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SURVEY OF HISTORY BASED ROUTING PROTOCOLS IN DELAY TOLERANT NETWORK

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ABSTRACT. *Frequent changes in topology and the lack of infrastructure compel disrupted networks to avoid the use of traditional routing protocols. Rather than defining paths towards destinations, the routing tables store access chances of known nodes towards a specific destination. History of a node's encounter is maintained in three different ways to find out its power of access to the rest of network nodes. The survey paper discusses various routing schemes based on the past encounter patterns of network nodes.*

***Keywords**:* (Delay Tolerant Network) DTN; routing protocols; history-based routing; frequency; encounter; inter-contact duration; recency.

1. **Introduction.** Advent of wireless and mobile devices has facilitated communication from anywhere and at anytime. The usual mode of connectivity is either through base stations in cellular technology or through access points in WLANs. However there are certain situations where infrastructure is absent. These situations appear in battle fields, wild life tracking, less privileged, and far flung urban areas, destruction-hit locations and in under-water networks. Lack of backbone connectivity network, mobility of nodes, obstacles, limited radio ranges, power outages and sleep mode of nodes make continuous presence of contact links impossible in these networks. Instead of specialized relay equipments, nodes act as message forwarders for each other.

In the above situation a bi-directional connectivity might not be present at the time of message transmission therefore routing of messages to an out of range destination becomes a challenge. Traditional routing protocols like AODV [1] and DSR [2], which assume the presence of end-to-end connectivity, fail to route messages in a disconnected network.

The disrupted networks can utilize the architecture of Delay-Tolerant Network [3] for enabling communication among frequently disconnected nodes. This architecture is based on the principal of *store-carry and forward* strategy which, rather than discarding a message of an unreachable destination, makes a node to hold a message until it expires or till the destination or a better relay node takes it.

Depending upon the movement pattern of network nodes the routing protocols of disrupted networks can be broadly divided into three parts [4] namely contact-ignorant, history-based and device-based routing protocols.

Contact-ignorant routing schemes are useful when future paths of network nodes cannot be predictable. These unpredictable networks either use flooding, multi-copy or single copy methods. Flooding and multi-copy schemes are exploited when early delivery is more important than efficient use of the resources like in Epidemic [5] and Spray and Wait Binary/Normal [6] methods. However single-copy protocols like Direct Delivery [7] and First Contact [8] are used when proper utilization of scarce resources is essential than the early message delivery.

Movement pattern of nodes in some of the disrupted networks e.g. in PSN [9], MSN and satellite network [10] is either scheduled or periodic. Mobility paths of such nodes are hence predictable and are exploited by history-based routing protocols for making decisions about message forwarders.

In some other networks the nodes are either static or move within a limited area thus dividing the network in separate parts. To enable communication across partitions device-based schemes are used. Relay devices with higher radio ranges, performances and storage capacities are deployed to enable cross-partition communication as is described in Pigeon [11] and Data Mule [12].

The paper presents a survey, on the second type of communication scheme i.e., on *history-based routing protocols* where message forwarding nodes are not selected randomly but on the basis of history of interactions between network nodes. Routing decision is based on any of the three different metrics i.e. frequency of encounters, inter-contact durations or on recency of an encounter.

i. *Frequency of encounters:* It is assumed that greater the number of times any two nodes have encountered in the past the higher is the chances of their future encounter.

ii. *Inter-Contact Duration:* High frequency of encounters does not assure that a pair of nodes will encounter in near future i.e. the two nodes may come within each other's radio ranges greater number of times at the start of a time period but the frequency may decrease in the later part of the interval. To deal with such situation information about average inter-contact durations is stored that helps in determining the time left for a node to encounter destination.

iii. *Recency of Encounter:* Rather than storing and updating encounter frequency and inter-contact durations a simple method is to store the last time when a pair of nodes encountered. Inter-contact duration may not be uniform thus making the forwarding decision incorrect. Recency metric assumes that the chances to meet, in near future, with a person met an hour before is higher than with a person who has met a few days before.

In literature, however, some of the researchers have used a combination of above metrics to achieve a better routing performance.

