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# Implementing a Small Scale MANET Testbed based on Geocast-Enhanced AODV-bis Routing Protocol

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***Abstract***

*Mobile Ad Hoc Network (MANET) has attracted extensive research interests over the past several years. However, far less effort has been done on the real-world basis, with intensive evaluations through simulations. This paper outlines our experiences of developing and implementing the MANET testbed based on geocast-enhanced Ad-hoc On-Demand Distance Vector-bis (AODV-bis) routing protocol. AODV-bis is an improved design of MANET routing protocol featuring path accumulation, from the lessons learned beyond the Experimental RFC AODV effort. To enhance AODV-bis, location information is utilized in route discovery phase to confine the request zone based on geocasting instead of broadcasting. Compared to AODV, we found that AODV-bis is a more powerful routing tool especially in route dissemination. Finally, its overall performance is further improved by the aid of location information.*

**Keywords:** MANET, testbed, AODV-bis, geocast, path accumulation

## 1. Mobile Ad-hoc Network (MANET)

MANET is a collection of mobile computing devices that communicate via wireless links, without the aid of infrastructures. Its topology changes unpredictably and nodes are free to join or leave arbitrarily. Unlike Wireless LAN, MANET, as illustrated in Figure 1, does not rely on centralized administration and the control of the network is distributed among the nodes. Each node may function as a router to assist others searching for route. MANET [1] can be applied in emergency services, conferences, home or community networking and battlefield communications.

An adaptive and robust routing protocol is necessary to cope with the dynamic nature of MANET. Classical routing protocols that were designed for static, wired environment can no longer [3] apply to MANETs due to node mobility and the fluctuating wireless channel. Consider the fact that mobile devices have limited power and radio transmission consumes extra energy, radio activity should be limited. Regular sending and maintenance of topology updates by proactive routing consumes large power and memory. It also tends to increase congestion and must be avoided. On-demand routing protocol eliminates route table updates for unnecessary routes, leading to the reduced traffic congestion. With less frequent control packets, processing requirements are reduced. Consequently, reactive protocols are more suitable for small low-power units with high mobility in MANET.

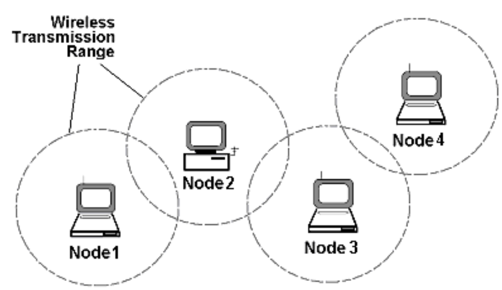


**Figure 1. Mobile ad hoc network (MANET)**

Over the past several years, more than 50 MANET routing protocols have been proposed. However, many of them are evaluated on the basis of simulation results. In reality, connectivity and performance of MANETs are affected by several factors [6] and simulations cannot account for all. Moreover, simulation often makes assumptions that are restricted to the expertise level of the researcher. Such limitations [4], therefore, motivate us to implement and evaluate ad hoc routing protocol in a real wireless MANET testbed.

## 2. AODV-bis Routing Protocol

AODV [11] has been promoted to the experimental RFC of IETF MANET charter [9] since July 2003. AODVjr [17] effort investigated an approach to simplify the overall AODV design. This simulation work has proved that, for networks of limited size, reliable communications can be managed by implementing only a very limited number of AODV features. Thus, AODV-bis was proposed as MANET Working Group Internet draft [18] in October 2003. Many features are no longer mandated in AODV-bis compared to AODV [12], which has several protocol semantics that provide little added benefit, considered as redundant. Many flags of AODV control messages are removed and replaced by more efficient mechanisms. These modifications are important especially for resource-limited mobile computing devices such as PDAs.

AODV-bis incorporates new performance enhancements and simplifies the requirements for implementations based on experiences gained during the development of AODV. As convergence can be eased by creating parameterized modular components, the modularity of AODV-bis aids IETF MANET WG's effort towards the standardization of MANET routing protocols. Three defined packet types are Route Request (RREQ), Route Reply (RREP) and the optional Route Error (RERR).

AODV-bis features the Path Accumulation (PA), with which the path from either the routing table or control packet may be used to route an RREP back to the requesting node during route discovery. This is an added advantage especially for nodes with limited resource since they can opt not to record the route during RREQ flooding. In addition, PA enables wider dissemination of route information in route discovery. Whenever a node receives an RREQ, it might update its route table for every path node listed in Accumulation Path List (APL). Consequently, the number of route discovery and broadcast messages is decreased. This is critical when the traffic internal to MANET is high. The PA feature is the preliminary attempt to converge AODV with Dynamic Source Routing (DSR) [8] before standardizing the ad hoc routing protocol.

