

## Routing Protocols using Directional Antennas in Ad Hoc Networks: A Comparative Review

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### Abstract

*Directional antennas have the potential to provide a fundamental breakthrough in ad hoc network capacity. Omni-directional nature of transmission restricts the network capacity, where distribution of energy in all directions other than the intended direction of the destination node not only generated unnecessary interference to other neighboring nodes but also decreases the potential range of transmission. Directional antenna systems are increasingly being recognized as a powerful way of increasing the capacity, connectivity, and covertness of MANETs. In this paper, we survey the state-of-the-art routing protocols and give a comparison result of them with respect to the important challenging issues. We study the advantages and disadvantages of the routing protocols using directional antenna and also highlight performance issues of each routing technique. At the end, an explicit comparison table is presented and discussed.*

**Keywords:** *Directional antennas; Omni-directional; Ad hoc networks*

### 1. Introduction

Directional antennas have the potential to provide a fundamental breakthrough in ad hoc network capacity. Omni-directional nature of transmission restricts the network capacity, where distribution of energy in all directions other than the intended direction of the destination node not only generated unnecessary interference to other neighboring nodes but also decreases the potential range of transmission. Directional antenna systems are increasingly being recognized as a powerful way of increasing the capacity, connectivity, and covertness of MANETs. Directional antennas can focus electromagnetic energy in one direction and enhance coverage range for a given power level. They also minimize co-channel interference and reduce noise level in a contention-based access scheme, thereby reducing the collision probability. Further, they provide longer range and more stable links due to increased signal strength and reduced multipath components. Increased spatial reuse and longer ranges translate into higher network capacity, and longer ranges also provide richer

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connectivity. On the receiving side, directional antennas enable a node to selectively receive signals only from a certain desired direction [1].

Researchers in the past have done much fundamental research on directional antennas in wireless networks that focused on medium-access control, spatial reuse, efficient power consumption, network capacity, and so forth. The work in [2–6] proposed adaptive Medium-Access Control (MAC) protocols to improve IEEE 802.11. These adaptive MAC protocols attempted to limit the disadvantages of IEEE 802.11 in spatial use. Power is another constrained source in some ad hoc network scenarios because in these cases the power for the antenna comes from batteries, which are energy-constrained. Sometimes, nodes equipped with batteries-powered antennas cannot recharge frequently. This is another reason for using directional antennas. Authors of [7, 8] described the advantages of using directional antennas to reduce power consumption in ad hoc networks. As directional antennas can increase spatial use [9], more than one directional antenna can send data at the same time. Directional antennas can also increase network capacity [10, 11].

Compared with omni-directional antennas, obviously, the most distinguished difference is the higher spatial reuse, higher network connectivity, lower interference, higher coverage range and higher complexity. In this paper, we survey the state-of-the-art routing protocols and give a comparison result of them with respect to the important challenging issues.

The rest of this paper is organized as follows. In Section 2, we state the concepts, terminology and relevance of directional antennas. Routing issues in DTNs are presented in Section 3. After briefly describing some routing protocols in Section 4, we get a comparison result of these routing protocols and present an explicit comparison table in Section 5. Finally, we conclude in Section 6.

## 2. Directional Antennas: Concepts, Terminology and Relevance

In this section, we discuss some concepts related to directional antennas. This is not intended to cover all aspects of this technology, nor do we cover it precisely or formally. Rather, the idea is to give the basics in an informal and intuitive fashion to equip the reader unfamiliar with this topic with just enough knowledge to understand the remainder of this paper. Readers familiar with directional antennas may skip this section. Readers wishing to explore this field in detail are referred to [1] and the citations therein.

### 2.1 Antenna Concepts

Radio antennas couple energy from one medium to another. An omni-directional antenna, which sometimes known as an isotropic antenna, radiates or receives energy equally well in all directions. A directional antenna has certain preferred transmission and reception directions, that is, transmits or receives more energy in one direction compared to the other.