The survey paper contains four sections. Section one gives an overview of frequency of encounters based routing protocols while section two elicits routing schemes that make routing decisions on the basis of inter-contact durations. Third section describes the protocols that select message forwarders using recency factor of nodes' encounters. Last section concludes the paper.

2. **Frequency of encounters based routing protocols**. Frequency-based routing schemes keep track of number of times any two nodes have encountered in the past. The high and low rate of meeting frequency of a node with a destination makes it select or reject as a message forwarder. The subsequent paragraphs, in this section, discuss some of the prominent routing protocols that prefer those relay nodes that have higher meeting probabilities with destination node.

In PRoPHET [13] every node maintains a variable called delivery predictability (DP) for every other node of the network with value ranging from zero to one. Higher value indicates that the nodes were accessible to each other either directly or indirectly much number of times in the past. During contact the value of mutual DP increases while it decreases when the two nodes are away. When source node comes in contact with a node other than destination, source node compares its own DP towards destination with that of the encountered node's. In case encountered node has higher DP then a message copy is handed over to it. If encounter frequency is uneven during length of the period then routing decision might be misleading at certain points in the time period.

An adaptive version of PRoPHET scheme [13] called PRoPHET+ is proposed by T. Huang et al [14] in order to achieve better routing using a single message instance. In addition to delivery predictability, forwarding decision in PRoPHET+ also takes into account the buffer space, power level, contact duration and popularity of the encountering node. It is because a short buffer space may lead to the dicarding of one of the message in candidate node (on the basis of FIFO), power outage and failure of the single popular node will result in loss of all buffered messages, short contact duration may hinder a node in full message transmission. Taking into consideration these four metrics along with delivery predictability of candidate node results in more realistic message forwarding decision.

Figure 1 shows message transfer from node *S* to node *D*, where the message is forwarded to a neighboring node that has higher delivery predictability (DP) towards destination than the current message carrier.

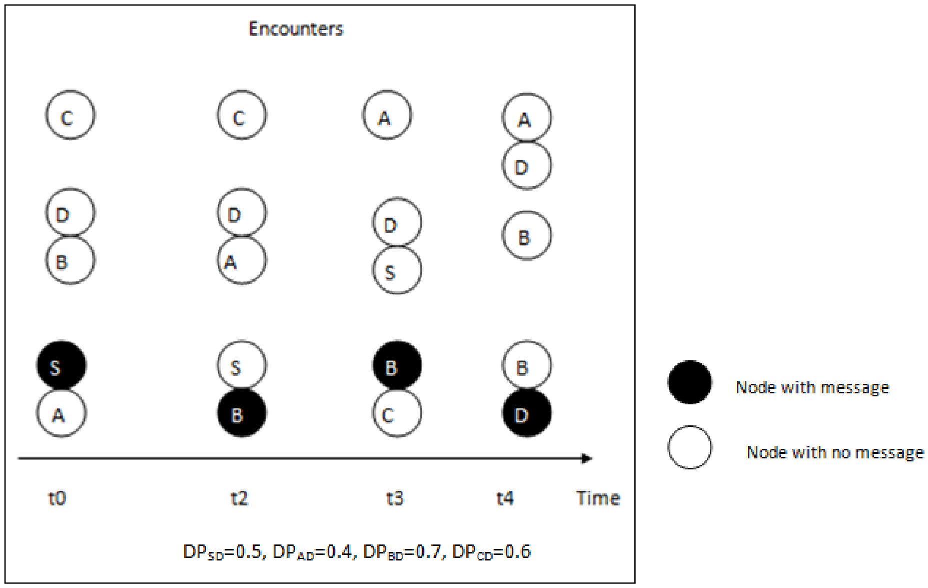

Figure 1. Message forwarding in a single copy frequency-based routing scheme

E. C. R. de Oliveira and C. V. N. de Albuquerque [14] proposed NECTAR where a variable, called Neighborhood Index (NI), is maintained between every pair of nodes and has similar functionality to that of DP [13]. NECTAR allows conditional flooding when message is quite new so that to increase the chances of successful delivery, however this process lays burden upon the system by un-intelligently forwarding message replicas. As message gets older no further copies are produced rather NI decides about forwarders of a message.

