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A Performance Comparison study of Unicast and Multicast Routing Protocols for Mobile Ad hoc Networks

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ABSTRACT

The network structures have changed significantly in the recent years. In spite of the wireless network challenges namely: changes in network topology, high error rates, power restrictions, bandwidth constraints and issues with link capacity, these networks have become popular. Researchers have contributed to a great extent to solve these challenges with innovative solution to support robust and efficient operation of mobile wireless network. Active research work for mobile ad hoc network is carried out mainly in the fields of medium access control, routing, resource management, power control and security. Because of the importance of routing protocols in dynamic multi-hop networks, a lot of mobile ad hoc network routing protocols have been proposed in the last few years. There are some challenges that make the design of mobile ad hoc network routing protocols a tough task. Firstly, in mobile ad hoc networks, node mobility causes frequent topology changes and network partitions. Secondly, because of the variable and unpredictable capacity of wireless links, packet losses may happen frequently. Moreover, the broadcast nature of wireless medium introduces the hidden terminal and exposed terminal problems. Additionally, mobile nodes have restricted power, computing and bandwidth resources and require effective routing schemes. One of the main areas of research is routing packets from source to destination. Different classification of Mobile network Ad hoc Routing protocols according to different criteria is presented. The Mobile Ad hoc network routing protocols and related problems are identified. Unicast and multicast routing protocols are compared from an analysis point of view based on the classification methods.

Index Terms— Mobile Ad hoc Network, Mobile internet network, Network Topologies, Routing Protocols.

I Introduction:

With the advances of wireless communication technology, low-cost and powerful wireless transceivers are widely used in mobile applications. Mobile networks have attracted significant interests in recent years because of their improved flexibility and reduced costs. Compared to wired networks, mobile networks have unique characteristics. In mobile networks, node mobility may cause frequent network topology changes, which are rare in wired networks. In contrast to the stable link capacity of wired networks, wireless link capacity continually varies because of the impacts from transmission power, receiver sensitivity, noise, fading and interference. Additionally, wireless mobile networks have a high error rate, power restrictions and bandwidth limitations. Mobile networks can be classified into infrastructure networks and mobile ad hoc networks [1] according to their dependence on fixed infrastructures. In an infrastructure mobile network, mobile nodes have wired access points (or base stations) within their transmission range. The access points compose the backbone for an infrastructure network. In contrast, mobile ad hoc networks are autonomously self-organized networks without infrastructure support. In a mobile ad hoc network, nodes move arbitrarily, therefore the network may experiences rapid and un predictable topology changes. Additionally, because nodes in a mobile ad hoc network normally have limited transmission ranges, some nodes cannot communicate directly with each other. Hence, routing paths in mobile ad hoc networks potentially contain multiple hops, and every node in mobile ad hoc networks has the responsibility to act as a router.

Mobile ad hoc networks originated from the DARPA Packet Radio Network (PRNet) [2] and SURAN project [3]. Being independent on pre-established infrastructure, mobile ad hoc networks have advantages such as rapid and ease of deployment, improved flexibility and reduced costs. Mobile ad hoc networks are appropriate for mobile applications either in hostile environments where no infrastructure is available, or temporarily established mobile applications which are cost crucial. In recent years, application domains of mobile ad hoc networks gain more and more importance in non- military public organizations and in commercial and industrial areas. The typical application scenarios include the rescue missions, the law enforcement operations, the cooperating industrial robots, the traffic management, and the educational operations in campus.

Active research work for mobile ad hoc network is carried out mainly in the fields of medium access control, routing, resource management, power control and security. Because of the importance of routing protocols in dynamic multi-hop networks, a lot of mobile ad hoc network routing protocols have been proposed in the last few years. There are some challenges that make the design of mobile ad hoc network routing protocols a tough task. Firstly, in mobile ad hoc networks, node mobility causes frequent topology changes and network partitions. Secondly, because of the variable and unpredictable capacity of wireless links, packet losses may happen frequently. Moreover, the broadcast nature of wireless medium introduces the hidden terminal and exposed terminal problems. Additionally, mobile nodes have restricted power, computing and bandwidth resources and require effective routing schemes. As a promising network type in future mobile applications, mobile ad hoc networks are attracting more and more researchers. This paper gives the state-of-the-art review for typical routing protocols for mobile ad hoc networks, including classical MANET unicast and multicast routing algorithms and popular classification methods. In this paper, related routing protocols are compared from an analysis point of view based on the classification methods.

II Related Works

To compare and analyze mobile ad hoc network routing protocols, appropriate classification methods are important. Classification methods help researchers and designers to understand distinct characteristics of a routing protocol and find its relationship with others. Therefore protocol characteristics which are used to group and compare different approaches are presented in this paper. These characteristics are mainly related to the information which is exploited for routing, when this information is acquired, and the roles which nodes may take in the routing process.

A) Proactive, Reactive and Hybrid Routing Protocols

One of the most popular methods to distinguish mobile ad hoc network routing protocols is based on how routing information is acquired and maintained by mobile nodes. Using this method, mobile ad hoc network routing protocols can be divided into proactive routing, reactive routing and hybrid routing. Proactive routing protocol is also called "table driven" routing protocol. Using a proactive routing protocol, nodes in a mobile ad hoc network continuously evaluate routes to all reachable nodes and attempt to maintain consistent, up-to-date routing information. Therefore, a source node can get a routing path immediately if it needs one.

