Cartesian Ad hoc Routing Protocols

Larry Hughes, Kafil Shumon, Ying Zhang

Department of Electrical and Computer Engineering
Dalhousie University
Halifax, Nova Scotia, B3J 2X4, Canada
{larry.hughes, kshumon, yzhang}@dal.ca *

Abstract. As ad hoc networks gain in popularity, some of their limitations are becoming apparent, notably power and bandwidth restrictions. Consequently, it is necessary to utilize protocols that reduce power consumption, reduce traffic, and restrict flooding. In this paper, two adaptive, connectionless protocols and their supporting subsystems are described. The protocols, when used with directional antennas, can reduce the number of nodes involved in a transmission, thereby addressing the issue of power consumption and bandwidth utilization.

Keywords: MANET, location awareness, direction awareness.

1 Introduction

A mobile ad hoc network (MANET) is a collection of wireless mobile nodes that are capable of communicating with each other without the use of a network infrastructure or any centralized communication [1]. Like most wireless networks, a MANET is both power and bandwidth sensitive. Communication in a MANET poses special challenges because the network is infrastructureless and topologically dynamic. Energy conservation also plays an important role in the performance of ad hoc networks since most mobile hosts are battery operated. In a relatively dense network with many nodes lying between the source and the destination, these two problems become even more prominent. A number of MANET protocols have been proposed, including on-demand protocols for saving bandwidth, such as DSR [2] and CBRP [3], and for power saving, such as power-aware localized routing [4] and energy conserved routing [5].

Cartesian Ad hoc Routing Protocols (CARPs) are a set of three adaptive, connectionless protocols that address the problems of routing and power consumption in MANETs; they are loosely based on the Cartesian Routing Protocol [6]. Each protocol operates at the physical layer (using directional antennas) and the network layer (through its adaptive protocols); all nodes are location and direction aware. The protocols designed for CARP have three objectives: restrict flooding, reduce power consumption, and reduce traffic. Due to space restrictions only two of the protocols are presented in this paper.

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2 CARP

All Cartesian Ad hoc Routing Protocols attempt to restrict transmission to those nodes that lie between the source and the destination. First, a directional antenna is used to create a *bounding box* with a horizontal beamwidth of 90°. Next, the protocol is used to limit the number of forwarding nodes in the bounding box by creating a *transmission area*. The source and destination nodes are at opposite ends of the transmission area; each node within the transmission area is referred to as an *intermediate node*. A *current node* is a node that is forwarding a packet.

Fig. 1 shows the CARP subsystems. When a source node is to transmit a packet, it uses the Transmission Area Creation subsystem to determine the transmission area. Antenna Selection is then employed to select the antenna facing the destination. The Location Verification subsystem of each intermediate node determines whether the node is within the transmission area; if it is, the steps used by the source node are repeated. This process continues until the packet reaches the destination[1].

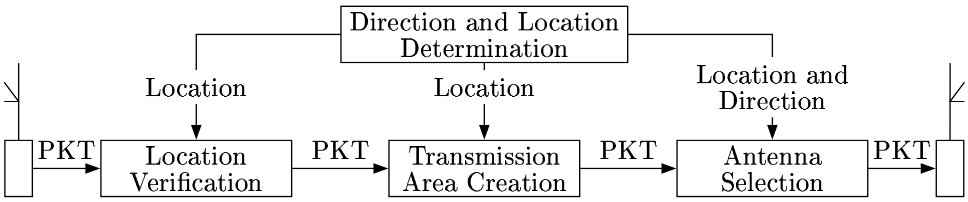


Fig. 1. CARP data flow diagram.

In addition to its payload, a CARP packet consists of the source address, the destination address, and transmission area information. At a minimum, the transmission area information is the address of the current node (x_c, y_c).

3 Transmission Area with Limiting Angle

If the transmission area has the same shape as the bounding box, unnecessary transmissions may occur especially in dense network. To reduce the number of potential intermediate nodes in the transmission area, the following protocol attempts to restrict the size of the area by employing a *limiting angle*.

