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A qualitative comparison evaluation of the greedy forwarding strategies in Mobile Ad Hoc Network

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ABSTRACT

The Mobile Ad Hoc Network (MANET) is wireless network which provides communication among wireless mobile hosts without the need of any standing network infrastructure. In such networks, and to facilitate communication between participating nodes, every node has to offer routing services. Routing in MANET is responsible for selecting and forwarding packets along optimal paths. Finding an optimal route is a crucial task in MANET where routes tend to be multi-hop. Many routing protocols have been proposed in literature. However, few of them are efficient when the network is sparse and highly dynamic. Position-based routing and forwarding provides the opportunity for improving the efficiency and performance of the existing MANET routing strategies. This research work presents an extensive overview of geographic forwarding techniques in MANET. In particular, it focuses on the presentation of the basic operation mode of geographic forwarding, which is greedy forwarding. Meanwhile, this research work presents a qualitative evaluation of the most current and popular greedy forwarding strategies used with position based routing protocols. Furthermore, the findings have been used to conclude the most appropriate unicast forwarding policy for future research efforts.

1. Introduction

Mobile Ad Hoc Networks (MANETs) are composed of wireless mobile devices (nodes) equipped with portable radios but without the aid of any centralized management or existing infrastructure such as base-station. MANETs are used in battlefield environments, disaster relief, and for commercial issues (Ambhaikar Sharma). MANETs have received significant attention due to their easy deployment for such usages. In MANETs, each node must act as a router and host at the same time. These mobile nodes themselves must be able to cooperate to allow communication among each other. Moreover, a routing protocol for MANET runs on every node and is affected by the limited resources at each Mobile Node (MNs). Hence, each MN takes a part in data packets forwarding process (Qadri and Liotta, 2009).

Nodes in such a network move in a freely and arbitrarily manner, thus a MANET topology changes frequently and unpredictably (Chlamtac et al., 2003). Moreover, MANET is limited in its resources (bandwidth and power). Meanwhile, it is expected to perform efficiently with such limitations. These constraints in combination with the MANET dynamics topology make the designing of routing in such networks a challenging task. This means that we need a more dynamic routing protocol that not only finds an optimal route between the communicating MNs, but also responds quickly to the topology changes, and optimally using limited recourses (Qadri and Liotta, 2009; Chlamtac et al., 2003; Ghosekar et al., 2010). To solve the addressed problems of routing in MANET, many routing protocols that are compatible with the characteristics of MANET have been proposed in the literature. However, few of them are efficient when the network is sparse and highly dynamic.

For the sake of classification of routing protocols in MANET, there are several approaches that have been adopted. One of those approaches is in regards to the required routing information that will be used in packet forwarding. As is pointed out in (Rubinstein et al., 2006), within the framework of the Internet Engineering Task Force (IETF), routing in MANET can be broadly classified into two main categories. These categories are position-aware (position-based), and position-unaware (topology-based) routing protocols.

Position-unaware routing protocols use information about links that exist in the network to perform packet forwarding. Position-aware routing protocols use the position information of nodes to make routing decisions (Mauve et al., 2001; Liu and Kaiser, 2005; Rajaraman, 2002). Position-based routing and forwarding approaches provides the opportunity for improving the

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efficiency and performance of the existing MANET routing strategies over topology-based protocols.

In this work, an extensive overview of geographic forwarding techniques for the position-based routing protocol introduced is presented. It focuses on the presentation of the basic operation mode of geographic forwarding, which is greedy forwarding. This work introduces in depth the basic principles involved and describe the classical techniques as well as the latest advances in this area. These techniques are the most current and popular greedy forwarding strategies used with position-based routing protocols.

Furthermore, the techniques under study have been analyzed and evaluated in terms of several qualitative characteristics. These criteria are transmission range, path strategy, deployed criterion, optimization criteria, optimization objective, memorization, communication complexity, implementation complexity, robustness, scalability, optimal path, guarantee delivery, and lastly, are they loop-free. The protocols that have been selected for analyses are; Greedy Forwarding Strategy, (GFS) (Finn, 1987), Most Forward within Transmission Range, (MFR) (Takagi and Kleinrock, 1984), Nearest with Forward Progress, (NFP) (Hou and Li, 1986), Compass Routing, (CR) (Kranakis, 1999), Random Progress, (RPF) (Nelson and Kleinrock, 1984), Angular Routing protocol, (ARP) (Giruka Singhal), Maximum by Conventional Geographic Routing, (MAGF) (Li and Shatz, 2008), Normalized Advance, (NADV) (Lee et al., 2010) and lastly, Greedy-based Backup Routing (GBR) (Yang et al., 2010).

2. Position-unaware routing protocols

During the last 10 years, there have been a number of location-unaware routing protocols that have been proposed for MANET (Perkins et al., 1999; Park and Corson, 1997; Jacquet et al., 2001; Johnson and Maltz, 1996; Perkins and Bhagwat, 1994). Location-unaware routing protocols use existing information about the network to forward packets (Royer and Toh, 1999). Such protocols as it pointed out in (Toh, 1999; Abolhasan et al., 2004; Al-Omari and Sumari, 2010), are divided into three categories: proactive, reactive and hybrid protocols.

However, experimentally it has been proven that, topology-based routing protocols are suitable for smaller networks with low mobility (Qadri and Liotta, 2009; Meghanathan, 2009; Jazyah and Hope, 2010). The scenario of high mobility and a large MANET, where participating nodes use any topology-based routing protocol lead to the generation of high control overhead traffic. Consequently, this leads to an increase in the node's battery power consumption, as well as the bandwidth being reduced. This is followed by more congestion and poor network performance (Qadri and Liotta, 2009; Chlamtac et al., 2003; Ghosekar et al., 2010; Meghanathan, 2009; Jazyah and Hope, 2010). In general, since MANET has limited resources in terms of bandwidth and battery power, using a topology-based routing protocol that tries to maintain its state appears to be not only impossible but also impractical. Moreover, it degrades the performance of the entire MANET.

3. Position-aware routing protocols

As, alluded to in the previous section the current unaware-position based routing protocols are hampered by many issues. Such protocols need to be enhanced to improve their packet delivery ratio, reliability, scalability, and to reduce their energy consumption. These issues have motivated researchers to look for better routing schemes. As a consequence, the well-known position-based routing protocols were proposed as an alternative. Position-based routing protocols have lately received significant attention due to the availability of a small, inexpensive, and low-power Global Positioning System (GPS) (Blackwell, 1985). Position-aware routing protocols use node location information, instead of link information to perform routing. These protocols require that a node have the ability to obtain its own, its neighbours' and its destination's geographical positions. For these reasons, these routing protocols are also referred to as location-based or geographic approaches (Kumar et al., 2010).

