A Link-Connectivity-Prediction-Based Location-Aided Routing Protocol for Hybrid Wired-Wireless Networks

Mintao Wu[1], Winston K.G. Seah[2,1] and Lawrence W.C. Wong[2,1]
[1] National University of Singapore 4 Engineering Drive 3 Singapore 117576
[2] Institute for Infocomm Research 21 Heng Mui Keng Terrace Singapore 119613
{stuwumt, winston, lwong}@i2r.a-star.edu.sg

ABSTRACT

A hybrid wired-wireless network comprises a fixed wired backbone network interconnecting wireless ad hoc networks. In such environments with promising potential commercial applications, efficient routing is critical to achieve good performance. Previous research in such hybrid network environment has not taken advantage of research on routing which exploits location information. In this paper, we propose a Link-Connectivity-Prediction-Based Location-Aided Routing (LLR) protocol specially designed for this hybrid network environment. We also propose a gateway discovery algorithm to help build *K-hop* subnets around gateways, which is fundamental to the proposed routing protocol. The efficiency of our protocol is verified using simulations.

Keywords: Hybrid Network, Routing Protocol, Location-Aided Routing, Link Prediction

1 INTRODUCTION

A hybrid wired-wireless network is defined to be a two-layer hierarchical network that contains both mobile hosts (MHs) and access points (APs). MHs, or mobile nodes (MNs) can communicate with other MNs, which can be multi-hops away. APs, or gateways (GWs), are nodes with both wireless and wired interface, e.g. Internet connectivity. GWs give MNs access to other MNs or fixed hosts (FHs) of wired network. For example, MN1 can reach MN7 in over a multi-hop path, while MN1 can also reach MN5 via the wired network.

One potentially useful application for this hybrid network is the inter-vehicle hybrid network [1][2][3]. Vehicles in the network form an ad hoc network in order to share information among them. At the same time, passengers in vehicles can access the Internet through the connections between vehicles and gateways deployed along the roads. For example, commuters in vehicles can communicate with other people in cars near to yours by chatting or playing interactive games, while at the same time you can check your email through the Internet.

Routing in such hybrid networks is a challenging task, since the network topology changes frequently due to the movement of MNs. The communication in this hybrid network environment can be categorized into two scenarios: (1) routing between a FH of wired network and an ad hoc MN and (2) routing between two ad hoc MNs with the same GW or with different GWs. The first scenario is also referred to as Internet connectivity. Several methods for achieving Internet connectivity have been proposed [11][12]. In this paper, we propose a simple but efficient gateway discovery algorithm to provide and maintain connectivity between MNs and GWs. However, since our focus here is on the peer-to-peer communication between MNs, which is the second scenario stated above, the communication between FHs and MNs are not studied.

Research effort has been carried out on such hybrid networks [5][6] and most use traditional reactive routing protocols like Ad-hoc On Demand Distance Vector Routing (AODV) [10] for multi-hop peer-to-peer communication between MNs. However, they do not take the advantage of the research that has been done in routing algorithms [4][8][9] which make use of location information. The performance of these routing protocols has been proven to be much better [4][9]. Motivated by research on the use of location information for routing in pure ad hoc network environments, we now study routing performance for multi-hop peer-to-peer communications between MNs complemented with the additional location information in this hybrid network environment.

A simple way to route in this hybrid network is to use the GWs as the default route. This means that all communications between MNs must go through the GWs, but this may increase the burden placed on the GWs. Therefore, one of our concerns in the routing protocol design is to distribute the traffic and avoid overusing key resources such as the GWs which may become bottlenecks.

