# COMPARATIVE STUDY OF MULTIPATH EXTENSIONS OF AODV

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## Abstract

*A mobile ad hoc network (MANET) is a multi-hop wireless network with dynamically changing topology. With the development of MANET technology, various routing protocols have been proposed over the years with minimum control overhead and network resources. AODV is the most popular routing protocol among others. It is a single path, loop free, On-demand type routing protocol and its performance is better than other routing protocols in MANET environment. However, single path abstraction is considered one of the biggest drawbacks of AODV. Also, it has more routing overhead both at the time of route discovery and route repair. In the networks with light traffic and low mobility AODV scales flawlessly to the larger networks with low bandwidth and storage overhead. But in networks with heavy traffic, a big number of routes will break resulting in repeated route discoveries and error reports in the network, which is an overhead. The mobile nodes in MANET have limited resources such as battery power, limited bandwidth which the single path protocols cannot handle efficiently. Thus routing is a vital issue in the design of a MANET. Multipath routing allows the establishment of multiple paths between a single source and single destination node. Researchers have proposed many multipath extensions of AODV protocol to establish reliable communication and ensure better load balancing than the conventional protocol. This paper reviews some multipath extensions of AODV routing protocol and a comparative study is done. There is no frontrunner of the comparison, but there are important inferences for scholars who will design new routing protocols in future.*

***Keywords:*** *MANET, Multipath Extensions, Routing Protocols, AODV, AODV-BR, SMORT, AOMDV and AODVM*

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## 1. INTRODUCTION

MANETs are wireless networks which are characterized by dynamic topologies and no fixed organization. Each node in a MANET is a computer that may be required to act both as a host and a router. Moreover, it maybe required to forward packets among nodes which cannot directly communicate with each other. It is an independent collection of mobile users that communicate over wireless links with bandwidth constraints. Since the nodes are mobile, the network topology may change promptly and arbitrarily over time. The network is dispersed, where all activity including discovering the topology and delivering messages must be executed by the nodes themselves.

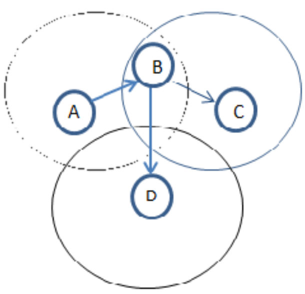


**Fig-1:** Illustration of a MANET

Research has gained a significant advance in the development of routing protocols for wireless ad hoc networks. Network topology changes frequently due to node mobility and power restrictions. Therefore, efficient routing protocols are necessary to organize and maintain communication between the nodes. The adhoc networking, with increase in portable devices and progress in mobile communications gaining importance with widespread applications The set of applications for MANETs range from small, static networks that are constrained by power sources, to large-scale, highly dynamic networks, e.g. military battlefield operations, civilian environments, emergency rescues, Personal Area Networks, mobile conferencing.

The mobile ad hoc networking field is very vast and there are certain limitations that have to be met. The most important scenario is the ability to establish a network in places where it is not possible otherwise. They have limited bandwidth and low power. Also, wireless networks are susceptible to attacks.

### Paper Outline

The rest of the paper is organized as follows: Section II presents routing in MANETs. Section III presents Introduction to AODV protocol. Section IV presents the related work.In V, the extensions to AODV are explained. VI concludes the paper.

## 2. ROUTING IN MANETs

Routing protocols proposed in MANETs are developed so as to handle topology changes well but they may have large control overhead which is the foremost challenge in making a protocol efficient. Different categories of routing protocols are presented in Fig.2.

