International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459 (Online), An ISO 9001:2008 Certified Journal, Volume 3, Special Issue 1, January 2013)

International Conference on Information Systems and Computing (ICISC-2013), INDIA.

# RELIABLE DATA DELIVERY FOR HIGHLY DYNAMIC MOBILE AD HOC NETWORKS USING OPR

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***Abstract***

**This paper addresses the problem of delivering data packets for highly dynamic mobile ad hoc networks in a reliable and timely manner. Most existing ad hoc routing protocols are susceptible to node mobility, especially for large-scale networks. Driven by this issue, we propose an efficient Position-based Opportunistic Petal Routing (OPR) protocol which takes advantage of the stateless property of geographic routing and the broadcast nature of wireless medium. In the case of communication hole, a Virtual Destination-based Void Handling (VDVH) scheme is further proposed to work together with OPR. Both theoretical analysis and simulation results show that OPR achieves excellent performance even under high node mobility with acceptable overhead and the new void handling scheme also works well.**

***Index Terms* — Geographic routing, opportunistic forwarding, Petal routing, reliable data delivery, void handling, mobile ad hoc network.**

## I. INTRODUCTION

MOBILE ad hoc networks (MANETs) have gained a great deal of attention because of its significant advantages brought about by multihop, infrastructure-less transmission. However, due to the error prone wireless channel and the dynamic network topology, reliable data delivery in MANETs, especially in challenged environments with high mobility remains an issue. Traditional topology-based MANET routing protocols (e.g., DSDV, AODV, DSR [1]) are quite susceptible to node mobility. One of the main reasons is due to the predetermination of an end-to-end route before data transmission. Owing to the constantly and even fast changing network topology, it is very difficult to maintain a deterministic route. The discovery and recovery procedures are also time and energy consuming. Once the path breaks, data packets will get lost or be delayed for a long time until the reconstruction of the route, causing transmission interruption.

Geographic routing (GR) [2] uses location information to forward data packets, in a hop-by-hop routing fashion. Directional flooding is used to select next hop forwarder with the minimum duplication and positive progress toward the destination while void handling mechanism is triggered to route around communication voids [3] by increasing the width'w' of the petal.

No end-to-end routes need to be maintained, leading to GR's high efficiency and scalability. However, GR is very sensitive to the inaccuracy of location information [4]. In the operation of greedy forwarding, the neighbor which is relatively far away from the sender is chosen as the next hop. If the node moves out of the sender's coverage area, the transmission will fail. In GPSR [5] (a very famous geographic routing protocol), the MAC-layer failure feedback is used to offer the packet another chance to reroute. In fact, due to the broadcast nature of the wireless medium, a single packet transmission will lead to multiple reception. If such transmission is used as backup, the robustness of the routing protocol can be significantly enhanced. However, most of them use link-statestyle topology database to select and prioritize the forwarding candidates. In order to acquire the internode loss rates, periodic network-wide measurement is required, which is impractical for mobile environment. Recently, location-aided opportunistic routing has been proposed which directly uses location information to guide packet forwarding. The main contributions of this paper can be summarized as follows:

- We propose a position-based opportunistic petal routing mechanism which can be deployed without complex modification to MAC protocol and achieve multiple reception without losing the benefit of collision avoidance provided by 802.11.

- The concept of in-the-air backup significantly enhances the robustness of the routing protocol and reduces the latency and duplicate forwarding caused by local route repair.
- In the case of communication hole, we propose a Virtual Destination-based Void Handling (VDVH) scheme in which the advantages of adjusting the petal width according to the need of nodes for flooding. Thus reducing collision and overheads and routing can still be achieved while handling communication voids.
- We analyze the effect of node mobility on packet delivery and explain the improvement brought about by the participation of forwarding candidates based on the petal area.
- The overhead of OPR with focus on buffer usage and bandwidth consumption due to forwarding candidates' duplicate relaying is also discussed. Through analysis, we conclude that due to the selection of forwarding area and the properly designed duplication limitation scheme, POR's performance gain can be achieved at little overhead cost.
- Finally, we evaluate the performance of OPR through extensive simulations and verify that OPR achieves excellent performance in the face of high node mobility while the overhead is acceptable.