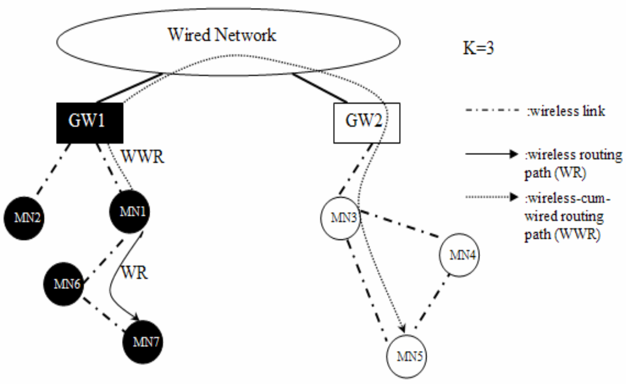

Figure 1: An example of hybrid wired-wireless network

We propose the Link-Connectivity-Prediction-Based Location-Aided Routing (LLR) protocol which is specially designed for the hybrid network environment of interest here. As this routing protocol has reactive mechanisms similar to AODV [10], we first provide a brief overview of AODV in Section 2.1. LLR also employs some special features that utilize the location information, viz., (a) it anticipates the duration of link connectivity, and reconstructs a new route before the connection breaks; and (b) it tries to restrict the flooding of control messages by using the same mechanism as that of the Location-Aided Routing protocol (LAR)[9]. The performance of our proposed routing protocol is verified through simulations.

In this paper, we also propose a gateway discovery algorithm that allows MNs to register with a GW. The GW forms a *K-hop* subnet around itself and maintains connectivity between itself and MNs within this *K-hop* subnet. The gateway discovery algorithm is essential part of LLR.

The paper is organized as follows. Section 2 gives a brief introduction on the related work in location-related routing protocols and hybrid networks, as well as the link estimation scheme used in our protocol. Section 3 explains the *K-hop* subnet concept and design of our gateway discovery algorithm. Section 4 describes the proposed LLR, followed by the simulation results in Section 5. Concluding remarks are made in Section 6.

2 RELATED WORKS

2.1 AODV Protocol

The AODV [10] routing protocol establishes routes only when they are required. A source MN wishing to communicate with a destination MN initializes a route discovery process by broadcasting a Route Request (RREQ) message. The RREQ sets up a temporary reverse path to the source MN for use later. Only the destination MN or an intermediate node with an up-to-date route to the destination can generate a Route Reply (RREP) message, which is sent back to the source MN along the temporary reverse path. As the RREP travels along the reverse path, it sets up the forwarding path to the destination MN. Upon receiving the RREP, the source MN can begin sending data using the forwarding path. Sequence numbers are also used to determine the freshness of routes.

2.2 Link Connectivity Prediction Scheme

The Link Expiration Time (LET) between two neighbors using the location information can be computed as proposed in [8]. Assume two nodes i and j are within the transmission range r of each other and let (x_i, y_i) be the coordinate of mobile node i and (x_j, y_j) be that of mobile node j. Also, let v_i and v_j be the speeds and θ_i and θ_j be the moving directions of nodes i and j, respectively. Then, the amount of time in which the two mobile nodes will stay connected is predicted by:

$$LET = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2}$$

where $a = v_i\cos\theta_I - v_j\cos\theta_j$, $b = x_i - x_j$, $c = v_i\sin\theta_I - v_j\sin\theta_j$ and $d = y_i - y_j$.

2.3 Location-Aided Routing Protocol (LAR)

LAR [9] is an on-demand routing protocol that searches for a path by flooding RREQs, similar to AODV, but it also uses location information to restrict the flooding area of the RREQs.

In LAR, before the route discovery phase, a source MN defines a circular area, called the *expected zone*, in which the destination may be located. The position and size of the circle is decided using the information: (a) destination location known to source; (b) time instant when the destination is located at that position; and (c) average moving speed of the destination. Then, the source MN needs to define a *request zone*. Only mobile nodes inside this area propagate the RREQs. Two ways of defining a request zone are proposed in [9] of which only one is relevant here. In this scheme, the smallest rectangular area that includes the expected zone and the source is the request zone. This information is attached to the RREQ by the source and the RREQ sent out. When a mobile node receives this packet, it checks whether it is inside the request zone and continues to relay the packet only if it is inside the request zone.