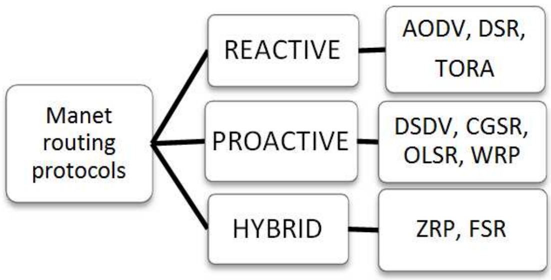


**Fig-2:** Basic categories of MANET routing protocols

In Reactive or on-demand routing protocols the routes are created only when they are needed. The application of this protocol can be seen in the Ad-hoc On-demand Distance Vector Routing Protocol (AODV) and TORA (Temporally Ordered Routing Algorithm)

Whereas in Proactive or Table-driven protocols the nodes keep updating their routing tables by periodical messages. This can be seen in DSDV (Destination-Sequenced Distance Vector) and OLSR (Optimized Link State Routing).

Hybrid routing protocols are designed by merging the good features of reactive and proactive routing protocols, to enhance scalability and to reduce the route discovery overheads. ZRP (Zone Routing Protocol) is a well-known hybrid protocol. The protocols can also be categorized into Location-aware (Geographical), Multipath, Hierarchical, Multicast, Geographical Multicast, and Power-aware [5].

## 3. INTRODUCTION TO AODV

AODV is an on-demand routing protocol for ad hoc networks. It uses hop-by-hop routing by maintaining routing table entries at intermediate nodes for a pre-specified expiration time. AODV only request a route when required and does not require nodes to maintain routes to destinations that are not actively used in communications. It is a flat routing protocol and does not need any central organizational system to handle the routing process. The protocol uses HELLO messages that are broadcast periodically to the immediate neighbors. These HELLO messages are local advertisements for the continued presence of the node and neighbors

AODV is a loop free protocol and avoids the count-to-infinity problem of other distance-vector protocols. The count-to-infinity problem is a result of how distance vector routing protocols, work: "Good news travels quickly, bad news travels slowly" [1]i.e. when the link cost for any link drops this good news travels very fast. However, when the link cost for any link increases, this bad news takes many iterations of the algorithm to travel. AODV evades this problem by using sequence numbers on route updates to determine an up-to-date path to the destination. As stated in [18] AODV was the only on-demand routing protocol promoted from an Internet-Draft to an experimental RFC in that year. As is the case with all reactive ad hoc routing protocols, AODV consists of two protocol procedures: Route discovery and route maintenance.

Route Discovery: The route discovery process is initiated when a source needs a route to a destination for which it does not have a route in its routing table. To initiate route discovery, the source floods the network with a route request (RREQ) packet specifying the destination for which the route is requested, the last known sequence number for the destination and a unique RREQ id that each node maintains and increments upon the sending of an RREQ. This propagation is illustrated in Fig. 3.

It may obtain multiple routes to different destinations from a single RREQ. The immediate neighbors broadcast it further to their neighbors until the request either reaches an intermediate node with a route to the destination or the destination node itself. Duplicate RREQ packets are discarded at intermediate nodes. On forwarding the RREQ packets to their neighbors, the intermediate nodes record in their route tables, the address of the neighbor from which the first copy of the packet has arrived. This recorded information is further used to construct the reverse path for the route reply (RREP) packet. If the same RREQ packets arrive later on, they are discarded.

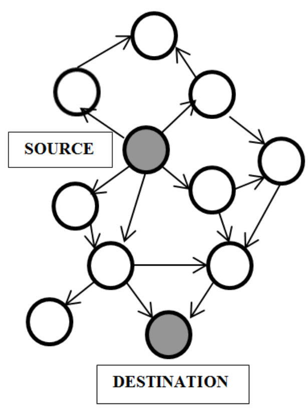


**Fig-3:** RREQ Propagation in AODV

Fig. 4 illustrates the forward and reverse path formation in the AODV protocol. When the RREQ reaches a node with a route to the destination (possibly the destination itself) a Route Reply (RREP), containing the number of hops to the destination and the sequence number for that route, is sent back along the reverse path. An intermediate node can reply to the RREQ only if it has a destination sequence number that is greater than or equal to the number contained in the route request packet header. A larger destination sequence number indicates a more current (or more recent) route.

