Topology vs Position based Routing Protocols in Mobile Ad hoc Networks: A Survey

Sonam Jain
Pursuing Master of Engineering in
Computer Science & Engineering
from Shri Ram Institute of Technology
Jabalpur, India

Sandeep Sahu
(M Tech, IIT Guwahati)
Assistant Professor,
Shri Ram Institute of Technology
Jabalpur, India

Abstract—**Mobile Ad hoc networks perform multi-hop communication in an environment without a dedicated fixed infrastructure, with mobile nodes and changing network topology. In the last 15 years, the wireless networking community designed hundreds of new routing protocols targeting the various scenarios of this design space. The objective of this paper is to create taxonomy of the mobile ad hoc routing protocols, and to survey and compare representative examples for the topology based and position based routing protocols.**

Keywords-topology based routing protocols;position based routing protocols;Mobile ad hoc Networks; styling; insert (key words)

1. INTRODUCTION

WLAN [1] based on the IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g and IEEE 802.11n standards became one of the most Omni present ways of networking with mobile nodes. Most of these networks, however, are deployed in the configuration which can be called ''wired everywhere, except the first hop''. If the aim of the user of the mobile computer is to connect to a web server located around the world, then the best strategy is to escape as quickly as possible from the challenges of wireless domain and enter the reliability of fiber optical networks. In such networks, all the nodes connect to an access point which usually has a wired connection to the Internet. In this scenario the nodes connected to the same WLAN communicate with each other only indirectly via access point. There are, however, many important applications where this model is not applicable. First, even if the goal is Internet access, the access point might not be able to cover all the relevant mobile nodes due to limitations in transmission range, cost or access rights constraints. Another case is when Internet access is of secondary importance, the main application being to communicate locally among a group of mobile nodes. These scenarios can be serviced only if we allow some (possibly all) routing hops to be performed in the wireless domain. Such networks can be set up in any location in an ad hoc manner, without the need of an existing fixed infrastructure. So these networks are known as ad hoc wireless networks [2], other proposed names being infrastructure less wireless networks, instant infrastructure [3] and mobile-mesh networking [4].One of the major technological challenges of such networks is that they require new types of routing protocols. As opposed to the wired infrastructure, because in ad hoc networks there are no dedicated router nodes: so the task of routing needs to be performed by the user nodes, which can be mobile, unreliable and have limited battery power and other resources. The goal of this paper is to survey the collection of technologies which have been proposed for routing in mobile ad hoc networks so far. This way, we hope to provide the student and researcher with a more clear description of the state of the art routing technologies developed so far. We hope that this systematic approach will help the researcher understand the open challenges in the field of mobile ad hoc networks, as well as those which have been satisfactorily solved. As early ad hoc routing protocols have been classified into on topology based routing protocols (demand and table-driven protocols) and position based routing protocols.

Rest of the paper is organized as follows: Section 2 introduces about the applications of the mobile ad hoc networks (MANETs) in various fields. Section 3 introduces Ad hoc routing protocols.

2. APPLICATION OF MANETS

Mobile Ad hoc networks, also defined in the broad sense by of the term as wireless networking in the absence of a wired fixed infrastructure, have a wide range of potential applications. Some of these applications have been already identified in early ad hoc literature [2]. In this section we briefly survey some application areas of interest for ad hoc networks. There are some applications where ad hoc networks are the only possible solution, for instance, networking in areas where no fixed infrastructure is available. Beyond these applications, however, there is a much larger field of various potential applications where ad hoc networks compete with other possible technical solutions. Finally, there are application areas where mobile ad hoc networks can be used as part of a combination of technologies are as follows.

1) **Application in network extension:** In this application of MANETs, the fixed networking infrastructure exists, but it has insufficient coverage range. So the goal of the participants of the network is to access internet, the goal of the ad hoc network is to extend the internet connectivity beyond the reach of the access points. Most routes of the ad hoc network will connect the access points to the remote nodes those are not having the direct connectivity with the internet access point.
2) **Application in local interconnection networks:** In this application no infrastructure is available (or the nodes choose not to use the fixed infrastructure). For example, when networking in remote areas, where the fixed infrastructure might not have been there to begin with. In other applications, such as the previously existing fixed infrastructure has been collapsed due to a natural hazard. In these applications, the communication partners of most nodes are within the network. Example applications include point-to-point messaging and audio and video conferencing.
3) **Application in ubiquitous computing:** In this area of networking between devices embedded in the environment. Communication patterns in ubiquitous computing are strongly influenced by the physical location and proximity – devices which are close to each other are more likely to communicate then remote devices. In contrast, on the wired internet, physical location is almost irrelevant. Ad hoc networks are a particularly good match for proximity based communication. Note, however, that in areas where a pervasive infrastructure is available, ad hoc networks compete with solutions which rely on the convenience of the default infrastructure, even when technologically suboptimal. A recent example involves solutions where a TV set-top box is controlled from a smart phone, through an internet connection traversing dozens of routers, even when the two devices are several feet from each other.
4) **Application in urban sensing:** This application area exploits the sensing and computation capabilities of smart phones, together with the wide range of their deployment in urban areas. Urban sensing is characterized by distributed sensing or data collection, and, in many cases, by distributed data customers. Smart phones can use both infrastructure based access and as well as ad hoc connections. Ad hoc approaches have the advantage of lower energy consumption, lower overall bandwidth consumption and improved privacy – but they inevitably involve more complex interaction patterns.
5) **Application in Vehicular networking:** This area covers applications where one of the communication partners is a vehicle. This definition covers a very wide range of technologies.
6) **Application in Personal area networks:** This application area refers to networking among the portable devices carried by a single user. As long as these devices move with the user, this system can be considered as a local area network with the individual components being in a fixed relative position. The most popular current PAN technology is based on the Bluetooth standards. Quite often, one or more of these devices has its own internet connectivity through long range communication. Very similarly with the vehicular networks, aspects of ad hoc networking come into play when the personal networks of different users will need to interact, or when devices of one users' PAN needs to establish a short range communication with infrastructure elements (such as when performing payment processing through near-field communication).

3. AD HOC ROUTING PROTOCOLS AND COMPARISONS

So far researchers have proposed a wide range of routing protocols for mobile ad hoc networks. But the basic goals [1] of these protocols are the same:

- *Maximizing throughput.*
- *Minimizing packet loss*
- *Minimizing control overhead*
- *Minimizing energy usage.*

But however, the relative priorities of these criteria in the routing protocol design for ad hoc networks differ among application areas of MANETs. In the reminder of this paper, we organize the discussed routing protocols into three categories based on their underlying architectural framework as follows (also shown in Fig. 1).

