Volume 2, Issue 12, December 2012 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Comparative Analysis of Non-Uniform Unicast Routing Protocols for Mobile Adhoc Networks

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Abstract:** An important and essential issue for mobile adhoc networks is routing protocol design that is a major technical challenge due to the dynamism of the network. Active research work for mobile adhoc network is carrying on 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 Adhoc network routing protocols have been proposed in the last few years. There are some challenges that make the design of mobile adhoc network routing protocols a tough task. Firstly, in mobile adhoc 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 promising network type in future mobile applications, mobile Adhoc networks are attracting more and more researchers. This paper gives the state-of-the-art review and a comparative analysis of related routing protocols from analysis point of view based on the classification methods for mobile Adhoc network

Keywords: ***Clusterhead Gateway Switch Routing (CGSR) - Hierarchical State Routing (HSR) - Cluster Based Routing Protocol (CBRP) – ZRP (Zone Routing Protocol) - Hybrid Adhoc Routing Protocol (HARP) - Zone-based Hierarchical Link State routing (ZHLS).***

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 Adhoc networks originated from the DARPA Packet Radio Network (PRNet) [2] and SURAN project [3]. Being independent on pre-established infrastructure, mobile Adhoc networks have advantages such as rapid and ease of deployment, improved flexibility and reduced costs. Mobile adhoc 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 Adhoc 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.

Mobile networks can be classified into infrastructure networks and mobile Adhoc 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 Adhoc networks are autonomously self-organized networks without infrastructure support. In a mobile Adhoc network, nodes move arbitrarily, therefore the network may experiences rapid and unpredictable topology changes. Additionally, because nodes in a mobile Adhoc network normally have limited transmission ranges, some nodes cannot communicate directly with each other. Hence, routing paths in mobile adhoc networks potentially contain multiple hops, and every node in mobile Adhoc networks has the responsibility to act as a router.

II. ANALYSIS AND COMPARISON OF TYPICAL ROUTING PROTOCOLS

Although so many routing protocols have been proposed for mobile Adhoc networks, 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 adhoc network routing. Table 1 lists the protocols reviewed in this paper.

TABLE 1
COMPARISON OF NON-UNIFORM ROUTING PROTOCOLS

Non Uniform Routing Protocols	**Zone Based Routing Protocols**	Zone Routing Protocol (ZRP)	Hybrid Routing Protocol.
		Hybrid Adhoc Routing Protocol(HARP)	Hybrid Routing Protocol also.
		Zone-Based Hierarchical Link State Routing Protocol(ZHLS)	Hybrid Routing Protocol also.
		Grid Location Service(GLS)	Location Service
	Cluster-Based Routing Protocols	Clusterhead Gateway Switch Routing Protocol(CGSR)	
		Hierarchical State Routing Protocol(HSR)	
		Cluster Based Routing Protocol (CBRP)	
	Core-Node Based Routing Protocols	Landmark Adhoc Routing (LANMAR)	Proactive routing Protocol
		Core-Extraction Distributed Adhoc Routing Protocol(CEDAR)	Proactive routing Protocol
		Optimized Link State Routing Protocol (OLSR)	Proactive routing Protocol

A. Cluster-based routing protocols

a) The Clusterhead Gateway Switch Routing (CGSR)

The Clusterhead Gateway Switch Routing (CGSR) [4] is a hierarchical routing protocol. The cluster structure improves performance of the routing protocol because it provides effective membership and traffic management. Besides routing information collection, update and distribution, cluster construction and clusterhead selection algorithms are important components of cluster based routing protocols.

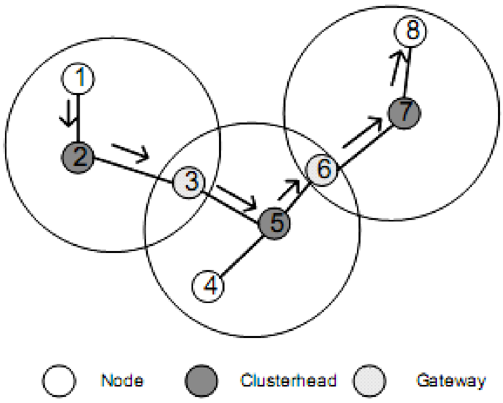

Fig 1. Cluster Structure in CGSR

In a dynamic network, cluster based schemes suffer from performance degradation due to the frequent elections of a clusterhead. To improve the performance of CGSR, a Least Cluster Change (LCC) algorithm is proposed. Only when changes of network topology cause two clusterheads merge into one or a node being out of the coverage of all current clusters, LCC is initiated to change current state of clusters.