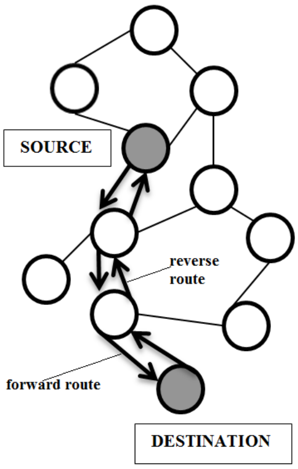


**Fig-4:** Forward Route formation in AODV

Route Maintenance: Route maintenance is the process of responding to changes in topology. Neighboring nodes periodically exchange hello message and absence of hello message indicates a link failure. When a node detects a broken link while attempting to forward a packet to the next hop, it generates a RERR packet that is sent to all sources using the broken link. The RERR packet erases all routes using the link along the way. The RERR contains a list of the unreachable destinations. If a source receives a RERR packet and a route to the destination is still required, it initiates a new route discovery process.

## 4. RELATED WORK

In this section, we have given a brief review of routing protocols which are developed as an extension to the AODV routing protocol under various scenarios.

The motivation of multipath routings is clearly to reduce the overhead and to guarantee a better network load balancing. Many studies have been conducted comparing AODV to other routing protocols in terms of Packet delivery ratio, Average end-to-end delay etc. subjected to change in no. of nodes and traffic type. One such simulation result is shown in[13]. DYMO performs better than AODV in terms of all above stated parameters.A number of modifications have been done on AODV to increase its performance in terms of various parameters. The AODV protocol needs to discover the route first in order to send the actual data. This results in search latency effectsof this protocol. To decrease route discovery rate in single path routing, some multipath routing protocols have been proposed to extend AODV [11], [6], and [15].

Mallapur Veerayya et al. in [16] proposed an energy-aware routing protocol for Quality-of-Service (QoS) support in an infrastructure-less ad-hoc network. The distinctiveness in their scheme was that it used only local information, requires no additional communication or co-operation between nodes.
Simmi Jain in [15]proposed a solution to improve multipath functionality in pure AODV protocol that helps to improve the performance of routing protocol for selecting best route and identification of misbehaving nodes.

Abderrahmen Mtibaa and Farouk Kamoun proposed a hybrid protocol MMDV in [14] that extends the AODV protocol with a dynamic MPR (Multipoint Relays) and multiple paths. Simulation resultsshow that MMDV enhance the packet delivery performance and reduce the overhead in comparison to AODV

Davide Cerri and Alessandro Ghioni in [12] state that till now many experimental RFCs have been produced by IETF MANET working group. However, none of these protocols specifies any security measure, effectively assuming that there are no malicious nodes participating in routing operations. They presented A-SAODV, a prototype implementation of the SAODV routing protocol adding security to AODV.

N.Jaisankar and R.Saravanan[7] proposed a multipath routing scheme which provides better performance and scalability by computing multiple routes in a single route discovery. They claimed the proposed scheme was better than AODV in discovering and maintaining routes.

Abdulsalam Alammari et al[1] subdivided multipath extensions to AODV into two types. MIAODV uses multiple paths saved with the intermediate node. NMIAODV uses one reverse and one forward route (the optimal) to both source and destination nodes respectively. Simulation results show that both types of AODV extensions extremely outperform traditional AODV. On the other hand, MIAODV type outperforms NMIAODV type in most mobility scenarios

## 5. MULTIPATH EXTENSIONS OF AODV

### 5.1 AOMDV (Ad Hoc on-demand Multipath Distance Vector Routing)

[12] Extends AODV to discover multiple paths between Source and Destination in route discovery. It is based on the distance vector concept and uses hop-by-hop routing approach. Mahesh K. Marina and Samir R. Das [9] developed AOMDV with the route discovery and route maintenance phase similar to AODV. The main difference lies in the route discovery process which has been modified to enable multiple paths. The basic structure of a routing table entry in the AOMDV in comparison to AODV is altered [8]. There are two main differences: (i) the hop-count is replaced by

advertised hop-count in the AOMDV and (ii) the next hop is replaced by the route list.