1) *Source-initiated (Reactive or on-demand) (Section 3.1).*
2) *Table-driven (Pro-active) (Section 3.2).*
3) *Location-aware (Geographical or Position based) (Section 3.2).*

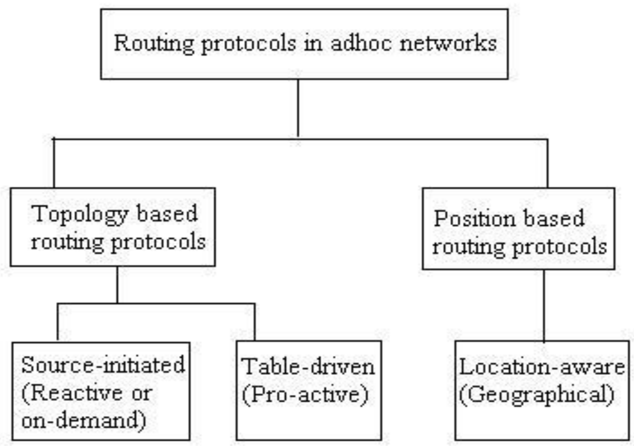

Fig. 1: Categories of ad hoc routing protocols

3.1. Source-initiated protocols (Reactive or on demand)

Source-initiated routing represents a class of routing protocols where the route is created only when the source requests a route to a destination. The route is created through a route discovery procedure which involves flooding the network with route request packets are flooded to starting with the immediate neighbors of the source. Once a route is formed or multiple routes are obtained to the destination, the route discovery process comes to an end. A route maintenance procedure maintains the continuity of the route for the time span it is needed by the source. Some of the examples of the source-initiated routing protocols are as follows:

Dynamic source routing (DSR) [5]: Johnson et al. propose one of the most widely known routing algorithms, called Dynamic Source Routing which is an ''on-demand ''algorithm and it has route discovery and route maintenance phases.

Ad hoc on-demand distance vector (AODV) [6]: The AODV routing protocol was developed by Perkins and Royer as an improvement to the Destination-Sequenced Distance-Vector (DSDV) routing algorithm [7]. AODV aims to reduce the number of broadcast messages forwarded throughout the network by discovering routes on-demand instead of keeping complete up-to-date route information.

Temporally ordered routing algorithm (TORA) [8, 9]: Park and Corson proposed TORA, an adaptive and scalable routing algorithm based on the concept of link reversal. It finds multiple routes from a source to a destination in a highly dynamic mobile networking environment.

Associativity-based routing (ABR) [10]: Toh proposes the ABR algorithm which considers route stability as the most important factor in selecting a route. Routes are discovered by broadcasting a broadcast query request packet. Using these packets, the destination becomes aware of all possible routes between itself and the source.

Signal stability-based adaptive routing (SSBR) [11]: Dube et al. propose the SSBR protocol in which the main routing criteria are the signal and location stability. As in other on-demand routing protocols, the route request is broadcast throughout the network, the destination replies with the route reply message and then the sender sends data through the selected route. Additionally, the signal strength (link quality) between neighboring nodes plays a major role in the route selection process in this protocol.

Preemptive routing in ad hoc networks [12]: In conventional protocols, a path is considered broken only after several retransmissions have timed out. The algorithm introduced by Goff et al. attempts to initiate the discovery process of an alternate route just before the probable route failure. The algorithm generates a preemptive warning when the signal power of the packet received drops below a predefined preemptive threshold. The correct setting of the preemptive threshold is the main challenge of the algorithm. If the value is too high, unnecessary warnings may be generated which can lead to greater overhead, unnecessary route discoveries and switches to possibly lower quality paths. On the other hand, if the value is too low, the path breaks much earlier than the alternate route is selected.

Ad hoc QoS on-demand routing (AQOR) [13]: Xue and Ganz propose AQOR, an on-demand routing protocol enabling QoS support in terms of bandwidth and end-to end delay. The AQOR mechanism estimates the bandwidth and end-to-end delay requirements and use these metrics to make admission and resource reservation decisions.

ARA-The ant-colony based routing algorithms [14]: Gunes et al. present a novel technique for ad hoc routing by using concepts of swarm intelligence and the ant colony meta-heuristic. This class of algorithms aims to solve the complex optimization and collaboration problems without direct communication among the participants. Indirect communication is achieved by stigmergy, the process of leaving traces in the environment, similar to the behavior of ants leaving pheromone signals.

Routing on-demand acyclic multipath (ROAM) [15]: ROAM algorithm by Raju and Garcia–Luna–Aceves coordinates among nodes in directed acyclic sub graphs. It is an extension of the DUAL [41] routing algorithm. The ROAM algorithm guarantees that route search query will fail to return a destination path only is all the routers agree that the destination is unreachable.

The flow oriented routing protocol (FORP) [16]: The FORP protocol proposed by Su and Gerla aims to transmit real-time data streams in ad hoc networks, which require in-order delivery of packets with tight delivery bounds. If alternate routes are not available to immediately redirect the data packets in case of route failures, real-time packets may be dropped. FORP introduces the ''multi-hop handoff'' mechanism in which the nodes use their mobility information to determine future route changes resulting in rebuilding of an alternate routes much sooner.

On-demand routing and channel assignment in multi-channel mobile ad hoc networks [17]: Gong et al. concentrates mainly on designing an efficient channel assignment algorithm at the MAC layer to be used with most on-demand routing strategies at the network level. The authors state that there are intra-flow and inter-flow interferences due to adjacent nodes on the same or different channels respectively. To mitigate the interference problems, the authors implement two enhanced versions of the AODV routing protocol: Enhanced 2-hop CA-AODV and Enhanced k-hop CA-AODV.

Space-content adaptive time routing (SCaTR) [18]: Boice et al. present a routing framework which takes into consideration the possibility of intermittent connectivity in a mobile ad hoc network. SCaTR uses past connectivity information by defining proxy nodes to route traffic towards the destination when no direct route is available. It is built upon the existing AODV protocol in such a way that when the network is fully connected, it works identical to AODV.

Distributed ant routing (DAR) [19]: Rosati et al. propose a distributed routing algorithm based on ant behavior in colonies. Ant colony optimization algorithms have been widely used in MANETs and the authors aim to design an algorithm incorporating the salient features of many existing approaches. The main design goal of DAR is to minimize the computation complexity.

