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A new approach to routing in Disruption Tolerant Networks

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***Abstract*—The architecture of Delay or Disruption Tolerant Networks (DTN) is particularly intended for scenarios in which it is difficult to build infrastructure and for networks characterized by one or more of i)lack of end-to-end connectivity, ii)frequent channel errors, ii)limited transmission opportunities, iv)highly asymmetric links, v)low data rates(high delivery delay), vi)heterogeneous network environments and vii)high RTT.DTN architecture is assumed to be implemented in any data network type from legacy connected to challenged intermittently connected mobile adhoc networks (IC-MANETs), from underwater to deep space communication via its adaption layer called Convergence Layer(CL).**

Despite the genericity of DTN architecture, DTN lacks well defined generic routing protocol. There are some papers on routing approaches, especially on georouting, in DTN.These proposed georouting approaches, however, have one or more of the following limitations: simulation based, lack details, genericity, practical applicability and conformance to standard frameworks, and/or are packet based.

This paper discusses an approach to a routing based on information given by geographic receivers.Although implementation scope of this paper is DTN, the author assumes its possible adaptability to other MANETs and future adaptability to other types of data networks.Especially, Sensor networks, vehicular communications, Intelligent Transport Systems(ITS), etc. benefit much from this approach.

***Index Terms*—Delivery predictability, characteristic time, $P_{first_{threshlod}}$**

I. Introduction

To date, the only routing protocol specified by DTNRG(DTN Research Group) for DTN is PRoPHET[RFC 6693]. PRoPHET expects the behaviour of the network to be probabilistic.Reflecting network behaviour in configuration of parameters is needed to use PRoPHET.According to assumption of PRoPHET, network behavior is static with respect to time.But this assumption has very limited application in real world.

In military scenario where nodes could move in random manner, e.g.in battle fields, it is difficult to predict the network behavior beforehand and configure the routing protocol accordingly.
One solution to such adverse conditions is routing based on the location, speed and heading of nodes and time elapsed since an encounter between nodes.

PRoPHET is not resource exhaustive unlike its predecessors epidemic and flooding. For this reason and for the sake of conformance, from implementation point of view, the skeleton of PRoPHET is used to exchange geographic data between nodes.Hence, the routing approach of this paper is named GeoPRoPHET.

A. Routing in DTN

1) Epidemic: A node gives every data it has to every node it comes in contact with. Simple but resource expensive scheme for getting DTN bundles to every encountered node and necessarily eventually to the intended destination, provided that bundle lifetime is adequate. The algorithm of Epidemic is that whenever two nodes encounter, they exchange any bundles they have that they do not already have. Because it tries every path, it finds the optimum path. Epidemic is feasible if we have large or infinite resource. But in practical situation, especially in ad-hoc networks it is difficult to have large resources.

2) Flooding: Flooding routing protocol seems to be used where there is no limit for resources (storage, bandwidth, power). It forwards in every interface other than through which the data is received. It forwards whether it senses the presence of a node to receive data or not.In this way, flooding guarantees data delivery to destination with minimum delay and less or no algorithms.

Due to exhaustive usage of resources and unintelligent behavior, flooding does not seem to be practical in ad-hoc networks which are usually characterized by scarcity of resource and /or bandwidth .

There seems no difference between flooding and epidemic but in flooding a node does not pass its own summary vector to neighbor.

3) PRoPHET: PRoPHET's concept was invented by Avri Doria and Anders Lindgren for the SNC (Sami Network Connectivity) project in 2002. Assumption of PRoPHET is based on opportunistic or predicted networks. That is the movement of nodes can be predicted or at least can be guessed.Such scenarios are common in public transport system. In public transport, systems not only the direction of movement of nodes but also the time interval can be predicted or known. This means, if a node encounters an other node several times, it has high probability of encountering the same node in the future.

The objective behind PRoPHET is to give optimum solution with respect to storage, delay, bandwidth and message delivery ratio when bandwidth and buffer are limited and nodes move in more over less predictable manner.

