Internet Connectivity for Mobile Ad Hoc Networks Using Hybrid Adaptive Mobile Agent Protocol

Velmurugan Ayyadurai[1] and Rajaram Ramasamy[2]
[1]Department of Electronics Engineering, Anna University, India.
[2]Department of Information Technology, Thiagarajar College of Engineering, India.

Abstract: *Internet-based Mobile Ad Hoc Networking (MANET) is an emerging technology that supports self-organizing mobile networking infrastructures. This is expected to be of great use in commercial applications for the next generation internet users. A number of technical challenges are faced today due to the heterogeneous, dynamic nature of this hybrid MANET. A new hybrid routing scheme AODV ALMA is proposed, which act simultaneously combining mobile agents to find path to the gateway and on-demand distance vector approach to find path in local MANET is one of the unique solution. An adaptive gateway discovery mechanism based on mobile agents making use of pheromone value, pheromone decay time and balance index is used to estimate the path and next hop to the gateway. The mobile nodes automatically configure the address using mobile agents first selecting the gateway and then using the gateway prefix address. The mobile agents are also used to track changes in topology enabling high network connectivity with reduced delay in packet transmission to Internet. The performance tradeoffs and limitations with existing solutions for various mobility conditions are evaluated using simulation.*

Keywords: *Hybrid MANET, mobile agents, AODV ALMA, adaptive gateway discovery.*

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1. Introduction

A Mobile Ad Hoc Network (MANET) is an autonomous network that can be formed without any established infrastructure. It consists of mobile nodes equipped with a wireless interface that are free to move and establish communication on the fly. The mobile nodes act as hosts and routers, having routing capabilities for multi-hop paths connecting nodes which cannot directly communicate. The idea of facilitating the integration of MANET and fixed IP network i.e., Internet has gained lot of momentum within the research community recently [11]. This kind of integration forms the basis for the next generation internet usage in which mobile nodes are expected to provide service information any time, any where for ubiquitous access. These kinds of networks are named as hybrid MANET which can be deployed quickly and easily. The potential applications are like conference meetings, wireless classrooms, vehicular operations in a highway, ubiquitous information processing in train, and airport.

Researchers presently make use of the social behaviours of insects and of other animals for developing a variety of different organized behaviours at the system level. In particular, ants have inspired a number of methods and techniques among which the most studied and the most successful is the general purpose optimization technique know as Ant Colony Optimization (ACO). ACO takes inspiration from the foraging behaviour of some ant species. These ants deposit pheromone on the ground in order to mark some favourable path that should be followed by other members of the colony. Because of the robustness and efficiency of ACO they have recently become a source of inspiration for the design of routing algorithms. Following the ACO principles, Ant like Mobile agents (ALMA) are simple packets that explore the network and collect data for routing [2, 3]. They communicate with one another indirectly by exchanging routing information by writing and reading data to from routing tables. This is similar to ants exchanging food information with each other. By using mobile agent exploration, the idea is to put the intelligence across the network and make the routing distributed with high connectivity. The important constraint in using the mobile agents for routing is that the overhead is proportional to the number of agents present in the network. This in return reduces the overhead compared with traditional routing protocols that use frequent updates and reactive updates.

Figure 1 shows the architecture in which the mobile nodes form local MANET access with multi-hop wireless links to provide service within them. The Internet Gateway (IGW) nodes form global access to provide internet service to mobile nodes. The main technical challenges faced today in this scenario are Internet gateway discovery, address auto-configuration and reaching the destination. The ACO mechanism is used as an adaptive reactive gateway discovery approach integrated with address auto-configuration. The new hybrid scheme, proposed in this paper, combines local access with global access, named as AODV ALMA. The remainder of the paper is organized as follows. The paper gives an overview of the related work in section 2. The new protocol description is given in section 3. The performance analysis is simulated and compared in section 4. The future enhancement is given as conclusion in section 5.

