Geographic information based Replication and Drop Routing (GeoRaDR): A Hybrid Message Transmission Approach for DTNs

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Abstract: Several approaches have been proposed to perform routing in Delay/Disruption Tolerant Networks (DTNs) which has a random connectivity pattern. As the routing path from the source to destination will not be available always it results in low delivery ratio and high end-end delay. Most routing schemes are based on uncontrolled replication mechanisms like full flooding or spraying to explore the diversities in routing paths in order to reduce data transmission delay and reliable message delivery. These methods create redundancy of the data in the network and thus cause high resource consumption like bandwidth and storage. In this paper various replication mechanisms used in different routing schemes are reviewed and a novel Replication and Drop Routing mechanism controlled by the location information (Geo-coordinates) & the velocity of the nodes dubbed as (GeoRaDR) is proposed. With the assistance of the derived moving vector (i.e) the direction and the distance between the encountered nodes with respect to the destination node and the number of nodes available in the forward progress region of the half plane of the candidate node, the replication, drop and routing decisions are made. Thus, GeoRaDR performs a knowledge based replication of messages reducing the problem of redundancy and buffer overflows, while handling the local maximum problem and increasing the link reliability.

Keywords: message replication, DTNs, local maximum problem, Forward Progress Region, Half Plane

Introduction

DTNs have attracted much research attention in the recent years due to a wide-range of potential applications such as vehicular networks, crisis /disaster recovery networks, sensor networks for environmental monitoring and underwater communications etc.

DTNs are characterized by sparse mobile node densities where the topology of the network changes dynamically and unpredictably. In DTNs the routing path from the source to destination is not available always and nodes may get disrupted quite often. Due to these reasons, DTNs are referred to as “challenged networks” by Warthman (2003). This lack of connectivity introduces link failures in routing messages and the messages have to be replicated with a hope that at least one will reach destination but there is no guarantee on delivery of the message. DTN nodes usually have limited energy and may prefer fewer transmissions for longer lifetime.

In this paper, knowledge based controlled replication and drop scheme utilizing the geographic information, velocity and direction of the nodes available in the forward progress region of the half plane of the source node is suggested. In GeoRaDR, it is assumed that each node is equipped with a Global Positioning System (GPS) as stated by Yue Cao et al. (2014) and knows its own geo-coordinates, speed and direction of its own and the source node knows the location of the destination node based on historic data as said in the paper by Mauve et al. (2001). With this information a node can easily calculate the Moving Vector (MV) which is a gradient function with respect to the destination node and route the messages accordingly. Combining MV and Replication Threshold (R_T) GeoRaDR handles the local maximum problem and buffer overflows with a controlled threshold based message relay scheme.

The reminder of the paper is organized as follows. Section 3 focuses on reviewing the various related replications based routing protocols. Section 3 presents the mathematical model and the details of the proposed GeoRaDR routing protocol. Section 4, concludes the paper.

Related Work

Variety of routing protocols has been designed for DTNs based on different sets of assumptions. But, generally these protocols are classified as Replication based and Forwarding based protocols. When pair of mobile nodes is within the communication range of each other a transmission opportunity arises between them and we call it as “they meet each other or node encounter”. In forwarding based routing only one copy exists across the network at a given time.

In DTNs, the knowledge about the network topology is minimal and hence replication based strategy is the best. Here, the same data is replicated to several nodes to achieve high delivery ratio and minimize delivery relay. But, this scheme is not optimal in terms of transmission bandwidth and buffer size. It is because, in uncontrolled replications, when two nodes meet, like node x and node y, all messages those are not available in y will be transferred from node x to node y. If the node y is not having a chance to meet the destination of any single message, then the resources of node will be exhausted without any use. Thus, it is a must to derive a message replication based on some knowledge about the destination of messages and the relay node.