In proactive routing protocols, all nodes need to maintain a consistent view of the network topology. When a network topology change occurs, respective updates must be propagated throughout the network to notify the change. Most proactive routing protocols proposed for mobile ad hoc networks have inherited properties from algorithms used in wired networks. To adapt to the dynamic features of mobile ad hoc networks, necessary modifications have been made on traditional wired network routing protocols. Using proactive routing algorithms, mobile nodes proactively update network state and maintain a route regardless of whether data traffic exists or not, the overhead to maintain up-to-date network topology information is high. Typical proactive mobile ad hoc network routing protocols, such as the Optimized Link State Routing (OLSR) Protocol[25], Wireless Routing Protocol (WRP) [4], the Destination Sequence Distance Vector (DSDV) [5] and the Fisheye State Routing (FSR) are introduced initially. Reactive routing protocols for mobile ad hoc networks are also called "on-demand" routing protocols. In a reactive routing protocol, routing paths are searched only when needed. A route discovery operation invokes a route-determination procedure. The discovery procedure terminates either when a route has been found or no route available after examination for all route permutations.

In a mobile ad hoc network, active routes may be disconnected due to node mobility. Therefore, route maintenance is an important operation of reactive routing protocols. Compared to the proactive routing protocols for mobile ad hoc networks, less control overhead is a distinct advantage of the reactive routing protocols. Thus, reactive routing protocols have better scalability than proactive routing protocols in mobile ad hoc networks. However, when using reactive routing protocols, source nodes may suffer from long delays for route searching before they can forward data packets. The Dynamic Source Routing (DSR) [6] and Ad hoc On- demand Distance Vector routing (AODV) [7] are examples for reactive routing protocols for mobile ad hoc networks.

Hybrid routing protocols are proposed to combine the merits of both proactive and reactive routing protocols and overcome their shortcomings. Normally, hybrid routing protocols for mobile ad hoc networks exploit hierarchical network architectures. Proper proactive routing approach and reactive routing approach are exploited in different hierarchical levels, respectively.

Typical proactive routing protocols

i) Optimized Link State Routing (OLSR) Protocol

The Optimised Link State Routing (OLSR) protocol [25] is a Table-Driven protocol based on the traditional Link State algorithm. The point-to-point OLSR routing protocol is a non- uniform proactive protocol. Under the OLSR routing protocol strategy, nodes in the network exchange periodical topology information with each other and select a set of neighbouring nodes called *MultiPoint Relays (MPRs)* to retransmit their packets. This technique minimizes the size of control messages and the number of rebroadcast nodes during a route update. Periodic *Hello* messages will be broadcasted from one node to all immediate neighbours to swap neighbour lists and calculate the *MPR* set. The node deduces from neighbour lists the nodes that are two hops away and computes the minimum set (*MPR* set) of one hop relay points vital to reach the two-hop neighbours. Each node notifies its neighbours about its *MPR* set in the *Hello* message. After receiving the *Hello* message, each node records the selected nodes and calls them *MPR selectors*. The frequency of link state updates is adjusted depending on the changes detected in the *MPR* set. With a stable *MPR* set, the period is increased until it reaches a refresh interval value, whereas with a changing *MPR* set, the period of link state exchange is set to a minimum value. Through link state messages, each node obtains network topology information and constructs its routing table. Routes used in OLSR only include *MPRs* as intermediate nodes, whereas each node determines, in terms of hops, an optimal route to every known destination using its topology information (from the topology table and neighbouring table), and stores this information in a routing table. Therefore, routes to every destination are immediately available when data transmission begins. Any node which is not *MPR* can read and process each packet, but cannot retransmit.

ii) The Wireless Routing Protocol (WRP)

The Wireless Routing Protocol (WRP) [4] is a proactive unicast routing protocol for mobile ad hoc networks. WRP uses improved Bellman-Ford Distance Vector routing algorithm. To adapt to the dynamic features of mobile ad hoc networks, some mechanisms are introduced to ensure the reliable exchange of update messages and reduces route loops. Using WRP, each mobile node maintains a distance table, a routing table, a link-cost table and a Message Retransmission List (MRL). An entry in the routing table contains the distance to a destination node, the predecessor and the successor along the paths to the destination, and a tag to identify its state, i.e., is it a simple path, a loop or invalid. Storing predecessor and successor in the routing table helps to detect routing loops and avoid counting-to-infinity problem, which is the main shortcoming of the original distance vector routing algorithm. A mobile node creates an entry for each neighbor in its link-cost table. The entry contains cost of the link connecting to the neighbor, and the number of timeouts since an error-free message was received from that neighbor. In WRP, a node checks the consistency of its neighbors after detecting any link change. A consistency check helps to eliminate loops and speed up convergence. One shortcoming of WRP is that it needs large memory storage and computing resource to maintain several tables. Moreover, as a proactive routing protocol, it has a limited scalability and is not suitable for large mobile ad hoc networks.

iii) The Destination Sequence Distance Vector (DSDV) routing protocol

The Destination Sequence Distance Vector (DSDV) [5] is a proactive unicast mobile ad hoc network routing protocol. Like WRP, DSDV is also based on the traditional Bellman-Ford algorithm. However, their mechanisms to improve routing performance in mobile ad hoc networks are quite different. In routing tables of DSDV, an entry stores the next hop towards a destination, the cost metric for the routing path to the destination and a destination sequence number that is created by the destination. Sequence numbers are used in DSDV to distinguish stale routes from fresh ones and avoid formation of route loops. The route updates of DSDV can be either time-driven or event-driven. Every node periodically transmits updates including its routing information to its immediate neighbors. While a significant change occurs from the last update, a node can transmit its changed routing table in an event-triggered style.