The general idea of position-based routing protocols is that when a node has data packets to be transmitted to another node, the forwarding decision to select the next hop(s) from among several neighbours within its transmission range, is entirely made based on the position of the destination and the position of its neighbours (Lemmon et al., 2009; Tomar and Tomar, 2008; Kuhn et al., 2003; Kuhn et al., 2002; Rührup, 2006). Contrary to the location-unaware routing protocols, position-based routing is characterized as a stateless routing protocol, where forwarding decisions are based on local knowledge.

Position-based routing protocols are stateless, hence, it is not necessary to create and maintain a global route from the sender to the destination (Lemmon et al., 2010; Khadar and Razafindralambo, 2009). Therefore, position-based routing protocols prevent extra overhead from occurring. Also, it prevents the latency of rout discovery incurred by traditional reactive routing protocols. These features of position-based routing protocols add to their new value. Thus, position-based routing protocols are simple, achieve better scalability and possess low routing overhead as well as better performance and robustness against frequent topological changes. Additionally, since position information avoids network-wide searches, both control and data packets are sent towards the known physical location of the destination node (Khadar and Razafindralambo, 2009; Blazevic et al., 2001; Chen and Varshney, 2009).

Primary geographic routing is comprised of two basic mechanisms, namely location service and the geographic forwarding strategy. The location service provides a mapping from a node's identity to its current geographic coordinates. Distance Routing Effect Algorithm (DREAM) (Basagni et al., 1998), and Grid Location Service (GLS) (Li et al., 2000) are examples of the existing location services.

The second mechanism of the primary geographic routing is the geographic forwarding strategy. There are three forwarding techniques for position-based protocols(Farooq and Di Caro, 2008), which are, Greedy forwarding (single-path), restricted directional flooding (multi-path), and hierarchical approaches (i.e. use position-aware and position-unaware routing protocols). The concern of this work is focused on the greedy approaches. For further reading, a survey of the others two techniques can be found in (Lemmon et al., 2009; Tomar and Tomar, 2008).

4. Packet forwarding strategies

Geographic forwarding is the process of making a routing decision locally at each participating node (Meghanathan, 2009; Rührup, 2006; Lemmon et al., 2010; Farooq and Di Caro, 2008). Packet forwarding is accomplished by the means of exploiting the participating nodes' location information. The forwarding decision by a node is primarily based on two main issues. The former issue concerns the accurate knowledge of location information for both destination and neighbouring nodes. With geographic forwarding neighbourhood location information is maintained through the broadcasting of periodic beacons that contain the node ID and its location. Meanwhile, destination location information is maintained using an appropriate distributed location service. Hence, geographic forwarding is a scalable and incurs low overhead; this is because, it avoids the overhead incurred by other types of ad hoc routing protocols (Khadar and Razafindralambo, 2009; Chen and Varshney, 2009).

The latter issue, concerns about the strategies that are used to select the next-relay node. We can distinguish three main packet-forwarding strategies for location-based routing they which are: restricted directional flooding, hierarchical approaches, and greedy forwarding. Once, a destination is located the used forwarding algorithms can be performed to route the data packets through the MANET. This means that, geographic forwarding algorithms have both proactive and reactive elements. They functions proactively to get the position information, and reactively to forward the data packets.

4.1. Hierarchical routing

This approach uses different types of mobile ad hoc routing protocols at different levels of the hierarchy. It allows networks to scale to a very large number of nodes, by applying different rules to long-distance and short-distance. An example of such an existing approach, which introduces a two-layer hierarchy to perform routing in MANET is the TERMINODES routing protocol (Blazevic et al., 2001).

The TERMINODES routing algorithm is a combination of position-based (Terminode Remote Routing (TRR)), and non-position-based (Terminode Local Routing (TLR)) routing algorithms. The involved part of the hierarchy mainly depends on the distance separating the source-destination pair. A position-based algorithm (a greedy approach) is used at the long-distance level when the forwarding node and the receiver are far away. Hence, this part has characteristics similar to those of greedy forwarding. While when a packet arrives close to the destination, a non-position-based (proactive distance vector) scheme is adopted. Terminode routing addresses by design a scalable, robust and simple approach. Hierarchical routing allows mobile ad hoc networks to scale to a very large number of nodes. It is shown that the introduction of a hierarchy can significantly improve the ratio of successfully delivered packets and the routing overhead as compared to the reactive ad hoc routing algorithms.

4.2. Restricted directional flooding

Flooding is used by reactive ad hoc routing protocols during the route discovery phase, which cause a high overhead problem. To relieve this problem, researchers have proposed the restricted directional flooding approach. By using this approach, the flooding is restricted to a certain area where the destination may be located during a certain time interval, hence, it considered as partial flooding. In restricted directional flooding, the sender forwards the data packet to all one-hop neighbours that are located in the direction of the destination. In order to determine this direction, a node calculates the region that is likely to contain the destination, called the expected region (Basagni et al., 1998).

These days, many routing protocols use the restricted directional flooding approach such as the Distance Routing Effect Algorithm for Mobility (DREAM) (Basagni et al., 1998). DREAM is classified as proactive routing protocol. Furthermore, Location Aided Routing (LAR) (Ko and Vaidya, 2000), LAR classified as a reactive routing protocol.

With both approaches, the source node propagates packets in the general direction of the destination. On their way to the destination, the position information in the packets may be updated if a node has more current information about the destination's position. LAR uses the partial flooding only to enhance the route discovery phase of reactive ad hoc routing approaches. Meanwhile, with DREAM, the sender of a packet uses the partial flooding to forward the packet to all one-hop neighbours that are located in the direction of the destination. To a bounded transmission direction, the source node calculates the region where the destination is supposed to be at that time.

Partial flooding is very robust at the coast of a the heavy network load (Ambhaikar Sharma; Al-Omari and Sumari, 2010; Jazyah and Hope, 2010). As in DREAM and LAR, both will have a communication complexity of O(n). Therefore, it does not scale to large networks with a high volume of data transmissions. On the other hand, using partial flooding is very robust against the failure of individual nodes and position inaccuracy, and is very simple to be implemented.