AOMDV is intended to provide efficient recovery from route failures and efficient fault tolerance. To achieve these goals, it computes multiple loop-free and disjoint alternate paths at every node [4]. A stress is given on link disjointness of multiple paths such that the paths may share nodes but no edges. Two main components of AOMDV process are- (i) a route update rule to establish and maintain multiple loop-free paths at each node. (ii) A distributed protocol to find link-disjoint paths.

When an intermediate node receives route request it sets the reverse path to all the multiple paths that are legal and sends a route reply to source. Same process is repeated by the destination when it receives a route request [4]. As stated in [12] duplicate copies of a RREQ are not immediately discarded. Each packet is examined to see if it provides a node-disjoint path to the source.Route maintenance in AOMDV is also similar to that in AODV. The difference is that, in AOMDV, a node only forwards a RERR packet for a destination when all paths to the destination break. Almost all the multipath routing protocols use the data flow to update the time-tags of the paths and keep them fresh, AOMDV makes use of periodic HELLO messages to detect the validity of the links.

Many performance comparisons have been done between AODV and its multipath extensions. Simulations by [9] show that AOMDV reduces the packet loss by up to 40% and reduces routing overhead by about 30% by reducing the frequency of route discovery operations. [11]States The advantage of using AOMDV is that it allows intermediate nodes to reply to RREQs, while still selecting disjoint paths. Abdulsalam Alammari et al. [1]consider restriction of link-disjoint routes a vital drawback of AOMDV. Many efficient routes can be missed, which leads to consumption of too much memory with increase in routing overhead. AOMDV deletes links when they seem to be failed and sometimes considers congested links as broken links. It removes such paths from the list.

Use of a large number of control packets for calculating and maintaining multiple routes between a source and destination is also a drawback of AOMDV [6]

### 5.2 AODV-BR (AODV with Backup Routing)

Sung-Ju Lee and Mario Gerla [10] proposed a scheme to improve existing on demand routing protocols by creating a mesh and providing multiple alternate routes. The scheme is applied to AODV. Neighboring nodes hear the route reply transmissions by being in unrestrained mode, and store a route to the destination through the neighbor that transmitted the reply packet. The new path thus found is called a backup path The algorithm tries to find a partial-route as a backup when the routing protocol detects a broken link in the primary current route. Backup route is maintained at each neighbor of the primary current route to be used when needed which means not all intermediate nodes will save backup route i.e. Alternate routes are utilized only when data packets cannot be delivered through the primary route. This also means only forward backup route can be offered while it does not take into consideration the reverse backup route [1]. It establishes the mesh and multiple paths without transmitting any extra control messages. Nodes on the primary path contain only single path to the destination. It is the neighboring nodes which store backup paths.

AODV-BR protocol uses the route discovery process of AODV. The alternate route creation part is established during the RREP phase, and uses the nature of wireless communications [7]. The destination sends a RREP via the selected route when it receives the first RREQ or later RREQs that traversed a better route (with fewer hops). When a node that is not part of the selected route overhears a RREP packet not directed to it. It records the sending neighbor as the next hop to the destination in its alternate route table. In this way a node may receive numerous RREPs for the same route, select the best route among them and insert it into the alternate route table. When an RREP finally reaches the source of the route, a primary route between that source and destination has been established.

All the nodes that have an alternate route to the destination in their alternate route table form a fish bone. Such a form is illustrated in figure 5. When the link between nodes b and c fails, node y of the mesh forwards the packet from node b directly to the destination node D without sending it through node c. An alternate path with the same path length as the primary route is used as backup.