iv) The Fisheye State Routing (FSR)

The Fisheye State Routing (FSR) [9] is a proactive unicast routing protocol based on Link State routing algorithm with effectively reduced overhead to maintain network topology information. As indicated in its name, FSR utilizes a function similar to a fish eye. The eyes of fishes catch the pixels near the focal with high detail, and the detail decreases as the distance from the focal point increases. Similar to fish eyes, FSR maintains the accurate distance and path quality information about the immediate neighboring nodes, and progressively reduces detail as the distance increases. FSR exhibits a better scalability concerning the network size compared to other link state protocols because it doesn't strive for keeping all nodes in the network on the same knowledge level about link states. Instead, the accuracy of topology information is reverse proportional to the distance. This reduces the traffic overhead caused by exchanging link state information because this information is exchanged more frequently with node nearby than with nodes far away.

Typical reactive routing protocols

i) The Dynamic Source Routing (DSR) Protocol

The Dynamic Source Routing (DSR) [6] is a reactive unicast routing protocol that utilizes source routing algorithm. In source routing algorithm, each data packet contains complete routing information to reach its destination. Additionally, in DSR each node uses caching technology to maintain route information that it has learnt. There are two major phases in DSR, the route discovery phase and the route maintenance phase. When a source node wants to send a packet, it firstly consults its route cache. If the required route is available, the source node includes the routing information inside the data packet before sending it. Otherwise, the source node initiates a route discovery operation by broadcasting route request packets. A route request packet contains addresses of both the source and the destination and a unique number to identify the request. Receiving a route request packet, a node checks its route cache. If the node doesn't have routing information for the requested destination, it appends its own address to the route record field of the route request packet. Then, the request packet is forwarded to its neighbors.

To limit the communication overhead of route request packets, a node processes route request packets that both it has not seen before and its address is not presented in the route record field. If the route request packet reaches the destination or an intermediate node has routing information to the destination, a route reply packet is generated. When the route reply packet is generated by the destination, it comprises addresses of nodes that have been traversed by the route request packet. Otherwise, the route reply packet comprises the addresses of nodes the route request packet has traversed concatenated with the route in the intermediate node's route cache. After being created, either by the destination or an intermediate node, a route reply packet needs a route back to the source. DSR has increased traffic overhead by containing complete routing information into each data packet, which degrades its routing performance.

ii) The Ad Hoc On-demand Distance Vector Routing (AODV) protocol

The Ad Hoc On-demand Distance Vector Routing (AODV) protocol [7] is a reactive unicast routing protocol for mobile ad hoc networks. As a reactive routing protocol, AODV only needs to maintain the routing information about the active paths. In AODV, routing information is maintained in routing tables at nodes. Every mobile node keeps a next-hop routing table, which contains the destinations to which it currently has a route. A routing table entry expires if it has not been used or reactivated for a pre-specified expiration time. Moreover, AODV adopts the destination sequence number technique used by DSDV in an on-demand way.

In AODV, when a source node wants to send packets to the destination but no route is available, it initiates a route discovery operation. In the route discovery operation, the source broadcasts route request (RREQ) packets. A RREQ includes addresses of the source and the destination, the broadcast ID, which is used as its identifier, the last seen sequence number of the destination as well as the source node's sequence number. Sequence numbers are important to ensure loop-free and up-to-date routes. To reduce the flooding overhead, a node discards RREQs that it has seen before and the expanding ring search algorithm is used in route discovery operation. The RREQ starts with a small TTL (Time-To-Live) value. If the destination is not found, the TTL is increased in following RREQs.

In AODV, a node uses hello messages to notify its existence to its neighbors. Therefore, the link status to the next hop in an active route can be monitored. When a node discovers a link disconnection, it broadcasts a route error (RERR) packet to its neighbors, which in turn propagates the RERR packet towards nodes whose routes may be affected by the disconnected link. Then, the affected source can re-initiate a route discovery operation if the route is still needed.

iii) The Temporally Ordered Routing Algorithm (TORA)

The Temporally Ordered Routing Algorithm (TORA) [10,11] is a reactive routing algorithm based on the concept of link reversal. TORA improves the partial link reversal method by detecting partitions and stopping non-productive link reversals. TORA can be used for highly dynamic mobile ad hoc networks. In TORA, the network topology is regarded as a directed graph. A Directional Acyclical Graph (DAG) is accomplished for the network by assigning each node i a height metric hi. A link directional from i to j means $hi > hj$. In TORA, the height of a node is defined as a quintuple, which includes the logical time of a link failure, the unique ID of the node that defines the new reference level, a reflection indicator bit, a propagation ordering parameter and an unique ID of the node. The first three elements collectively represent the reference level. The last two values define an offset with respect to the reference level. Like water flowing, a packet goes from upstream to downstream according the height difference between nodes. DAG provides TORA the capability that many nodes can send packets to a given destination and guarantees that all routes are loop-free.