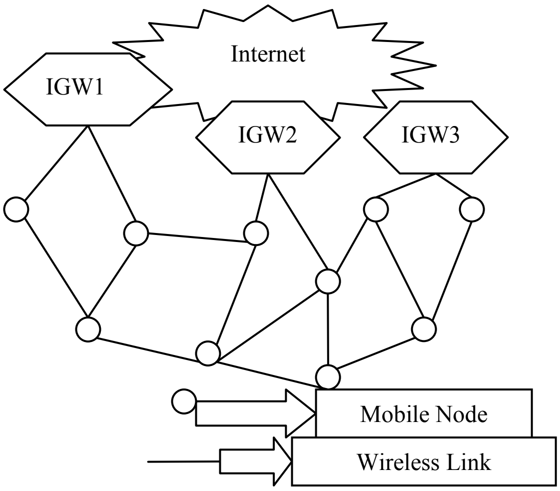

Figure 1. Mobile ad hoc network connectivity with Internet.

2. Related Existing Proposals

The first proposal by Broch *et al*. [2] is based on integration of Mobile IP and MANET, employ a source routing protocol. The second proposal MIPMANET [6] followed a similar approach based on AODV, but works only with Mobile IPv_4 approach, because it requires Foreign Agents (FAs). The proposal by Ammari *et al*. [1] gives a mobile gateway approach based on DSDV protocol and analyzed the performance. In Ratanchandani *et al*. [8] proposal, a hybrid scheme for propagating the advertisements up to a certain number of hops is given. The mobile nodes located out of this propagation scope will reactively find the gateways when needed. The performance of this approach depends on the Time-To-Live (TTL) value, set for particular scenario and network conditions under consideration. In Lee [5] proposal, another more sophisticated hybrid approach the advertisements are sent out only when changes in topology are detected. However, they rely on a source based routing protocol, which limits the applicability to particular type of routing protocol. In Ruiz *et al*. [9] proposal, an adaptive gateway discovery mechanism that outperforms existing hybrid approaches is proposed. The key scheme is that TTL value for proactive gateway advertisements is adjusted dynamically to network conditions. The mobile nodes out of the propagation scope reactively find the gateways. The proposals available till date focused only on gateway discovery and are not a complete solution for inter-working with fixed IP networks.

The complete proposals available to integrate both auto configuration and gateway discovery are namely Wakikawa [12], Jelger [4] and Singh *et al*. [11]. In Wakikawa [12], mobile nodes discover the gateway either reactively or proactively to configure their IP address automatically. In the proactive approach, gateway periodically floods the gateway advertisement messages up to certain number of hops in the MANET. In the reactive approach, mobile nodes flood the gateway solicitation message to all gateways reachable. The gateway receiving the gateway solicitation will unicast back the gateway advertisement to the mobile nodes. The gateway advertisement message contains the global IPv_6 address of the gateway, the network prefix advertised by the gateway, the prefix length and the lifetime associated with this information.

In Jelger *et al*. [4] proposal, proactive approach is used in which the gateways advertise themselves by periodically flooding gateway information messages. The flooding of these messages is based on the idea of prefix continuity. A mobile node selects the best path towards the gateway using one of the metrics such as distance, stability, or delay from all the gateway information messages received. By selecting the gateway information messages, the mobile node configures an IPv_6 address based on the selected prefix. This approach does not require the use of routing headers

In Singh *et al*. [11] proposal, gateways act as nodes that are one hop away from the access router. The access routers are equipped with a wireless interface. The first node becoming a gateway is called the default gateway, and it is responsible for sending out periodic gateway advertisements. The other gateways for a given router are called candidate gateways. A candidate gateway becomes a default gateway when it stops receiving gateway advertisements from the default gateway for some time. It defines gateway selection based on bandwidth balancing, but unfortunately bandwidth parameters and their use not described in the current version of the specification.

3. Proposed Protocol Description: AODV ALMA

In hybrid MANET network, connectivity of mobile nodes with gateway nodes and mobile nodes with other active mobile nodes is uncertain due to the dynamic network topology. The mobility of mobile nodes cause more delay in finding the route to destination either in Internet or in local MANET.