The fundamental parameter in PRoPHET is characteristic time, the expected time duration between encounters.Characteristic time gives expected time duration needed for traffic to be delivered to final destination. It is scenario dependent and is parameter on which PRoPHETs configuration

Routing protocol	Metric parameters
Connected interface	
Static route	
EIGRP	bandwidth, delay, load, reliability
IGRP	bandwidth, delay, load, reliability
OSPF	cost
IS-IS	cost
RIP	Hop count
Unknown	
GeoPRoPHET	Heading, D_xy, D_z, V_xy, V_z, k

TABLE I
ROUTING PROTOCOLS AND METRIC PARAMETERS

[1]is based. If PRoPHET is configured properly, it builds local model of the expected pattern of network that can be used to optimize the usage of resources by reducing unnecessary traffic. The analogy in traditional networks is link state routing protocols, which maintain topology map of the network they are involved in. e.g. OSPF. The more frequently two nodes encounter, the higher delivery predictability is between them.

B. Georouting

There are some papers on georouting.

1) LARODLoDiS: LARODLoDiS is a routing protocol proposed for Intermittently Connected Mobile Ad Hoc Networks(IC- MANETs).LARODLoDiS assumes forwarding of data on a per-packet basis . As DTN message is bundle based it can not be used in DTN directly.Moreover, its algorithms to utilize geographic information are not public.

2) geoDTN(Geographic Routing in Disruption Tolerant Networks): geoDTN considers only two(latitude and longitude) parameters out of 7 available geographic information.

3) Contention-based forwarding for mobile ad hoc networks: This is packet based and considers only two(latitude and longitude) parameters out of 7 available geographic informations.As we know from legacy routing protocols, the more metric parameters a routing protocol uses, the more reliable it is. In a similar fashion, if we are confined to latitude and longitude parameters in georouting, if a drone flies straight upward, we will not have information about the exact location of the drone.Rather, it is wrongly assumed that the drone stays at its initial position.

C. Methodology

The calculation and definition of equation is based on how GPS [2] receiver gives geographic information.The GPS receiver gives geographic information as follows
Longitude:in degrees[minimum 0, maximum 180]
Latitude:in degrees[minimum 0, maximum 90]
Altitude:height from see level in ft or in m
Speed:2 dimensional speed(speed in latitude-longitude or x-y plane) in ft/s or m/s
Heading:direction of movement in degrees with respect to North Pole(minimum 0, maximum 360)
Climb:vertical speed(speed in altitude or z direction) ft/s or m/s
Based on GPS information, the momentary relative speed and distance between 2 nodes can be calculated. For development and implementation, the IBR-DTN framework is used.However, the the mathematical equations used to utilize the geographic information can be used in other DTN architectures [JDTN, DTN2, Bytewella, NAC, ION, DTNLite] and other packet based architectures. The message format for the exchange of geographic information and some terms like Delivery Predictability, $P_{first_{threshold}}$ are adapted from RFC 6693 for the sake of conformance. [3]

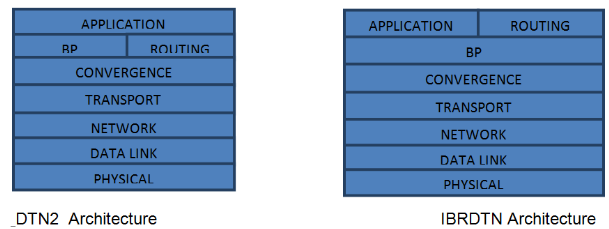


Fig. 1. DTN vs IBRDTN

1) Displacement from degree Coordinates in to m : Assumption: the earth is perfectly round because of relatively small distances[radio range].
Equatorial Radius($(equa_{rad}$)=6378200m.
Polar Radius=6356750m.
Geometric arc or sector length

$$s = theta * radius \tag{1}$$

, where theta is in radians.
Latitude Displacement

$$(lat_{displmnt}) = |Lat_1 - Lat_2|/360 * polar_{radius} * 2 * pi \tag{2}$$

=

$$|Lat_1 - Lat_2| * (pi/180) * polar_{radius} \tag{3}$$

Calculating displacement between 2 longitudes is a bit more complicated because it requires the respective latitudes in the formula as distance between two longitudes depends on latitude.An average between the latitudes is used.
Longitude Displacement, $long_{displmnt}$

$$= |Lon_1 - Lon_2|/360 * equa_{rad} * 2 * pi * cos((Lat_1 + Lat_2)/2) \tag{4}$$

$$= |Lon_1 - Lon_2| * (pi/180) * (equa_{rad} * cos((Lat_1 + Lat_2)/2) \tag{5}$$

Altitude if read in ft, in m=ft/3.2808.Altitude Displacement

$$alt_{displmnt} = Alt_1 - Alt_2 \tag{6}$$

[1]D_xy, D_z, V_xy, V_z denote displacement in latitude and longitude plane, altitude displacement, speed in latitude and longitude plane and speed in altitude direction respectively.
[2]The receiver could be Galileo, Glonass, Beiduo or other type.
[3]BP:Bundle Protocol(RFC 5050)