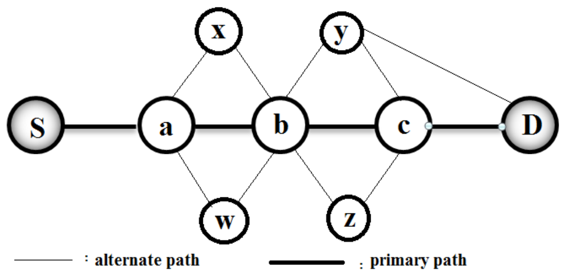


**Fig-5:** Multiple routes depicting Fishbone-type structure

Data packets are not dropped when the route break occurs. The node that detects the link break also sends a RERR to the source node to initiate a route discovery. To distinguish between the fresh and out-of-date routes Timer mechanism is used. Routing overhead of AODV-BR is same as that of

AODV and packet delivery ratio is more because it uses a longer route to deliver the packets that are dropped in AODV. According to authors in [6] AODV-BR is not really a multipath protocol in the sense that nodes only maintain one path per destination.

This scheme has two disadvantages [17]. Firstly, after a node detects a link break, the future data packets it receives are broadcasted for which there is no link layer acknowledgment. So, the recipient that has a backup path has to send an explicit network layer acknowledgment to inform the safe reception of data packets, which increases the control overhead. Secondly, this scheme works only if the nodes that moved away are within the transmission range of its immediate upstream node on the path and one of its neighbors that have backup paths stored. Abdulsalam Alammari et al. [1]state a drawback that only the nodes that are involved by a primary current route will save backup route so, AODV-BR will have limited number of routes.

### 5.3 SMORT (Scalable Multipath on Demand Routing)

L. Reddeppa Reddy and S.V. Raghavan [17] proposed Scalable Multipath On-demand RouTing (SMORT) protocol. They based its development on the fact that as the size of the network increases, on-demand routing protocols cease to perform due to large routing overhead generated while repairing route breaks. SMORT computes multiple fail safe paths and is a multipath extension to AODV routing protocol.The path between the source and the destination is considered as a fail-safe to the primary path, if it bypasses one or more intermediate nodes on the primary path. Fail safe paths can have both links and nodes in common. As SMORT is a reactive routing protocol, the routing process can be categorized into three phases: route discovery, route reply and route maintenance.

The route discovery phase of SMORT is same as that of the route discovery phase of AODV except the fact that in SMORT, RREQ packet does not have any destination sequence numbers. Also, the nodes can accept multiple RREQ packets for computation of multiple fail safe paths and can rebroadcast only the first RREQ. The protocol computes fail safe paths in the route discovery cycle as it reduces the route recovery time and path maintenance overhead more effectively. Reduction in the control overhead allows the protocol to scale to larger networks [19]. The fail-safe paths have higher fault tolerance.

Figure 6(a) shows a set of fail-safe paths which together bypass all nodes on the primary path. e.g., the paths S→w→n→y→z→D and S→w→x→y→l→D are fail-safe paths to the primary path S→w→x→y→z→D. Even if node x and node z move away, the session between node S and node D is unchanged because the packets can be redirected to the fail-safe paths.

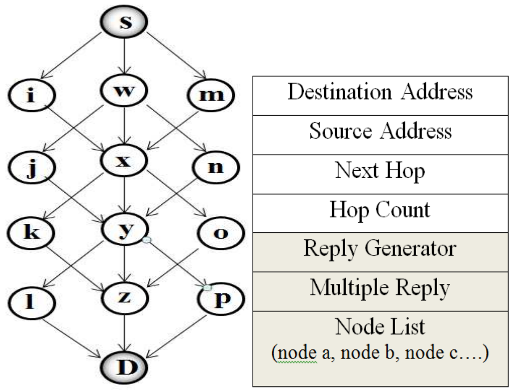


**Fig.-6** (a) Multiple fail-safe paths; (b) Route-reply packet format

SMORT RREP (Fig. 6(b)) contains three extra fields to compute multiple fail safe paths and to avoid routing loops. These are Reply Generator, Multiple Reply and Node List. The Reply generator field is used to store the address of the packet generator. The Multiple reply field is a Boolean variable to distinguish the first RREP packet. Nodes accept only the first received RREP, and store the route information carried by it in its routing table.