The newly proposed hybrid mechanism AODV ALMA overcomes this by combining the on demand distance vector approach with ACO. The on demand distance vector approach, i.e., AODV used to find the path in local MANET. The ACO approach, i.e., ALMA (Ant like Mobile Agents) used to find the path to the gateway. The hybrid mechanism operates simultaneously when a route to the destination is needed by the source mobile node. The routing table structure of mobile node is dynamically updated on demand using the proposed hybrid mechanism is shown in Table 1. The gateway contains two routing tables, one to update information in local MANET and another to update the information from Internet is shown in Table 2.

Table 1. Routing table in mobile nodes.

Destination address
Next Hop address
Number of Hops
Sequence number for the destination
Active neighbours for this route
Expiration time for the route table entry
Pheromone value
Pheromone decay time
Balance index

Table 2. Routing table in gateway for local MANET.

Source address
Next Hop address
Number of Hops
Sequence number for the source
Active neighbours for this route
Expiration time for the route table entry
Pheromone value
Pheromone decay time
Balance index

After getting the route to the destination in the mobile node using the proposed hybrid mechanism, data packets can be forwarded. The data packets forwarded from the mobile nodes can be either to the Internet or to the local MANET using the routing table entries available reactively. The data packets to the destination in Internet are forwarded to the gateway using the entries created by ACO mechanism such as number of hops, next hop, pheromone values, and pheromone decay time with balance index. The data packets to the destination in the local MANET are forwarded using the entries created by AODV such as number of hops, next hop, and active neighbours for this route with expiration time. The data packets follow the IPv_6 format for transmission.

The main reason for using ACO in gateway discovery is to set the link adaptive parameters based on the current topology of the links traversed by the mobile agent packets in particular time. This is similar to the way ants walking to and from a food source deposit on the ground a substance called pheromone.

The other reason for using ACO is to take the decision in selecting the stable path to the gateway based on the pheromone concentration on the current node provided for each possible link. This will provide service access to the mobile node and next hop to the gateway with high network connectivity for a long period of time. The ACO principle in a unifying framework with the on demand distance vector approach is the first approach of this kind for hybrid MANET access.

3.1. Gateway Discovery in AODV ALMA

The proposed protocol is used to discover paths and to maintain paths in local MANET for dynamic topology changes. The mobile nodes initially use the available temporary address for broadcasting before configuring the address based on the gateway. The mobile nodes flood ACO messages and AODV messages simultaneously to discover routes either in global Internet or in local MANET. The ACO message first sent to discover the gateway is the Forward Routing Mobile Agent (FRMA) message. The FRMA message is multicast with the all manet gateway multicast address. The intermediate mobile nodes in the path to the gateway receive the FRMA message and mark the message with its node information into the history field. The FRMA message on traversing the link through the intermediate nodes to the gateway will get the link stability factor in terms of the pheromone value and pheromone decay time. The intermediate node after marking the FRMA message will rebroadcast in local MANET until it discovers the gateway. The FRMA message keeps the list of mobile nodes [1, 2, …, n] it has visited in the history field. The Route Request Message (RREQ) of AODV is used to find the path in local MANET.

The FRMA packet updates the routing table entries of active intermediate mobile nodes with link probability value in terms of the pheromone value with decay time. The gateway detecting the FRMA packet transfer the history field with the total link probability value and gets converted as Backward Routing Mobile Agent (BRMA). The pheromone value in the FRMA packet is bound to decay with time and number of hops travelled. The decision process is that larger the value of pheromone, then shorter the time taken to reach the gateway, but smaller the value of pheromone longer the time to reach the gateway. The BRMA packet has got higher priority over FRMA packet in traversing the links in the reverse direction.