TORA has three basic operations: route creation, route maintenance and route erasure. A route creation operation starts with setting the height (propagation ordering parameter in the quintuple) of the destination to 0 and heights of all other nodes to NULL (i.e., undefined). The source broadcasts a QRY packet containing the destination's ID. A node with a non-NULL height responds by broadcasting a UPD packet containing the height of its own. On receiving a UPD packet, a node sets its height to one more than that of the UPD generator. A node with higher height is considered as upstream and the node with lower height is considered as downstream. In this way, a directed acyclic graph is constructed from the source to the destination and multiple paths route may exist.

B) Multicast routing protocols

Most classification methods used for unicast routing protocols for mobile ad hoc networks are also applicable for existing multicast routing protocols. For example, multicast routing algorithms for mobile ad hoc networks can be classified into reactive routing and proactive routing. The Ad-hoc Multicast Routing (AMRoute) [12] and Ad hoc Multicast Routing protocol utilizing Increasing id- numberS (AMRIS) [13] belong to category of proactive multicast routing and the On-Demand Multicast Routing Protocol (ODMRP) [14] and Multicast Ad hoc On-demand Distance Vector (MAODV) [15] are reactive multicast routing protocols.

There is a classification method particularly used for multicast routing protocols for mobile ad hoc networks. This method is based on how distribution paths among group members are constructed. According to this method, existing multicast routing approaches for mobile ad hoc networks can be divided into tree based multicast routing, mesh based multicast routing, core based multicast routing and group forwarding based multicast.

Tree based multicast routing protocols can be further divided into source-rooted and core-rooted schemes according to the roots of the multicast trees. In source-rooted tree based multicast routing protocols, source nodes are roots of multicast trees and execute algorithm for distribution tree contraction and maintenance. This requires that a source must know the topology information and addresses of all its receivers in the multicast group. Therefore, source-rooted tree based multicast routing protocols suffer from control traffic overhead when used for dynamic networks. The AMRoute [12] is an example for source-rooted tree multicast routing.

In a core-based multicast routing protocol, cores are nodes with special functions such as multicast data distribution and membership management. Some core-based multicast routing protocols utilize tree structures also, but unlike source-rooted tree based multicast routing, multicast trees are rooted at core nodes. For different core-based multicast routing protocols, core nodes may perform various routing and management functions. For example, in CTB [16] and AMRIS, cores are cross points for all traffic flows of multicast groups and may becomes bottlenecks of the network. On the other hand, in protocols like CAMP, core nodes are not necessarily part of all routing paths.

In a mesh-based multicast routing protocol, packets are distributed along mesh structures that are a set of interconnected nodes. The mesh structure is more robust than the tree structure when used for multicast routing in dynamic networks because a mesh provides alternate paths when link failure occurs. However, the cost for maintaining mesh structures are normally higher than trees. The ODMRP [14] and Core-Assisted Mesh Protocol (CAMP) [17] are mesh-based multicast routing protocols proposed for mobile ad hoc networks. In the group forwarding based multicast routing, a set of mobile nodes is dynamically selected as forwarding nodes for a multicast group. Forwarding nodes take the responsibility for multicast packet distribution. Using this scheme, it is possible to get multiple routing paths, and duplicate messages will reach a receiver through different paths. ODMRP is a group forwarding based multicast routing protocol using adaptive forwarding groups.

Typical multicast routing protocols

i) The Ad-hoc Multicast Routing (AMRoute)

The Ad-hoc Multicast Routing (AMRoute) [12] is a tree based multicast routing protocol for mobile ad hoc networks. AMRoute relies on the existence of an underlying unicast routing protocol. AMRoute has two key phases: mesh creation and tree creation. This protocol can be used for networks in which only a set of nodes supports AMRoute routing function. Using AMRoute, bi-directional unicast tunnels are continuously created between pairs of group numbers that are close together. In contrast to the multicast group members, some nodes for tunnel construction don't support AMRoute. When send a packet to a logically adjacent member, the packet will be physically sent on a unicast tunnel and may pass through many routers. The unicast tunnels form a mesh for each multicast group. AMRoute constructs a multicast distribution tree periodically for each multicast group based on the mesh links available. The group members forward and replicate multicast traffic along the branches of the virtual tree.

In AMRoute, every receiver and sender of a group must explicitly join a multicast group. Each group has at least one logical core that is responsible for member management and tree maintenance. New group members select themselves as cores initially. Each core floods JOIN_REQ messages using expanding ring search to find other group members. When a member of the same group (core or non- core) receives the JOIN-REQ from a core of the same group but a different mesh segment, it replies with a JOIN-ACK and marks that node as a mesh neighbor. A new bidirectional tunnel is established between the core and the responding node of the other mesh. When multiple cores appear after mesh merging, a simple core resolution mechanism is used to select a single core. Members of a group retain knowledge of the current core. If a member receives the TREE_CREATE message from a new core, it resets the current core to the new one only if some deterministic criteria is met (e.g., higher IP address wins). In this way, one mesh is created for each group.

To build a shared tree, each core periodically transmits TREE-CREATE packets to mesh neighbors along the unicast tunnels in the mesh. The period is dependent on the size of the mesh and the node mobility. After receiving a non-duplicate TREE_CREATE message, a group member forwards it on all mesh links except the incoming and marks the incoming and outgoing links as tree links. If a member receives a duplicate TREE_CREATE message, it discards the TREE-CREATE message and sends a TREE-CREATE-NAK message back along the incoming link. The node receiving a TREE-CREATE- NAK marks the link as mesh link instead of tree link. When a node wants to quit the group, it sends JOIN-NAK messages to its neighbors and does not forward any data packets for the group. Group members detect core failure if no TREE_CREATE message is received from current core within a preset period. After random waiting, the group member designates itself as the new core and generates TREE_CREATE messages and propagates the messages over mesh links.