3 *K-HOP* SUBNET AND GATEWAY DISCOVERY ALGORITHM

In this section, we describe the *K-hop* subnet concept and gateway discovery algorithm, which is used to form the *K-hop* subnet. A *K-hop* subnet is a wireless subnet of a GW where MNs inside the subnet are at most K hops away from this particular GW. An example of *K-hop* subnets is shown in Figure 1. With K equals to 3, MN1, MN2, MN6 and MN7 form the subnet of GW1, while nodes MN3, MN4 and MN5 form the subnet of GW2. Formation of the *K-hop* subnet is essential in our routing protocol design. Inside the *K-hop* subnet, the GW proactively maintains the connectivity between itself and the MNs. In order to form such *K-hop* subnets, a simple efficient gateway discovery algorithm is proposed.

3.1 Gateway Discovery Algorithm

The gateway discovery algorithm is used to form the *K-hop* subnets around the GWs. After forming the *K-hop* subnets, connectivity between GWs and MNs is maintained: a GW keeps track of the MN's ID, current location information, and next-hop to this MN, while the MN keeps track of the GW's ID, geographical location information, next-hop to this GW, and the number of hops from this particular GW. Using the gateway discovery algorithm, the location information of MNs are collected and maintained at the GWs to be used later by the routing protocol. The proposed gateway discovery algorithm consists of a gateway selection mechanism and a location update mechanism.

3.1.1 Gateway Selection Mechanism

Each GW periodically broadcasts Gateway Advertisement messages. The Gateway Advertisement message is only propagated up to *K* hops away from the originating GW. When a MN receives a Gateway Advertisement message, it updates its routing table for the GW and responds with a Gateway Acknowledgement message under the following three conditions: (a) If MN is not registered with any other GW yet, it attempts to join the *K-hop* subnet of originating GW by issuing Gateway Acknowledgement message. (b) The MN will also attempt to join the *K-hop* subnet from the GW with which it is currently registered. (c) If MN receives Gateway Advertisement messages, which originated from GW that are different from its currently registered GW, MN compares the hop count, and/or geographical distance from the GWs and selects a new GW, which is closest to itself, and registers with it. Upon receiving the Gateway Acknowledgement message, the new registered GW is responsible for informing the previous GW of the registration change.

3.1.2 Location Update Mechanism

A periodic updating mechanism is used to keep routing and location information up-to-date at the GWs. An MN periodically sends out location update messages, containing its current location information, to its current registered gateway. The location update message is unicasted towards the current registered GW and upon receiving the location update message the GW will update its routing table and location information table for this MN.

4 LINK-CONNECTIVITY-PREDICTION-BASED LOCATION-AIDED ROUTING (LLR) PROTOCOL

The LLR protocol essentially consists of three separate phases: (a) Wireless Routing path (WR) route discovery phase; (b) Route maintenance phase; and (c) route soft-handoff phase. First, we introduce some terminologies. WR is a wireless multi-hop path directly from source to destination, while a Wireless-cum-Wired Routing path (WWR) is a wireless multi-hop path from source to destination via GWs, as shown in Figure 1 accordingly. Another term used in the subsequent discussion is the Route Expiration Time (RET), which is the minimum LET along the path from source to destination.

Source MN always tries to find the local routing path by initializing local route discovery, which is called WR route discovery process. This aims to find a WR path, when source MN and destination MN are in the same subnet, or they are close to each other. If no WR path is found, source MN uses the WWR by forwarding the data packet towards its currently registered GW, since MN maintains the connectivity with its currently registered GW through the gateway discovery algorithm presented in section 3. After a routing path has been setup, the route needs to be maintained. The detail routing algorithm is explained in the later subsections below.

4.1 WR Route Discovery

Whenever a source MN has data packets to send, it first checks its routing table to determine whether it has a current route to that destination MN. If none exists, it initiates the route discovery process similar to that of AODV. Unlike AODV, the RREQ is broadcasted only to nodes in the region within a few hops away from the source MN instead of the whole network. This region should include the current registered GW of the source MN. This can be done by specifying the TTL of the RREQ to be the number of hops away from the current registered GW of the source MN. This means the RREQ can propagate at most *K* hops away, since MN is inside the *K-hop* subnet of the GW. The reverse route is setup by RREQ, same as AODV.