The BRMA packet is unicast from the gateway to the source mobile node will pass through the list of intermediate nodes visited by the FRMA packet. The BRMA packet updates and verifies the routing table entries created by the FRMA packet by finding the topology changes affecting the link. The BRMA packet contains the following information, the global IPv_6 address of the gateway, the network prefix of the gateway, the prefix length, lifetime, pheromone value, pheromone decay time with the balance index. After reaching the source mobile node the BRMA packet update the routing table with the information collected for the link traversed. The source mobile node selects the stable path to the gateway based on the total link probability towards the gateway using the pheromone value and the pheromone decay time detected by the mobile agents. The balance index will give the load in the gateway based on the maximum number of mobile nodes active to the number of mobile agents present in the network. The balance index value lesser means minimum the load in the gateway. To forward the data packets mobile node has to first select the gateway based on the stable path and next with the balance index information updated by BRMA packets. The proposed protocol is adaptive since it reinforces the route to the gateway information based on the link probability value with time using mobile agents. The source mobile node receiving more than one BRMA packet selects the adaptive gateway by getting maximum link probability value with lesser balance index. The source mobile node auto-configures its IP address after selecting the gateway using the prefix of the gateway with the suffix wireless interface address.

The active intermediate mobile nodes also maintain the adaptive information set by the BRMA packet before the link probability reaches minimum threshold value over time. On reaching the threshold value the active intermediate mobile node generate a new FRMA packet with the source mobile node address available from its routing table. The generated FRMA packet updates the route to the gateway with either the new active node or the old active node for forwarding the data packets. The FRMA and BRMA packets explore and quickly reinforce the paths to the gateway adaptively. They also ensure the previously discovered paths do not get saturated when the actual link fails. The flowchart in Figure 2 shows the process the mobile node uses the mobile agents to discover the route to the gateway. The proposed hybrid scheme will reduce the route discovery latency with less convergence time.

3.2. Analytical Model

The analytical model gives the mapping of ACO to find routes to the gateway in hybrid MANET. It assumes a Fixed Radius Model as the topology model with $\Re$ the mobile nodes communication range. The mobile node find route to the nearest gateway for internet access to prevent mobile node isolation using multi-hop communication to the gateway. The density and radius must be large enough to keep the proportion of mobile nodes which do not belong to the geographical area very less. The proposed protocol use mobile agents to find the path between the source mobile node v_s and the gateway node v_g is mapped to the connected graph $G=(V,E)$ with $n=|V|$ nodes. The path length in G is given by the number of nodes on the path. Each edge in G, i.e., $e(i,j)\in E$, connecting the nodes v_i and v_j has a pheromone value $\varphi_{i,j}$ which is modified using mobile agents visiting the intermediate nodes. The pheromone concentration $\varphi_{i,j}$ is an indication of the usage of this edge.

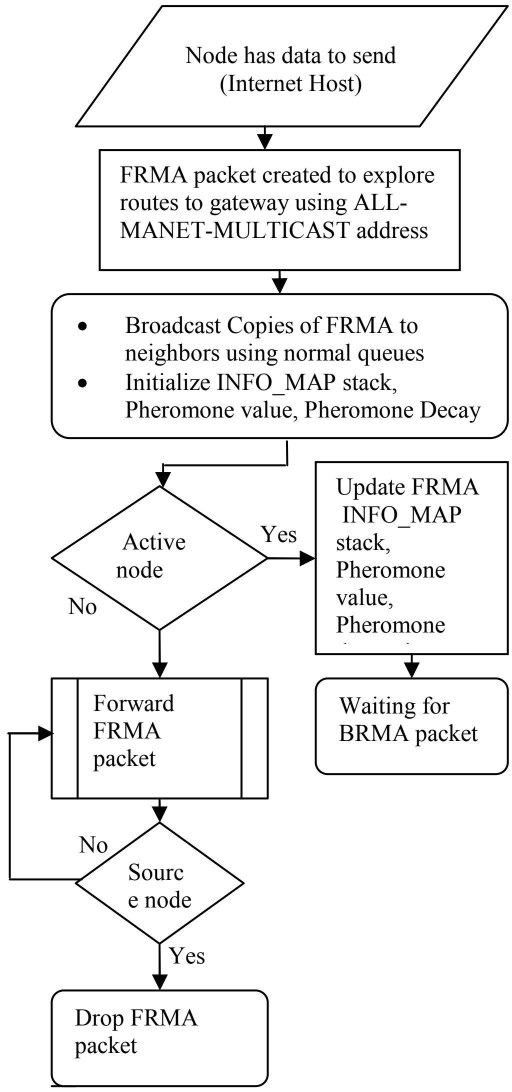

Figure 2. Process in mobile source node using AODV ALMA.

