA) is an entity that receives a delegation of authority from the FA. The g-FA is created in the neighborhood of the FA. Its main role is to advertise the FA presence from a neighbor FA.

Figure 11.a shows how an g-FA acts on behalf of LFA2 (Leaf Foreign Agent), so any MN can include that FA as a potential place for handoff when in LFA1 range. Once the MN has moved to the vicinity of LFA2 (coming from LFA1), registration has already been done, and resources have been allocated for the MN. Once the registration message is received by either the HA or HFA (hierarchical Foreign Agent), a new tunnel is created towards the MN new location and data is forwarded as shown in Figure 1.b. Additionally, the g-FA has updated the information of available FAs in the MN and handoff decisions can be taken quicker. Another useful feature of the g-MN is the possibility of buffering the incoming traffic from the Correspondent Host (CH) towards the MN that could have been lost during handoff. This feature was not implemented in the current protocol for the g-MN and g-FA.

Similarly, the same approach can be described for a g-MN and the interaction performed by the duality (g-MN and g-FA) allocates resources preemptively rather than passively acknowledge packets. However, both approaches separate and hide handoff from the potential bottleneck layers.

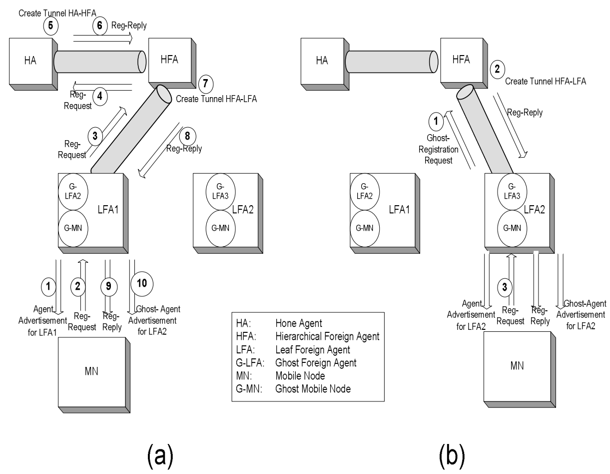


Figure 1. Ghost-Mobile IP implementation of handoff management

4. Location Tracking via Kalman Filter

The Kalman filter is used to determine the amount of time before the g-MN can send a registration message and act on behalf of the real mobile node.

Kalman filters have been used in numerous applications ranging from location tracking and control of physical variables; wireless protocols are not the exception. D. Dailey, et al [18] solved the problem of tracking a vehicle and the time of arrival to a certain destination using the Kalman filter. The prediction done by the predictor is used to inform bus riders, and anyone with a smart phone, of the waiting time of a bus route in Seattle, WA.

The Kalman filter [19] addresses the problem of trying to estimate the state: $x \in \mathbf{R}^n$ of a discrete-time controlled process that is governed by a linear stochastic difference equation. In general the process is composed of the state (Eq 1) and the measurement vectors. (Eq 2)

The Kalman filter assumes that there is a state vector x such that:

$$x_k = Ax_{k-1} + Bu_k + w_{k-1} \quad (1)$$

with a measurement vector $z \in \mathbf{R}^n$ such that:

$$z_k = Hx_k + v_k \quad (2)$$

For the measurement-update equations, the first equation (Eq 3) computes the Kalman gain, K_k, the second equation (Eq 4) calculates the value of x_k to compute the predicted value of the state vector. The third equation (Eq 5) updates the covariance matrix P_k.. The value of the co-variance matrix R=E{v_k v_k^T] is needed and, in general, is the easier to determine since we already know how to measure the position vector and we can easily dedicate some samples to determine the co-variance of v_k.

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1} \quad (3)$$

$$x_k = x_k^- + K_k (z_k - Hx_k^-) \quad (4)$$

$$P_k = (I - K_k H) P_k^- \quad (5)$$

Figure 2 shows the predicted and measured values of x and y at a sampling rate of 1 sec and speeds ranging from 0 to 80m/s.

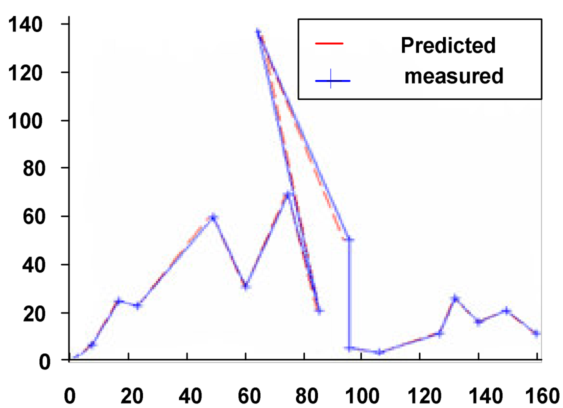


Figure 2. Predicted and measurement location tracking in a 2-D scenario using Kalman Filter. (T=5sec)

As expected, accuracy of the prediction diminishes as the sampling interval increases. In our scenario, the sampling interval is equivalent to the agent solicitation timer. The result of our experiment shows that the level of uncertainty or predicted location could go from 10 to 100m with an agent solicitation timer of 1 to 5 sec. Position update intervals higher than 10 seconds are not suitable for our application scenario.