In CGSR, when forwarding a packet, a node firstly checks both its cluster member table and routing table and tries to find the nearest clusterhead along the routing path. As shown in Figure 4, when sending a packet, the source (node 1) transmits the packet to its clusterhead (node 2). From the clusterhead node 2, the packet is sent to the gateway node (node 3) that connecting to this clusterhead and the next clusterhead (node 5) along the route to the destination (node 8). The gateway node (node 6) sends the packet to the next clusterhead (node 7), i.e. the destination cluster-head. The destination clusterhead (node 7) then transmits the packet to the destination (node 8).

b) The Hierarchical State Routing (HSR)

The Hierarchical State Routing (HSR) [5] is a multi-level cluster-based hierarchical routing protocol. In HSR, mobile nodes are grouped into clusters and a clusterhead is elected for each cluster. The clusterheads of low level clusters again organize themselves into upper level clusters, and so on. Inside a cluster, nodes broadcast their link state information to all others. The clusterhead summarizes link state information of its cluster and sends the information to its neighboring clusterheads via gateway nodes. Nodes in upper level hierarchical clusters flood the network topology information they have obtained to the nodes in the lower level clusters.

In HSR, a hierarchical address is assigned to every node. The hierarchical address reflects the network topology and provides enough information for packet deliveries in the network. Mobile nodes are also partitioned into logical sub networks corresponding to different user groups. Each node also has a logical address in the form of <subnet, host>. For each sub network, there is a location management server (LMS) which records the logical addresses of all nodes in the sub network. LMSs advertise their hierarchical addresses to the top level of hierarchical clusters.

The routing information, which contains LMSs' hierarchical addresses, is sent down to all LMSs too. If a source node only knows the logical address of the destination node, before sending a packet, the source node firstly checks its LMS and tries to find the hierarchical address of the destination's LMS. Then the source sends the packet to the destination's LMS, and the destination's LMS forwards the packet to the destination. Once the source knows the hierarchical address of the destination, it sends packets directly to the destination without consulting LMSs. In HSR, logical addresses reflect the group property of mobile nodes and hierarchical addresses reflect their physical locations. Combining these addressing schemes can improve adaptability of the routing algorithm.

c) Cluster Based Routing Protocol (CBRP)

In the Cluster Based Routing Protocol (CBRP) [12], nodes are divided into clusters and the clustering algorithm is performed when a node joins the network. Before joining, a node is in the "undecided" state. The "undecided" node initiates the joining operation by setting a timer and broadcasts a Hello message. If a clusterhead receives the Hello message, it replies with a triggered Hello message. Receiving the triggered Hello message, the "undecided" node changes its state to "member" state. If the "undecided" node has bi-directional links to some neighbors but does not receive a message from a clusterhead before the local timer generates a timeout, it makes itself a clusterhead. Otherwise, the node remains in "undecided" mode and repeats the joining operation later.

In CBRP, every node maintains a neighbor table in which it stores the information about link states (uni-directional or bi-directional) and the state of its neighbors. In addition to the information of all members in its cluster, a clusterhead keeps information of its neighboring clusters, which includes the clusterheads of neighboring clusters and gateway nodes connecting it to neighboring clusters.

If a source node wants to send a packet but has no active route which can be used, it floods route request to clusterhead of its own and all neighboring clusters. If a clusterhead receives a request it has seen before, it discards the request. Otherwise, the clusterhead checks if the destination of the request is in its cluster. If the destination is in the same cluster, the clusterhead sends the request to the destination, or it floods the request to its neighboring clusterheads. Source routing is used during the route search procedure and only the addresses of clusterheads on the route are recorded. The destination sends a reply including the route information recorded in the request if it successfully receives a route request. If the source doesn't receive a reply in the specified time period, it starts an exponentially backoff algorithm and sends the request later.