In order to forward a data packet towards the gateway node v_g, the forwarding equation is formulated in the proposed protocol to give link probability using pheromone value present between neighbouring nodes v_i and v_j. The equation (1) maps the total probability of the link towards the gateway v_g with pheromone on each outgoing link v_i at node v_j as $p_{i,j,g}$. The mobile agent located in node v_i use pheromone value of each link to the gateway as $\varphi_{i,j,g}$. The specific next hop neighbour is chosen according to the probability distribution in each link.

$$p_{i,j,g} = \begin{cases} \dfrac{(\varphi_{i,j,g} + K)^F}{\sum_{j=1}^{N_i} (\varphi_{i,j,g} + K)^F} & if\ j \in N_i \\ 0 & if\ j \notin N_i \end{cases} \quad (1)$$

The forwarding Equation 1 gives N_i the number of neighbours to node$_i$, the constant *F* and *K* is used in tuning the routing behaviour of the proposed protocol. The pheromone threshold value *K*, determines the sensitivity of the link probability calculations to small amounts of pheromone. If $K \geq 0$ larger, then large amounts of pheromone will be present before an appreciable effect will be seen in the link probability. The pheromone sensitivity value $F \geq 0$, used to modulate the differences between pheromone amounts present in link probability. If the value of *F*>1 will accentuate differences between links, while *F*<1 will deemphasize them and F=1 gives a simple normalization form. The link probability $p_{i,j,g}$ of the node v_i fulfils the constraint in giving transition probabilities as in Equation 2.

$$\sum_{j \in N_i} p_{i,j,g} = 1,\ i \in [1, N] \quad (2)$$

During the route finding process to the gateway mobile agents deposit pheromone on the edges. The pheromone concentration is varying from one edge to another between the nodes connecting them by an amount φ. The pheromone value change at the edge $e(v_i, v_j)$ when mobile agents moving from node v_i to node v_j are given in Equation 3.

$$\varphi_{i,j,g} = \varphi_{i,j,g} + \Delta\varphi \quad (3)$$

The pheromone value $\varphi_{i,j,g}$ can be used to compute the link probability $p_{i,j,g}$ of the node v_j as the next hop to reach the gateway node g from node v_i. A link connecting nodes v_i and v_j is added to the graph as $\ell_{i,j}$ and this path is selected to the gateway in the proposed protocol. The decision gives the fact that the Euclidean distance between the nodes connecting the gateway is less than $\Re$ and the path selected is stable with the threshold value set. The condition assumes the case in which all nodes are distributed randomly. The mobile agent mapping with link probability detection in finding the optimal stable path between the nodes connecting the gateway is the first approach of this kind.

3.3. Route Maintenance

The second stage in the proposed protocol is route maintenance in local MANET and to Internet. In local MANET it is responsible to keep paths to local destination by getting special packets i.e. hello messages from intermediate nodes. In Internet it is responsible to keep paths to the gateway through intermediate nodes for high network connectivity. The route maintenance to gateway for getting services from Internet is done automatically using the data packets forwarded through the intermediate active nodes selected in gateway discovery. The mobile agents traversing the link establish a pheromone track by setting the pheromone values from the source node to the gateway node. The path established keeps updating the pheromone value in association with the decay factor, i.e., pheromone decay time. The pheromone decay time is set based on the link life time predicated by mobile agents. The pheromone value gets increased by a predefined value to maintain the route based on the sensitivity factor *F* for each data packet traversed. The pheromone value gets decreased by a predefined value to know the path is not used any more.