Forwarding Dilemma game (FDG) [20]: Naserian and Tepe propose a game theoretic approach to forwarding flooding packets in MANET with AODV as the underlying routing protocol. The game is played within the network only when a node receives a HELLO or any other flooding message since the nodes are the players. The game, called the forwarding dilemma game (FDG), is composed of the number of players receiving the packet, the forwarding cost and the network gain factor and it offers primarily two strategies – forwarding or dropping the packet.

Long lifetime route (LLR) [21]: Cheng and Heinzelman argue that many routes in ad hoc networks are short lived, triggering frequent route discovery processes, which in turn account for extra control overhead and packet latency. They propose two techniques which allow the network to select long lifetime routes (LLR).

Polarized gossip protocol for path discovery [22]: Beraldi looks at gossip protocols for path discovery, where a node forwards a packet with some predetermined probability. In contrast to classical gossip algorithms which forward each message with the same probability, this work considers the probability dependent on node locations and distances between each other.

On-demand packet forwarding scheme (OD-PFS) [23]: Al-Karaki and Kamal propose a clustering approach followed by a routing protocol exploiting the clustering framework in MANETs. A fixed and scalable virtual wireless backbone, called the virtual grid architecture (VGA), is created. The physical network topology is mapped onto a virtual grid topology. The routing is then carried out using a combination of hierarchical and virtual backbone routing.

QoS routing with traffic distribution (QMRB) [24]: Ivascu et al. use a mobile routing backbone to support QoS in a MANET. The mobile routing backbone (MRB) dynamically distributes traffic within the network and selects the route with the best QoS between a source–destination pair.

Adjusted probabilistic route discovery [25]: Abdulai et al. observe that rebroadcasting route request packets in a MANET leads to extensive control overhead and high levels of channel contention. This work proposes two probabilistic methods aiming to reduce the number of RREQ packets using a predetermined fixed-value forwarding probability. Unlike other similar algorithms, the proposed mechanism does not use GPS based devices for location tracking but mainly relies on basic topology information.

Adaptive backup routing (AODV-ABR) [26]: Lai et al. provide an extension to the AODV-BR scheme which used the concept of backup routes to AODV. It sets up a mesh and multipath routing using RREP messages and aims to reduce control overhead. The mesh structure is created by overhearing data packets transmitted from the nodes in the neighborhood

Low overhead dynamic route repairing [27]: Yu et al .repair broken routes dynamically by using information from overhearing the nodes. Once the route is down, the proposed protocol intelligently replaces the failed links with backup links along the main route.

Link availability-based QoS-aware (LBAQ) routing [28]: Yu et al. propose the LBAQ routing protocol based on node mobility prediction and link quality measurement. While a node moves, it may experience varying capacity, reliability and bandwidth availability. Instead of trying to predict the mobility patterns of the mobile links, the link availability is incorporated into the routing metrics to help choose the link with the highest availability in the route.

Labeled successor routing (LSR) [29]: Rangarajan and Garcia–Luna–Aceves notice that many modern on-demand protocols are built on top of AODV, using the same destination sequence numbers. Thus, they inherit the performance problems of AODV: (a) most route requests are answered by the destination and (b) it can suffer from temporary loops, de facto partition and count-to-infinity. The LSR approach is an attempt to overcome these problems by using the information already needed in route requests to establish and maintain loop-free routes and allows other nodes than the destination to initiate route replies.

Stable weight based on demand routing protocol (SWORP) [30]: Wang et al. propose a weight based mechanism for routing in MANETs. Weights are assigned to different routes during route discovery using the route expiration time (RET), the error count (EC) and the hop count (HC). Route discovery in SWORP is similar to DSR with a source node initiating a RREQ message. The destination node sends the RREP when it receives an RREQ for itself.

Recycled path routing (RPR) [31]: Eisbrener et al. present a new strategy towards broadcasting route request (RREQ) packets in MANETs during route discovery. It uses expired routes stored in the route cache to make an educated decision on forwarding RREQ packets towards the destination. The authors implement controlled flooding in the direction of the destination node but without any prior location information.

Gathering based routing protocol (GRP) [32]: Ahn presents the gathering based routing protocol which collects network information during route discovery to be used later by the source node. Initially, the source node broadcasts a destination query (DQ) packet which is continuously forwarded towards the destination.

Source routing with local recovery (SLR) [33]: Sengul and Kravets start from the observation that although on demand routing reduces the cost of routing in high mobility environments, the route discovery process, which is typically done through network-wide flooding, consumes a significant amount of bandwidth. This is especially expensive if the route discovery must be repeated due to links broken due to node mobility. To alleviate this problem, the authors propose bypass routing, a process which patches a route using local information acquired on-demand, without the need of network-wide flooding. The SLR protocol is an implementation.

Hint based probabilistic protocol [34]: Beraldi et al. propose a probabilistic forwarding framework which uses meta-information to forward packets towards the general direction of the destination. The meta-information is provided in terms of hints at each node.

Labeled distance routing (LDR) [35]: LDR, by Garcia–Luna–Aceves et al., is based on AODV but uses distance labels instead of sequence numbers to ensure loop freedom in the network. It utilizes a loop free invariant for each destination with the sequence numbers which can only be incremented by the destinations. The sequence numbers are used for path resets.

Dynamic backup routes routing protocol (DBR2P) [36]: Wang and Chao present an on-demand routing protocol which does not require any routing table. Destination nodes send back entire routes to the source node while setting up multiple backup routes dynamically.

Refinement based routing (RBR) [37]: Liu and Lin propose a refinement based route maintenance mechanism which adds proactive route selection and maintenance to on-demand routing approaches.

3.2 Table-driven protocols *(Pro-active)*

Table driven also called Pro-active routing protocols always maintain up-to-date information of routes from each node to every other node, means that a source node to every possible node in the network. Routing information is stored in the routing table of each mobile node and route update packets are propagated throughout the network to keep the routing information as update as possible. Different protocols keep track of different routing state information; however, all of them have the common goal of reducing route maintenance overhead as much as possible. These types of protocols are not suitable for highly dynamic networks due to the extra control overhead generated to keep the routing tables consistent and fresh for each node in the network.

Destination-Sequenced Distance-Vector (DSDV) [38]: Perkins and Bhagwat introduced Destination-Sequenced Distance-Vector (DSDV), one of the earliest ad hoc routing protocols. As many distance-vector routing protocols, it relies on the Bellman-Ford algorithm. Every mobile node maintains a routing table which contains the possible destinations in the network together with their distance in hop counts. Each entry also stores a sequence number which is assigned by the destination. Sequence numbers are used in the identification of stale entries and the avoidance of loops.