2) Equations to utilize geo information for GeoPRoPHET : Heading difference between two nodes $= 180°$or$= -180°$ when moving in opposite direction, and $= 0°$ when moving in the same direction.
Let $V1 = speed$ of node 1 in X-Y plane
$Theta1 = heading$ of node1
$V2 = speed$ of node 2 in X-Y plane
$Theta2 = heading$ of node 2
$Theta = theta1 - theta2$
$Climb1 = climb$ of node 1
$Climb2 = climb$ of node2
$V = relative$ speed
$Climb = Climb1 - Climb2$[vertical speed]
$D = Displacement$ between node1 and node2
Then the relative [4] speed, v, is defined as :

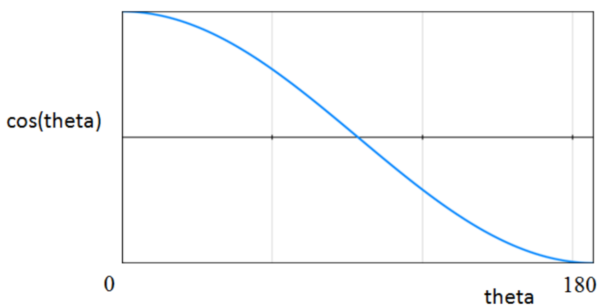


Fig. 2. Cosine function

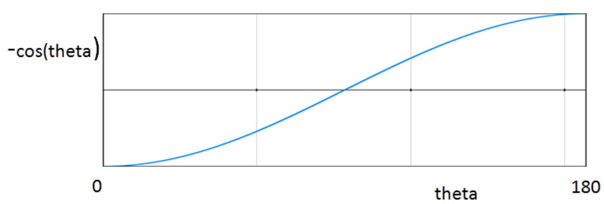


Fig. 3. Negative of cosine function

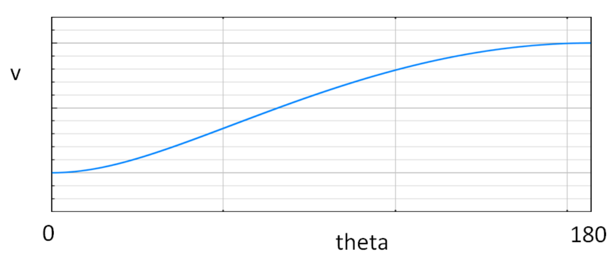


Fig. 4. $V = \sqrt{v1^2 + v2^2 - 2 * v1 * v2 * cos(theta)}$ for $v1 = 5$ and $v2 = 10$

$$v = \sqrt{v1^2 + v2^2 - 2v1 * v2 * cos(theta) + climb^2} \quad (7)$$

[if $0° \leq theta \leq 180°$]

$$v = \sqrt{v1^2 + v2^2 - 2 * v1 * v2 * |cos(theta)| + climb^2} \quad (8)$$

[4]Relative speed in this context does not necessarily mean Physics' relative speed, rather equation that treats fairly so that the decision made is fair.

PRoPHET	GeoPRoPHET	remark
β	β	Transitivity factor([0,1])
γ	γ	Aging factor ([0,1])
δ		History of encounter factor
P_encounter_first		
P_encounter_max		
P_threshold	P_threshold	Min value of deliverability
k	k	Number of time units

TABLE II
PROTOCOL PARAMETERS OF GEOPROPHET VS PROPHET

[if $180° < theta$ or $theta < -180°$]
The condition when nodes move towards each other is not yet treated by the above equations.As the theta is 180° or $-180°$, it is treated as if the nodes are moving away.But the remedy is that the distance decreases and eventually becomes 0 when the nodes meet and DP_{xy} becomes high enough.