4.3. Greedy forwarding strategies

From early the 2000 s, up to now, the research effort has focused on geographic unicast routing. With such routing protocols the underlying forwarding technique is mostly accomplished by using a greedy forwarding mode. Due to its simplicity and efficiency, greedy routing has received a lot of attention since its the first appearance in the 1980 s. In the literature, the number of the new proposed geographic routing approaches was increased every year considerably and the tendency is to keep increasing them. In greedy routing, all nodes of the network have a local table, in which all neighbours of the node are listed by name (ID) and position. A proactive broadcast refreshes the table of each node within a regular time interval (beacons).

By using greedy routing, the packet is forwarded to an one one-hop neighbour, which the source has selected as an intermediate node for the next hop that is lying in the general direction of the destination (Lemmon et al., 2009). The procedures that are executed by the sender of a packet perform the following sequence; first, the source node must obtain the position of destination; this information is gathered by an appropriate location service system. The destination location will be integrated in the header of the data packet. Next, the source node checks in its local table (where the positions of all its neighbours in the range are listed) to see which node is laying in the general direction of the destination. Thus, depending upon this list source the node makes its decision to choose the best-next hop (with regards to the used criterion). All of the nodes between the source and the destination that receive the data packet will perform the same procedure that the source node did; this continues until the data packet arrives at the destination node.

In greedy strategies, a node tries to forward the packet to one of its neighbours that is closer to the destination than itself. Up to this end, this node, may mainly encounter two possible scenarios, in the first scenario, if no neighbour closer to the destination exists than itself exists. In the, second scenario if one or more than a neighbour exists closer to the destination than itself (Rührup, 2006). For the first case, newly proposed rules are included in the greedy strategies to find an alternative route; these approaches are called recovery strategies (Karp and Kung, 2000; Bose et al., 2001). The second scenario, where more than one neighbour closer to the destination are available, nodes that operate a greedy forwarding algorithm have to make a decision to select the best-next-hop node that makes positive progress towards the destination.

For the next-hop selecting process, there are different optimizations criteria that a node can use to decide to which neighbour a given packet should be forwarded. As is standard with all greedy routing used, exactly one copy of a packet is forwarded along a route (Ambhaikar Sharma; Meghanathan, 2009; Tomar and Tomar, 2008;

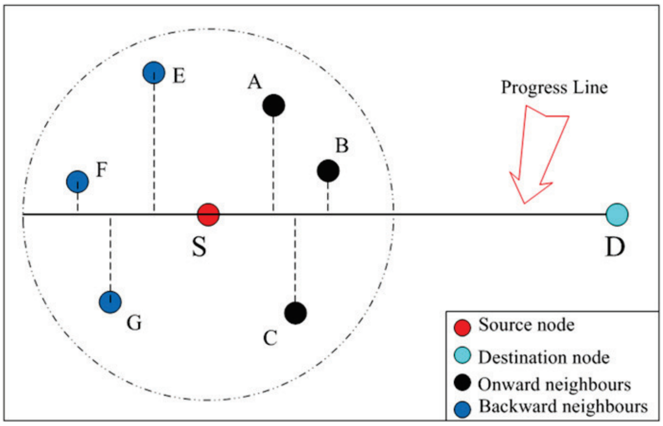

Fig. 1. Positive and negative progress.

Kuhn et al., 2003; Chen and Varshney, 2009). While their goal is to utilize available location information in the MANET, their means to achieve it are quite different. The entire basic proposed forwarding techniques use one of these concepts; distance-based (hop count), progress-based (length of projection), or direction-based (angle value against the straight line between the source and the destination). Those concepts depend on geometric calculations.

In the distance-based strategies such as, Greedy Forwarding Strategy, GFS, and Nearest with Forward Progress, NFP, a packet is forwarded to a neighbour that has the minimum distance towards the destination. In a progress-based strategy such as, Most Forward within Transmission Range, MFR, and Random Progress RPF, a packet is forwarded to a neighbour that has the best progress towards the destination. In the direction-based strategy such as, the Compass Routing, a packet is forwarded to a neighbour that is closest to the direction of the destination.

The used concept of progress used with all greedy strategies, as illustrated in Fig. 1, is defined as the distance between the source/forwarder (*S*) node and receiving node projected onto a line drawn from the source/forwarder node toward the destination (*D*).

A next-relay node attains positive progress if it is in the onward direction (nodes *A*, *B*, and *C*). Otherwise, it is said to be in the backward direction, negative progress (nodes *E*, *F*, and *G*). Progress-based, distance-based, and direction-based forwarding, all of them use these concepts to select from among their neighbours the next-relay node.

For the simplicity's sake, this work classifies greedy forwarding into two main categories. This classification depends on the different optimizations criteria used by the greedy scheme. Namely, geometric-based greedy forwarding algorithms, if the technique solely uses the geometric calculation metric and hybrid-based greedy forwarding algorithms, if the technique uses another metric-besides the geometric calculation metric.

5. Geometric-based greedy forwarding algorithms

In literature, a considerable numbers of greedy algorithms have been proposed. Those algorithms have adopted geometric calculations as the criteria to select the next relay node. Some of them are free of looping while performing their functionality, such as GFS. Meanwhile, others are characterized as a non-loop free, such as MFR. In practice, the looping free approaches are more desirable, that as they can guarantee a packet is delivered to its ultimate target.

5.1. *Loop free algorithms*

These types of approaches guarantee that loops can always be avoided. In other words, the data packet does not propagate more than once for the same selected neighbours in its path to the detention. Hence, by using these criteria criterions the formed path is a loop-free path. Adding to that, they avoid timeouts decrease packet loss, and increase delivered packets to the destination. An example of such approaches and the most popular one is GFS.

5.1.1. *Cartesian routing policy*

Finn (1987), proposed the Greedy Forwarding Scheme GFS. GFS is based on geographic distance; it is also called Cartesian routing. GFS uses the position information of nodes to forward packets in the direction of the destination node. Greedy forwarding selects the next relay neighbour as the farthest node from it and the closest to the destination. GFS follows the shortest path, since it makes the largest possible movement towards the destination. Hence, GFS has been proposed to minimize the hop count and the energy consumption.

In general, a straight line between two nodes is the shortest distance between them. Hence, GFS always tries to select the neighbours having the smallest distance to the destination node (closest to the destination). In the example of Fig. 2, in the case that all nodes apply GFS, source node *S*, will select neighbour *E* as the most appropriate node; node *E* is closest to the destination *D*, and thus has more advance than other neighbours.

One of the most GFS drawbacks (in sparse MANETs) is that, it allows a forwarded packet to move to a neighbour that is beyond the destination. This happens if the next-relay node is closer to the destination than the forwarder node itself, which causes a deviant path. Another drawback is that the message delivery is only guaranteed if each node in the MANET has a neighbour that is closer to the destination than itself. When there is no node closer to the destination than the current node, the algorithm does not guarantee delivery. The author Finn (1987) argued that his algorithm has no loops, since it always forces message to make a step closer to the destination.