The rest of this paper is organized as follows: we present the protocol design of OPR and complementary mechanisms in Section 2 reviews the related work and conclusions are given in Section 3.

## II. Position-Based Opportunistic Petal Routing

### *2.1 Overview*

The design of POR is based on geographic routing and opportunistic forwarding. The nodes are assumed to be aware of their own location and the positions of their direct neighbors. Neighborhood location information can be exchanged using one-hop beacon or piggyback in the data packet's header. While for the position of the destination, we assume that a location registration and lookup service which maps node addresses to locations is available just as in [5]. It could be realized using many kinds of location service. In our scenario, some efficient and reliable way is also available. For example, the location of the destination could be transmitted by low bit rate but long range radios, which can be implemented as periodic beacon, as well as by replies when requested by the source.

When a source node wants to transmit a packet, it gets the location of the destination first and then attaches it to the packet header. To deal with such issue, additional check for the destination node is introduced. At each hop, the node that forwards the packet will check its neighbor list to see whether the destination is within its transmission range. If yes, the packet will be directly forwarded to the destination, similar to the destination location prediction scheme described in [4]. By performing such identification check before greedy forwarding based on location information, the effect of the path divergence can be very much alleviated. In conventional opportunistic forwarding, to have a packet received by multiple candidates, either IP broadcast or an integration of routing and MAC protocol is adopted. The use of RTS/CTS/DATA/ACK significantly reduces the collision and all the nodes within the transmission range of the sender can eavesdrop on the packet successfully with higher probability due to medium reservation. As the data packets are transmitted in a multicast-like form, each of them is identified with a unique tuple (src_ip, seq_no) where src_ip is the IP address of the source node and seq_no is the corresponding sequence number.

### *2.2. Towards robust multipath routing*

In this section we present a robust on-demand routing scheme for wireless ad hoc networks that we call Petal Routing. This routing technique utilizes the broadcast nature of wireless networks to combine multiple transmissions from one node to one transmission [5]. The basic idea is as follows. Given a source and destination, the network carries out constrained flooding to send the packet to the receiver. The flooding is constrained to transmissions within an area that we call a petal and it is determined by the reliability metric, which can be defined on a per transmission basis. The shape of the flooding area is intuitively modeled as a 'petal', as shown in Figure 2, the two ends of which converge at the source and destination. This technique also allows for further enhancements to reduce the number of transmissions within the petal. Since the underlying protocol is flooding, the individual nodes do not need any prior information about their neighbors or maintain any end-to-end paths. Such protocols that do not need neighborhood information are called beaconless protocols . A parameter, called the petal parameter, helps an intermediate node determine whether it is located within the petal or outside.

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Before discussing the Petal Routing technique in greater detail, we first state the assumptions and the failure model that are considered.

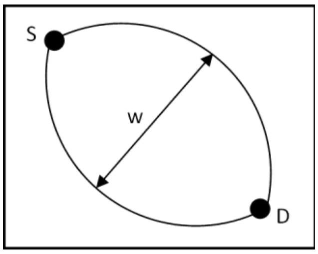


**FIG 1: visualizing a petal**

*2.3. Assumptions*

The Petal Routing methodology uses node locations to minimize the number of individual transmissions in the network. The location of a node determines whether or not it would take part in a certain transmission. It is assumed that a node always knows its current loca- tion. In addition to that, the source is expected to know the location of the destination. The (x, y) coordinate of a node is in the form: (longitude, latitude). Other than the source (that knows the location of the destination), no other node knows the location of any other node, other than itself. In addition to that, the nodes in the network need not maintain routes to any other node in the network, or know who their neighbors are. The routing protocol is so designed, that the addressing is using location co-ordinates. A node's latitude and longitude uniquely identifies it. In other words, the geographic location of a node is its ad- dress. The source always send a packet to a location and not to any IP address. We consider this to be an equivalent of the source sending the packet to the node at the location specified.