The robustness comes from the virtual mesh links used to establish the multicast tree in AMRout and a core failure does not prevent data flow. It doesn't need to handle node mobility (done by the unicast protocol) and the non-members do not need to support multicast. AMRoute is efficient by constructing a shared tree for each group. It can operate over any unicast routing protocol; seamlessly over multiple domains and can be extended to wired networks. The major disadvantage of the protocol is that it suffers from temporary loops and creates non-optimal trees when mobility is present.

ii) The Ad hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS)

The AMRIS [13] is a proactive shared tree based multicast routing protocol, which is independent of the underlying unicast routing protocol. The unique feature of AMRIS is that to each node in the multicast session a session specific multicast session member id (msm-id) is assigned. The msm-id provides a heuristic height to a node and the ranking order of msm-id numbers directs the flow of datagrams in the multicast delivery tree. Every node calculates its msm-id during the initialization phase, which is initiated by a special node called Sid. Normally, the Sid is the source node if there is only one source for the session. Otherwise, the Sid is the source node that has the minimum msm-id.

The sid broadcasts a NEW_SESSION message to its neighbors. The NEW_SESSION message comprises the Sid's msm-id, the multicast session id, and the routing metrics. After receiving the NEW_SESSION message, a node calculates its own msm-id, which is larger than the one specified in the NEW_SESSION message, but the msm-ids are not consecutive. Before re-broadcast the NEW_SESSION message again, a receiver replace the msm-id field with its own msm-id and the routing metrics of the message. A random jitter is introduced between the reception and re-broadcast of a NEW_SESSION message to prevent broadcast storms.

Every node maintains a Neighbor-Status table. An entry of the Neighbor-Status table stores information for a neighboring node, which includes the unique-id, msm-id, relation (parent/child), remaining timeout value, and routing metric. The Neighbor-Status table is updated based on the contents of NEW-SESSION messages. Additionally, every node is required to broadcast beacons to its neighbors. A beacon message contains the node id, msm-id, membership status, registered parent and child's ids and their msm-ids, and partition id.

When a node joins a multicast session, it firstly determines from received NEW_SESSION and beacon messages which neighboring nodes have smaller msm-ids then itself. Then, it sends a unicast JOIN_REQ to one of its potential parent nodes. If the receiver of the JOIN_REQ already has been a part of the multicast session, it replies with a JOIN_ACK message. Otherwise, it sends a JOIN_REQ_PASSIVE message to its potential parent. If a node fails to receive a JOIN_ACK or receives a JOIN_NAK after sending a JOIN_REQ, it performs a Branch Reconstruction (BR). The BR operation is executed in an expanding ring search until the node succeeds in joining the multicast session. In AMRIS, the tree maintenance procedure operates continuously and locally to ensure a node's connection to the multicast session delivery tree. If a node has not received any beacon message for a predefined interval of time, it is assumed that a link disconnection has happened. When a link breaks, the node with the larger msm-id (child) is responsible for rejoining. It tries to rejoin the delivery tree by sending JOIN_REQ message to a new potential parent that is one-hop away. If it fails to rejoin the session because that there is no qualified neighbor, the node performs the BR process as described above. In AMRIS, packets loss will happen if a link in the tree breaks until the tree is reconfigured.

iii) The On-Demand Multicast Routing Protocol (ODMRP)

The On-Demand Multicast Routing Protocol (ODMRP) [14, 18] is a reactive mesh based multicast routing protocol. ODMRP uses a forwarding group concept for multicast packet transmission, in which each multicast group G is associated with a forwarding group FG. Nodes in FG are in charge of forwarding multicast packets of group G. In a multicast group of ODMRP, the source manages the group membership, establishes and updates the multicast routes on demand.

Like reactive unicast routing protocols, ODMPR comprises two main phases: the request phase and the reply phase. When a multicast source has a packet to send but it has no routing and group membership information, it floods a Join Request packet to the entire network. Join Request packets are member-advertising packets with piggybacked data payload. When a node receives a non-duplicate JOIN Request, it stores the upstream node ID in its routing table and rebroadcasts the packet. When the JOIN Request packet reaches a multicast receiver, the receiver refreshes or creates an entry for the source in Member Table and broadcasts JOIN TABLE packets periodically to its neighbors. When a node receives a JOIN TABLE packet, it checks each entry of the table to find out if there is an entry in the table whose next node ID field matches its ID. If there is a match, the node recognizes that it is on the path to the source, thus it is part of the forwarding group. Then it sets the FG_FLAG and broadcasts its own JOIN TABLE built upon matched entries.