5.2. *Non-loop free algorithms*

In the next-hop node selection criteria, most of the greedy forwarding algorithms do not guarantee a loop-free path. For this reason using such approaches as an underlying forwarding algorithm incurs a decrease in the packets ratio delivered to the destination, and more delay. Examples of such approaches are, MFR, RPF, CR, and NFP.

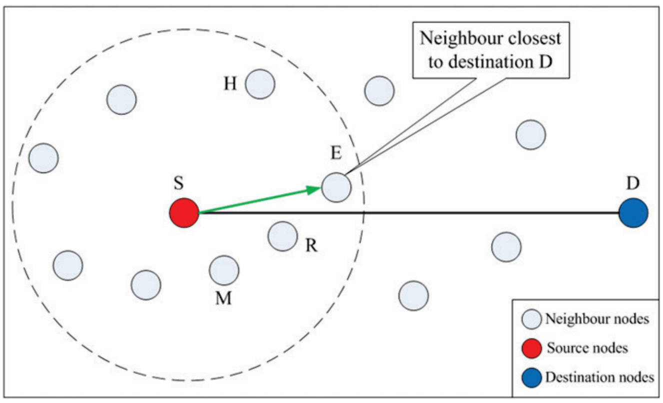

Fig. 2. Next-hop node selection criteria using greedy forwarding functionality.

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5.2.1. Most forward within transmission range

Takagi and Kleinrock (1984) proposed the Most Forward within Radius MFR. The MFR is the earliest position-based routing algorithm. The MFR criterion is based on the notion of progress-based strategy. In MFR, a packet is sent to the neighbour with the greatest progress (the farthest from the source in the direction of the destination) toward the destination (or the least backward progress) as the next-relay. This criterion tries to minimize the number of hops a packet has to traverse in order to reach the final target. The number of hops is related to performance objectives such as packet delay.

In Fig. 3, *S* is the source node, and the circle around it represents its' transmission range and *D* is the destination node. Given the imaginary line connecting sender node *S* and destination nod *D*, the progress of a neighbour node *R* is defined as the projection onto that line; hence progress is the distance between the source and the projection of *R* on that line.

From this definition two progresse types may be exist, positive and negative progress. With positive progress as is shown in Fig. 3, *S* needs to send packets to destination *D*. *S* will compute the distance of all its neighbours with the line joining it with *D* and based on the furthest neighbour in the general direction of *D*, *S* selects *R* as the best next-hop as an intermediate node, a neighbor *F*, is said to be in the forward direction on the path towards the destination.

With negative progress as is shown in Fig. 4, *S* is the source node and the circle around it represents its' transmission range while, *D* is the destination node. *S* will compute the distance of all its neighbours with the line joining it with *D*. Based on the furthest neighbour in the general direction of *D*, *S* selects *R* as the best-next-hop choice as an intermediate node, a neighbour *R* is said to be in the backward direction. MFR falls under the category of minimum-weight routing since this type of routing protocol tries to select minimum hop paths.

With the most forward within radius technique, the intended achievable progress is measured from the current node to the final target. As a consequence, MFR has two main disadvantages that make it unsuitable to be extensively used with MANET. The former one, that since MFR limits progress to the forward direction only, MFR does not avoiding the looping problem. And lastly, the packet might be continue to move away from the destination, even though there are nodes that are physically closer or on a more direct trajectory.

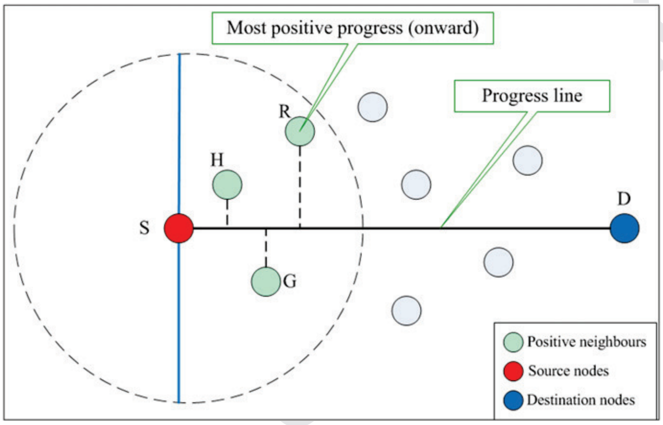

Fig. 3. Next-hop selection criteria using MFR functionality (positive progress).

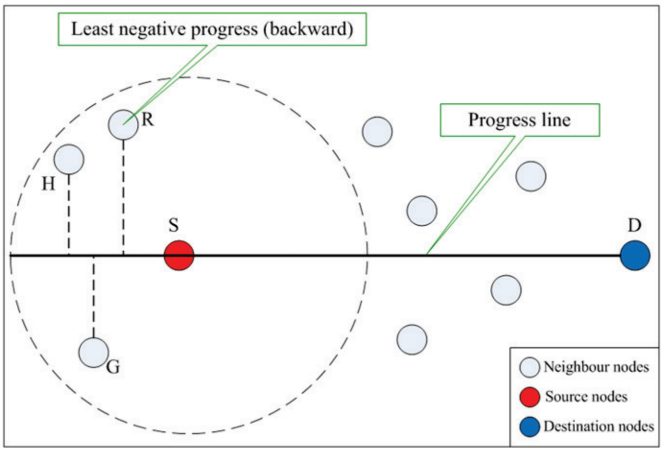

Fig. 4. Next-hop selection criteria using MFR functionality (negative progress).

5.2.2. Nearest with forward progress

Hou and Li (1986) presented the Nearest Forward Progress NFP method. NFP was proposed to mitigate the drawback that appears during MFR implementation. NFP is based on distance-based strategies. By using the NFP criterion, a source makes its forwarding decision by selecting the neighbour that has the minimum distance towards the destination. Thus, a node transmits the packet to the nearest neighbour (closest to itself not the destination), that will result in forward progress to the destination.

Fig. 5 shows the functionality of NFP. In this figure, *S* is a source node and the circle around it represents its' transmission range. The *S* node needs to send packets to destination *D*. Firstly, node *S* find out its neighbour in the general direction of the final target next it computes its distance with these neighbours. Based on the minimum distance node, *S* selects the neighbour node *R* as the best-next amongst the other neighbours *M*, *A*, *H*, and *E*. Since, *R* is the nearest neighbour node to node *S*.