When a node v_i relays a data packet toward the gateway v_g to a neighbour node v_j, it increases the pheromone value of the entry (v_g, v_j, φ) by $\Delta\varphi$, i.e., the path to the gateway is strengthened by the data packets. In contrast, the next hop v_j increases the pheromone value of entry (v_s, v_i, φ) by $\Delta\varphi$, i.e., the path to the source also strengthened. The evaporation process of the real pheromone is simulated by regular decreasing of the pheromone value according to the Equation 4 given below.

$$\varphi_{i,j} = (1-q).\varphi_{i,j}\ \ q \in [0,1] \quad (4)$$

The mobile nodes recognize duplicate reception of data packets, based on the source address and sequence number in IPv_6 routing header. If a mobile node receives a duplicate packet, it sets the DUPLICATE_ERROR flag and sends the packet back to the previous node. The previous node deactivates the link to this node, so that data packets are not sent in this direction any more.

3.4. Route Failure Handling

The third stage in the proposed protocol is route failure, due to the active intermediate or source nodes having mobility which changes the gateway access. The proposed protocol recognizes the route failure in local MANET through a missing acknowledgment from MAC layer. If a mobile node gets a ROUTE ERROR message for a certain link in local MANET, it first deactivates that link by setting the hop count to 0.

The new route discovery process started using AODV messages. For Internet the routing table entries in the intermediate or source node has a pheromone decay time predicated by mobile agents during gateway discovery. The pheromone decay time gets decreased until it reaches a threshold value. The threshold value *K* gives an indication that link break is going to occur in the path to the gateway. The mobile agents are broadcasted to rediscover a new route or to update the old route to the gateway. If the mobile active node in the path to the gateway is moving it sends a mobile agent with the source address available in the routing table. The mobile agent searches for an alternate link to the gateway. If a second gateway link available in the routing table with pheromone value and pheromone decay time not reaching the minimum threshold value then data packet sent in this path. Either the data packet can be transported to the gateway or to local active MANET node else the backtracking continues to the source node.

4. Performance Evaluation

The performance evaluation of proposed protocol compared with existing proposals of Wakikawa and Jelger using the network simulator ns-2. The source code of AODV protocol modified with the proposal of Wakikawa as AODV Wahiawa and OLSR protocol modified with the proposal of Jelger as OLSR Jelger. The proposed protocol AODV ALMA uses mobile agent code available as open source**.** The simulation scenario description is given in Table 3 with the traffic type set for all nodes as same ftp traffic.

4.1. Simulation Results

The main performance metrics under consideration are those recommended in RFC 2501:

- Packet Delivery Ratio (PDR): the percentage of successfully delivered data packets over all the data packets sent out by the sources.
- Normalized control overhead: the total number of control packets sent and forwarded over the number of successfully delivered data packets. This metric gives the cost in terms of the overhead in different approaches.
- Gateway discovery overhead: the total number of control messages associated with the discovery of gateway. This metric gives information about the control overhead to provide Internet connectivity.
- Connectivity: the average number of mobile nodes required in hybrid MANET to get unexpired routes.
- End-to-End delay: time taken to send data packets from source to destination normalized with the time taken to discover the route.

4.2. Packet Delivery Ratio (PDR)

Figure 3 gives the comparisons results of PDR for AODV ALMA, AODV Wakikawa, and OLSR Jelger.

Table 3. Simulation scenario.

Transmission range	250 mts
Physical layer	two-ray propagation
Link layer	IEEE 802.11
Queue buffer size	64 packets
Routing buffer size	50 packets
Channel capacity	2 Mbps
No. of gateway	3
No. of mobile node	50
Area	1500 x 300 mts
Speed	0-10 m/s
Pause time	0-600 sec
Traffic type	CBR
Sources	10
Sending rate	4 packets/sec
Packet size	512 bytes
Mobile agent packet	10
History size	6 hops
Simulation time	900 seconds

The PDR of AODV ALMA is giving high throughput with that of the reactive AODV Wakikawa. The change of performance for high pause times caused when the network is quite sparse and static giving a condition that nodes become unreachable for long periods. The OLSR Jelger has very less PDR compared to the proposed protocol. The reason for this in OLSR Jelger is that link break in selected path to either gateway or local MANET handled after some time gap. In AODV ALMA the link break to the gateway is monitored by the change in the pheromone value. The pheromone decay time associated with life time of the link. The route maintenance is done with the threshold value for each link in the path to the gateway. After carefully analyzing the simulation results, AODV ALMA use the pheromone value to adaptively select next hop to the gateway giving topology changes strong to mobility.