Pure Flooding Based Replication

Vahdat et al. (2000) described Epidemic routing as a pure flooding scheme that results in massive duplication of messages. It is mobility assisted routing mechanism. Transmitted data is continuously replicated until all nodes receive a copy with a hope that a path towards the receiver will become available any time in the future and the copy will be utilized for successful delivery. High delivery ratio of Epidemic comes with a cost of being 10 times more expensive than all of the predictive algorithms. Moreover, it occupies more system bandwidth and node buffer space and energy. However, most mobile nodes in DTNs have limited energy and may prefer fewer transmissions than flooding to conserve energy, and to prolong network lifetime as stated by Saranya et al. (2014). MaxProp is another flooding based protocol reported by Burgess et al. (2006), since, if resources and mobility allow, it is possible for every node in the network to have a replica of the same message.

In order to limit the replication and to achieve tradeoffs between network resource consumption and protocol performance two methodologies are used. First is to fix the number of copies and spread them through distinct nodes *(Spraying-based Replication)* and use metrics based historical encounters between nodes to decide whether to send a copy or not *(Conditional /Metric based Replication).*

Spraying-based Replication

Spray And Wait as stated by Spyropoulos et al. (2005) mitigates the overhead problem of epidemic schemes by limiting the number of copies maximally found in the network. It has two phases. In the Spray phase it sprays (i.e., distributes) the copies to intermediate nodes and then in the Wait phase it waits until one of them meets the destination node in order to deliver the message. In Spray and Focus stated again by Spyropoulos et al. (2007) uses a similar spray phase, followed by focus phase, where single copies can be forwarded to help maximize a utility function. Another variation in spraying phase can be source spraying or binary spraying. In the source spray scheme, the source node sprays copies to each encountered relay nodes and the relay node enters in to wait or focus phase. In binary spray scheme, half of the message copies are forwarded to each encountered node and the encountered node again sprays half of the copies to another encountered node. While both Spray and Wait and Spray and Focus succeed in limiting some of the network overhead of flooding based protocols, their deliver ratios are low.

Conditional Replication

ProPHET protocol proposed by Lindgren et al. (2003) considers the history of node encounters and transitivity information to estimate probabilistic metric called delivery predictability. Message is replicated during opportunistic node contacts if the delivery predictability of the destination of that bundle is higher at that node. This helps to limit the replication overhead. The main drawback of this scheme is that there is a message exchange prior to each transmission. In the papers of Li et al. (2008),Cao et al. (2012) it is described that message is replicated using location based utility metric assuming that the real-time or historic location information of the destination is known to all available nodes of the network. More of them are discussed in the next section.

Distance Model based Conditional Replication

Some routing Protocols like GeoDTN by Link et al. (2011), DEAR by Huang et al. (2007), VR by Kang et al. (2008), POR by Li et al. (2008), ORWAR by Sandulescu et al. (2010) considers both location information and message replication for routing. GeoDTN uses a score model and a distance based model and forwards messages towards a better candidate node based on the historical location information. DEAR is a hybrid approach combining forwarding and flooding. A node replicates messages to all contact nodes closer to the message destination, otherwise forwards the message to a contact node and clears its buffer. POR adopts the distance metric for message replication, but only replicating messages to one of its neighboring nodes and not to all contact nodes. Both DEAR and POR assume that the real-time location information of all nodes is available. In VR, one node driving in a horizontal direction copies messages to all contact nodes moving in the vertical direction. In ORWAR in addition to spray and wait, the connection time between two contact nodes is predicted to avoid incomplete message transmission.

All the above protocols location based protocols assume that location information of destination is available, which is impractical to obtain. GeoRaDR proposed by us uses the real time GPS location information for all relay nodes and uses the historical location information for destination nodes.