NFP has the ability to modify its transmitting power to suit the selected connection. Hence, the probability of packet collisions in the region around the sender is reduced. This results in increasing the packet delivery ratio at the destination. As a consequence, NFP is often designed to stay with the selected route as long as it exists, to decrease the energy consumption and bandwidth usage at the cost of an increased hop count. Hence, NFP could fit into the category of routing protocols based on stability.

5.2.3. The random progress forwarding

Nelson and Kleinrock proposed the Random Progress Forward method (RPF) in Nelson and Kleinrock (1984). With RPF criterion, packets are destined toward the destination with equal probability towards one intermediate neighbouring node that has positive progress. As illustrated in Fig. 5, when the participating nodes use RPF as the forwarding technique, source node *S*, can

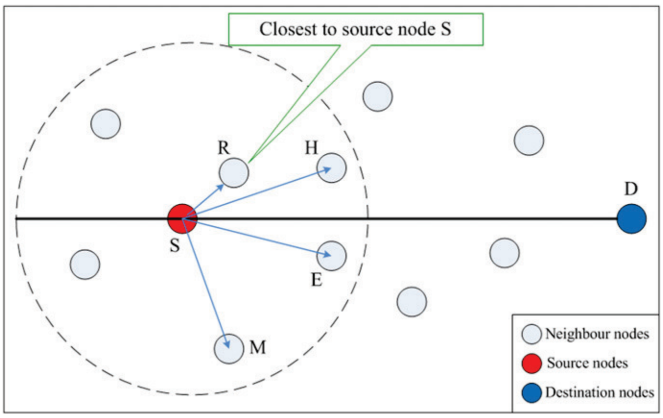

Fig. 5. Next-hop selection criteria using nearest forward progress functionality.

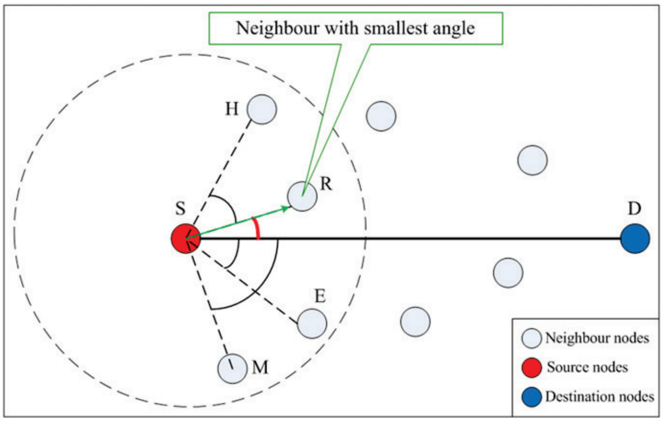

Fig. 6. Next-hop selection criteria using compass forwarding functionality.

select any one of the neighbours in the positive direction (*M*, *H*, E, or *R*). The RPF criterion offers the advantage of distributing the traffic load; hence, it is used to forward packets in the presence of congested nodes.

However, in comparison to the previous geographic forwarding strategies this approach does not use any measure of progress to differentiate any single candidate next hop as better than another. Thus, this strategy minimizes the accuracy of the information needed about the position of the neighbours and reduces the number of operations required to forward a packet. Moreover, this criterion tries to trade-off progress and transmission reliability performance, with the assumption that the transmission power can be adjusted to the distance between the two nodes.

5.2.4. *Compass routing*

Q7 Kranakis proposed the Compass routing algorithm CR in (Kranakis (1999). CR is based on the direction-based strategy. In the CR criterion, a source makes its forwarding decision by selecting a neighbour that is closest to the progress line i.e. having a minimum angle between the lines from the source to next-relay node and progress line. Thus, compass routing tries to minimize the spatial distance that a packet travels which results in a packet to following the most direct trajectory from the source to the destination. With the compass routing algorithm, each node makes forwarding decisions solely based on the position of itself, its neighbours and the destination.

Fig. 6 illustrates compass routing functionality, *S* is a source node and the circle around it represents its' transmission range *S* needs to send packets to destination *D*. *S* computes the angle of all its neighbours with the line joining it with *D* and based on the minimum angle *S* selects the neighbour node *R* as a best-next hop amongst the other neighbours *M*, *A*, *H*, and *E*. since *R* has the minimum angle with the straight line from the source node to the destination node. This process continues until the message is delivered to *D* or dropped due to non availability of a path.

It has been shown in Kranakis (1999) that compass routing produces shortest hop paths for certain geometric embeddings (e.g., trees) of planar graphs. Hence, compass routing could be included in the class of protocols based on the minimum-weight path based routing. This algorithm is inherently not loop free. Hence, compass forwarding can result in a routing loop.

6. Hybrid-based greedy forwarding algorithms

In geometric-based greedy forwarding algorithms, the only metric used in the decision making is just the geometric calculations. Due to this solely usage, greedy approaches may fail to deliver packets to the final destination. Hence, many researchers in the state of the art adopt another metrics to be included in the next-relay node selection criteria besides geometric criteria.

For different optimization purposes, the adopted metrics could be one or a combination of link stability, power consumption, reluctance to forward packets, delay, node's residual battery power, connectivity degree, and node queue size. Furthermore, other researchers have proposed enhanced greedy approaches combining two geometric criteria such as GFS and CR. In the enhanced algorithms, neighbours with positive progress are only considered thus; loop-free property is guaranteed. Due to using such algorithms, the desired MANAT performance can be achieved. We name some of those efforts that have been proposed in the literature, such as, Angular Routing Protocol (ARP), the Maximum by Conventional Geographic Routing (MAGF), Normalized Advance (NADV), and Greedy-based Backup Routing (GBR).

6.1. *Greedy-based backup routing*

Yang et al. proposed Greedy-based Backup Routing (GBR) in (Yang et al. (2010). The GBR protocol considers both route length and link lifetime to achieve high route stability. In GBR, the primary path is constructed based on a greedy forwarding mechanism that achieves the smallest hop count. The primary rout is considered as loop-free. On the other hand, the local-backup path for each link is established according to the link lifetime, which is constructed during the primary path discovery procedure. A loop might occur during the local-backup path's setup. When a link in the primary path fails, the upstream node of the failed link in the primary path can continue the data delivery using the local-backup path. GBR has excellent performance compared with some current stable and greedy-based routing protocols, in terms of route lifetime, packet delivery ratio, and control overhead. GBR has O(*n*) communication complexity.