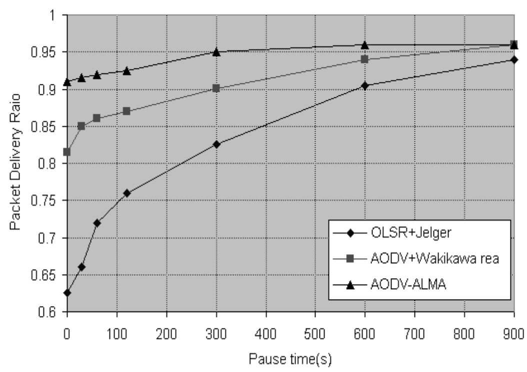

Figure 3. Packet delivery ratio.

4.3. Normalized Control Overhead

Figure 4 gives the overhead comparison results for AODV ALMA, AODV Wakikawa, and OLSR Jelger. The OLSR_Jelger due to its proactive nature has high control overhead in high mobility conditions. As the mobility become static overhead decreases but not as less than AODV Wakikawa. The AODV Wakikawa due to its reactive nature has less control overhead in high mobility conditions and reducing further as the network becomes static. The proposed AODV ALMA has a control overhead that is optimized to that of AODV Wakikawa in high mobility conditions and slightly higher for low mobility conditions.

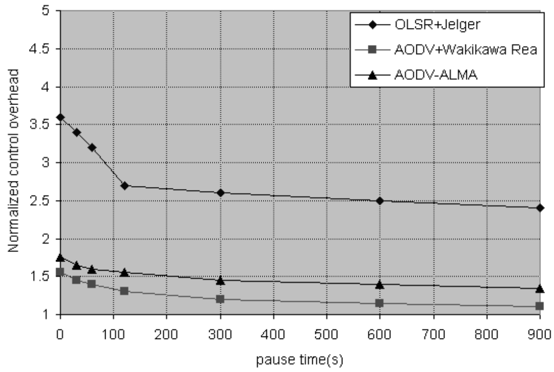

Figure 4. Normalized control overhead.

4.4. Gateway Discovery Overhead

The gateway discovery functions different in all the proposals and comparison results shown in Figure 5. The AODV ALMA gateway discovery approach overhead is less in high and low mobility conditions. The reason is the size and number of mobile agent packets multicast with priority to discover the path to destination simultaneously with local MANET messages. The AODV Wakikawa approach gateway discovery overhead is higher in high mobility conditions. The reason is that time value (TTL) set to discover the gateway does not change for mobility conditions. The OLSR Jelger due to its limited periodic flooding approach the gateway discovery overhead is higher compared to that of AODV ALAM and varies with mobility.

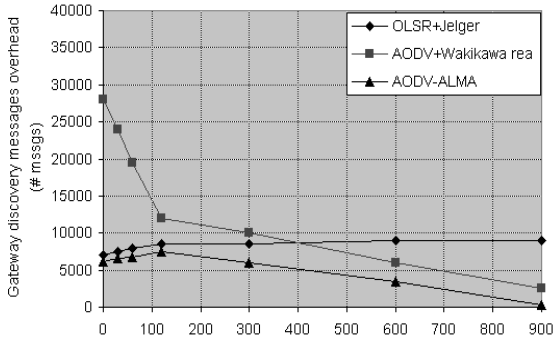

Figure 5. Gateway discovery overhead.

4.5. Connectivity Maintenance

The connectivity of nodes gives path for data packets to be forwarded without loss and comparison results shown in Figure 6. The AODV ALMA achieves high connectivity in high mobility conditions due to its adaptive pheromone value changes and updating by data packets forwarded to the gateway. The connectivity in the path tracked by link probability values predicated by mobile agents selected for forwarding. In OLSR Jelger connectivity is slightly lesser than AODV ALMA with proactive route updating. In AODV Wakikawa connectivity is very less due to the rediscovery of new routes to the gateway and to changes in link break for high mobility conditions.