The gain of an antenna is an important concept, and is used to quantify the directionality of an antenna. For a given direction  $\vec{d} = (\theta, \phi)$ , the gain of the directional antenna is given by

$$G(\vec{d}) = \eta \frac{U(\vec{d})}{U_{avg}}$$

where  $U(\vec{d})$  gives the power density in direction  $\vec{d}$ ,  $U_{avg}$  is the average power density over all directions, and  $\eta$  is the efficiency of the antenna which accounts for losses. The gain gives the relative power in one direction as compared to an omni-directional antenna, and higher

gain means a higher directionality. The peak gain is the maximum gain taken over all directions. When a signal value is given for the gain of an antenna, it usually refers to the peak gain. Gain is generally measured in decibels (dBi), where  $G_{\text{dBi}} = 10 \log_{10}(G_{\text{abs}})$ . An omni-directional antenna has a gain of 0 dBi.

An antenna pattern is the specification of the gain values in each direction in space, sometimes depicted as projections on the azimuthal and elevation planes. It typically has a main lobe of peak gain and (smaller gain) side lobes. As is common practice, we use the word beam as a synonym for “lobe”, especially when discussing antennas with multiple beams.

## 2.2 Smart Directional Antennas

The simplest way of improving the “intelligence” of antennas is to have multiple elements. The slight physical separation between elements, or diversity can be used to counteract multipath effects. There are two well-known methods. In switched diversity the system continually switches between elements so as to always use the element with the best signal. While this reduces the negative effects of fading and multipath, there is no increase in gain. In diversity combining, the phase error of multipath signals is corrected and the power combined to both reduce multipath and fading, as well as increase the gain.

The next step in sophistication involves incorporating more control in the way the signals from multiple elements (the antenna array) are used to provide increased gain, more beams and beam agility. Again, there are two main classes of techniques, as described below.

## 2.3 Relevance for Ad Hoc Networks

When considering the use of directional antennas for ad hoc networks, a question is: Aren't directional antennas too expensive or too big for ad hoc networks? In this section, we argue that there do exist antenna techniques with suitable price and form-factor combinations.

Applications for ad hoc networking may be classified broadly into three categories: military, commercial outdoor and commercial indoor, each with its own distinctive profile, and able to accommodate different antenna technologies.

Military networks, which are by far the most prevalent application of mobile ad hoc networks, contain a significant number of large nodes (such as tanks, airplanes). The size of these platforms makes the form factor of most antennas quite irrelevant. Further, each platform by itself is so expensive that the cost of even the most sophisticated antenna is dwarfed by comparison. Thus, directional antennas are extremely relevant to military networks [12].

## 3. Routing Issues Using Directional Antennas

The peculiar properties of directional antennas inevitably raise a number of interesting issues:

### 3.1 Directional Neighborhood

The notion of directional neighborhood becomes even more subtle if we consider higher gain provided by the directional antennas. There are two kinds of neighborhood relationship: one is Directional-Omni (DO) neighbors [13], where the transmission of the node takes

advantage of directional antenna and the reception of the neighbor node takes advantage of omni-directional antenna. The other is Directional-Directional (DD) neighbors [13], where both of the neighbors use directional antennas toward each other.

### 3.2 Deafness

Deafness is defined as the phenomenon when a node X is unable to communicate with a neighbor node A, as A is presently tuned to some other directional antenna beam. Deafness is a serious issue in directional antennas as it may considerably impact performance, not only at the routing layer but also at the MAC layer and upper layers [14].

Therefore, unless node A informs all its neighbors in advance that it is going to start communicating with node B, its neighbors might unsuccessfully try to contact it. On the other hand, a large overhead may be generated in informing a node's neighbors about a forthcoming communication. Clearly, this raises a tradeoff issue between deafness and overhead, and is discussed in detail in later sections.

### 3.3 Broadcasting

As we have seen so far, broadcasting is a widely employed mechanism in ad hoc networks. Routing protocols including DSR, AODV, ZRP, LAR, and so on, use variants of a network-wide broadcasting to establish and maintain routes. Ultimately, these protocols use simple flooding for broadcasting. Simple flooding causes redundancy and increases the level of contention and collision in a network.

A simple solution to broadcasting with directional antennas is to sequentially sweep across all the pre-defined beams of the antenna system. However, broadcast by sweeping incurs a sweeping delay [15]. Therefore, it is of paramount importance to investigate the issue of broadcasting over directional antennas such that efficient schemes can be designed to take the antenna system characteristics into consideration, and hence reduce redundancy and the sweeping delay [16].