In contrast to AODV, beaconing in AODV-bis is invoked only when the node participates in the routing of data packet. This prevents an inactive node from continuously beaconing *HELLO* messages to its neighbor(s), resulting in the waste of resource and possibly traffic congestion. Precursor Lists feature is removed with the introduction of PA since route updates can be done on each path node appended in RREQ and RREP. In addition, expanding ring search deployed by AODV has been proved [19] to cause the highest latency. Other major differences between AODV-bis and its previous versions can be found in [18]. It is important to develop and thus study the performance of AODV-bis to determine the essential features of routing protocol required by MANET devices.

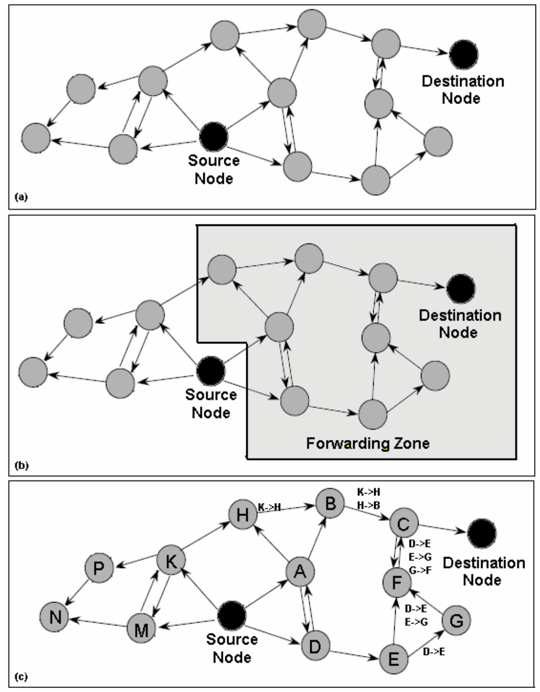


**Figure 2. (a) RREQ broadcast (b) Geocast-enhanced route discovery (c) Path accumulation feature**

## 3. Geocast Enhancement

As illustrated in Figure 2(a), RREQ is broadcasted to all neighbors in both AODV and AODV-bis. According to IEEE 802.11, each node must process every broadcast message received. Frequent broadcast causes network congestion, possibly broadcast storm, and degrades the performance of routing protocol. This could be proved by several performance observations [19] that the number of RREQ in the network increases linearly with the node population. The ratio of control packet over data packet even reaches 5000 in one of the experiments.

As such, we suggest utilizing geocast mechanism to enhance AODV-bis. Geocasting algorithm defines request zones based on the expected location of the destination node at the time of route discovery. By restricting the forwarding area, routing overhead in MANET is reduced significantly especially in a dense network. Position information can be obtained from any location detection tool. In Figure 2(b), RREQs are forwarded only to the request zone. Simulation work [10] has proved that with the aid of position information, saving of wireless bandwidth could be achieved since RREQ is only sent to a confined search area.

In our experiment, a GPS-free location tracking tool based on Received Signal Strength Identifier (RSSI) is installed in each participating node. Unlike the GPS system, this tool is capable to obtain the node position situated multihop away only after the route is constructed following the procedures of [18]. In case of link breakage, subsequent route requests are initiated based on geocasting. According to Figure 3, RREQ is only forwarded by neighbors who have shorter distance to reach the destination node compared to the distance between source and destination (e.g. DIST(ad) < DIST(sd)).

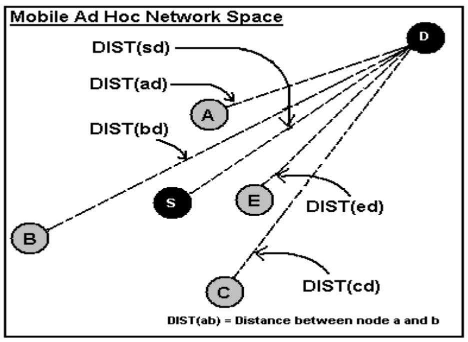


**Figure 3. Location-aided route discovery**

In this way, geocasting is capable to reduce routing overhead due to regular broadcast of RREQs. Simultaneously, since node position is utilized only in the route discovery phase of AODV-bis, we avoid the waste of a large portion of wireless bandwidth caused by periodic updates of routing tables in pure geographical forwarding (considered as a proactive routing protocol). Position-based RREQ forwarding prevents the messages from flooding the whole network, leading to significant message savings.