Geographic Replication and Drop Routing (GeoRaDR): A Hybrid Message Transmission Approach

The new proposed routing protocol exploits a slightly variant conditional replication strategy as used in *Spraying-based Replication and Conditional /Metric based Replication* methodologies. Apart from the above, message replication is also controlled by a Moving Vector which is *distance Model based* utilizing the historical location information of the destination node as described in GeoDTN . Our proposed GeoRaDR utilizes slightly variant approach from DEAR, POR, VR protocols for message Replication or Forwarding. GeoRaDR uses the historic data of the number of nodes present in the region between the source node and the destination node to calculate the Replication threshold and combines it with the messages Time To Live (TTL) threshold for replication and forwarding of messages.

In GeoRaDR, it is assumed that each node knows its own geo-coordinates, speed and direction of its own and the source node knows the location of the destination node based on historic data [3]. Replication decisions are made at every node encounters based on the combination of real time information of the encountered nodes and the historic location information of the destination node. The historic location information about the destination node, is required because in sparse networks getting the real time information about the destination is not possible on time.

Basic Idea and Notations used

With the real time location information of encountered nodes and the historic location information of the destination node, a node can easily predict the distance and direction of movement of nodes and compute the Motion Vector (MV). Based on the MV an encountered node is classified as Focus *Nodes* or *Deviating Nodes*. MV is combined with a Replication Threshold (R_T), which is derived from the approximate number of nodes available in the forward progress region of the Half Plane of the source node upon encounter. MV and R_T are used to choose better relay mechanisms, either Replicating or Forwarding of messages by the source node to the encountered nodes.

Table I. List of Notations

Variable	Definition
A	Message Carrier Node
B	Encountered Relay Node
D	Destination Node
M	Message
N	Total number of nodes in the Forward half Plane of a Node
TTL	Time To Live of message M
R_T	Replication Threshold of a node- maximum number of replications allowed to a node
RC	Replication Count –incremented every time a message M is replicated by a node
R-List	Replication List-List of IDs of encountered nodes to which message M is replicated and RC incremented
M-List	Message List-List of IDs of messages in the buffer
D-List	List of IDs of dropped messages with TTL
t_{elap}	Time elapsed for message M since inception
t_{rem}	Remaining Life Time of message M (TTL- t_{elap})
$L_t(D,A)$	Historical geo location (x_d, y_d) of destination D as recorded by A
$L_t(D,B)$	Historical geo location (x_d, y_d) of destination D as recorded by B
d_A	Distance from A to $L_t(D,A)$

d_B	Distance from B to L_t(D,B)
R	Radius of movement range of D
θ_A	Moving direction of A w.r.t. D
θ_B	Moving direction of B w.r.t. D
Φ_A	Relative Angle between θ_A and d_A
Φ_B	Relative Angle between θ_B and d_B
S_A	Moving speed of node A
S_B	Moving speed of Node B
MV	Motion Vector as a function of Φ, S

Assume Node A encounters Node B;

Node B is a ***Focus node***, when MV is $\Phi_B < \pi/2 \cap S_B > S_A$;
This means that Node B is currently moving towards the range of destination D and the speed of node B is greater than node A.

Node B is a ***Deviating Node*** when, MV is $\Phi_B >= \pi/2 \cap S_B > S_A$; or $\Phi_B >= \pi/2 \cap S_A > S_B$;
This means that Node B is currently moving away from the range of destination D regardless of the speed of node B being greater than or less than node A. Φ values are calculated as given in paper by Cao et al. (2014).

We also consider two types of message relays in this protocol.

(i) Message Replication, where the source Node A relays a copy of the message to an encountered Node B, while maintaining the original message.

(ii) Message Forwarding, where the source Node A relays the message to an encountered node, without maintaining a copy of the message with it. This happens when a source node finds an encountered which would be a better carrier of the message for efficient message delivery to the destination than the source node.

Formulation of the Half Plane (HP) and Forward Progress Region (FPR)

We consider unicast communication from a source A to a destination C in a DTN with N wireless nodes, moving within constrained area (forward progress region of half plane). Half plane is derived by connecting the source node and the destination node with an imaginary line and drawing a line perpendicular to it with reference to the source node as shown in figure 1 below.