5. Predictable Mobile IP Performance in an Emulation Environment

The implementation of the g-MN and g-FA was developed in C and the g-FA is part of Dynamics HUT [16]. The experiment conducted with the emulated topology using RAMON and a similar topology shown in Hernandez, et al [4]. On average, the predicted approach is better in 30 to 50% for TCP average throughput. Figure 3 shows the Performance improvement of ghost's extensions for Mobile IP. The performance improvement was observed assuming the MN reported its position on 5 sec intervals. This enhancement is expected since in the tcp-sequence plot, the majority of packets are being sent during the first few seconds of transmission, and as successive handoff occurs, fewer packets reach the destination nodes. In the same experiment run with the filter and g-MN there are certain handoff gaps and small disruptions due to a UDP registration missing at the FA level.

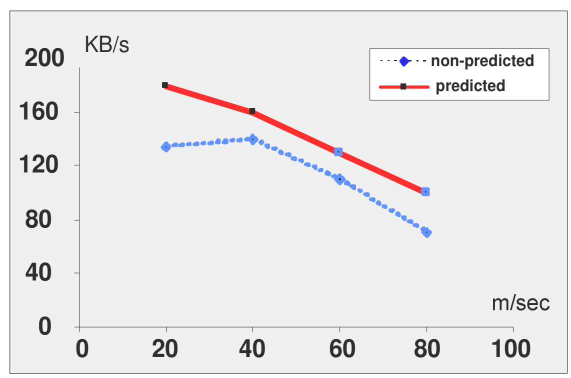
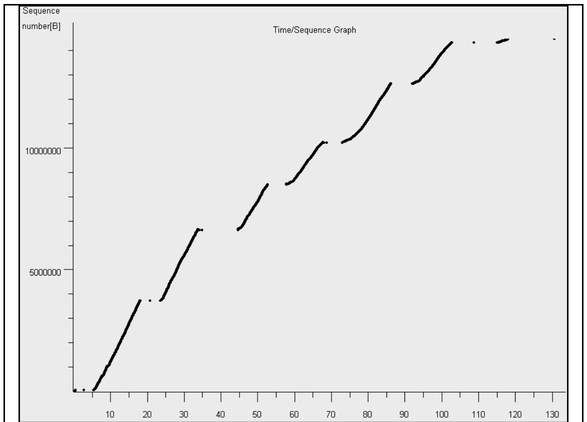
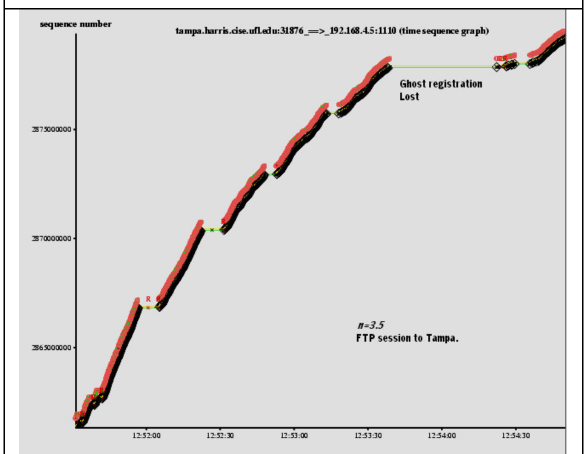


Figure 3. Performance improvement of ghosts extensions for Mobile IP

Figures 4.a and 4.b show that more packets were transferred during the same experimentation time. At 40 m/s, we observed that TCP registered almost 20 million packets transferred, while in the non-predictive case Figure 4.b about 14 million packets arrived from the FTP server. For 80 m/s, we observed that more than 10 million packets arrived to the mobile node using the predictive algorithm, while about 6 million made it during the non-predictive case. Our experiment over 40 m/s through 80 m/s shows an improvement of approximately 1.5 times (average).



(a) non-predicted



(b) predicted

Figure 4. Predicted Mobile IP Sequence-time plot (40 m/sec)

6. Conclusions

Mobile IP requires registration, tunneling, and triangular routing in order to provide seamless roaming among foreign networks. The drawbacks of these mechanisms are found in the large overhead required by the infrastructure, which affects the communication process at speeds greater than 20 m/s (72 Km/hr). Traditionally, the study and determination of the performance bottlenecks is done with network simulators. One of the most commonly used simulators by the research community is *ns* or the "network simulator". Through simulation experiments we found that the design of the wireless infrastructure requires a-priori knowledge of the protocols used as well as speed characteristics of the mobile hosts. Cells can be interleaved at different distances and configurations depending on the speed and mobility behavior of the mobile units. We observed that providing full wireless coverage is unnecessary and can represent a potential a waste of resources at high speed.

Mobile networking protocols such as Mobile IP are not designed to handle high-speed gracefully. Such protocols produce considerable overhead and high forwarding delay. We found out that protocols based on registration and non-aware packet re-routing is not appropriate for speeds higher than 20 m/s.

In a rapid mobility, non-assisted and reactive handoff time is closed in magnitude to the dwell time in the cell. In order to minimize this factor, the mobile protocol should be able to be preemptive and predict potential locations where the rapid mobile units are forecasted to be positioned, and handoff will gracefully occur even at high speed. We showed that a Kalman filter can increase the location tracking capability of a mobile node and greatly improve the mobility protocol. In fact, a Mobile IP can identify the predicted path of a mobile node with an uncertainty level of 10 to 100m if the agent solicitation timer of 1 to 5secs. We proposed two ghost-entities for Mobile IP that can interact on behalf of the mobile node and foreign agent. These entities use predicted information to improve the performance of Mobile IP at high-speed. Our results showed that the predicting mechanisms improved the average throughout from 60 Kbytes/sec to 90 Kbytes/sec (almost 1.5 times increase) at 80 m/s. Therefore, prediction and forecasting are a requirement for protocols suited for rapid mobility scenarios.

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