### 3.4 Power Control

The directional antenna system can be configured to do link power control on a per-packet basis, where the transmit power is just about sufficient to activate the link. This reduces interference, as well as battery consumption [17].

A straightforward way of doing this within the RTS/CTS framework is as follows. The RTS is sent at a predetermined power (for instance, the maximum power). The receiver determines the difference  $\delta$  between the received power for the RTS and its receive threshold. The value of  $\delta$  is sent along with the CTS. When transmitting the DATA, the sender uses a power that is  $\delta$  less than the power used for the RTS [18].

## 4. Routing Protocols Using Directional Antennas

Most of the efforts on the study of directional antennas for ad hoc networks have concentrated on the MAC protocols. Until now, however, there is no comprehensive study of routing protocols using directional antennas. We now discuss existing work on routing for directional antennas.

### 4.1 Directional Routing Protocol (DRP)

Directional Routing Protocol (DRP) [19] is a cross layered routing protocol which is specifically tuned to the underlying directional antennas. DRP attempts to alleviate

some of the inherent drawbacks involved in directional communications while exploiting the potential benefits such as increased coverage range and directionality. DRP has a substantial decrease in route discovery latency as well as directional broadcasting overhead as compared to DDSR. The efficient route recovery mechanisms in DRP prevent any throughput degradation due to frequent movements of intermediate nodes. However, it is worthwhile to note that throughput gain in case of directional antenna systems depends on the topology under consideration.

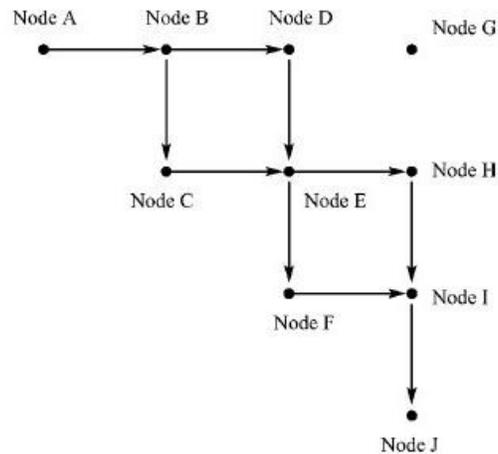
DRP is built on top of MAC protocol for Directional Antenna (MDA) [20]. To minimize the effect of deafness and hidden node problems in directional environment, MAC layer of DRP (termed as MDA) employs a special form of sweeping of both RTS and CTS, namely, the Diametrically Opposite Directions (DOD) procedure. In addition, the Enhanced Directional Network Allocation Vector (EDNAV) mechanism incorporated in MDA considerably improves performance by accurately differentiating between deafness and collision scenarios.

In DRP, routes are generally associated with the antenna beam to be used to reach a particular next hop. Hence, any change in the location of the next hop which changes the beam, even within the transmission range, needs to be handled carefully. Similar to DSR, in DRP, when originating or forwarding a packet using a source route, each node transmitting the packet is responsible for confirming that data can flow over the link. A link layer acknowledgment as in IEEE 802.11 is used for this purpose.

#### **4.2 Directional Dynamic Source Routing (DDSR)**

As the name implies, Directional Dynamic Source Routing (DDSR) [21] is the original DSR over directional antennas. The best route from the source node to the destination node is selected according to hop count, power budget and overlap count.

In order to calculate the overlap count in a specific route, positional information of the current node will be inserted into the RREQ and RREP of the proposed DDSR routing protocol. As shown in Figure 1, the source node A initiates the route discovery process to destination node J by broadcasting RREQ to its neighboring nodes. In this RREQ, the position information of node A is inserted into the route record, along with the address of node A. Once node B receives the RREQ from node A, it adds its own address, along with its positional information to the route record and relays RREQ to its neighboring nodes. After receiving the RREQ from node B, node D creates a backward route to node A in its route cache. Furthermore, node D calculates the DOAs of  $A \rightarrow B$ ,  $A \rightarrow D$  and  $D \rightarrow B$  according to the positional information of node A and B in the received RREQ. Since the transmit beam  $A \rightarrow B$  overlaps with the receive beam  $D \rightarrow B$ , node D increases the overlap count to one and adds it to the route to node A. In node C, the transmit beam of  $A \rightarrow B$  does not overlap with that of  $C \rightarrow B$ , so we have an overlap count of 0. Similarly, when node G receives the RREQ from node D, it sets up a route to node A with the overlap count being 3, since the transmit beam  $A \rightarrow B$  overlaps with the receive beams  $D \rightarrow B$  and  $G \rightarrow D$  while the transmit beam  $B \rightarrow D$  overlaps with the receive beams  $D \rightarrow B$ . The unicast of RREP has a same procedure of calculating the overlap count.