The shortening route is proposed in CBRP for performance optimization. Because CBRP uses a source routing scheme, a node gets all information about the route when receiving a packet. To reduce the hop number and adapt to network topology changes, nodes exploit route shortening to choose the most distant neighboring node in a route as next hop. Another optimization method exploited by CBRP is local repair. Whenever a node has a packet to forward and the next hop is not reachable, it checks the routing information contained in the packet. If the next hop or the hop after next hop in the route is reachable through one of its neighbors, the packet is forwarded through the new route.

d) Comparison of cluster based hierarchical routing protocols presented

Different clustering algorithms have been introduced to group mobile nodes and elect clusterheads in cluster based routing protocols. In HSR, hierarchical addressing is used and the network may have a recursive multi-level cluster structure. Moreover, a location management mechanism is used in HSR to map the logical address to the physical address. CGSR is based on DSDV, a proactive routing protocol for mobile Adhoc networks, and every node keeps routing information for other nodes in both the cluster member table and the routing table. In CBRP every node keeps information about its neighbors and a clusterhead maintains information about its members and its neighboring clusterheads. CBRP exploits the source routing scheme and the addresses of clusterheads along a route are recorded in the data packets.

B. Zone based hierarchical routing protocols

a) The Zone Routing Protocol (ZRP)

The Zone Routing Protocol (ZRP) [8,20] is a hybrid routing protocol for mobile Adhoc networks. The hybrid protocols reduce the control overhead of proactive routing approaches and decrease the latency caused by route search operations in reactive routing approaches. In ZRP, the network is divided into routing zones according to distances between mobile nodes. Given a hop distance *d* and a node N, all nodes within hop distance at most *d* from N belong to the routing zone of N. Peripheral nodes of N are N's neighboring nodes in its routing zone which are exactly *d* hops away from N.

In ZRP, different routing approaches are exploited for inter-zone and intra-zone packets. The proactive routing approach, i.e., the Intra-zone Routing protocol (IARP), is used inside routing zones and the reactive Inter-zone Routing Protocol (IERP) is used between routing zones, respectively. The IARP maintains link state information for nodes within specified distance *d*. Therefore, if the source and destination nodes are in the same routing zone, a route can be available immediately. Most of the existing proactive routing schemes can be used as the IARP for ZRP. The

IERP reactively initiates a route discovery when the source node and the destination are residing in different zones. The route discovery in IERP is similar to DSR with the exception that route requests are propagated via peripheral nodes.

b) The Hybrid Adhoc Routing Protocol (HARP)

The Hybrid Adhoc Routing Protocol (HARP) [11] is a hybrid routing scheme, which exploits a two- level zone based hierarchical network structure. Different routing approaches are utilized in two levels, for intra-zone routing and inter-zone routing, respectively. The Distributed Dynamic Routing (DDR) [11] algorithm is exploited by HARP to provide underlying supports. In DDR, nodes periodically exchange topology messages with their neighbors. A forest is constructed from the network topology by DDR in a distributed way. Each tree of the forest forms a zone. Therefore, the network is divided into a set of non-overlapping dynamic zones.

A mobile node keeps routing information for all other nodes in the same zone. The nodes belonging to different zones but are within the direct transmission range are defined as gateway nodes. Gateway nodes have the responsibility forwarding packets to neighboring zones. In addition to routing information for nodes in the local zone, each node also maintains those of neighboring zones. As in ZRP, the intra-zone routing of HARP relies on an existing proactive scheme and a reactive scheme is used for inter-zone communication. Depending on whether the forwarding and the destination node are inside the same zone, the respective routing scheme will be applied.

c) The Zone-based Hierarchical Link State routing (ZHLS)

The Zone-based Hierarchical Link State routing (ZHLS) [10] is a hybrid routing protocol. In ZHLS, mobile nodes are assumed to know their physical locations with assistance from a locating system like GPS. The network is divided into non-overlapping zones based on geographical information. ZHLS uses a hierarchical addressing scheme that contains zone ID and node ID. A node determines its zone ID according to its location and the pre-defined zone map is well known to all nodes in the network. It is assumed that a virtual link connects two zones if there exists at least one physical link between the zones. A two-level network topology structure is defined in ZHLS, the node level topology and the zone level topology. Respectively, there are two kinds of link state updates, the node level LSP (Link State Packet) and the zone level LSP. A node level LSP contains the node IDs of its neighbors in the same zone and the zone IDs of all other zones. A node periodically broadcast its node level LSP to all other nodes in the same zone. Therefore, through periodic node level LSP exchanges, all nodes in a zone keep identical node level link state information.