Consequently, each member of a forwarding group propagates the JOIN TABLE packets until the multicast source is reached via the shortest path. This process constructs (or updates) the routes from sources to receivers and builds a mesh of nodes, the forwarding group. Multicast senders refresh the member-ship information and update the routes by sending JOIN Request periodically. It uses a soft state approach for group maintenance. Member nodes are refreshed when needed and do not send explicit leave messages. If nodes in the network have access to geographical information through equipments like GPS, ODMRP then can adapt to node movements by utilizing mobility prediction [18]. With the mobility prediction method, the protocol becomes more resilient to topology changes. Mobile nodes forward non-duplicated data packets if they are forwarding nodes. Since all forwarding nodes relay data, redundant paths (when they exist) are available for data packets delivery when the primary path is disconnected. ODMRP also operates as an efficient unicast routing protocol, and doesn't need support from another underlying unicast routing protocol.

iv) The Core-Assisted Mesh protocol (CAMP)

The Core-Assisted Mesh protocol (CAMP) [17, 19] is a proactive multicast routing protocol based on shared meshes. The mesh structure provides at least one path from each source to each receiver in the multicast group. CAMP relies on an underlying unicast protocol which can provide correct distances to all destinations within finite time. Every node maintains a Routing Table (RT) that is created by the underlying unicast routing protocol. CAMP modifies this table when a multicast group joins or leaves the network. A Multicast Routing Table (MRT) is based on the Routing Table that contains the set of known groups. Moreover, all member nodes maintain a set of caches that contain previously seen data packet information and unacknowledged membership requests.

CAMP classifies nodes in the network as duplex or simplex members, or non-members. Duplex members are full members of the multicast mesh, while simplex members are used to create one-way connections between sender-only nodes and the rest of the multicast mesh. Unlike CBT[16], in which all traffic flows through core nodes, the core nodes in CAMP are used to limit the control traffic when receivers are joining multicast groups. The creation and maintenance of meshes are main parts of CAMP. A receiver-initiated method is used in the mesh creation procedure. When a node wants to join a multicast mesh, firstly it consults a table to determine whether it has neighbors that are already members of the mesh. If so, the node announces its membership via a CAMP UPDATE. If it does not have such a neighbor, it either propagates a JOIN REQUEST towards one of the multicast group "cores", or attempts to reach a group member by broadcasting requests using an expanding ring search algorithm. Any duplex member of the multicast group can respond to the request with a JOIN ACK, which is propagated back to the request sender.

CAMP exploits special mechanisms (Heartbeat, Push Join) to ensure the validity of all reverse shortest paths (from receiver to source). Periodically, a receiver node reviews its packet cache to determine whether the data packets it has received are from those neighbors that are on the reverse shortest path to the source. If not, the node sends either a HEARTBEAT or a PUSH JOIN message towards the source along the reverse shortest path. This process ensures that all nodes along reverse shortest paths from all receivers to all senders are included in the mesh. Anchors in

CAMP are neighbor nodes that are required to rebroadcast any received non-duplicate data packets. Mobile nodes periodically choose and refresh their selected anchors to the multicast mesh by broadcasting updates. A node can leave a group if it is not interested in the multicast session and doesn't act as an anchor for neighboring nodes any more.

v) The Multicast operation of Ad-hoc On-demand Distance Vector (MAODV)

The Multicast operation of Ad-hoc On-demand Distance Vector (MAODV)[15], is a reactive tree-based multicast routing protocol. MAODV is an extension of the unicast routing protocol Ad-hoc On- demand Distance Vector (AODV). Using MAODV, all nodes in the network maintain local connectivity by broadcasting "Hello" messages with TTL set to one. Every node maintains three tables, a Routing Table (RT), a Multicast Routing Table (MRT) and a Request Table. RT stores routing information and has the same function as in AODV. Each entry in MRT contains the multicast group IP address, the multicast group leader's IP address, the multicast group sequence number, the hop count to multicast group leader, the hop count to next multicast group member, and the next hops. The next hops field comprises interface and IP address of next hop, the link direction and the activated flag indicating whether the link is added into the multicast tree. Each entry of the Request Table stores the IP addresses of a node, which has sent a request, and the IP address of the requested multicast group. The Request Table provides needed information for optimization.

When a node wants to join a multicast group or sends data packet to a multicast group to which it has no route, it floods a route request (RREQ) message. After receiving an RREP, a node responds to the join request only if it is a member of the desired group. Any node that has fresh route information to the multicast group may respond to the non-join RREQ. A node rebroadcasts the RREQ messages to its neighbors if it is not a member of the desired group or it has no useful routing information for the multicast group. During the broadcasting of RREQ messages, nodes set up pointers to establish the reverse paths. For non-join RREQ messages, the operation is the same as the AODV. For join RREQ, extra operations are needed to maintain the corresponding route entries in MRT. Currently the Enabled flag of this entry is set to FALSE, and it will be set to TRUE only after the node is added to the multicast distribution tree.

After receiving a RREQ message, a member of the desired multicast group responds if the locally recorded group sequence number is fresher than the one contained in the RREQ. The responding node updates its RT and MRT by placing next hop information for the requesting node in the tables. Then, the responding node generates a RREP message and unicasts the message to the source node. The RREP message contains the group sequence number and the IP address of the multicast group leader. Additionally, the Mgroup_hop field in RREP indicates the distance from a source to the multicast group leader. As nodes along the path to the source node receive the RREP, they add entries both in RT and MRT for the node from which they received the RREP. After increasing the hop count and Mgroup_hop fields in the RREP, these nodes continue forwarding RREP towards the source node. Therefore, the forward path is created.