Analysis of a randomized congestion control scheme with DSDV routing in ad hoc wireless networks [39]: Boukerche et al. describe a randomized version of the DSDV protocol (R-DSDV) where the control messages are propagated based on a routing probability distribution. Local nodes can tune their parameters to the traffic and route the traffic through other routes with lighter load. This implies implementing a congestion control scheme from the routing protocol's perspective.

Optimized link state routing (OLSR) [40]: Clausen et al. designed the OLSR algorithm which improves on the classical link state protocols through several optimizations targeted towards wireless ad hoc networks. These optimizations are centered on specially selected nodes called multipoint relays (MPR).

A hierarchical proactive routing mechanism for mobile ad hoc networks (HOLSR) [41]: Villasenor-Gonzalez et al. networks where some nodes have significantly higher resources (transmission range, bandwidth, directional antenna and so on). The authors notice that traditional, flat routing protocols cannot efficiently exploit the capabilities of the nodes with high resources. For this scenario, the authors propose the HOLSR algorithm which builds upon the OLSR protocol by introducing a hierarchical architecture with multiple ad hoc networks at distinct logical levels within the network.

Clusterhead gateway switch routing (CGSR) [42]: The CGSR protocol, by Chiang et al., uses a distributed algorithm called the Least Cluster Change (LCC). By aggregating nodes into clusters controlled by the clusterheads, a framework is created for developing additional features for channel access, bandwidth allocation and routing. Nodes communicate with the clusterhead which in turn communicates with other clusterheads within the network.

Wireless routing protocol (WRP) [43]: Murthy and Garcia–Luna–Aceves propose WRP which builds upon the distributed Bellman-Ford algorithm. The routing table contains an entry for each destination with the next hop and a cost metric. The route is chosen by selecting a neighbor node that would minimize the path cost. Link costs are also defined and maintained in a separate table and various techniques are available to determine these link costs.

Global state routing (GSR) [44]: Chen and Gerla propose the GSR protocol, where the control packet size is adjusted to optimize the MAC throughput. Each node maintains the neighbor list and three routing tables containing the topology, the next hop, and the distance respectively. The neighbor list contains all neighbors of the current node. The topology table contains the link state information and a timestamp indicating the time in which the link state information is generated. The next hop table contains a list of next hop neighbors to forward the packets while the distance table maintains the shortest distance to and from the node to various destinations. A weight function computes the distance of a link which may be replaced by other QoS routing parameter.

Source-tree adaptive routing (STAR) [45]: Garcia– Luna–Aceves and Spohn propose STAR where each node maintains a source tree which contains preferred links to all possible destinations. Nearby source trees exchange information to maintain up-to-date tables. A route selection algorithm is executed based on the propagated topology information to the neighbors.

OLSR with quality of service (QOLSR) [46]: Munaretto and Fonseca design the QOLSR protocol by adding the QoS parameters of delay and bandwidth to the standard OLSR. Three new heuristics, QOLSR1, QOLSR2 and QOLSR3, are proposed for multipoint relay selection.

Zone routing protocol (ZRP) [47]: The ZRP protocol, designed by Samar et al. is designed to be used in large scale networks. The protocol uses a pro-active mechanism of node discovery within a node's immediate neighborhood while inter-zone communication is carried out by using reactive approaches.

Fisheye state routing (FSR) [48]: Pei et al. propose the FSR protocol which takes inspiration from the ''fisheye'' technique of graphic information compression proposed by Kleinrock and Stevens. When adapted to a routing table, this technique means that a node maintains accuracy distance and path quality information about its immediate vecinity, but the amount of detail retained decreases with the distance from the node. Each node considers a number of surrounding fish-eye scopes, areas which can be reached with 1, 2 . . . hops. A higher frequency of update packets are generated for nodes within smaller scope while the updates are fewer in general for farther away nodes. Each node maintains a local topology map of the shortest paths which is exchanged periodically between the nodes. With an increase in size of the network, a ''graded'' frequency update plan can be adopted across scopes to minimize the overall overhead.

Landmark ad hoc routing (LANMAR) [49]: Pei et al. propose LANMAR which builds subnets of groups of nodes which are likely to move together. A landmark node is elected in each subnet, similar to FSR [48]. The LANMAR routing table consist of only the nodes within the scope and landmark nodes. During the packet forwarding process, the destination is checked if it is within the forwarding node's neighbor scope. If so, the packet is directly forwarded to the address in the routing table. If a packet on the other hand is destined to a farther node, it is first routed to its nearest landmark node.

Relative distance micro-discovery ad hoc routing (RDMAR) [50]: RDMAR, by Aggelou and Tafazolli, has distinct route discovery and route maintenance phase. However, the route discovery broadcast messages are limited by a maximum number of hops calculated using the relative distance between the source and the destination.

Scalable location update based routing protocol (SLURP) [51]: SLURP, by Woo and Singh, develops an architecture scalable to large size networks. A location update mechanism maintains location information of the nodes in a decentralized fashion by mapping node IDs to specific geographic sub-regions of the network where any node located in this region is responsible for storing the current location information for all the nodes situated within that region.

Zone based hierarchical link state routing protocol (ZHLS) [52]: Joa-Ng and Lu propose ZHLS routing protocol where a hierarchical structure is defined by non-overlapping zones with each node having a node ID and a zone ID. These IDs are calculated using an external location tool such as GPS. The hierarchy is divided into two levels: the node level topology and the zone level topology. There are no clusterheads in ZHLS.

Distributed spanning tree (DST) routing [53]: Radhakrishnan et al. present a routing algorithm which uses distributed spanning trees. There can be regions of different stability in the network and a backbone network must be created within the stable regions. All the nodes in the network are aggregated into a number of trees rooted at a particular node.

Distributed dynamic routing (DDR) Algorithm [54]: Nikaein et al. propose a tree-based routing protocol without the need of a root node. Periodic beacon messages are exchanged among neighboring nodes to construct a strategy tree.

A4LP routing protocol [55, 56]: A4LP, by Wang et al., is specifically designed to work in networks with asymmetric links. The routes to In-, Out-, and In/Out-bound neighbors are maintained by periodic neighbor update and immediately available upon request, while the routes to other nodes in the network are obtained by a path discovery protocol. A4LP proposes an advanced flooding technique– m-limited forwarding.

Hybrid ant colony optimization (HOPNET) [57]: Wang et al. present a hybrid routing algorithm based on Ant Colony Optimization (ACO) and zone routing. It considers the scenario of ants hopping from one zone to the next with local proactive route discovery within a zone and reactive communication between zones. The algorithm borrows features from ZRP and DSR protocols and combines it with ACO based schemes.