In ZHLS, gateway nodes broadcast the zone LSP throughout the network whenever a virtual link is broken or created. Consequently, every node knows the current zone level topology of the network. Before sending packets, a source firstly checks its intra-zone routing table. If the destination is in the same zone as the source, the routing information is already there. Otherwise, the source sends a location request to all other zones through gateway nodes. After a gateway node of the zone, in which the destination node resides, receives the location request, it replies with a location response containing the zone ID of the destination. The zone ID and the node ID of the destination node will be specified in the header of the data packets originated from the source. During the packet forwarding procedure, intermediate nodes except nodes in the destination zone will use inter-zone routing table.

d) Comparison of ZRP, HARP and ZHLS

As zone based mobile Adhoc network routing protocols, ZRP, HARP and ZHLS use different zone construction methods, which have critical effect on their performance. In ZRP, the network is divided into overlapping zones according to the topology knowledge for neighboring nodes of each node. In HARP, the network is divided into non-overlapping zones dynamically by DDR through mapping the network topology to a forest. For each node in HARP, the topology knowledge for neighboring nodes is also needed and the zone level stability is used as a QoS parameter to select more stable route. ZHLS assumes that each node has a location system such as GPS and the geographical information is well known, and the network is geographically divided into non-overlapping zones. The performance of a zone based routing protocol is tightly related to the dynamics and size of the network and parameters for zone construction. However, because zones heavily overlap, ZRP in general will incur more overhead than ZHLS and HARP.

All three zone-based routing protocols presented in this subsection use proactive routing for intra-zone communication and reactive routing for inter-zone packet forwarding. Performance of a zone based routing protocol is decided by the performance of respective proactive and reactive routing protocols chosen and how they cooperate each other.

C. Core-node based routing protocols

a) Landmark Adhoc Routing (LANMAR)

In the Fisheye State Routing protocol (FSR), every node in the network needs to maintain whole network topology information. This strictly limits its scalability. The Landmark Adhoc Routing (LANMAR) [9] is proposed as a modification of FSR and aims to gain better scalability. In contrast to FSR, LANMAR belongs to the non-uniform routing category of mobile Adhoc networks. In LANMAR, mobile nodes are divided into predefined logical subnets according to their mobility patterns, i.e., all nodes in a subnet are prone to move as a group. A landmark node is pre-specified for every logic subset to keep track of the subnet.

Using LANMAR, every mobile node has a hierarchical address that includes its subnet identifier. A node maintains the topology information of its neighbors and all landmark nodes, which represent logical subnets. Similar to FSR, neighboring nodes in LANMAR periodically exchange topology information and the distance vector of landmark nodes. When a source sends packets to the destination inside its neighboring scope (i.e., the source and the destination belong to the same subnet), desired routing information can be found from the source's routing table. Otherwise, the subnet identified in the destination node's address will be searched. Then, according to the distance vector, the packets will be routed towards the landmark node of the logical subset.

Compared to FSR, LANMAR is more efficient because the need to exchange topology information is reduced substantially. However, LANMAR assumes that nodes are grouped into subsets according to their movement patterns and the membership of each subnet remains unchanged during the lifetime of the network, so it is only suitable for specific application scenarios.

b) The Core-Extraction Distributed Adhoc Routing (CEDAR)

The Core-Extraction Distributed Adhoc Routing (CEDAR) [22] is a non-uniform routing protocol. In CEDAR, a subset of nodes in the network is identified as the "core". Core is determined according to a distributed algorithm and the number of core nodes is kept to be small. To select core nodes, neighboring nodes periodically exchange link state messages. Every mobile node in the network must be adjacent to at least one core node and picks this core node as its dominator. The algorithm guarantees that there is a core node at most 3 hops away from another core node. Every core node determines paths to core node nearby using localized broadcasts. The link state information is propagated only among core nodes. The propagation distance of a link state through the network is a function of its stability and bandwidth. Only the state of stable links with high bandwidth is propagated far away and the link state information includes dominators of link endpoints. Hence, in CEDAR, a core node not only knows the state of local links but also the state of stable and high bandwidth links far away.