With regard to nodal density in the network, we assume that the network is reasonably dense. This is pertinent, because we use a multipath routing technique. If no path exists within the area of the petal, then the routing would fail. However, this is a simplifying assumption, and in case of a sparsely populated network, our approach could be used in combination with table-driven approaches to store neighbor information, which can assist in calculating the optimal width of the petal.

In a densely populated wireless network, collisions are an important concern that can lead to poor performance.

MAC layer algorithms for contention resolution in wireless networks have been studied extensively. Moreover, the multihop path occurs through a time scale that is more coarse grained, and it does not affect the overall end-to-end per- formance. We assume that the contention resolution and scheduling issues at the hop time scale are handled by the MAC layer. In the network layer, we provide some heuristic en- hancements using back-off time, to reduce the probability of collisions.

Node locations are obtained from a positioning system, such as the GPS. In our basic implementation, we assume that the location obtained from the GPS is precise enough for our calculations.

We also assume that the nodes in the network are capable of omnidirectional transmis- sion. There are no special requirements on directional transmission for Petal Routing. In addition to that, we assume that all nodes in the network are roughly identical and have similar transmission range. Thus, if the wireless network were to be converted into a directed graph, all links would be unidirectional. This does not affect the correctness of our protocol, but it improves the efficiency of the back-off mechanism described in Section 4.5. With these assumptions in consideration, we present the failure model that is used for testing the Petal Routing protocol.

*2.3.1. Using location co-ordinates for addressing*

Even though Petal Routing uses node locations for addressing, this does not reduce the generality of our contribution. Any other addressing scheme, such as IP, can easily co-exist with the addressing scheme in Petal Routing. Consider a network using Petal Routing along with other routing protocols such as AODV. Assume that AODV uses IP addresses to re- fer to specific nodes. All packets in the network would use IP headers with an exception. The petal packets would have an extra layer of encapsulation after the IP headers, where the petal parameters, such as source and destination location co-ordinates would be stored. This ensures coexistence of multiple addressing schemes. The exact format of petal packets is defined in subsequent sections.

*2.4. Failure model*

We follow the failure models provided in [10, 31] to test our contribution.

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The failure models that have been considered for Petal Routing include both failures from natural disruption as well as failures due to malicious activity. The subsequent sections discuss the failure models that we consider

*2.4.1. No failure*

The case of no failures, all nodes in the network function correctly. All the nodes are able to transmit and receive packets as expected. We use this model, only to test if our protocol functions correctly in the absence of failures. It is almost impossible to practically realize a reasonably sized model without any failures.

*2.4.2. Intermittent Node Failure*

This model captures independent node failures. Thus some nodes in the network fail, but there is no pattern by which the nodes fail. Isolated failures occur in reality. Such failures can take place due to energy dissipation or localized environment effects [10]. For instance, if the density of nodes in a certain region in the network is low, then a node in that region would trigger higher physical activity. This would lead to such a node dissipating all its energy, independent of neighboring nodes. Since there are no physical links in wireless net- works, environmental failures do not affect individual links in the network.

*2.4.3. Jamming Model*

The jamming model captures geographically correlated failures, or patterned failures. Such a failure, affects all wireless links in a circle of radius $R_p$ . The choice of the circle is somewhat arbitrary, but it attempts to model radio wave propagation. In reality, this model can be justified with the fact that environmental effects within a geographic region can cause correlated failures. We use the jamming model in [31]. We assume that a jammers can operate at any location in the network at a given time. The jamming power to signal ratio (JSR) at the receiver determines the degree to which jamming is successful. In general the JSR can be expressed as follows.

$$JSR = \frac{JammingPowerReceived}{SignalPowerReceived}$$

$$JSR = \frac{P_J}{P_T}\left(\frac{D_{TR}}{D_{JR}}\right)^n$$

Where $P_J$ is the jamming signal's transmit power, $P_T$ is signal's transmit power, $D_{TR}$ is the distance between the transmitter and receiver, $D_{JR}$ is the distance between jammer and receiver and n is the path loss exponent.