S.C Nelson et al [16] presented the idea of Encounter Based Routing (EBR) where forwarding decision and the number of message replicas that are to be handed over to an encountered node depends upon its Encounter Value (EV) with destination. EV has similar functionality to that of DP [13] however in EBR there is no rule for the number of message replicas generation. Therefore a fixed number of message replicas for every situation with lack of message discard mechanism may lead to drawbacks of flooding scheme.

SMART [16] protocol has three phases namely *normal spraying*, *companion spraying* and *direct transmission*. Initially Spray and Wait Binary [6] procedure is used to create a certain amount of message replicas. If source is not a companion of destination, then using (normal) spraying phase of Spray and Wait Binary Protocol, message copies are distributed among encountered nodes. When a single message is left with a node, it is delivered either to the destination or to the companion nodes of destination node. The term companion means a frequently encountering node. In case a message copy arrives at companion node of the destination, it reproduces certain number of message replicas and disseminates them to other companion nodes of destination nodes using Spray and wait Binary mechanism (called companion spraying). When a companion node is left with a single copy, it is no more in companion spray phase, rather it switches to direct transmission phase. In this last phase message is only delivered to destination node. Every node maintains a Companion Value (CV) for each encountered node. CV is directly proportional to number of encounters; however its value decreases with increasing age of encounter and large inter-contact durations. It is calculated for current finished time period which means an updated value determines companionship. Though the scheme increases good put and reduces latency yet it ultimately increases congestion and burdens the network links and buffers.

BubbleRap [17] is proposed for a social-based community scheme which maintains *local ranking* and *global ranking* for each node. *Local ranking* and *global ranking* of a node represent number of distinct nodes with which this node has encountered within its community and in different communities respectively in the recently ended time slot. If source and destination belong to same community then the message is forwarded through the encountered node which has higher local ranking than the current node while global ranking is used when destination belongs to a separate community. This procedure continues until message arrives at the destination. Though BubbleRap provides a simple solution yet high ranking does not ensure that the node will meet destination node.

E. Bulut et al [18] proposed Friendship Based Routing (FBR) protocol. Here each node finds out its friendship community via its link quality with other nodes in the network. To calculate weight of the friendship link it takes into account three features i.e. high frequency of meeting, longevity and regularity. Social Pressure Metric (SPM) incorporates all these features in a single metric and shows the average forwarding delay of a message from one node to another node. A node can have different friendship lists for different time periods of a day therefore when the encounter of two nodes occurs near the end of current period, i.e. below certain threshold time, then forwarding choice is done on the basis of next friendship period. Instead of using threshold time value, a better solution can be to calculate expected time left to encounter destination. This time should be then compared with the time left for current period to end. If it is found that encountered node will meet destination before its current period finishes; the message will be transferred to it, else next friendship period should be used.

Rather than considering encounter frequency of node towards destination, J. Ghosh et. al [19] proposed the message copies to be forwarded towards the most visited locations of destination node. Every node creates its mobility profile which contains the most regularly visited locations called hubs (e.g. schools, libraries, parks etc) of a person along with the probabilities of its presence at a particular place at a particular time period. A mobile node dessiminates its mobility profile in network to help others in making appropriate message forwarding decisions. A node is considered to be a good carrier of message copy if it shares one or more hubs with destination node. If total number of message copies that a carrier can forward are k in number, then k/2 message copies are forwarded to those neighboring nodes that have high probability to visit the most visited hub of the destination node. The remaining k/2 copies are given to those nodes that have high probability of visiting the second frequently visited hub of the destination. Same process is repeated by each message holding node until it reaches the destination node.

M. Xio et al [21] proposed an efficient community-aware opportunistic routing scheme (CAOR) where a frequently visited location of a node is considered its home community. If destination belongs to the home of source node then source node forwards the message through that intermediate node (called throw-box) which is either permanently residing or mostly present at the home community. In case destination belongs to a separate community then source node delivers the message through the first encountered node from a set of relay nodes who are members of both source and destination communities.