In MAODV, each multicast group has a group leader. A group leader periodically broadcasts "Group Hello" messages through the entire network. The "Group Hello" messages contain IP addresses and corresponding group sequence numbers of the multicast groups of which the sender is the group leader. Nodes update their request table after they received the "Group Hello" messages. Members update their distance to the group leader according to the "Group Hello" messages. MAODV uses a straightforward group leader election method: the first member of a multicast group becomes the leader. This node remains acting as the group leader until it decides to leave the group or a partitioned multicast group merges.

Links in the multicast tree are monitored to detect link breakages, and the downstream node of the break link takes the responsibility for tree maintenance. If the tree cannot be repaired, a new leader for the disconnected downstream nodes is chosen. If a group member initiates the route rebuilding, it becomes the new multicast group leader of the disconnected part. On the other hand, if the initiating node is not a group member and has only one next hop for the tree, it sends its next hop a prune message and leaves the tree. This operation continues until a group member is reached.When a group member receives a "Group Hello" message for the multicast group and finds that the group leader information contained in the message is different from what it already has, it compares the group leader's IP addresses. If it is a member of the partition whose group leader has the lower IP address, it initiates reconnection of the multicast tree.

III Analysis and comparison of typical routing protocols

Many routing protocols have been proposed for mobile ad hoc networks. It is impossible to cover all of them in this review paper. Therefore, this paper presents typical protocols selected from the class of similar approaches that can reflect the state-of-the-art of research work on mobile ad hoc network routing. Table 1 and 2 list the protocols reviewed in this paper. Additionally, analysis and comparison are given to protocols that belong to same category. In this way, distinct features, inheriting relationships and performance characteristics of these routing protocols can be distinguished and evaluated. A comparison of a couple of unicast routing protocols for mobile ad hoc networks is also given. The parameters used for comparison can be grouped into:

- Complexity analysis, including time complexity, communication complexity and storage complexity;
- Mechanism characteristics: such as the route metric, the way for route computation, the way to trigger routing update and the destination for those updates, the need for Hello messages;
- Properties can be used to determine applicable scenarios, for example, the multiple routes support, the unidirectional link support, the multicast capability, and network structure type.

Table 1. Unicast routing protocols

Uniform routing	Proactive routing	Wireless Routing Protocol (WRP)	
		Destination Sequence Distance Vector (DSDV) Routing protocol	Location-based routing
		Fisheye State Routing (FSR)	
		Distance Routing Effect Algorithm for Mobility (DREAM)	
	Reactive routing	Dynamic Source Routing (DSR) protocol	
		Temporally Ordered Routing Algorithm (TORA)	
		Ad hoc On-demand Distance Vector Routing (AODV) protocol	
		Location Aided Routing (LAR)	Location-based routing.
		Associativity Based Routing (ABR) protocol	Link-stability based routing protocol.
		Signal Stability-base adaptive Routing protocol (SSR)	Link-stability based routing protocol.
Non-uniform routing	Zone-based routing	Zone Routing Protocol (ZRP)	Hybrid routing protocol.
		Hybrid Ad hoc Routing Protocol (HARP)	Hybrid routing protocol also.
		Zone-based Hierarchical Link State routing (ZHLS)	Hybrid routing protocol also.
		Grid Location Service (GLS)	Location service.
	Cluster-based routing	Clusterhead Gateway Switch Routing (CGSR)	
		Hierarchical State Routing (HSR)	
		Cluster Based Routing Protocol (CBRP)	
	Core-node based routing	Landmark Ad hoc Routing (LANMAR)	Proactive routing
		Core-Extraction Distributed Ad hoc Routing (CEDAR)	Reactive routing
		Optimized Link State Routing protocol (OLSR)	Proactive routing

a) Comparison of Proactive Protocols (OLSR, WRP, DSDV and FSR)

Control traffic overhead and loop-free properties are the two important issues when applying proactive routing to mobile ad hoc networks. The proactive routing protocols used for wired networks normally have predictable control traffic overhead because topology of wired networks change rarely and most routing updates are periodically propagated. However, periodic routing information updates are not enough for mobile ad hoc routing protocols. The proactive routing in mobile ad hoc networks needs mechanisms that dynamically collect network topology changes and send routing updates in an event- triggered style. Although belonging to the same routing category for mobile ad hoc networks, OLSR, WRP, DSDV and FSR have distinct features. Both WRP and DSDV exploit event-triggered updates to maintain up-to- date and consistent routing information for mobile nodes. In contrast to using event-triggered updates, the updates in FSR are exchanged between neighboring nodes and the update frequency is depends on the distance between nodes. In this way, update overhead is reduced and the far-reaching effect of OLSR is restricted.

Different mechanisms are used in OLSR,

WRP, DSDV and FSR for loop-free guarantee. WPR records the predecessor and the successor along a path in its routing table and introduces consistence-checking mechanism. In this way, WRP avoids forming temporary route loops but incurs additional overhead. Every node needs to maintain more information and execute more operations. In DSDV, a destination sequence number is introduced to avoid route loops. FSR is a modification of traditional Link State routing and its loop-free property is inherited from Link State routing algorithm. WRP, DSDV and FSR have the same time and communication complexity. Whereas WRP has a large storage complexity compared to DSDV because more information is required in WRP to guarantee reliable transmission and loop-free paths. Both periodic and triggered updates are utilized in WRP and DSDV; therefore, their performance is tightly related with the network size and node mobility pattern. As a Link State routing protocol, FSR has high storage complexity, but it has potentiality to support multiple-path routing and QoS routing.