*2.5. Petal routing*

In this section we discuss the Petal Routing methodology. In this protocol, when the source transmits a packet, it encapsulates the payload with petal headers. We first define a petal packet, which we call petalgram. Figure 3 shows the structure of a petalgram.

| | | | | | |
|---|---|---|---|---|---|
| ID | Sloc | Dloc | Tloc | W | Payload |

**FIG: structure of a petalgram**

The headers in a petalgram are as follows.

- Packet ID (ID ): a number that uniquely identifies a packet
- Source Location ($S_{loc}$ ): co-ordinates of the source
- Destination Location ($D_{loc}$ ): co-ordinates of the destination
- Transmitter Location ($T_{loc}$ ): location co-ordinates of the node that is transmitting (or transmitted) the packet
- Petal Parameter (W ): this parameter specifies the width of the petal

Point to point communication on a per hop basis cannot be realized in wireless networks. So, all nodes broadcast any packet that they are sending. When a node receives a packet, it needs to determine whether or not the packet was intended for it.

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If not, then it is an intermediate node in the transmission, and it now needs to determine whether it is inside the petal or not. A node can determine whether or not it is inside the petal, using the location co-ordinates of the source, destination and the width of the petal, all of which are embedded in the header of the petalgram. The calculation of whether a node is inside a petal has been dicussed in section 4.4. To aid in visualizing a petal, consider Figure 2, where S and D represent the source and destination nodes respectively and w is the width of the petal. The shape of a petal more-or-less resembles the shape shown in Figure 2. If no geographic source-destination path exists within the area of the petal, then then it is up to the source to detect failure of transmission using end-to-end acknowledgement. To restransmit a packet, the width of the petal should be increased in order to find such geographic paths. The shape of the petal has been selected so that it converges at the source and destination locations. If an intermediate node is inside the petal, it adds the packet to a waiting buffer $B_{wait}$ after a back-off time.

*2.6.Random Back-off*

As a simple form of Petal Routing, the value of $t_{backoff}$ can be selected as a random number (with some pre-defined upper bound). This would ensure that different nodes back-off for different periods of time. Although there is no pattern in the back-off values of the different nodes, it would still alleviate some medium contention issues.

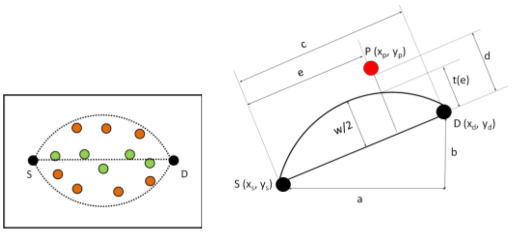


**FIG 2: (a) Choosing back-off time based on node location (b) Calculating petal parameters.**

Varying the back-off time based on node locations, we consider that $t_{backoff}$ is least along the S-D line ($t_{lb}$ ), and it uniformly increases to reach an upper bound ($t_{ub}$ ) at the edge of the petal. This phenomenon is illustrated in Figure 7(a). It should be noted that the curve in Figure 7(a) does not represent actual back-off values.

Instead, if the back-off value of the curve at a certain location is $t_{loc}$, we choose $t_{backoff}$ such that, $0 \leq t_{backoff} \leq t_{loc}$.

Further, if a node is made to back-off from its downstream neighbors, then there is a higher chance of the downstream neighbors receiving the packet, without this node's transmission.