6.2. *Normalized advance*

Lee et al. proposed in Lee et al. (2010) a new link metric called normalized advance NADV for geographic routing in MANET. The NADV criterion selects neighbours with the optimal trade-off between the advance and link cost, coupled with the local next-hop decision in geographic routing, instead of the neighbour closest to the destination. The proposed algorithm enables an adaptive and efficient cost-aware routing strategy depending on the data packets' priority. The authors argued that, through using the NADV framework, MANET protocols could minimize various types of link costs. The researchers claim that using NADV can minimize the hop count between the source and the destination.

6.3. *Maximum by conventional geographic routing*

Li and Shatz proposed the local maximum by conventional geographic routing MAGF in Li and Shatz (2008). MAGF takes Q8 advantage of mobility to enhance greedy forwarding in geographic routing. With MAGF, the authors adopted a concept named motion potential, combining node mobility patterns with node position information, to make forwarding decisions. In MAGF a refined greedy forwarding technique based on geographic routing was provided. With a high mobility environment, and dense MANET, the authors argued that MAGF behaved well in terms of average hop count and packet delivery rate. Also, they argued that the produced computation overhead is limited, and the complexity of the next-hop node selection for the MAGF scheme is identical to the greedy forwarding scheme.

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6.4. Angular routing protocol

Giruka and Singhal proposed the Angular Routing protocol ARP (Giruka Singhal). With ARP, participating nodes use a combination of geographic forwarding schemes to route packets to the ultimate destination. In sparse networks, if the greedy forwarding fails, the algorithm will convert to the use of angle-based forwarding scheme to overcome this failure.

With ARP, the scenario where source node *S* has a data packet to be sent to the destination *D*, it first performs GFS functionality to select the next-hop. Each intermediate node follows the same selection criterion, much as possible.

In the case, where, no neighbour is closer to the destination than the source/forwarder node itself, the source/forwarder selects a neighbouring node that makes the minimum angle, among available neighbours within its transmission range. The neighbour who ends up with greedy failure appends its ID to the packet header.

For each data packet, the ARP header memorizes a maximum number of last visited hops in order to prevent choosing a next-hop whose ID is presents in the ARP header. This memorization technique helps ARP to avoid local loops. The authors argued that ARP is scalable and achieves a high packet delivery rate while incurring a lower overhead as compared to others position-based routing protocols.

7. Comparison of basic and enhanced selected forwarding strategies

This section provides a qualitative evaluation of the greedy forwarding strategy evolution since the early 1980s up to date. Although, it adopted the qualitative evaluation metrics suggested by (Corson and Macker, 1999), this work used several other metrics used lately in literature. The goal of this work is to show the most appropriate technique among the current proposed strategies to be used as an underlying forwarding strategy with position-based routing protocol. Tables 1 and 2, summarizes the discussed protocols together with the used evaluation criteria.

7.1. Evaluation criteria

Below is an explanation of the criteria used for the intended comparison:

Forwarding Strategy Method: This criterion indicates the basic technique used for data packet forwarding.

Transmission Range: The transmission range affects the forwarding technique performance from the viewpoint of connectivity (Takagi and Kleinrock, 1984; Hou and Li, 1986). In MANET, a node's transmission range is inversely proportional to the number

Table 1
Characteristics of the selected basic and enhanced forwarding algorithms.

	MFR	RPF	NFP	GFS	CR	ARP	MAGF	NADV	GBR
Year	1984	1984	1986	1987	1999	2005	2008	2010	2011
Tr.R.	Fixed circle	Adj. circle	Adj. circle	Fixed circle	Fixed circle	Fixed circle	Fixed circle	Fixed circle	Fixed circle
Pa.S.	Single path	Single path	Single path	Single path	Single path	Single path	Single path	Single path	Single path
De.Cr.	Hop count	Hop count	Hop count	Hop count	Hop count	Hop count	Hop count+motion Attributes	Hop count+link cost	Hop count+link cost
Op.Cr.	Maximum progress to destination (progress-based)	Random with equal probability (progress-based)	Nearest to source node (distance-based)	Maximum advance to destination (distance-based)	Closest direction to destination (direction-based)	Maximum advance and closest direction (hybrid-based)	Maximum Advance+motion attribute (hybrid-based)	Maximum advance+least cost (hybrid-based)	Maximum advance+link lifetime (hybrid-based)
Op.Ob.	To minimize the number of hops	To trade off progress and transmission reliability	To reduce the probability of packet collisions	To minimize the number of hops	To minimize the spatial travel distance	To minimize the number of hops or spatial travel distance	To minimize the number of hops with accurate motion attribute	To minimize the number of hops with most reliable link	To minimize the number of hops with most stable link
Memo.	No	No	No	No	No	No	No	No	No
Com².	$O(\sqrt{n})$	$O(\sqrt{n})$	$O(\sqrt{n})$	$O(\sqrt{n})$	$O(\sqrt{n})$	–	–	–	$O(n)$
Im.Co.	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Sca.	Low	Low	Low	Low	Low	Low	Low	Low	Low
Pa.Ov.	Yes/dense	Yes/dense	Yes/dense	Yes/dense	Yes/dense	Yes	Yes	Yes	Yes
Rob.	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Op.Pa.	Medium	Medium	Medium	Medium	Medium	High	High	High	High
Gu.De.	No	No	No	No	No	Yes	Yes	Yes	Yes
Lo.Fre.	No	No	No	Yes	No	Yes	Yes	Yes	Yes

Table 2
Abbreviations meanings in Table 1.

MFR: Most Forward within Transmission Range	De.Cr.: Deployed Criterion
RPF: Random Progress Forwarding	Opt.Cr.: Optimization Criterion
NFP: Nearest with Forward Progress	Opt.Ob.: Optimization Objectives
GFS: Greedy Forwarding Strategy	Memo.: Memorization
CR: Compass Routing	Com2.: Communication Complexity
ARP: Angular Routing protocol	Im.Co.: Implementation Complexity
MAGF: Maximum by Conventional Geographic Routing	Pa.Ov.: Packet Overhead
NADV: Normalized Advance	Sca.: Scalability
GBR: Greedy-based Backup Routing	Lo.Fre.: Loop-Freedom
Tr.R.: Transmission Range	Op.Pa.: Optimal Path
Pa.S.: Path Strategy	Gu.De.: Guaranteed message delivery
Rob.: Robustness	

of intermediate nodes needed to reach the ultimate destination, and to the possibility of a node to breaking the link with its neighbours while it is moving. To sum up, a node's transmission range is directly proportional to the overall MANET connectivity (Gomez and Campbell, 2004). This work lists the transmission range as a fixed or adjustable circle.