b) Comparison of Reactive Protocols (DSR, AODV and TORA)

As reactive routing protocols for mobile ad hoc networks, DSR, AODV and TORA are proposed to reduce the control traffic overhead and improve scalability. In the appendix, their main differences are listed. DSR exploits source routing and routing information caching. A data packet in DSR carries the routing information needed in its route record field. DSR uses flooding in the route discovery phase. AODV adopts the similar route discovery mechanism used in DSR, but stores the next hop routing information in the routing tables at nodes along active routes. Therefore, AODV has less traffic overhead and is more scalable because of the size limitation of route record field in DSR data packets. Both DSR and TORA support unidirectional links and multiple routing paths, but AODV doesn't. In contrast to DSR and TORA, nodes using AODV periodically exchange hello messages with their neighbors to monitor link disconnections. This incurs extra control traffic overhead. In TORA, utilizing the "link reversal" algorithm, DAG constructs routing paths from multiple sources to one destination and supports multiple routes and multicast [21].
In AODV and DSR, a node notifies the source to re-initiate a new route discovery operation when a routing path disconnection is detected. In TORA, a node re-constructs DAG when it lost all downstream links. Both AODV and DSR use flooding to inform nodes that are affected by a link failure. However, TORA localizes the effect in a set of node near the occurrence of the link failure. AODV uses sequence numbers to avoid formation of route loops. Because DSR is based on source routing, a loop can be avoided by checking addresses in route record field of data packets. In TORA, each node in an active route has a unique height and packets are forwarded from a node with higher height to a lower one. So, a loop-free property can be guaranteed in TORA. However, TORA has an extra requirement that all nodes must have synchronized clocks. In TORA, oscillations may occur when coordinating nodes currently execute the same operation. Performances of DSDV, TORA, DSR and AODV are compared in [22] based on simulation. The simulation results showed that DSDV performs well when node mobility rates and speed of movements are low. When the number of source nodes is large, the performance of TORA decreases. As shown in [22], both AODV and DSR perform well for different simulation scenarios. DSR outperforms AODV because it has less routing overhead when nodes have high mobility. A simulation-based comparison of two reactive mobile ad hoc network routing protocols, the AODV and DSR, is reported in [23]. The general result of [23] was that DSR performs better than AODV when number of nodes is small, lower load and /or mobility, and AODV outperforms DSR in more demanding situations.

c) Comparison of multicast routing protocols (*AMRoute, AMRIS, ODMRP, CAMP, MAODV*

For mobile ad hoc networks, the basic idea behind designing multicast routing protocols is to adaptively establish and maintain connections among group members with minimal redundancy and effort. Various algorithms have emerged to achieve this goal using different mechanisms.
Table 2 below, gives a comparison of typical multicast routing protocols for mobile ad hoc networks. Metrics used for comparison are the multicast delivery structure, how to acquire and maintain routing information, whether they are loop-free, the dependency on underlying unicast routing protocol, is the control packet flooding being used, the requirement for periodic control messages, the routing hierarchy and their scalability. As a special case of multicast, flooding is also presented in the table. Additionally, a performance study of various multicast routing protocols can be found in [24].
In mobile ad hoc networks, generally multicast routing protocols based on a mesh structure outperform those based on a tree structure. When node mobility causes link failures, mesh structure provides alternative paths and reduces the loss of data packets. However, mesh based multicast routing protocols normally requires extra overhead for maintenance.

Node mobility may cause formation of route loops, which is critical for mobile ad hoc routing protocols. Except AMRoute, most of multicast protocols discussed previously are loop-free. Some multicast routing protocols are dependent on certain unicast routing protocols, such as MAODV and CAMP. The former is an extension of the corresponding unicast mechanism, and CAMP relies on the inherent properties of its underlying unicast routing protocol to provide correct and timely distance information.

As in unicast routing protocols for mobile ad hoc networks, multicast routing protocols can be divided into categories as either reactive routing or proactive routing. Among them, AMRoute, AMRIS and CAMP are reactive routing protocols. ODMRP and MAODV are reactive multicast routing protocols. Reactive routing protocols try to reduce overhead by limiting periodically message flooding throughout the network. However, most of existing reactive multicast routing protocols still need periodical network-scale flooding of multicast group membership information.

Table 2. Comparison of multicast routing protocols for mobile ad hoc networks

	AMRoute	***AMRIS***	***ODMRP***	***CAMP***	***MAODV***
Multicast delivery structure	Tree	Tree	Mesh	Mesh	Core based tree
Routing info acquirement /maintenance	Proactive	Proactive	Reactive	Proactive	Reactive
Loop free	No	Yes	Yes	Yes	Yes
Dependency on unicast routing protocol	Yes	No	No	Yes	Yes
Control packet flooding	Yes	Yes	Yes	No	Yes
Periodic messages requirement	Yes	Yes	Yes	Yes	No
Routing hierarchy	Flat	Flat	Flat	Flat	Flat
Scalability	Fair	Fair	Fair	Good	Fair

IV Conclusion

Routing is an essential component of communication protocols in mobile ad hoc networks. The design of the protocols are driven by specific goals and requirements based on respective assumptions about the network properties or application area. The survey tries to review typical routing protocols and reveal the characteristics and trade-offs. There are still many issues which have not been considered in this paper e.g. related to quality of service or recent work on position-based and geographical routing. This will be subject of further investigations.

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