The limiting angle, ϕ, defines the shape of the transmission area between the current node, C, and the destination node, D, as shown in Fig. 2. Each intermediate node forms an angle ϕ_i with the current node and the destination node.

[1] Since the destination may move during a transmission, a circular *expected zone* is created [7]. Unless otherwise indicated, the expected zone and its related calculations are beyond the scope of this paper.

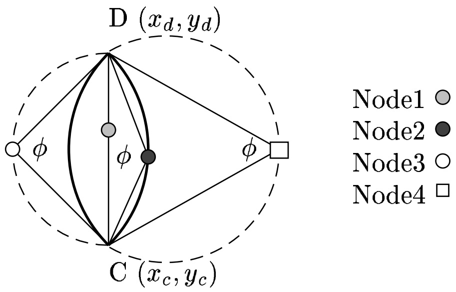


Fig. 2. Transmission area with limiting angle

3.1 Transmission Area Creation Subsystem

The value of ϕ is determined by the source. Table 1 shows the relationship between ϕ and the shape of the corresponding transmission area.

Table 1. Nodes in the network

Value of ϕ	Shape of Transmission Area	Example	Path Length
$\phi = 180°$	line connecting current and destination	Node1	Shortest
$90° < \phi < 180°$	two symmetric minor arcs	Node2	↓
$\phi = 90°$	circle	Node3	
$\phi < 90°$	two symmetric major arcs	Node4	Longest

As the value of ϕ decreases, the size of the transmission area increases, potentially adding more nodes to the area, increasing the possible route length, and the number of packets. Therefore, there is a trade-off between the robustness of the protocol and the volume of traffic. Different ϕs can be defined based upon the density to determine the shape of the transmission area: the greater the density, the larger the value of ϕ.

Initially, the source node assigns its value of (x_s, y_s) to (x_c, y_c), while the intermediate nodes assign their address, (x_i, y_i), to (x_c, y_c) if they are to forward the packet. The transmission area information for this algorithm includes the value of ϕ_s (the value of ϕ determined by the source).

3.2 Location Verification Subsystem

When a packet arrives at an intermediate node, (x_i, y_i), it contains the limiting angle, ϕ_s, and the addresses of the destination and current nodes, (x_d, y_d) and (x_c, y_c), respectively. From this, the intermediate node can determine its value of ϕ_i as follows:

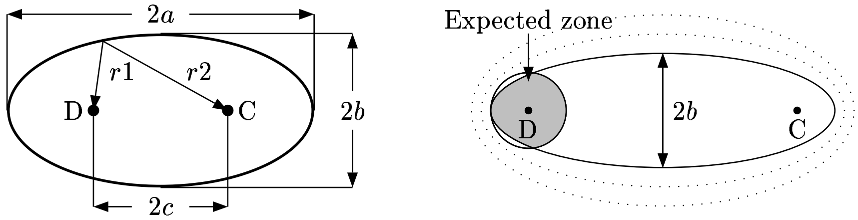
$$\phi_i = \arctan \frac{(y_c - y_i)(x_d - x_i) - (y_d - y_i)(x_c - x_i)}{(x_c - x_i)(x_d - x_i) + (y_c - y_i)(y_d - y_i)} \tag{1}$$

ϕ_i is then compared with the packet's ϕ_s. If $\phi_i > \phi_s$, the packet will be forwarded; otherwise it is discarded.

4 Transmission Area with Fixed Path Length

As well as making the transmission area with a limiting angle, the area can also be determined from the path length. Since nodes with a fixed path length form an ellipse, the second CARP algorithm uses an ellipse as the transmission area.

In Fig. 3(a), the current and destination nodes are two foci of an ellipse; the distance between these two nodes is $2c$. The major axis of the ellipse is $2a$ and the minor axis of ellipse is $2b$.