A RREP can be generated by the destination MN, or intermediate neighbors with up-to-date route to the destination. The WR path from source to destination is then setup as RREP travels back to the source. Upon receiving RREP, source MN starts sending data packets along the WR path. If the source MN receives no RREP, the WWR path is used. WWR path is always available since each MN establishes and maintains a route towards it current registered GW during the gateway discovery process. When source MN receives no RREP, it sends data packets towards its current registered GW and sets a flag for that destination MN in the routing table to indicate it is using WWR path. Each data packet is embedded with the ID of the destination. After the data packets reach the GW, the GW checks its routing table for the next-hop node towards the destination MN and sends out the data packet accordingly. If both paths exist, source MN always prefers WR over WWR.

During the connection, the source MN appends the following information to each data packet: (a) its current location information; (b) its moving speed and direction; and (c) flag indicating whether it is WWR or WR.

4.2 Route Maintenance

As explained earlier, there are two possible routing paths: (a) WR path, which is the short routing path without going through GWs and (b) WWR path, which is the longer routing path via GWs. These two different paths are maintained by different processes.

4.2.1 WWR Maintenance

WWRs are maintained by the gateway discovery algorithm. Gateway discovery algorithm provides frequently route updates between MNs and GWs by exchanging gateway advertisement messages, gateway acknowledgement messages and location update messages. The freshness of a WWR depends on how frequently these messages are exchanged.

4.2.2 WR Maintenance

During the duration of a WR connection, intermediate nodes keep updating the RET in each data packet based on the LET, enabling the destination MN to receive RET prediction together with the latest source MN related information from each data packet.

When the destination MN determines the route is about to expire, during this "*critical time*" period, it computes both the *expected zone* and *request zone*, in a similar manner as LAR. The "*critical time*", T_c, is defined as follows [8]:

$$T_c = RET - T_d$$

where T_d is the delay experienced by the latest packet which has arrived along the route.

It then attaches the information to a *specific RREQ* (SRREQ) and broadcasts it. Only the source MN can reply to this SRREQ which also contains the current RET. Intermediate nodes first checks whether it is inside the request zone and only nodes within the *request zone* can forward the SRREQ. An intermediate node also checks the LET of last link that SRREQ was received from and if the LET is less than or equal to RET of SRREQ, the SSREQ is dropped instead forwarded. After the source receives the SRREQ, it chooses the best route on which to reroute the data packets based on the information contained in the SRREQ (e.g. number of hops, destination sequence number, etc). After that, source starts sending data packets along the new route.

4.3 Route Soft-Handoff

Here, we refer to route soft-handoff as either switching from WWR to WR or vice versa. It is sometimes necessary to do such route handoff in order to achieve better routing performance. For example, when both source and destination MNs move into the same subnet while the communication between them is still going through GWs, it may be better to switch from WWR to WR.

A new metric is used to decide whether to do the route soft-handoff. This metric, called *percentage metric*, is calculated by summing the percentage improvement in both *number of hop counts* and *RET*. Let us assume two possible routes are present. Let nh_1 be the number of hop counts between source and destination of route 1 and nh_2 be that of route 2. Also, let RET_1 and RET_2 be the route expiration times of route 1 and route 2 respectively. Then, the percentage improvement of route 1 over route 2, Δ_{12}, is obtained as follows:

$$\Delta_{nh} = -\frac{nh_1 - nh_2}{nh_1} \times 100\%$$

$$\Delta_{RET} = \frac{RET_1 - RET_2}{RET_1} \times 100\%$$

$$\Delta_{12} = \Delta_{RET} + \Delta_{nh}$$

The gateway discovery algorithm ensures that GWs know where the source and destination MNs are and under which GW. When the source or destination MN registers with a new GW, the GW helps the destination MN initiate the handoff process by providing the destination with routing information of the WWR path. The selection of the routing path then depends on the *percentage metric*.

5 SIMULATION

5.1 Simulation Environment

The simulations were done using the well-known Network Simulator 2 (NS2) to evaluate the performance of LLR. We compared the performance of LLR with LAOD [13] and AODV.