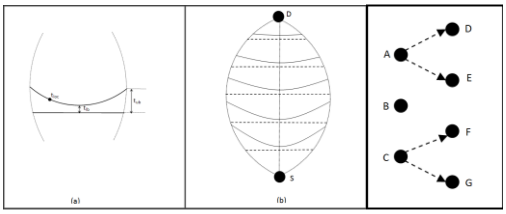


**Figure 3 : (a) Curve representing back-off time varying from center of petal to edges (b)flattening of curve from source to destination(c) back off time to reduce transmission**

To realize this phenomenon, we consider that the value of the upper bound of the curve ($t_{ub}$) decreases from the source to the destination. Any individual node inside the petal would back-off from its more centrally located adjacent nodes, as well as from its downstream neighbors. Thus, the upper bound of $t_{backoff}$ is decreased gradually from the source to the destination. In other words, the curve of the back-off values, would become more flattened as it approaches the destination. This feature can be visualized in Figure 3(b). Note that the curves presented in 3(b) are not to scale. The algorithm to select a back-off time based on the location of a node with respect to a petal, is provided in Algorithm 3. Note that instead of using a curve, we use straight lines to compute the value of back-off to reduce the number of computations. The variables c, e, d, and t(e) represent the same variables as in Section 4.4. The algorithm assumes the minimum and maximum values of the curve to vary from 0 to 10 (seconds) respectively.

This method involves the same steps as in Algorithm 3. However, instead of selecting the value on the curve (shown in Figure 3) at a certain location, a random number between $t_{lb}$ and the value on the curve is selected. This allows for more randomness, rather than choosing a specific value based on the curve.

*2.7 Cancelling pending transmissions*

After a back-off time expires, a ndoe has to decide whether it should transmit the packet.

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The buffer $B_{wait}$ contains a count of the number of nodes from which this node heard the packet. If the value of count, is less than k the node would transmit the packet. The value of k is calculated using the node density of the network. The node density of a network is defined as the average number of nodes per unit area of the network. Using the locations of all nodes from which the transmissions were heard, the current node creates a convex hull. If the current node is outside the convex hull, it does not transmit the packet. This is shown in Figure 8(a), where node A is outside the convex hull. Otherwise, using the node density, the current node knows the number of nodes that should be in the area enclosed by the convex hull, and this value is set to k. If the current node hears the packet from fewer than k nodes then it transmits. For example, in Figure 8(b), if k > 6, node B will transmit the packet.

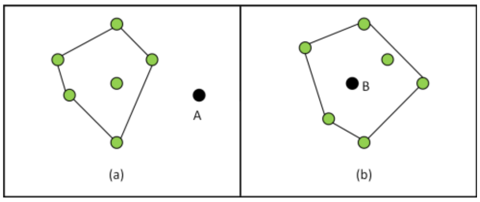


**Figure 4 : Determining whether to transmit a packet**

## III. CONCLUSIONS

One way of assuring that data packets reach the destination in wireless ad hoc networks, is by using multipath routing algorithms. This method, however, increases the overall traffic substantially. In this report, we survey the literature for existing multipath routing tech- niques. We then present a routing technique that we call Petal Routing, which minimizes the number of transmissions while maximizing reliability. Individual nodes in this routing technique do not need to maintain any routing tables or neighbor information. We test our routing protocol using simulations on NS2. Simulation results show that the coordinated back-off method works best in terms of the number of transmissions, while the randomized coordinated back-off works best in terms of the delay.

In a network with failures, the number of transmissions is reduced due to failed nodes, but the delay is high. In addition to that, it is observed that the reliability increases with increase in petal width and decrease in node failure probability.

We compare our approach to a multipath routing technique that uses network coding to increase the redundancy of data and thereby increase the reliability and greedy forwarding. Simulation results show that the Petal Routing approach is more reliable in a network with patterned failures or jammers. We also conclude that the number of transmissions in Petal Routing is low in a network with fewer failed nodes, since we use the concept of back-off. Thus, even though the number of transmissions is higher for Petal Routing in networks with high failure, the increase is to maintain higher reliability

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