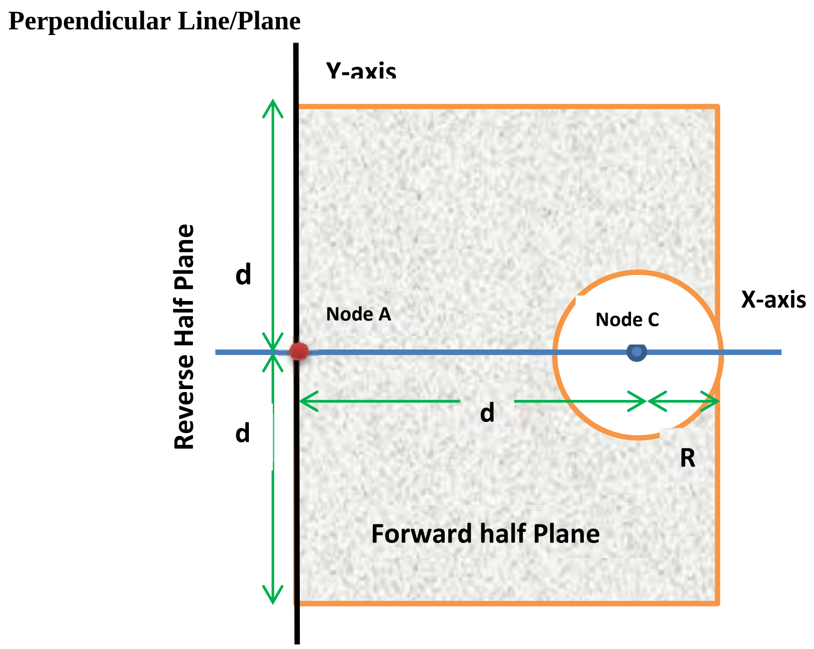

Figure 1: Forward Progress Region of a Node in the Half Plane

The forward progress region of a node in the half plane could be established using the distance *d* between Node A and Node C (destination node). This could be calculated by using their location information. If the Node C is not stationary, its historic movement range is assumed to be a circular region with radius *R* as described in by Cao et al. (2014).

So the FPR of a node in the HP is established by assuming the finite boundaries as follows:

(i) The length and width of the HP is 2*d*

(ii) The FPR is the region in the front of the HP (i.e) the region between the HP and the destination node as shown in Figure 1. In a two dimensional (2D) representation a rectangular region of length *(d+R)* and width *2d* and area *2d (d+R)*, would be considered, and could be called as the 2D forward half plane of Node A. But practically it would be a three dimensional (3D) space.

Formulation of the Replication Threshold of a Node

In order to determine the Replication Threshold (R_T) of Node A, the nodes available in the forward progress region of a node A is considered. This is also assumed to be got from the historic data of the number of nodes expected to be available in a particular geographic region. Let N be the total number of nodes available in the forward progress region of Node A.

In our proposed algorithm R_T is assumed to be 15% of N. R_T of a node is calculated during its first encounter (meeting a node which does not have a copy of the message M) to a relay node. For example if N=20, R_T = 3. Therefore, Node A can replicate only to three encountered nodes. The encountered nodes should be Focus nodes and not Deviating Nodes.

Likewise, every node on its first new encounter to transfer the message M, calculate its R_T based on the number of nodes available in its forward progress region and replicates message M based on R_T and by checking if the encountered node is a Focus node. Eventually, for nodes close to destination, the distance to destination is less and hence its forward progress region is less and the total number of nodes N present is less, reflecting on a low $R_{T.}$ Therefore, for nodes within the range of destination node C, R_T would be Zero and hence the message M will be forwarded (i.e) M delivered to destination. Thus, Replication threshold R_T limits the copies of message M in the network and saves buffer space and energy of nodes as well as network overhead.