## 4. Development and Implementation

### 4.1 Setting up of MANET testbed

A multi-hop MANET testbed based on AODV-bis has been set up and verified successfully. Both laptops and PDAs in the testbed are configured to run in ad-hoc mode, Wireless Fidelity (Wi-Fi) capable, and conform to IEEE802.11b. Laptops run on Linux RedHat while PDAs run on Familiar [16], which is also based on Linux kernel. Linux Operating System is chosen as our developing platform due to its open-source nature that provides access to the network protocol stack freely. Figure 4 shows the routing architecture of our system. AODV-bis routing daemon and the GPS-free location monitoring tool run in kernel and user space respectively. All AODV-bis packets are sent to port 654 using UDP.

Our AODV-bis routing module is developed as a Loadable Kernel Module (LKM) in the kernel space by C language. It does not only [14] save memory and ease configurations, but most importantly, it avoids the costly kernel-to-user crossing [15] for store-and-forward and increases overall efficiency. The delay caused by the crossings will degrade the performance of the on-demand routing algorithm, which already has higher latency over proactive routing protocol during route establishment. Netfilter is utilized in our code to capture incoming and outgoing packets into AODV-bis functions.

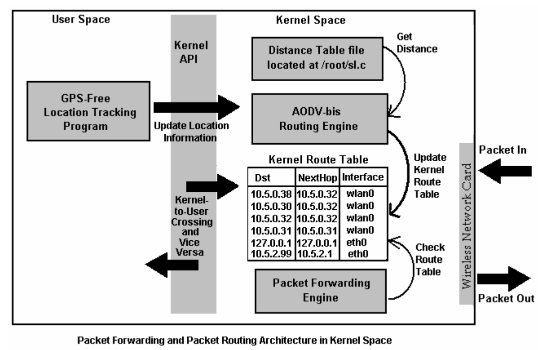


**Figure 4. AODV-bis routing architecture**

### 4.2. Verifying Path Accumulation Feature

Figure 5 illustrates the logical view of the experimental 7-hop MANET testbed. The developed routing module has been tested to verify the operation of AODV-bis with the aid of MACKill [2] tool. MACKill is used to filter packets with MAC addresses we wish to block at link layer. This enables testing and debugging tasks to be done within close physical distance to each other. Initially, all nodes are inactive when AODV-bis routing module is invoked and there is no communications (no beaconing) among them. During the test, a *PING* session is initiated from A to the unknown destination H. Output handler detects the unknown IP and invokes AODV-bis module to create and broadcast RREQs to its neighbor.

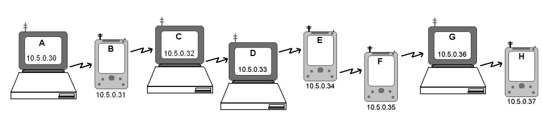


**Figure 5. Logical view of 7-hop MANET testbed**

The outcome is reflected on the log messages generated by A, in Figure 6. (Note that the log messages are based on the testbed illustrated in Figure 5.) Node A's sequence number, which is introduced to ensure loop-freedom, is incremented once a *PING* is generated and sent. When B gets the RREQ and has no route to H, it appends itself in the RREQ's Accumulated Path List (APL) and forwards the packet to its neighbors. At the same time, it updates its route table and starts beaconing *HELLO* messages until the node is inactive. This applies to all participating nodes. They update their route table by adding the corresponding route information. When C receives the forwarded RREQ from B and if the route to node H is unknown, it appends itself in APL and forwards it. Otherwise, C generates and unicasts an intermediate RREP towards originator A. In the experiment, we set the Destination flag (D-flag) of RREQ. Thus, the latter case does not apply. The same process is carried out from Node D to G. Finally, the intended destination node H generates and unicasts RREP towards A, via the path recorded in APL of the forwarded RREQ from G.