Link reliability based hybrid routing (LRHR) [58]: Xiaochuan et al. observe that frequent topology changes in MANETs may require the dynamic switching of table driven and on demand routing strategies. The LRHR protocol achieves this switching in a smooth and adaptive fashion.

Fisheye zone routing protocol (FZRP) [59]: Yang and Tseng combine the zone routing protocol with the fisheye state routing mechanism. By using the concept of a fisheye, a multi-level routing zone structure is created where different levels are associated with different link state update rates

Ad hoc networking with swarm intelligence (ANSI) [60]: Rajagopalan and Shen propose a hybrid routing protocol utilizing swarm intelligence (SI) to select good routes in a network. SI allows self-organizing systems and helps maintain state information about the network. ANSI employs a highly flexible cost function which uses information collected from local ant activity. The protocol takes advantage of the basic principles of ant based routing algorithms which allows the maintenance of multiple routes to a destination.

Mobility aware protocol synthesis for efficient routing [61]: Bamis et al. propose a new stability metric to determine the mobility level of nodes in a network. Using this metric, the nodes can be classified into different mobility classes in which they in turn determine the most suitable routing technique for a particular source–destination pair.

Load balancing in MANET shortest path routing [62]: Souihli et al. achieve load balancing to enable efficient routing in MANETs. It has been observed that the load is maximal at the center while it decreases farther from the center of the network. Essentially, the load becomes minimal at the network edges. The authors state that such a load imbalance takes place due to shortest-path routing and propose a new routing metric, the node's centrality, when choosing the best route.

3.3 Location-aware routing protocols *(Geographical or Position based)*

Location-aware routing schemes in mobile ad hoc networks assume that the individual nodes are aware of the locations of all the nodes within the network. The best and easiest technique is the use of the Global Positioning System (GPS) to determine exact coordinates of these nodes in any geographical location. This location information is then utilized by the routing protocol to determine the routes.

Location-aided routing (LAR) [63, 64]: Ko and Vaidya present the LAR protocol which utilizes location information to minimize the search space for route discovery towards the destination node. LAR aims to reduce the routing overhead for the route discovery and it uses the Global Positioning System (GPS) to obtain the location information of a node. LAR essentially describes how location information such as GPS can be used to reduce the routing overhead in an ad hoc network and ensure maximum connectivity.

Distance Routing Effect Algorithm for Mobility (DREAM) [65]: Basagni et al. propose the DREAM protocol which also uses the node location information from GPS systems for communication. DREAM is a part proactive and part reactive protocol where the source node sends the data packet ''in the direction'' of the destination node by selective flooding.

Greedy Perimeter Stateless Routing (GPSR) [66]: GPSR, by Karp and Kung, also uses the location of the node to selectively forward the packets based on the distance. The forwarding is carried out on a greedy basis by selecting the node closest to the destination. This process continues until the destination is reached. However, in some scenarios, the best path may be through a node which is farther in geometric distance from the destination. In this case, a well known right hand rule is applied to move around the obstacle and resume the greedy forwarding as soon as possible.

Dynamic route maintenance (DRM) for geographic forwarding [67]: Chou et al. propose a dynamic beaconing scheme to be used in geographic forwarding algorithms in MANETs. In beacon based protocols, each mobile node transmits periodic beacons to its neighbors to update and maintain its routing table. The beacons are generally forwarded at fixed intervals of time. During low mobility, a longer interval would be the best as it would reduce control overhead while providing accurate location information. However, in cases of higher mobility, determining an appropriate beacon interval is rather difficult. In DRM, beacon interval and route information are carried out dynamically. Based on the node's mobility information, its beacon interval is computed while the route management function updates the routing table entries. The DRM algorithm is applied to GPSR forwarding algorithm.

Improvements to location-aided routing through directional count restrictions [68]: Colagrosso et al. aims to reduce the control packet overhead by reducing duplicate route formation packets. The enhancements are proposed to the LAR Box algorithm which is based on count restriction [69] of rebroadcasts.

Adaptive location aided mobile ad hoc network routing (ALARM) [70]: The Adaptive Location Routing (ALARM) algorithm, by Boleng and Camp, uses feedback for adaptation and location information for performance improvements. While using location information has shown to increase efficiency, feedback is suggested as a mobility metric assisting ad hoc network protocols adapt to the current network scenario [71].

A region-based routing protocol for wireless mobile ad hoc networks (REGR) [72]: The REGR protocol, proposed by Liu et al., dynamically creates a pre-routing region between the source and the destination, hence control the flooding of route request packets within this region. The correct selection of the region, which should not be too small, is important for the discovery of the optimal routes.

Location aided knowledge extraction routing for mobile ad hoc networks (LAKER) [73]: Li and Mohapatra The LAKER protocol, by Li and Mohapatra, minimizes the network overhead during the route discovery process by decreasing the zonal area in which route request packets are forwarded. During this process, LAKER extracts knowledge of the nodal density distribution of the network and remember a series of ''important'' locations on the path to the destination. These locations are named ''guiding routes'' and with the help of these guiding routes the route discovery process is narrowed down.

A location-based routing method for mobile ad hoc networks [74]: Blazevic et al. propose Terminode Routing, a combination of a location-based routing protocol called Terminode Remote Routing (TRR) and a link state routing called Terminode Local Routing (TLR). TRR is used for nodes located some distance away from the source node, while TLR is used for local nodes. Terminode routing also uses a unique flooding scheme called Restricted Local Flooding (RLF) for flooding control packets during route discovery. Anchors are geographical points serve as pointers for source nodes to route the packets.

Movement-based algorithm for ad hoc networks (MORA) [75]: MORA, by Boato and Granelli, takes into account the direction of the movement of the neighboring nodes in addition to forwarding packets based on the location information. The metric for making the forwarding decision is a combination of the number of hops which have an arbitrary weight assigned and a function independent of each node.

On-demand geographic path routing (OGPR) [76]: Giruka and Singhal propose a geographic path routing protocol which does not depend on a location service to find the position of the destination. OGPR is stateless and uses greedy forwarding; reactive route discovery and source based routing. It is a hybrid protocol incorporating the effective techniques of other well known routing protocols for MANETs. OGPR constructs geographic paths to route packets between a source and a destination node.