Proposed GeoRaDR Routing Algorithm

Source A has message M to be transmitted to the destination C with the help of intermediate relay nodes. A transmission opportunity arises when a pair of Focus nodes "meet", they are within the communication range of each other. Each Node locally maintains some metadata, and exchanges part of them with a newly encountered node. The message format of GeoRaDR is show in Figure 2.

Destination ID	Source ID	M-List	R-List, RC	Initiation time of M	TTL

Figure 2: Message Format of GeoRaDR

Each node in the network is identified by a unique ID. When node A meets Node B, Information exchange takes place, where M-list and R-List and D-List are exchanged first to confirm whether the encountered node B has received any of the messages in M-list from other nodes already, whether Node B has been already encountered already by Node A and message M replicated and whether Node B has received the message M and has dropped it by becoming a Deviating Node at some point of time in the Network.

Once the updates have been done, then the Motion Vector (MV) of Node B is received and compared with that of Node A. Then message M is replicated to Node B, if R_T is less than or equal to RC and Node B is a Focus Node. The ID of the candidate node (Node A) will be recorded into R-List and RC is incremented after each successful message replication.

Within the range of R_T greater than or equal to RC and the message M remaining life time is greater than threshold T_{rem} , and Node A being a Focus Node, it can Replicate or Forward the message to any encountered Node B. The reference value of T_{rem} is assumed to be 25% of the TTL of M. Under normal conditions a node may drop messages when its buffer overflows.

In order to avoid this *buffer overflow* problem we have set the following condition in our protocol. Node drops the corresponding messages, once it becomes a Deviating node with reference to the Destination Node. This is due to the fact that a deviating node takes a different route and as the T_{rem} of the message is less, there is least probability that message carried by it will reach the destination node.

In order to handle the *Local Maximum Problem* we have set the following condition. Even if a Node A continues to be a Focus node it replicates the message to any encountered node, when the remaining TTL of the message is less than the threshold T_{rem} for handling the *Local Maximum Problem*. In this case even a Deviating Node can get the message and there is a possibility of it encountering a Focus Node and maintaining link reliability. Thus the *Local Maximum Problem* is handled.

The proposed algorithm of GeoRaDR is described below.

Proposed Algorithm: GeoRaDR

When Node A encounters Node B;
 both A and B update the R-List, and RC
 both A and B update the M-List and D-List
If (B is a destination node D ∩ No copy of M) **then**
  Forward message M
 else
  Both A and B compute Φ_A ,$\Phi_{B,}$ S_A, S_B
  Node A Compute R_T for first encounter
End if
If (RC < $R_{T\,,}$ ∩ B is Focus node) **then**
   message M *Replicated* to B
   RC=RC + 1
   R-List updated
 else If (RC >= R_T ∩ Node A is Focus Node) **then**
    If (Remaining TTL of M >T_{rem}) **then**
     message M is *Carried* by Node A;
    else message M is *Forwarded* to encountered node
    End If
   else If (Node A is Deviating) **then**
     message M *Dropped* by node A;
     D-List updated
    End If
   End If
 End If

Conclusion

In this paper, a new knowledge based controlled replication and drop Routing protocol for DTNs has been proposed. The protocol exploits the geographic information, velocity and direction of the nodes. With this information a node's Moving Vector (MV) is calculated and the messages are routed accordingly. Combining MV with the Replication Threshold (R_T) GeoRaDR handles the buffer overflow and network overhead problems. The local maximum problem and link reliability is handled by setting a threshold on the TTL of the message and proper relay of messages.

In the proposed protocol the message M is replicated only to the nodes available in the Forward Progress Region of the Half Plane between the source and the destination node. Here the unique idea of selecting a Replication threshold for each node based the number of nodes present in their forward half Plane is used to control message replication. This controls unwanted message replication and flooding of messages in the network and avoids redundancy problems. Moreover, buffer overflow problems and Local Maximum problem were handled by utilizing appropriate TTL threshold levels. It is suggested that the threshold levels fixed for

Replication R_T and Remaining Life Time T_{rem} of messages could be varied to fit different application scenarios of DTNs.

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