Path Strategy: Greedy approaches are localized algorithms (Estrin et al., 1999; Na et al., 2010). In a localized routing algorithm, the source/forwarder makes the decision as to which neighbour to forward the message to, based solely on the location information of the participating nodes and itself. Using geographic forwarding, the source can use a single path (shortest path is the most used), or multipath or a combination of both of them. This research lists the used forwarding strategy with respect to the used approach either single path or multipath.

Deployed Criterion: Arguably, and an ideal MANET environment, there are two main assumptions while using geographic forwarding. Firstly, that node cannot adjust its transmission radii in order to reach the desired neighbour with minimal power. And, the delay to deliver a specific data packet to the intended destination is proportional to the hop count.

Most forwarding schemes use hop count as the metrics, where the hop count is the number of transmissions on a route from a source to a destination. Using the hop count is not enough to be used as the only deciding metric. Hence, most forwarding does not guarantee delivery, and incurs packet loss. This loss means that packets must be retransmitted to reach ultimate node, thus, it introduces more delay. This comparison lists geographic forwarding in terms of metrics used to make the forwarding decision.

Memorization: Some proposed forwarding schemes require participating nodes to memorize the last visited nodes in order to memorize the best path found in the search process. Memorization—sometimes—has a negative influence on the performance of the proposed routing protocol. Hence, it is better to avoid memorizing past traffic at any node, if possible. However, in the scenario of some proposed protocols where using memorization is essential, those approaches should add a technique to make the timeout of outdated traffic safely and fast quickly removed from memory when there is no more need for it to be used. This work lists the forwarding strategies as those which use memorization and those that do not.

Communication Complexity: This metric is relevant to the needed average number of the hop count to send a packet between a pair of nodes under the assumption that the location of the ultimate destination is known. It indicates the complexity in performing the used forwarding scheme with respect to the existing number of the population and if it increases with the same size of MANET.

Implementation Complexity: This metric shows the difficulty of the implementation level of the forwarding algorithm during the implementation phase. This complexity degree could be measured by testing the (new design or redesign) algorithm by using the available measurement tools such as simulation, before it is deployed in realistic usage. The discussed forwarding strategies in this work could be listed as: high, medium, and low in terms of implementation complexity.

Packet Overhead: This metric measures the bandwidth consumption due to the amount of control packets generated by the used forwarding strategy for discovery (Na et al., 2010), establishment and maintenance of the next-relay node.

Arguably, the traffic overhead increases when the network density increases. Also, the traffic overhead is almost the same for different participating nodes speed, and increases while using location services to support the used forwarding technique. The forwarding strategies can be listed as: high, medium, and low overhead.

Scalability: Any new design or redesign of forwarding algorithms should perform well with a dense MANET and a high mobility level of its participating nodes. The scalability of forwarding algorithms is judgmental for specific implementations, and/or dependent on the performance evaluation outcome.

This work lists the forwarding strategies as high, medium and low in terms of scalability. High scalability is when the proposed algorithm is able to maintain a good performance with a high density and mobility of nodes. Medium scalability means that the proposed algorithm can handle MANET with a reasonable size. Low scalability is restricted to the proposed algorithm that works just well enough in small networks in terms of size, population and mobility.

Robustness: The robustness degree of any new design or redesign of forwarding algorithms is relevant to the ability of this algorithm to cope with the MANET dynamicity [51]. Furthermore, it should have backup techniques, which allow data packets to reaching a destination even when the participating nodes' positions changes.

The forwarding strategy, has high robustness if the failure of a single next-relay node does not prevent the packet from reaching its destination. It is medium if the failure of a single next-relay node might lead to the loss of the data packet but does not require the setup of an alternative path. Finally, the robustness is low if the failure of a single next-relay node might result in packet loss and the setting up of an alternative path.

Optimal Path: Optimality within used forwarding schemes, somehow, indicates their ability to find the best path among other available routs in MANET. A preferable property for any used forwarding scheme is directly proportional to the probability of it to finding and using the shortest path in MANET.

Guaranteed message delivery: Delivery rate can be defined as the ratio of the number of received messages by the destination to the messages sent by the senders. One of the most important goals of any new design or redesign of a routing scheme is to increase the delivery rate at the destination side. This work lists the forwarding strategies as to whether it guarantees delivery or not.

Loop-Freedom: A desirable property for a forwarding strategy in MANET is that it is free of loops. If the used forwarding strategy is loop-free, it will decrease the delay in to delivering the data packet to its final destination. Also, it decreases the congestion and the collision that could occurr, which decrease packet loss. As an outset, this will guarantee that a packet will be successfully delivered to its ultimate destination, and the performance of the used routing protocol will be increased. The discussed strategies are listed as a loop-free property or not.

7.2. Analysis

For the analysis sake, it is handled from the perspective of the preceded classification of geographic forwarding strategies. The first category represents the basic greedy approaches, the geometric-based greedy forwarding algorithms. All greedy methods use a single path to transmit data packets between a pair of nodes. Experimentally, it has been improved so that in most network topologies, GFS and MFR schemes discover the same path to the destination. Similarly, NFP and CR schemes also discover the same path in most network topologies.

Applying greedy methods results in optimal (the shortest path), or near-optimal paths. This result refers to the two underlying assumptions when applying with greedy algorithms. First that a MANET contains the best route to any of its nodes (there is always a connected path from source to destination). Moreover, those nodes have their accurate geographic location information all the time. However, these two assumptions are invalid in any realistic deployment. Given resources limitations (power, and the advent of short-range), and rapidly changing network topology conditions, over which MANET must be deployed, in some scenarios it is likely that these two assumptions are invalid. Hence, practically all geographic greedy forwarding methods may not find (or it may fail to find) the optimum path, even when a rout exists. Hence, their probability of finding an optimal path is considered as a medium.

The geographic forwarding methods adopt a hop count as the only deciding factor in the selection process. Simulations have shown that all algorithms perform well with hop count as metric, specifically in dense MANET. Hence, they all provide a simple, low overhead, technique for routing in MANET. Furthermore, they have the advantage that they do not incur the overhead involved in building, maintaining and distributing distance vector or link state routing tables, or incur the control overhead and latency of route discovery incurred by reactive topology-based routing protocols.

Hence, Geometric-based greedy forwarding algorithms have medium robustness since the failure of an individual node may cause the loss of a packet in transit, but it does not require the setting up of a new route. Furthermore, they are memory-less schemes, because while they are performing, no information needs to be stored in the transmitted packet header to memorize the last visited nodes.