Secure position-based routing protocol [77]: Song et al. propose a secure geographic forwarding (SGF) algorithm which provides source authentication, neighbor authentication, and message integrity. It is combined with a secure grid location service (SGLS) to enable any receiver to verify the correctness of the location messages. SGF uses both greedy and directional flooding with unicast messages being encrypted with pair-wise shared keys between source and destination.

Sociological orbit aware location approximation and routing (SOLAR) [78]: Ghosh et al. first propose a macro level mobility framework termed ORBIT. It is a deterministic orbital movement pattern of mobile users along specific places called hubs. The movement pattern is based on the fact that most mobile nodes are not truly random in their movements but actually move around in an orbit from hub to hub. Each hub may be a rectangle and movement may take place either inside a hub or in between hubs. Example orbital models discussed are random orbit, uniform orbit, restricted orbit, and overlaid orbit.

Load balanced local shortest path (LBLSP) routing [79]: Carlsson and Eager propose a distributed routing algorithm which uses both local shortest path (LSP) and weighted distance gain (WDG) to finalize the forwarding node. The two non-Euclidian distance metrics provide load balanced routing around obstacles and hotspots. Static nodes with lifetimes longer than the time required to route around an obstacle are considered.

Geographic landmark routing (GLR) [80]: The GLR algorithm, by Na and Kim, solves the blind detouring problem and the triangular routing problem in MANETs. The blind detouring problem occurs when a packet arrives at a dead-end when the next node is blindly selected.

Maximum expectation within transmission range (MER) [81]: Kwon and Shroff propose a packet forwarding algorithm for location aware networks. In most cases, location estimates have significant error rates which may be overlooked in most location based routing protocols. These location errors could induce either transmission failures or backward progress in greedy mode. The former occurs when the selected node is out of transmission range while the latter takes place when the next hop node is actually farther than the destination. This leads to looping within the network.

Implementation framework for trajectory based routing (TBR) [82]: Yuksel et al. study various implementation issues of TBR in this work. A proposed method encodes trajectories into packets at the source node before sending them to the destination. Bezier curves are utilized as possible path trajectories to efficiently forward the packets. These curves provide flexibility in the greedy forwarding of TBR with the possibility of multiple types of curves.

4. Conclusions

In this paper, we introduced taxonomy of ad hoc routing protocols. We have divided the ad hoc routing protocols into three categories:

(i) source-initiated (reactive or on-demand)
(ii) table-driven (pro-active)
(iii) location-aware (geographical)

For each of these classes, we reviewed several representative protocols. While different classes of protocol operate under different scenarios, they usually share the common goal to reduce control packet overhead, maximize throughput, and minimize the end-to-end delay. The main differentiating factor between the protocols is the ways of finding and/or maintaining the routes between source–destination pairs.

The development of the ad hoc routing protocols over the last 15 years is an example of one of the most systematic explorations of a design space in the history of computer science. Although, clearly, newer protocols have built upon the earlier ones, we cannot identify a single ‘‘best’’ protocol. Almost all the protocols we discussed in this paper have their own sweet spot deployment scenarios and performance metric combinations where they outperform their competitors.

From the point of view of the practitioner, this creates a serious problem. To deploy an ad hoc network with an optimal performance, it requires a very careful analysis of the scenario and its requirements, and the appropriate choice of the routing protocol from the dozens applicable in the context. We hope that the taxonomy presented in this paper will be a helpful instrument for making this decision.

References

[1] Azzedine Boukerche, Begumhan Turgut, Nevin Aydin, Mohammad Z. Ahmad, Ladislau Bölöni, Damla Turgut," Routing protocols in ad hoc networks: A survey",ELSEVIER May 2011.

[2] C. Perkins (Ed.), Ad hoc Networking, Addison Wesley, 2001.

[3] R. Bagrodia, M. Gerla, L. Kleinrock, J. Short, T. Tsai, A hierarchical simulation environment for mobile wireless networks, Technical report, Dept. of Computer Science, University of California at Los Angeles, 1996.

[4] J. Al-Karaki, A. Kamal, Efficient virtual-backbone routing in mobile ad hoc networks, Computer Networks 52 (2) (2008) 327–350.

[5] D.B. Johnson, D.A. Maltz, J. Broch, DSR: the dynamic source routing protocol for multi-hop wireless ad hoc networks, in: C.E. Perkins (Ed.), Ad Hoc Networking, Addison-Wesley, 2001, pp. 139–172 (Chapter 5).

[6] C. Perkins, E. Royer, Ad hoc On-demand Distance Vector Routing, in: Proceedings of the Second IEEE Workshop on Mobile Computing Systems and Applications, 1999, pp. 99–100.

[7] C. Perkins, P. Bhagwat, Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers, in: ACM SIGCOMM, August–September 1994, pp. 234–244.

[8] V.D. Park, M.S. Corson, A highly adaptive distributed routing algorithm for mobile wireless networks, in: Proceedings of INFOCOM, April 1997, pp. 1405–1413.

[9] Temporally ordered routing algorithm. Available from web page <http://wiki.uni.lu/secan-lab/temporally ordered+routing+algorithm.html>.

[10] C.-K. Toh, Associativity-based routing for ad-hoc mobile networks,Wireless Personal Communications Journal 4 (2) (1997) 103–139.Special Issue on Mobile Networking and Computing Systems.

[11] R. Dube, C.D. Rais, K.Y. Wang, S.K. Tripathi, Signal stability-based adaptive routing (SSA) for ad hoc mobile networks, IEEE Personal Communications Magazine (1997) 36–45.

[12] T. Goff, N.B. Abu-Ghazaleh, D.S. Phatak, R. Kahvecioglu, Preemptive routing in ad hoc networks, Journal of Parallel Distributed Computing 63 (2) (2003) 123–140.

[13] Q. Xue, A. Ganz, Ad hoc QoS on-demand routing (AQOR) in mobile ad hoc networks, Journal of Parallel Distributed Computing 63 (2) (2003) 154–165.

[14] M. Gunes, U. Sorges, I. Bouazizi, Ara-the ant-colony based routing algorithms for manets, in: Proceedings of IEEE ICPP Workshop on Ad Hoc Networks (IWAHN), August 2002, pp. 79–85.

[15] J. Raju, J. Garcia-Luna-Aceves, A new approach to on-demand loopfree multipath routing, in: Proceedings of the Eight IEEE International Conference on Computer Communications and Networks (IC3N), April 1999, pp. 522–527.

[16] W. Sum, M. Gerla, IPv6 flow handoff in ad-hoc wireless networks using mobility prediction, in: Proceedings of IEEE GLOBECOM, December 1999, pp. 271–275.