**Figure 1. Directional route discovery process**

In DDSR, instead of discarding every duplicate RREQ, intermediate nodes will forward the RREQs whose hop counts are not bigger than that of the previously received RREQs; even if they have the same ID. Therefore the source node may receive multiple RREPs and obtain all possible routes to the destination. DDSR avoids interference from nodes hops away by exploiting the directionality of the beams.

#### 4.3 Directional Ad-hoc On-demand Distance Vector (DAODV)

In DAODV [21], positional information of the current node will be inserted into the RREQ and RREP. As shown in Figure 1, the source node A initiates the route discovery process to destination node J by broadcasting RREQ to its neighbor nodes. In this RREQ the positional information of node A is inserted. Once node B receives the RREQ from node A, it adds its own positional information to the RREQ and forwards it to the neighboring nodes. After receiving the RREQ from node B, node D creates a backward route to node A in its routing table entries. According to the positional information of node A and B in the received RREQ, node D calculates the DOAs of  $A \rightarrow B$ ,  $A \rightarrow D$  and  $D \rightarrow B$ . Here the overlap count is one and is added on to the route to node A.

Once the next hop becomes unreachable because of the link break caused by mobility and packet collision, the node upstream of the break empties its buffer and propagates a route error (RERR) packet to all active upstream neighbors. Similarly, these nodes, fresh out of their buffer, delete all the related routes and relay the RERR to their upstream neighbors and so on until the source node is reached. A new route discovery procedure will be initiated by the source if the route to the destination is still needed.

DAODV avoids interference from nodes hops away by exploiting the directionality of the beams. However, DDSR routing protocol achieves a better performance than the DAODV routing protocol because of its capability of learning multiple routes to the destination in a single request cycle.

#### **4.4 Energy Efficient Directional Routing (EEDR)**

EEDR [22] is a novel routing protocol and seeks to achieve high throughput, network lifetime and fairness across flows. The salient features of EEDR are (i) Robustness – EEDR is self-configuring and robust to the dynamics of the WSN topology. It achieves actor-actor communication (AAC) with minimal disruption even under conditions of high actor node mobility. We emphasize that, while EEDR is designed for AAC in partitioned actor networks, it works perfectly well even when the actor network is fully connected. (ii) Energy awareness – EEDR maximizes the network lifetime and the amount of data transferred under the constraints of limited energy of the sensor nodes. (iii) Fairness – Given the limited energy of the bridging sensor nodes, it is important to ensure that this constrained resource is fairly distributed and no actor flow is starved. The algorithm that EEDR operates on ensures high fairness across all the flows.

There are two kinds of nodes in EEDR: sensor nodes and actor nodes. When a source actor node needs to send data to a destination actor node, it searches in its route-cache and checks if any route is available to the destination. If so, it sends data packets along the route. Otherwise, it initiates the route-discovery process. The actor node first sends the RREQ packet to its partition leader node. If the leader node knows that the destination actor node belongs to the same partition, it forwards the packet to the actor node directly. Otherwise, it forwards the RREQ packet to all actor nodes of the partition and initiates a directional broadcast. After directional broadcast and sensor bridging, the route selection is completed.

#### **4.5 Directional Antenna Multipath Location Aided Routing (DA-MLAR)**

DA-MLAR [23] is an extension of Multi-path Location Aided Routing (MLAR) with directional antenna capability. DA-MLAR minimizes the protocol overhead of reactive routing protocols. The extension not only further reduces MLAR's protocol overhead, but also improves the packet delivery ratio and the end-to-end delay. This is because the long radio transmission range obtained using directional antenna can avoid network partitions so as to reduce the number of rebroadcasts and cut down on the number of routing hops.