$$D = \sqrt{(lat_{displmnt})^2 + (long_{displmnt})^2 + (Alt_{displmnt})^2} \quad (9)$$

D. GeoPRoPHET

1) Metric Parameters: The motivation behind GeoPRoPHET is to have optimum routing protocol which is not resource(bandwidth, power and memory) exhaustive, yet with expectation of random movement of nodes.

$$DP_{ab} = \frac{1}{D_{ab} + 1} + \frac{1}{S_{ab} + 1} \quad (10)$$

, where DP_{ab}, D_{ab} and S_{ab} are delivery predictability, distance and relative speed between nodes a and b respectively. $DP_{ab} = \frac{1}{D_{ab}+1} + \frac{1}{S_{ab}+1}$ is preferred to $DP_{ab} = \frac{1}{D_{ab}+S_{ab}+1}$ or $DP_{ab} = \frac{1}{D_{ab}*S_{ab}+1}$ because its gradient is low and changes slowly.

$$DP_{ac} = \frac{1}{D_{ac} + 1} + \frac{1}{S_{ac} + 1} * \gamma^k * beta \quad (11)$$

, where k is number of time units elapsed since b encountered c.

$$P_{first_{threshold}} = \frac{1}{max.radio_range} + \frac{1}{max.speed} \quad (12)$$

.

$$DP_{xy} = DP_{xy} * \gamma^k \quad (13)$$

.
For GeoPRoPHET, $p_{first_{threshold}}$ is not fixed value unlike 0.1 in PRoPHET.$P_{first_{threshold}}$,[5] in GeoPRoPHET, depends on relative distance and speed between two nodes as the delivery predictability is dependent on relative speed and distance. It depends on the radio range used in scenario which, in turn, depends on the power of transmission and

[5]To reduce data forwarded, delivery predictabilities smaller than $P_{first_{threshold}}$ are discarded.Care must be taken to ensure $P_{first_{threshold}}$ is less than any delivery predictability value which may exist in the network

frequency and maximum expected relative speed between nodes. Imagine two nodes having distance 5om and relative speed 80km/h(22.2m/s) and the radio range used is 1km.At this moment(k=0) $P_{first_{threshold}} = 1/22.2 + 1/1000 = 0.046045045045045$, which is much less than 0.1.But if we use $p_{first_{threshlod}} = 0.1$(PRoPHET's $p_{first_{threshlod}}$), the $p_{first_{threshlod}}$ can not depict the real situation. We have two approaches to use $p_{first_{threshlod}}$ in GeoPRoPHET:

1)Using

$$p_{first_{threshlod}} = \frac{1}{maxradio_{r}ange} + \frac{1}{max_{expectedrelativespeed}} \tag{14}$$

as it is.But this value becomes very small, especially in military scenario where low frequency and high power may be used. Due to approximations, it may be difficult to distinguish between two distinct values.

2)Keeping $p_{first_{threshlod}}$ and multiplying $\frac{1}{D+1} + \frac{1}{S+1}$ by $m * \frac{max_{radiorange} * max_{expectedrelativespeed}}{max_{radiorange} + max_{expectedrelativespeed}}$, where m is a constant dependent on :

i)The amount of available storage for RIB[6] .

ii)The number of network elements.

iii)The amount of maximum time we want an entry for a node to stay in RIB.

In this case the values become large and coarse enough to be distinct.The author proposes the second approach.

Thus, even if the skeleton of PRoPHET used, the philosophy of GeoPRoPHET is different.In GeoPRoPHET, there are no parameters history of encounter, δ and probability of encounter. In general GeoPRoPHET has the following advantages over PRoPHET:

1)It does not matter whether the encounter of nodes is opportunistic, deterministic or random.

2)It is not obligatory to reflect network behavior in configurations of parameters.

In PRoPHET, configuration of constants should reflect the behavior of the network.e.g if we set characteristic time lower value than nodes are expected to encounter, delivery predictability values decay soon and there may be no entries for many of nodes.This is because the aging factor is higher than the update factor that the delivery predictability (DP) age out and become less than $P_{first_{threshold}}$.Even though PRoPHET specification mentions that it can work in random environments, no simulation or implementation results are mentioned as backup.