[17] M. Gong, S. Midkiff, S. Mao, On-demand routing and channel assignment in multi-channel mobile ad hoc networks, Ad Hoc Networks 7 (1) (2009) 63–78.

[18] J. Boice, J. Garcia-Luna-Aceves, K. Obraczka, Combining on-demand and opportunistic routing for intermittently connected networks,Ad Hoc Networks 7 (1) (2009) 201–218.

[19] L. Rosati, M. Berioli, G. Reali, On ant routing algorithms in ad hoc networks with critical connectivity, Ad Hoc Networks 6 (6) (2008) 827–859.

[20] M. Naserian, K. Tepe, Game theoretic approach in routing protocol for wireless ad hoc networks, Ad Hoc Networks 7 (3) (2009) 569–578.

[21] Z. Cheng, W. Heinzelman, Discovering long lifetime routes in mobile ad hoc networks, Ad Hoc Networks 6 (5) (2008) 661–674.

[22] R. Beraldi, The polarized gossip protocol for path discovery inmanets, Ad Hoc Networks 6 (1) (2008) 79–91.

[23] J. Al-Karaki, A. Kamal, Efficient virtual-backbone routing in mobile ad hoc networks, Computer Networks 52 (2) (2008) 327–350.

[24] G. Ivascu, S. Pierre, A. Quintero, QoS routing with traffic distribution in mobile ad hoc networks, Computer Communications 32 (2) (2009) 305–316.

[25] J.-D. Abdulai, M. Ould-Khaoua, L. Mackenzie, Adjusted probabilistic route discovery in mobile ad hoc networks, Computers and Electrical Engineering 35 (1) (2009) 168–182.

[26] W. Lai, S.-Y. Hsiao, Y.-C. Lin, Adaptive backup routing for ad-hoc networks, Computer Communications 30 (2) (2007) 453–464.

[27] C. Yu, T.-K. Wu, R. Cheng, A low overhead dynamic route repairing mechanism for mobile ad hoc networks, Computer Communications 30 (5) (2007) 1152–1163.

[28] M. Yu, A. Malvankar, W. Su, S. Foo, A link availability-based QoSaware routing protocol for mobile ad hoc sensor networks,Computer Communications 30 (18) (2007) 3823–3831.

[29] H. Rangarajan, J. Garcia-Luna-Aceves, Efficient use of route requests for loop-free on-demand routing in ad hoc networks, Computer Networks 51 (6) (2007) 1515–1529.

[30] N.-C. Wang, Y.-F. Huang, J.-C. Chen, A stable weight-based ondemand routing protocol for mobile ad hoc networks, Information Sciences 177 (24) (2007) 5522–5537.

[31] J. Eisbrener, G. Murphy, D. Eade, C. Pinnow, K. Begum, S. Park, S.-M.Yoo, J.-H. Youn, Recycled path routing in mobile ad hoc networks, Computer Communications 29 (9) (2006) 1552–1560.

[32] C. Ahn, Gathering-based routing protocol in mobile ad hoc networks, Computer Communications 30 (1) (2006) 202–206.

[33] C. Sengul, R. Kravets, Bypass routing: an on-demand local recovery protocol for ad hoc networks, Ad Hoc Networks 4 (3) (2006) 380–397.

[34] R. Beraldi, L. Querzoni, R. Baldoni, A hint-based probabilistic protocol for unicast communications in MANETs, Ad Hoc Networks 4 (5) (2006) 547–566.

[35] J. Garcia-Luna-Aceves, M. Mosko, C. Perkins, A new approach to ondemand loop-free routing in networks using sequence numbers,Computer Networks 50 (10) (2006) 1599–1615.

[36] Y.-H. Wang, C.-F. Chao, Dynamic backup routes routing protocol for mobile ad hoc networks, Information Sciences 176 (2) (2006) 161–185.

[37] J.-S. Liu, C.-H.R. Lin, RBR: refinement-based route maintenance protocol in wireless ad hoc networks, Computer Communications 28 (8) (2005) 908–920.

[38] C. Perkins, P. Bhagwat, Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers, in: ACM SIGCOMM, August–September 1994, pp. 234–244.

[39] A. Boukerche, S.K. Das, A. Fabbri, Analysis of a randomized congestion control scheme with DSDV routing in ad hoc wireless networks, Journal of Parallel and Distributed Computing 61 (7) (2001) 967–995.

[40] T. Clausen, P. Jacquet, A. Laouiti, P. Muhlethaler, A. Qayyum, L. Viennot, Optimized link state routing protocol for ad hoc networks, in: Proceedings of IEEE INMIC, December 2001, pp. 62–68.

[41] L. Villasenor-Gonzalez, Y. Ge, L. Lamont, HOLSR: a hierarchical proactive routing mechanism for mobile ad hoc networks, IEEE Communications Magazine 43 (7) (2005) 118–125.

[42] W.L.C. Chiang, H. Wu and M. Gerla, Routing in clustered multihop, mobile wireless networks, in: Proceedings of IEEE SICON, April 1997, pp. 197–211.

[43] S. Murthy, J.J. Garcia-Luna-Aceves, An efficient routing protocol for wireless networks, MONET 1 (2) (1996) 183–197.

[44] T.-W. Chen, M. Gerla, Global state routing: a new routing scheme for ad-hoc wireless networks, in: Proceedings of IEEE ICC, vol. 1,June 1998, pp. 171–175.

[45] J.J. Garcia-Luna-Aceves, M. Spohn, Source-tree routing in wirelessnetworks, in: Proceedings of IEEE ICNP, October–November 1999,pp. 273–282.

[46] A. Munaretto, M. Fonseca, Routing and quality of service support for mobile ad hoc networks, Computer Networks 51 (11) (2007) 3142–3156.

[47] P. Samar, M. Pearlman, S. Haas, Independent zone routing: an adaptive hybrid routing framework for ad hoc wireless networks,IEEE/ACM Transactions on Networking 12 (4) (2004) 595–608.

[48] G. Pei, M. Gerla, T.-W. Chen, Fisheye state routing in mobile ad hoc networks, in: Proceedings of IEEE ICDCS Workshop on Wireless Networks and Mobile Computing, April 2000, pp. D71–D78.

[49] G. Pei, M. Gerla, X. Hong, LANMAR: Landmark routing for large scale wireless ad hoc networks with group mobility, in: Proceedings of ACM MobiHoc, August 2000, pp. 11–18.

[50] G.N. Aggelou, R. Tafazolli, RDMAR: A bandwidth-efficient routing protocol for mobile ad hoc networks, in: Proceedings of ACM WOWMOM, August 1999, pp.26–33.