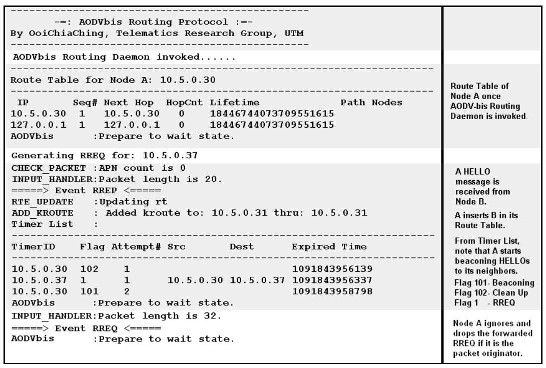


**Figure 6. Log messages of node A: HELLO invocation**

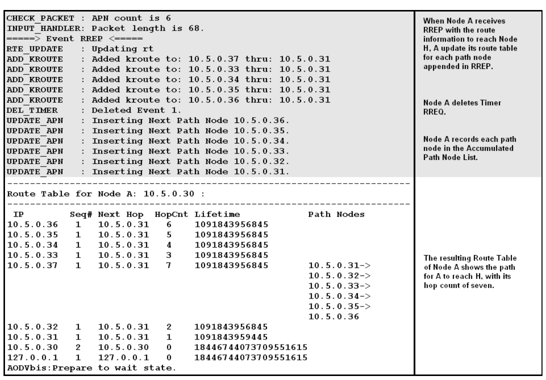


**Figure 7. Log messages of node A: Route table with accumulated path nodes**

Once A receives the forwarded RREP from B, it updates its route table by creating a new route entry for each corresponding APL node, resulting in the route table shown in Figure 7. Also, note that all path nodes appended in the packet are recorded in the route table entry of Node H. Now onwards, any data packet destined for H can be routed through Node A as long as the route is active.

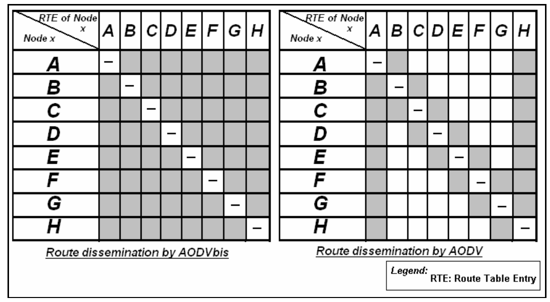


**Figure 8. Comparison of route dissemination based on AODV-bis and AODV**

Compared with AODV, AODV-bis is a more powerful routing protocol especially in disseminating route information. Running similar test as described above in the same testbed (figure 5) but based on AODV produces little route knowledge for each MANET node. According to Figure 8, each participating node knows the route to reach any node in the testbed with the path accumulation feature in AODV-bis. However, for AODV, a node only has the route knowledge of its neighbor, packet originator and destination. It must run route discovery if it intends to reach other node, resulting in higher processing time, network load and consequently performance degradation.

### 4.3 Verifying Route Repair

**Table 1. List of neighbors**

| Node | IP | Neighbors |
|---|---|---|
| A (Source) | 10.5.0.30 | E,F |
| B | 10.5.0.31 | E,F,G,H |
| C | 10.5.0.32 | G,H,K,M |
| E | 10.5.0.34 | A,B,F |
| F | 10.5.0.35 | A,B,E |
| G | 10.5.0.36 | B,C,H |
| H | 10.5.0.37 | B,C,G |
| J | 10.5.0.38 | K,M |
| K | 10.5.0.39 | C,M,J |
| M (Destination) | 10.5.0.40 | C,K,J |

To verify route repair of AODV-bis, similar procedures are repeated on the mobility experimental testbed illustrated in Figure 9 but with node A and J as the originator and destination host respectively. Table 1 shows the IP address and neighbors of each participating node. Referring to route table of node A in Figure 9, route A->**E**->B->H->C->K->J is established initially. To emulate the mobility of node E, its wireless card is removed, triggering a route repair process. We found that an alternate route A->**F**->B->H->C->K->J is constructed as shown in Figure 10. Route repair of AODV-bis has been verified successfully.