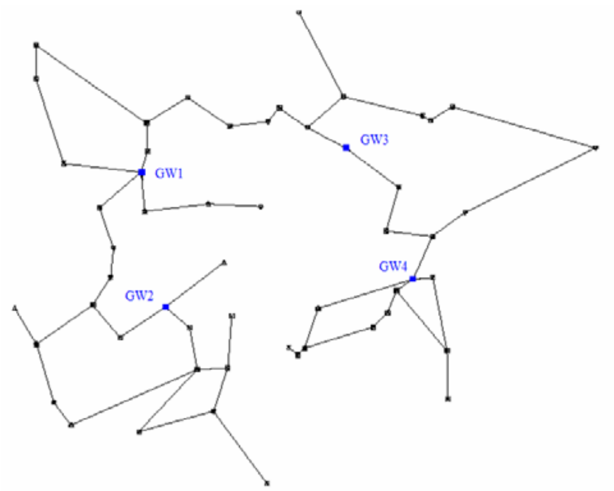

Figure 2: The city area graph used in the simulations

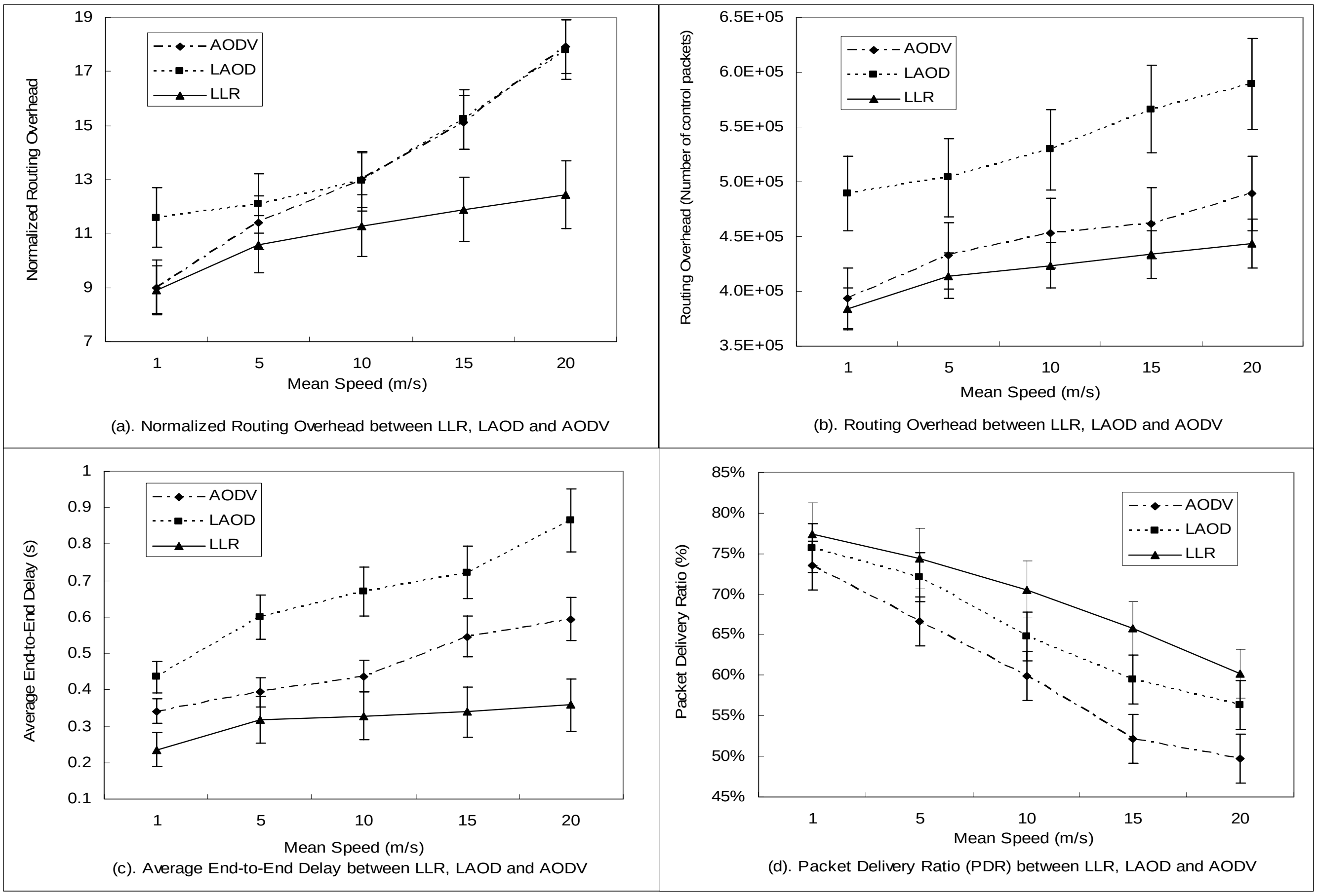

Figure 3: Performance comparison between LLR, LAOD and AODV

The scenario chosen for the simulations is based on the graph-based mobility model [7]. To describe the movement of vehicles moving around the city area, this is modeled as a graph as shown in Figure 2. The graph used for the simulations contains 54 vertices representing significant locations and 59 edges representing road segments interconnecting them, covering an area of approximately 2500m by 1800m. Each node moves from one randomly chosen location to the next on a shortest path along the edges. After reaching the destination, a node pauses for 5 to 10 seconds, and moves to another randomly selected vertex.

In all simulations, the number of nodes is fixed at 150, with the average moving speed varying from 1m/s to 20 m/s. There are four fixed GWs, which are interconnected with each other through the wired backbone, deployed as shown in Figure 2. Each gateway broadcasts Gateway Advertisement messages every 5 seconds with K=6 for the *K-hop* subnet. Each simulation lasts for 900 seconds of simulated time. All simulations use Constant Bit Rate (CBR) traffic flows with sources and destinations chosen randomly. Each CBR flow sends at a rate of 4 data packet per second, with packet size of 512 bytes. The IEEE 802.11 Medium Access Control (MAC) protocol is used and both gateways and mobile nodes have the same transmission range of 250m and bandwidth of 2Mbps.

The following metrics are used to evaluate the performance of the protocol:

- *Packet Delivery Ratio*: The fraction of data packets sent that are successfully delivered to their destination
- *Average End-to-End Delay*: The average time interval between a data packet sent by a source and its arrival at its destination.
- *Normalized Routing Overhead:* The number of routing packets transmitted per data packet delivered at the destination.

5.2 Simulation Result and Discussion