[51] S.-C. Woo, S. Singh, Scalable routing protocol for ad hoc networks,Wireless Networks 7 (5) (2001) 513–529.

[52] M. Joa-Ng, I.-T. Lu, A peer-to-peer zone-based two-level link state routing for mobile ad hoc network, IEEE Journal on Selected Areas in Communications 17 (8) (1999) 1415–1425.

[53] S. Radhakrishnan, N. Rao, G. Racherla, C. Sekharan, S. Batsell, DST –a routing protocol for ad hoc networks using distributed spanning trees, in: Proceedings of IEEE WCNC, September 1999,pp. 100–104.

[54] N. Nikaein, H. Labiod, C. Bonnet, DDR: distributed dynamic routing algorithm for mobile ad hoc networks, in: Proceedings of ACM MobiHoc, August 2000, pp. 19–27.

[55] G. Wang, Y. Ji, D.C. Marinescu, D. Turgut, A routing protocol for power constrained networks with asymmetric links, in: Proceedings of the ACM Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN),October 2004, pp. 69–76.

[56] G. Wang, D. Turgut, L. Bölöni, Y. Ji, D. Marinescu, Improving routing performance through m-limited forwarding in power-constrained wireless networks, Journal of Parallel and Distributed Computing (JPDC) 68 (4) (2008) 501–514.

[57] J. Wang, E. Osagie, P. Thulasiraman, R. Thulasiram, Hopnet: a hybrid ant colony optimization routing algorithm for mobile ad hoc network, Ad Hoc Networks 7 (4) (2009) 690–705.

[58] X. Xiaochuan, W. Gang, W. Keping, W. Gang, J. Shilou, Link reliability based hybrid routing for tactical mobile ad hoc network, Journal of Systems Engineering and Electronics 19 (2) (2008) 259–267.

[59] C.-C. Yang, L.-P. Tseng, Fisheye zone routing protocol: a multi-level zone routing protocol for mobile ad hoc networks, Computer Communications 30 (2) (2007) 261–268.

[60] S. Rajagopalan, C.-C. Shen, ANSI: A swarm intelligence-based unicast routing protocol for hybrid ad hoc networks, Journal of Systems Architecture 52 (8-9) (2006) 485–504.

[61] A. Bamis, A. Boukerche, I. Chatzigiannakis, S. Nikoletseas, A mobility aware protocol synthesis for efficient routing in ad hoc mobile networks, Computer Networks 52 (1) (2008) 130–154.

[62] O. Souihli, M.Frikha,M.Hamouda, Load-balancing in MANET shortest path routing protocols, Ad Hoc Networks 7 (2) (2009) 431–442.

[63] Y. Ko, N. Vaidya, Location-Aided Routing (LAR) in mobile ad hoc networks, in: Proceedings of ACM MobiCom, October 1998, pp. 66–75

[64] Y.-B. Ko, N.H. Vaidya, GeoTORA: A protocol for geocasting in mobile ad hoc networks, in: Proceedings of IEEE ICNP, November 2000, pp.240–249.

[65] S. Basagni, I. Chlamtac, V.R. Syrotiuk, B.A. Woodward, A distance routing effect algorithm for mobility (DREAM), in: Proceedings of the ACM MOBICOM, October 1998, pp. 76–84.

[66] B. Karp, H. Kung, GPSR: Greedy Perimeter Stateless Routing for Wireless Networks, in: Proceedings of ACM MobiCom, August 2000,pp. 243–254.

[67] C.-H. Chou, K.-F. Ssu, H. Jiau, Dynamic route maintenance for geographic forwarding in mobile ad hoc networks, Computer Networks 52 (2) (2008) 418–431.

[68] M. Colagrosso, N. Enochs, T. Camp, Improvements to location-aided routing through directional count restrictions, in: Proceedings of International Conference on Wireless Networks (ICWN), June 2004,pp. 924–929.

[69] B. Williams, T. Camp, Comparison of broadcasting techniques for mobile ad hoc networks, in: Proceedings of ACM MobiHoc, June 2002, pp. 194–205.

[70] J. Boleng, T. Camp, Adaptive location aided mobile ad hoc network routing, in: Proceedings of IEEE International Performance,Computing, and Communications Conference (IPCCC), April 2004,pp. 423–432.

[71] J. Boleng, Exploiting location information and enabling adaptive mobile ad hoc networking protocols, Ph.D. Thesis, Colorado School of Mines, 2002.

[72] Y. Liu, X. Hu, M. Lee, T. Saadawi, A region-based routing protocol for wireless mobile ad hoc networks, IEEE Network 18 (4) (2004) 12–17.

[73] J. Li, P. Mohapatra, LAKER: Location aided knowledge extraction routing for mobile ad hoc networks, in: Proceedings of IEEE WCNC, March 2003, pp. 1180–1184.

[74] L. Blazevic, J.-Y.L. Boudec, S. Giordano, A location-based routing method for mobile ad hoc networks, IEEE Transactions on Mobile Computing 4 (2) (2005) 97–110.

[75] G. Boato, F. Granelli, MORA: a movement-based algorithm for adhoc networks, in: Proceedings of The Tenth International Conference on Distributed Multimedia Systems (DMS), 2004, pp.171–174.

[76] V. Giruka, M. Singhal, A self-healing on-demand geographic path routing protocol for mobile ad-hoc networks, Ad Hoc Networks 5 (7) (2007) 1113–1128.

[77] J.-H. Song, V. Wong, V. Leung, Secure position-based routing protocol for mobile ad hoc networks, Ad Hoc Networks 5 (1) (2007) 76–86.

[78] J. Ghosh, S. Philip, C. Qiao, Sociological orbit aware location approximation and routing (solar) in manet, Ad Hoc Networks 5 (2) (2007) 189–209.

[79] N. Carlsson, D. Eager, Non-euclidian geographic routing in wireless networks, Ad Hoc Networks 5 (7) (2007) 1173–1193.

[80] J. Na, C.-K. Kim, Glr: a novel geographic routing scheme for large wireless ad hoc networks, Computer Networks 50 (17) (2006) 3434–3448.

[81] S. Kwon, N. Shroff, Geographic routing in the presence of location errors, Computer Networks 50 (15) (2006) 2902–2917.

[82] M. Yuksel, R. Pradhan, S. Kalyanaraman, An implementation framework for trajectory-based routing in ad hoc networks, Ad Hoc Networks 4 (1) (2006) 125–137.