(a) An ellipse

(b) Transmission area

Fig. 3. Fixed path length shapes

The following equations are of interest:

$$r_1 + r_2 = 2a \tag{2}$$
$$b^2 + c^2 = a^2 \tag{3}$$

All the nodes located on the ellipse boundary have the same path length $2a$, as shown in equation 2, while nodes located inside the ellipse have a shorter path length. These nodes are inside the transmission area.

An expected zone is defined as the overlapping area of a circle (centred at the destination) and the ellipse as shown in Fig. 3(b).

The transmission area information for this algorithm is the current node address (x_c, y_c).

4.1 Transmission Area Creation Subsystem

The parameters a, b and c determine the shape of the ellipse; however since they are correlated as illustrated in equation 3, if any two of them are known, the third can be calculated.

The value of a is related to the radius of the expected zone, r, and the distance between the source and the destination, $2c$. Since the positions of the current and destination nodes are assumed to be fixed at the transmission of the packet, a is determined from the radius of the expected zone, r, which is related to the speed of the destination [7].

An ellipse in a sparse network has a larger value of b than that in a dense network to include more nodes in the area. Fig. 3(b) shows the transmission area with different values of b in networks with different densities.

When an intermediate node forwards the packet, it substitutes the current node co-ordinates with its own to create the transmission area for the next hop.

4.2 Location Verification Subsystem

When an intermediate node receives a packet, it calculates the following:

- its distance to the source $r1$ and to the destination $r2$
- distance between source and destination $2c$
- major axis of the ellipse $2a = 2c + 2r$

If $r1 + r2 < 2a$, the node is inside the transmission area and is to forward the packet towards the destination; otherwise it is to discard the packet.

5 Supporting Hardware

Each CARP node must be direction and location aware, in addition, it needs to select the proper antenna(s) for packet transmission.

5.1 Direction and Location Determination Subsystem

The Direction and Location Determination subsystem consists of two distinct units.

A *Direction Unit*, which is responsible for determining magnetic North to make the node direction aware. A magnetoresistive sensor chip can be employed to act like an electronic compass [8]. The compass has a fixed orientation with the antenna subsystem (described below) so that the direction in which each antenna is facing is always known. The sensor gives a deviation angle of 0° while facing towards the earth's magnetic North and the angle of deviation increases as the antenna module rotates clockwise and resets after each complete rotation.

The *Location Unit* is responsible for determining the location of the node. Any location detection system, such as GPS [9], can be used to provide the location co-ordinates.

5.2 Antenna Selection Subsystem

This subsystem selects the proper antenna or antennas in the antenna module by taking the destination coordinates from the packet and the local node and direction information provided by the direction and location determination subsystem. The antenna module consists of four directional antennas with each having a horizontal beamwidth of 90° and a vertical beamwidth of 180°.

The appropriate antenna or antennas are then chosen as follows. First, the angle of inclination (θ) is determined with reference to the x-axis between the current and destination nodes using their coordinates. Since a positive inclination with reference to the x-axis is required, 180° is added to θ if θ is less than 0°. Then the angle of inclination is conditioned to determine the direction of the destination node. Next the angle of deviation of the compass is added to θ. Finally, θ is conditioned to be in the range from 0° to 360°.

Once the final θ is calculated the selection of the antenna or antennas can be made easily. When θ is a multiple of 90°, the two antennas on two sides of the angle are chosen.

6 Concluding Remarks

This paper described two of the Cartesian Ad hoc Routing Protocols. These are adaptive and connectionless routing protocols which:

- restrict any flooding to within the transmission area.
- reduce power consumption of nodes outside the transmission area, since they are not involved in the communication.
- reduce the number of nodes in the communication by dynamically adjusting the transmission area and deploying directional transmission.

In this paper, it has been assumed that the intermediate nodes have a uniform density between the source and destination; however, in a real network environment, this may not be the case. For example, the number of intermediate nodes may appear to be dense, when in reality, there may be a peak around the source or destination only. We are in the process of examining non-uniform network densities with the OPNET modelling tool.

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