Exhaustive simulations using large networks confirmed that SMORT is scalable, and performs better even at higher mobility and tra□c loads, when compared to the AODV protocol [17]. AODV has higher routing overhead than SMORT because AODV involves additional route computations and RERR packet transmissions for recovering from route breaks [20]. However, SMORT has to maintain the request-received table which being an additional overhead is a disadvantage.

### 5.4 AODVM (AODV-Multipath)

AODVM is the first modified version of the AODV protocol which is able to detect multiple node-disjoint paths between a sending source and a receiving destination. The modifications are mostly to route request and reply processes while route recovery and maintenance are similar to that of AODV. AODVM is said to be more reliable and to obtain a better overall performance compared to AODV. Unlike in AODV, duplicate RREQ packets are not systematically discarded in AODVM. Instead of neglecting the duplicate RREQ packets, intermediate nodes store the information included in these packets in a table called RREQ table as a new entry and rebroadcasts the RREQ-packet.

The destination generates a new RREP, containing a new field called “last-hop-ID”, for every received RREQ-packet and

sends it back to the related node. Only the destination node replies to a request since we want to guarantee node-disjoint routes. Edge-disjointness is not chosen on purpose due to the fact that multiple paths passing through one intersecting node might fail simultaneously upon the failure of that one node
Overhearing RREP-packets for neighbor nodes is a distinct property in AODVM. To ensure that nodes do not participate in more than one route, whenever a node overhears one of its neighbors broadcasting an RREP packet, it deletes that neighbor from its RREQ table and adds a routing entry to its routing table as a route to the destination. Routing loops are prevented in AODVM because nodes are not allowed to forward more than one RREP. For confirmation of the route, the source sends back a Route Confirmation (RRCM) message to the destination upon receiving an RREP.

Stephen Mueller and Dipak Ghosal [3] describe some modifications and optimizations in this protocol in the form of AODVM/PD i.e. AODVM with path diversity. Its main objective is to find more diverse paths, or to minimize the correlation factor of the discovered paths. It uses information gained from overheard packets (like AODVM) to accomplish this.

**Table -1:** Comparative analysis of Protocols

| Protocols | Route Selection | Route Reconfigur-ation | Stored Information | Update Information | Advantages | Disadvantages |
|---|---|---|---|---|---|---|
| **AODV** | Newest and shortest path | Delete route, Inform source | Next hop for desired destination | Route Error packet | Flexible to highly dynamic topologies | Scalability problems, Unnecessary bandwidth consumption |
| **AOMDV** | Newest & First available route | Delete route, Inform source | Next hop, last hop, hop count for desired destination | Route Error packet | Low inter-nodal coordination overhead. | Do not scale well in moderate to sparse networks. |
| **AODV-BR** | Newest & shortest path | Local repair, Inform source & neighbors | Next hop, number of hops, destination | Route Error packet | Better throughput Performance than AODV | Not efficient in heavilyloaded dynamicnetworks. |
| **SMORT** | Newest path | Replace primary route with secondary route | Next hop, number of hops, life time, full path | Route Error packet | Reduced overhead, increased scalability even in large networks | Transmission of RERR over multiple paths increases overhead |
| **AODVM** | Strictly node disjoint, selected by destination | Delete route, Inform source | Source Id, Next hop, last hop, hop count | Route discovery Error message | Efficient Load Balancing | Consumes too much memory with increasein routing overhead |

## CONCLUSIONS AND FUTURE WORK

Multipath routing protocols have been proposed for mobile ad hoc networks throughout years. Multipath routing can provide load balancing and reduce the frequency of route discovery mechanism effectively in comparison to their single path counterparts. Researchers have made vast progress in ad hoc networks, but skepticism remains regarding the fact that which of them has an overall superior performance. Many multipath extensions of AODV have been suggested. However, we cannot make a comparative study amongst these protocols, basically because there are several shortcomings in each of them and it is difficult to choose the best of them all. This paper strives to study these extensions based on their characteristics and compares them with respect to the described comparison framework. The table that holds all the comparative data is shown above. In future, a new protocol can be developed keeping in mind the various advantages and disadvantages of these extensions.

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