MLAR tries to reduce the protocol overhead by using two strategies. The first strategy limits the transmission area (using box method) [24] thus reducing the number of nodes participating in the forwarding of the route request packets. Only the nodes in the box region will participate in forwarding, others just discard the route request packet they received. The second strategy makes use of multiple alternative paths [25] to reduce the number of consecutive routing requests in case the first one fails. The alternative paths can be tried for sending the packet if the first priority path does not work. Even when some nodes are not in the box region and they do not participate in forwarding the route request packet to the destination, they are still affected as they are within the communication radio region of the sender node. However, when using the directional antenna, the nodes out of the box region get isolated. They are unaware of

the route request packets sent by the sender node to the destination node for which they are not in the forwarding region.

#### **4.6 Multipath Directional Antenna Ad Hoc Routing (MDAR)**

Multipath Directional Antenna ad hoc routing (MDAR) [26] is a reactive source routing protocol for ad hoc networks using directional antennas. In MDAR, every node maintains a routing table, which lists the paths from the sender to each possible destination. Each node updates the routing table according to the overheard packets no matter what their destinations are. A distinctive feature of MDAR is that the routing table records multiple choice of routes to each destination, so when one route encounters busy channel, an alternative route can be selected immediately. The source node puts the whole path into the packet header, and intermediate nodes forward the packet according to the specified path in its header. When there are packets to be sent and there is no available route to the destination, a route discovery process is initiated.

During the route discovery process, the sender broadcasts a route request message using sweeping mechanism. When a neighbor node receives the route request, it will search through its own routing table. If it finds no available route to the destination, it will re-broadcast the route request immediately over all its antenna elements except for the one where it received the message. In the packet forwarding process, each node delivers the packet to the next hop according to the route specified in the packet header. If the first attempt fails, MDAR assumes a possible collision and will try two more times. If all these attempts fail, MDAR assumes that this neighbor node is busy and an alternative route is used immediately. If an alternative route is not available or it is much more costly than the original route in term of hop count, the node will keep using the original route until it assumes that this link is indeed broken. Multipath routing can minimize per hop delay, and therefore effectively reduce the overall end-to-end delay. The number failures for each next-hop attempt are recorded and when it exceeds some threshold, MDAR assumes that this neighbor node may have moved to another location.

### **5. Comparison Results**

We compare the state-of-the-art routing protocols proposed so far in the literature. We evaluate the routing protocols over directional antennas in terms of various characteristics including important performance metrics. Antenna models, MAC protocols, maximum antenna gain, number of directional antenna beams, directional neighborhood, multipath support, network throughput, end-to-end delay, and routing overhead are studied in the comparative analysis. Table 1 summarizes the comparison results of these routing protocols.

From the comparison tables and our comparative analysis, some conclusive comments can be inferred: The DRP is the best of the routing protocol using directional antennas thanks to its many outstanding features even although it has some drawbacks such as no multipath support.

**Table 1. Comparison of the routing protocols over directional antennas**

	Antenna models	MAC protocols	Max. antenna gain	No. of directional antenna beams	Directional neighborhood	Multipath support	Network throughput	End-to-end delay	Routing overhead
<b>DRP</b>	Switched beam antenna	MDA	4dB, 23.31dB, 55.71dB	4, 8, 12	DO/DD	No	Good	Short	Normal
<b>DDSR</b>	Switched beam antenna	DMAC	15.56dB	9	DO	No	Normal	Normal	High
<b>DAODV</b>	Switched beam antenna	DMAC	15.56dB	9	DO	No	Bad	Long	High
<b>EEDR</b>	Switched beam antenna	DMAC	4dB, 12.00dB	4, 6	DD	No	Good	Normal	Normal
<b>DA-MLAR</b>	Switched beam antenna	DRTS ORTS	4dB, 12.00dB, 23.31dB	4, 6, 8	DD	No	Good	Long	High
<b>MDAR</b>	Switched beam antenna	DMAC	-	-	DO	Yes	Good	Short	Normal

## 6. Conclusions

With current technological advancements, there is no doubt that directional antennas will become an integral part of future MANETs as means to considerably enhance its capacity. However, a directional antenna creates many difficulties with regard to protocol design as it impacts almost all layers of the protocol stack. In this paper, we focus on investigating the routing protocols over directional antennas and give a comparison result of them with respect to the important challenging issues. We study the advantages and disadvantages of the routing protocols using directional antenna. Although many of these routing techniques have good performance, there are still many challenges need to be solved.

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