3)In PRoPHET, malicious nodes may have configuration to seem better forwarder and to disrupt delivery of bundles.But in GeoPRoPHET as delivery predictability is not exchanged and determined only locally, a malicious node can not produce fake geo information continuously which may make it seem better candidate to forward bundles.

If we exchange delivery predictability in GeoPRoPHET, as depicted in the following figure, B can not tell right information about C to A.

[6]Routing Information Base

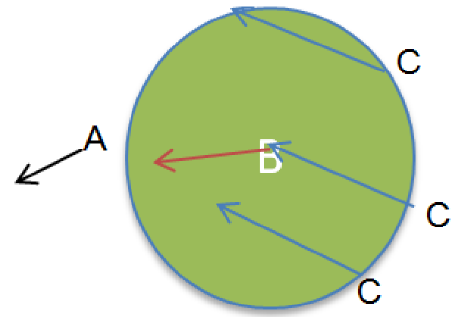
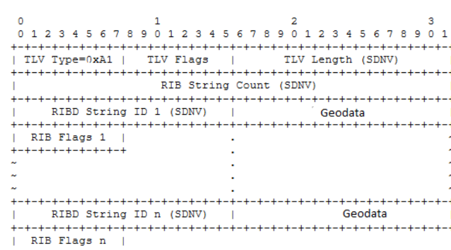


Fig. 5. Invalidity of exchanging locally determined DPxy in GeoPRoPHET

In figure 5, for node B, all Cs have the same displacement and velocity.For node A, all Cs have respective different displacement and velocity. For this reason B transfers to A its DP_{bc} and coordinates, speed and heading about C with time stamp rather than delivery predictability determined by B about C. A uses geographic information of C transferred by B with time stamp. A computes DP_{ac} and compares to D_{bc} whether it is better candidate for c than B is. It is obvious that in 3D the number of possible different positions and velocities for the same value of DP_{bc} increases.

2) Message format: As the skeleton of PRoPHET is used in GeoPRoPHET, there is no significant difference between the message formats of PRoPHET and GeoPRoPHET. The only difference is in the message format of Routing Information Base TLV format.In GeoPRoPHET, geographic information is exchanged instead of probability values of PRoPHET. The geographic information includes latitude, longitude, altitude, speed, climb, heading and time stamp at the time of contact with the other node. The probability values in prophet are in float format, where as in GeoPRoPHET all the 7 geographic information values are in double format.Hence, there is a significant increase in the number of bits used to exchange and store routing information.



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| TLV Type=0xA1 |   TLV Flags   |       TLV Length (SDNV)       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    RIB String Count (SDNV)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     RIBD String ID 1 (SDNV)   |            Geodata            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  RIB Flags 1  |               .                               ~
+-+-+-+-+-+-+-+-+               .                               ~
~                               .                               ~
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+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     RIBD String ID n (SDNV)   |                Geodata        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  RIB Flags n  |
+-+-+-+-+-+-+-+-+
```

Fig. 6. RIB TLV format of GeoPRoPHET

E. Future work

1)Evaluation of performance of georouting approach presented in this paper in a scenario where nodes move in random manner and flexibility with respect to different values of characteristic time.

2)As resource is scarce in adhoc networks, particularly in DTN, applying entropy coding in DTN saves much bandwidth and storage resources.

F. Limitations in real world scenarios

Factors that can degrade the GPS signal and thus affect accuracy include the following:

1)Ionosphere and troposphere delays: The satellite signal slows as it passes through the atmosphere. The GPS system uses a built in model that calculates an average amount of delay to partially correct for this type of error.

2)Signal multi path: This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.

3)Receiver clock errors: Built in clock of receiver is not as accurate as the atomic clocks onboard the GPS satellites. Therefore, it may have very slight timing errors.

4)Orbital errors: Also known as ephemeris errors, these are inaccuracies of the satellites reported location.

5)Number of satellites visible: The more satellites a GPS receiver can see, the better the accuracy.

6)Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. GPS units typically will not work indoors, underwater or underground.

7)Satellite geometry/shading: This refers to the relative position of the satellites at any given time.Ideal satellite geometry exits when the satellites are located at wide angles relative to each other; where as poor geometry results when the satellites are located in a line or in a tight grouping.

8)Intentional degradation of the satellite signal: Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. DoD.SA was intended to prevent military adversaries from using the highly accurate GPS signals.The government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers.

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