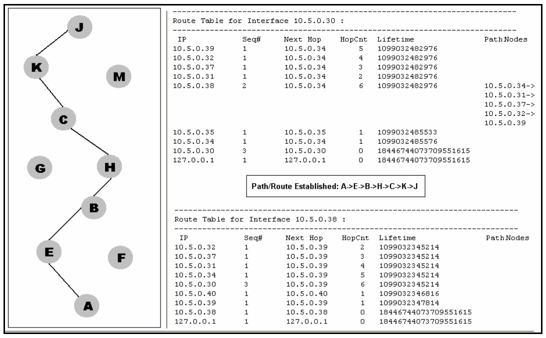


Figure 9. Route tables prior to link loss

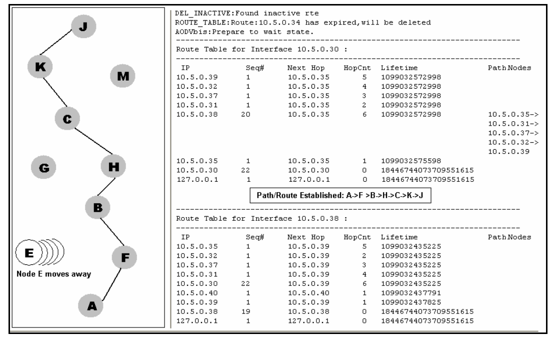


Figure 10. Route tables after link loss

## 4.4 Verifying Geocast Module

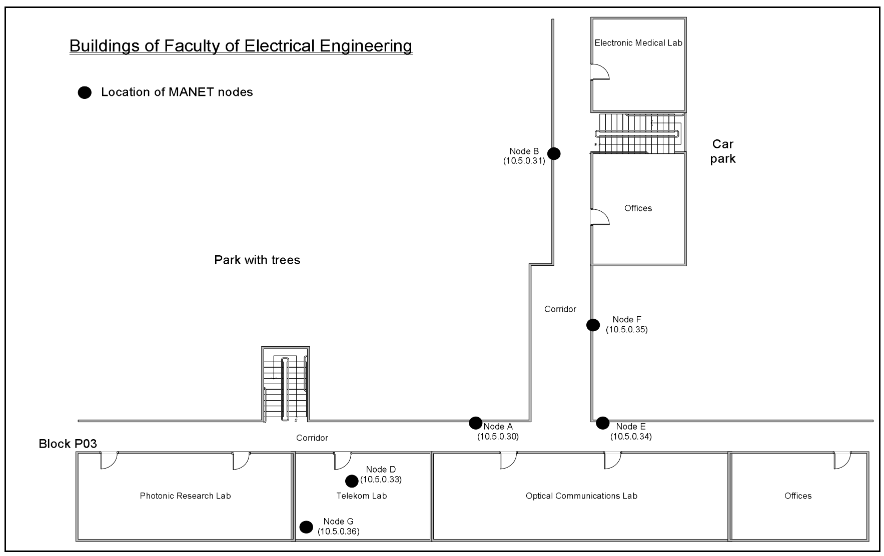


Figure 11. Node position in geocast-verifying experiment

For geocast enhancement purpose, the RREQ packet format of AODVbis has been modified as shown in Figure 12. An additional *Distance* field is introduced so that the requesting node appends the distance (in meter) between the intended destination and itself during the route discovery invoked by link breakage. According to [5], in an open environment, the maximum reachable range is 400m with the data transfer rate of 1Mbps. Thus, the memory space of 1-byte is allocated to the *Distance* field, making its maximum value equal to 512 in decimal.

To verify geocasting module, MANET nodes are located around Block P03 of Faculty of Electrical Engineering in Figure 11. It works as detailed in section 3. The GPS-free location tracking program updates the distance table regularly. Table 2 indicates the distance obtained after the initial route discovery. Then, node B moved further away from the network, causing link loss. Route discovery is initiated immediately if node D has data destined for node B. Nodes receiving the modified RREQ can then retrieve, compare the distance values and determine if it should forward the packet. In this scenario, we found that only node A and E forwards the RREQ as they are closer to B compared to D (e.g. DIST(AB)<DIST(DB)) by referring to the log messages generated by each node.

| Type | D | G | Reserved | Distance | Hop Count |
|---|---|---|---|---|---|
| RREQ ID | | | | | |
| Destination IP Address | | | | | |
| Destination Sequence Number | | | | | |
| Originator IP Address | | | | | |
| Originator Sequence Number | | | | | |
| Path Node IP Address | | | | | |
| Path Node Sequence Number | | | | | |
| (additional path node IP address and sequence number pairs) ... | | | | | |

Figure 12. Modified packet format of RREQ

**Table 2. Position information (distance x-y, meter) stored in MANET nodes**

| x \ y | A | B | D | E | G |
|---|---|---|---|---|---|
| A | - | 19.2 | 17.5 | 6.6 | 23.5 |
| B | 19.2 | - | 39.2 | 23.7 | 42.5 |
| D | 17.5 | 39.2 | - | 20.9 | 4.0 |
| E | 6.6 | 23.7 | 20.9 | - | 25.0 |
| G | 23.5 | 42.5 | 4.0 | 25.0 | - |

Due to the restricted forwarding zone, the number of RREQs forwarded in MANET is reduced significantly especially in dense network, resulting in less routing load. Consequently, the cooperation of AODV-bis with both PA and geocasting features improves its overall performance with lower control overhead.

## 5. Conclusion

MANET technology has been receiving increasing attention among researchers in recent years. This paper details the implementation of AODV-bis that makes use of advantages from both on-demand and distance vector characteristics. Verifications of PA, route repair and geocast feature have been done successfully on the developed MANET testbed. Compared to AODV, the modularity of AODV-bis helps IETF MANET WG's effort towards convergence and standardization of ad hoc routing protocol. While the PA feature is designed to increase route dissemination, geocast enhancement is introduced to further decrease the number of broadcast within MANET. Consequently, the overall performance of AODV-bis routing protocol is improved.

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