In a dense MANET, geographic forwarding methods have high delivery rates; on the other hand, they have low delivery rates for sparse MANET. For both, dense and sparse MANET, and regardless of mobility degree, geographic forwarding methods do not guarantee delivery, since a packet can be dropped for several reasons. This drawback is due to using hop count as the only deciding factor with greedy strategies.

Geometric-based greedy forwarding algorithms are performing efficiently, with a communication complexity of $O(\sqrt{n})$ (Mauve et al., 2001). This means that the count of hops between two communicating nodes increases proportional to the square root of the number of the population for the same MANET size. This can be generalized regardless of the mobility degree of the communicating nodes.

The CR method represents one of the direction-based criterions. Moreover, MFR, and RPF methods consider as a progress-based criterion, adding to them the NFP method, which is considered as a distance-based criterion. In all of those methods, the next-hop node might be selected from a set of neighbours with positive or negative progress; hence none of these methods is loop-free. Unlike the above methods, an advanced-based criterion GFS, can guarantee that a loop-free path can always be formed. The reason is that a next-hop node is selected only from a set of neighbours with positive progress. Hence, loops can always be avoided.

And lastly, the proposed geometric-based greedy forwarding algorithms can be divided into two groups in terms of their transmission range. GFS, MFR, and CR, have fixed transmission range as a circle surrounding the node. On the other hand, NFP, andRPF, have adjustable transmission ranges to cover the intended distance between the two communicating nodes.

The second category represents the enhanced approaches of the basic greedy routing. These algorithms are characterized as non-geometric-based greedy forwarding algorithms. They use another metrics besides hop count and shape a trade-off between them during the decision making process, to avoid the drawbacks occurred while using the pure greedy forwarding scheme.

ARP inherits the most characteristics of the basic GFS. ARP memorizes the last visited hops while it functioning. With ARP, the loop-free property can be guaranteed, since it uses the memorization approach added in the header of data packet. Moreover, using an angle-based forwarding scheme to avoid the local maximum makes it applicable in sparse and network dense MANETs.

MAGF takes advantage of mobility to enhance greedy forwarding in geographic routing. MAGF, also, (as with the other enhanced schemes) inherits the most of the characteristics of the basic GFS except for the selection criterion that is used by it. In MAGF a refined greedy forwarding technique based on geographic routing was is provided. With MAGF, the loop-free property can be guaranteed, since it just forward packets to the neighbour that achieves positive progress. The authors argued that MAGF behaved well in terms of average hop count and packet delivery rate, with high node mobility and dense MANET. Moreover, the authors argued that the produced computation overhead is limited, and the complexity of the next-hop node selection for the MAGF scheme is identical to that of the greedy forwarding scheme.

NADV selects neighbours with the optimal trade-off between the advance and link costs. As in GBR, it inherits all of the GFS characteristics except for the selection criterion that is used by it. Also, the recovery approach can be used in the case of greedy failure. NADV is considered as a loop-free algorithm since it just forwards packets to the neighbour that achieves positive progress. The researchers claim that using NADV will minimize the hop count between a source and a destination.

GBR inherits most of the characteristics of the basic GFS; in addition, it uses route stability as another factor to make the selection decision. This kind of trade-off increases the packet delivery rate at the destination side. Also, using a secondary recovery strategy besides the primary enhanced greedy, guarantees delivery at the destination side. GBR is considered as a loop-free algorithm since it just forwards packets to the neighbour that achieves positive progress. The authors argued that GBR has excellent performance compared with greedy-based routing protocols in terms of route lifetime, packet delivery ratio and control overhead.

8. Directions of future research

In this survey, it has been shown that there are many techniques in the state-of-the-art proposed to perform geographic forwarding. However, this work has mainly focused on single path unicast geographic forwarding schemes. To sum up, from the conducted survey, it seems that GFS is the most suitable forwarding scheme.

The current standard of the GFS considers the shortest path with minimum hop count as a measure of route cost in making routing decisions. GFS can be used as a standalone routing scheme for its simplicity and scalability compared with other forwarding strategies. However, there still exists a number of issues and problems that need to be addressed to enhance GFS as a standalone routing technique. The failure of GFS to guarantee data packet delivery is related to several reasons.

To improve the packet delivery ratio, greedy routing has been enhanced by several researchers' efforts in literature. These efforts have been concerned with providing guaranteed delivery by using recovery techniques (Bose et al., 2001; [51]) besides the greedy mode. Using recovery techniques is essential to provide a trade-off between efficiency, effectiveness on one side to ensure packet delivery and complexity, long path, more delay, and high communication overhead on the other side. Consequently, GFS requires being studied through using other deciding factors in addition to distance to select the best-next relay node. By achieving this goal, greedy routing will have the ability to increase the packet delivery ratio, decrease packet loss, and

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achieve a high performance level so that there will be no more need to make greedy coupled with another recovery strategy.

9. Summary and conclusions

Mobile ad hoc networks, which run by wireless mobile devices, are in the highest demand. The importance of such networks comes from the fact that they have a higher class advantage over traditional wired networks. MANET extends the access to various applications. Thus, mobile nodes can be provided with these services, anywhere and anytime. Furthermore, the use of such networks can be easily extended to places which cannot be wired; thus, it enhances all kinds of daily life implementation, such as rescue operations.

In mobile ad hoc networks, nodes may move arbitrarily and in an unpredictable manner. Hence, routing is a challenging task, because of frequent topology changes without prior notice. Consequently, designing an efficient and reliable routing protocol for such a network is a fundamental and challengeable task. To solve the addressed problems of routing in MANET, many routing protocols that are compatible with the characteristics of MANET have been proposed in literature. However, few of them are efficient when the network is sparse and highly dynamic.

Recently, position-aware routing protocols have been given a special interest due to their several benefits against position-unaware routing protocols. That is, position-based routing algorithms eliminate some of the drawbacks of topology-based routing algorithms by using position information. In position-based routing algorithms, the forwarding decision at each node is based on the destination's position information and of the neighbouring nodes. This information is inserted in the header of the forwarded data packet destined to that destination. Thus, position-based routing algorithms do not require the establishment or maintenance of routes as needed in topology-based routing algorithms.

The effort of this research has presented an extensive survey of the current state of the unicast geographic forwarding techniques. Also, it has provided a qualitative evaluation of the proposed schemes from the early 1980s up to date. At the end, opportunities which could lead to further improvements have been identified to give the GFS the ability to be a standalone routing technique without the aid of external supports. These recommendations were concluded after the comparison of the current solutions had been compared with the basic GFS.

Uncited reference

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