When a source node wants to send packets to its destination, it informs its dominator core node. Then the dominator of the source finds a route in the core network to the dominator of the destination. This is done by means of a DSR-like route discovery process among core nodes. Then, core nodes involved in the previous step build a route from the source to the destination. Locally available link state information is used according to the QoS requirement such like bandwidth. It is not necessary for the route to include core nodes.

c) The Optimized Link State Routing protocol (OLSR)

The Optimized Link State Routing protocol (OLSR) [16] is a proactive non-uniform Link State routing approach. In the original Link State algorithm, each node propagates its link state information to all other nodes in the network. OLSR reduces the overhead and only fewer nodes re-broadcast link state information. In OLSR, every node transmits its neighbor list using periodical beacons. So, all nodes can know their 2-hop neighbors. Like in CEDAR, OLSR uses an extraction algorithm for multipoint relay (MPR) selection. The multipoint relay set of a node N is the minimal (or near minimal) set of N's one-hop neighbors such that each of N's two-hop neighbors has at least one of N's multipoint relays as its one-hop neighbor. In OLSR, each node selects its MPR independently and only the knowledge of its two-hop neighbors is needed.

When a node broadcasts a message, all of its neighbors will receive the message. Only the MPRs, which have not seen the message before, rebroadcast the message. Therefore, the overhead for message flooding can be greatly reduced. Using OLSR, each node periodically floods the link state information of its MPR set through the network. The frequency of link state updates is adjusted according to whether a change of the MPR set has been detected. If the MPR set has been changed, the period of link state exchange is set to a minimum value. If the MPR set remains stable, the period is increased until it reaches a refresh interval value. Each node obtains network topology information and constructs its routing table through link state messages. Routes used in OLSR only include multipoint relays as intermediate nodes.

d) Comparison of CEDAR, OLSR and LANMAR

In a core-node based routing protocol, the core-node extraction method is a key component. CEDAR, OLSR and LANMAR apply totally different approaches for core node extraction purpose. In LANMAR, the landmark nodes are application related and pre-defined according to their mobility pattern. Obviously, landmark nodes are suitable for tracing groups of nodes that have the same movement patterns. LANMAR is only suitable for specific mobile applications, which meet the assumptions that during the network lifetime, landmark nodes will not change their roles and mobile nodes will not change their mobility patterns.

In CEDAR, a minimal (or nearly minimal) set of core nodes is selected to cover the network according to a certain optimization algorithm. The core nodes can be thought as a dynamically constructed "backbone" as in a cellular network. Core nodes keep link state information of the network. The link state information may include bandwidth, stability or delay information that can be exploited for QoS support and route optimization. The link state propagation is a function of link stability and quality. Only core nodes are involved during route discovery operations. The main disadvantages of CEDAR are that the core extraction algorithm is needed and core nodes have to handle additional traffic associated with route discovery and maintenance.

Different from CEDAR, a node selects its MPR independently in OLSR. A node propagates its MPR set changes through the network, but only MPRs re-broadcast control messages. Thus, OLSR reduces the traffic overhead and improves scalability.

III. CONCLUSION

The Non-Uniform Unicast Routing Protocols for Mobile Adhoc Networks is one of the essential areas to be focused in the context of communication protocols in mobile Adhoc networks. The design of the non-uniform routing protocols is driven by specific goals and requirements based on respective assumptions about the network properties and application area. In this paper, an attempt has been made to throw light on the comparative analysis of Non-Uniform Unicast Routing Protocols for Mobile Adhoc Networks which may aid in selecting the best typical routing protocol needed. So far many issues have not yet been thoroughly analyzed in non-uniform Unicast routing protocols. It is evident that further in-depth research work has to be carried out in this area.

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