All the results are plotted against increasing node speed. Figure 3(a) shows the normalized routing overhead while Figure 3(b) shows the actual number of control packets transmitted. All three protocols show more overhead as nodes' speed increase because more route breakages occur, invoking route recovery procedures. However, LLR has lower overhead in general because the number of control messages during route recovery is reduced by limiting the broadcast to a smaller region. Consequently, as shown in Figure 3(c), LLR outperforms the other two routing protocols in terms of average end-to-end delay. This is because AODV and LAOD incur longer route (re)discovery latency after route breaks during which data packets are buffered while waiting for the new route to be constructed. LLR uses link connectivity prediction to perform rerouting prior to route disconnection, thus reducing the route discovery latency.

The packet delivery ratio (PDR) is shown in Figure 3(d). It is observed that fewer packets are delivered as speed increases, which is expected. As MNs move faster, link connectivity changes more often and more control messages are broadcasted to make adjustments to the network topology change, contributing further to collisions, congestion, contention, and packet drops. LLR is least affected by mobility, since it limits the broadcasting of control messages during the route recovery process. Besides reducing collisions, contention and packet drops with less broadcasting of control messages, LLR avoids route disconnection using link connectivity prediction. This helps to reduce packet drops too, since packets are more likely to be dropped during route disconnection due to buffer overflows, timeouts and other causes.

6 CONCLUSION

In this paper, we have proposed the link-connectivity-prediction-based location-aided routing protocol (LLR), together with the supporting gateway discovery algorithm, for hybrid wired-wireless network environments. LLR features the use of location information to predict the link connectivity and restrict broadcasting control messages so that more packets can be delivered to their destinations successfully. LLR's better performance in terms of higher packet delivery ratio, less routing overhead and lower end-to-end delay, has been verified through simulations.

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