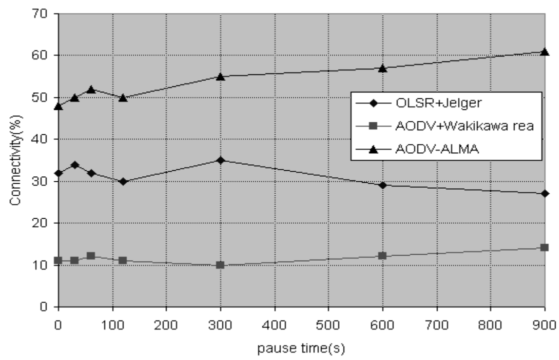

Figure 6. Connectivity Maintenance.

4.6. End-to-End Delay

The end-to-end delays include buffering, queuing delay at interface queue, retransmission delay, propagation and transfer time delay. The assumption for simulation is that all other delay values are same except the route discovery delay. Figure 7 gives the comparison results of end-to-end delay.

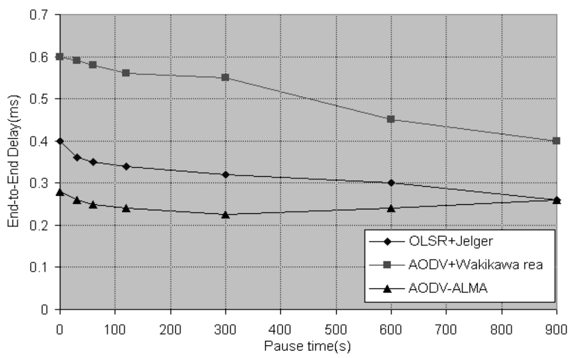

Figure 7. End-to-End Delay.

The proposed protocol AODV ALMA has less delay with separate discovery process simultaneously for gateway and for local MANET. The different mobility condition gives the end-to-end delay variable due to changes in pheromone value. The OLSR Jelger proactive approach discovers route to destination periodically giving slightly higher delay due to the time gap in finding the route separately. The AODV

Wakikawa reactive approach discovers route to destination when needed by first searching in local MANET and then to gateway has higher delay. The time extension value (TTL) for initial route discovery in MANET up to network diameter and after some time for the gateway vary with mobility conditions.

5. Conclusion

This paper proposed a new hybrid adaptive gateway discovery mechanism for hybrid MANET using mobile agents combined with reactive distance vector. The performance tradeoffs and limitations with existing proposals are compared with the proposed protocol using simulation. The proposed protocol gives high network connectivity to gateway and reduced end-to-end delay in packet transmission to destination. The results compared for mobility condition only, it can also be tested for different traffic and scalability conditions. The proposed protocol can be extended with other internetworking related issues such as improved DAD mechanism, efficient support of DNS, discovery of application and network services, network authentication and integrated security mechanism.

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Velmurugan Ayyadurai is a lecturer in electronics engineering department in Madras Institute of Technology at Anna University, India. He holds MSc degree in microwave and optical engineering from Madurai Kamaraj University in 1997. He is currently pursuing his research work for PhD degree in information and communication engineering. He has more than 10 years of experience in teaching and research. He is supervising MSc student thesis in wireless internet, wireless security and wireless TCP/IP integration. He teaches courses at both BSc degree and MSc degree levels in electronics and communication engineering.

Rajaram Ramasamy is a professor & head of the Department of Computer Science & Engineering, Thiagarajar College of Engineering, Madurai. He has a BSc Degree in electrical and electronics engineering from University of Madras in 1966. He secured the MSc in electrical engineering from IIT Kharagpur in 1971 and the PhD degree from Madurai Kamaraj University in 1979. He has been teaching computer hardware and software and supervising research activities. He has published nearly 32 papers in journals, seminars and symposia. His areas of interest are neural networks, fuzzy systems, and genetic algorithms. He has published more than 11 text books for schools and colleges in English and one book in computer science in Tamil. He served at the Makerere University, Kampala, Uganda during 1977-1979 and at the Mosul University, Iraq during 1980-1981. He secured two best technical paper awards from the Institution of Engineers (India), one from the Indian Society of Technical Education.