L. Vu et al [22] also presented a community-based protocol, COMFA, which divides the network into communities and makes a node to split its whole period of activity into time slots. Contact probability for each node in each time slot is maintained by keeping a record having fields < Day type, time slot, contact probability of each node of the community> where day type can be weekend or weekday. This division overcomes the problem of wrong forwarding decision which is made when a node though has high meeting probability towards destination, but before message expiry it has no chance to encounter destination. In COMFA source node attaches current day type with the message and forwards it to the node having higher chances of delivery before its expiry. If a node receives a message at weekday and has opportunity to forward it at weekend then day type field of the message is updated. If schedule varies for each weekday then instead of two different types of days, contact probabilities for each of the seven different days are kept in routing table. Incase current node and encountered node have same probability then the decision of custodian be made on the greater number of distinct nodes that the two nodes have encountered. In COMFA each node maintains its own contact probability table, there is no need to transfer and share each other’s tables, but the scheme can work well when the network is strictly scheduled. However finer granularity increases routing table size.

In PRO [23] each node maintains a local observation table where each record in the table stores observation rankings of encountered nodes in a particular time slice of the week. Observation ranking denotes probability of observing a node periodically in that particular time interval. Intra community forwarding is done using observation score (OS). OS is the probability of observing the destination node with respect to maximum delay tolerance. An encountered node with greater OS towards destination than the current node is preferred to be the custodian of the message.

The space-time routing protocol [24] assumes network to be strictly periodic in nature. To cope with changing topology, each node maintains a space-time routing table that maintains different next hops to a destination with respect to different time slots within a time period. These next hops are selected by applying Floyd-Warshall algorithm on available paths in a particular time slice. Besides the calculation of shortest path; the collection of possible paths towards destination, where a complete path in a single time slice is rare, is quite complex.

W. Gao and G. Cao [25] point out that contact distribution of mobile nodes during short time periods varies much from their cumulative contact characteristics therefore selection of forwarders, on the basis of later metric, may not be the best selection in a limited time constraint. They propose to forward a message by taking into consideration possibility of a node to meet a destination within limited time duration. This is done by storing transient contact information. Transient meeting rate of a node with destination is calculated and updated by counting their direct contacts for every time portion, separately, in whole time period. Transient contact distribution table is maintained by every node to help in best selection of the next forwarder with respect to current portion of the time period. This near to optimal selection results in low delivery delay and high delivery ratio. Authors plan to enhance the scheme by including transitive connectivity along with direct contact for calculating transient contacts.

In Sociability-based routing scheme [26] a variable, called sociability indicator (SI), is associated to each node. SI presents the total number of encounters of a node within a time period divided by maximum possible number of encounters in that time period. A high SI indicates that a node is social and has chances to meet many nodes in a given time interval. The SI of an unsocial node having a highly social neighbor increases by taking into account k-hop encounters.

The protocol [26] is much better than blind flooding in the sense that a node hands over a copy of its message to the encountered node only if encountered node has higher SI than it. This means that a high social node does not create and forward its copy to any other node while an isolated source accesses destination by making and distributing copies of message to its social neighbors.

Routing Protocol	**Message Copies**	**Knowledge Oracle**	**Delivery Ratio**	**Delivery Delay**	**Message Discard Policy**	**Chances of Congestion**
PRoPHET	Multiple	Summarized	Medium	Medium	Yes	Medium
PRoPHET+	Single	Summarized	Medium	Medium	No	Low
NECTAR	Multiple (variable)	Summarized	High	Low	Yes	High
EBR	Multiple (pre defined)	Summarized	High	Low	No	Medium
SMART	Multiple (variable)	Summarized	High	Low	No	High
BubbleRap	Single	Very limited	Low	High	No	Low
FBR	Single	Detailed	High	Low	No	Low
Mobility profile based routing	Multiple	Limited	Medium	Medium	No	Medium
CAOR	Single	Summarized	High	Medium	No	No
COMFA	Single	Very Detailed	High	Low	No	Low
PRO	Multiple (pre-defined)	Detailed	High	Low	No	Medium
Space Time routing		Detailed				
Exploiting Transient Contact Patterns	Single	Detailed	High	Low	No	Low
Sociability-based Routing	Multiple	Very Limited	Medium	Medium	No	High

Table 1. Characteristics of frequency-based routing schemes

3. **Inter-Contact Duration-based Routing Protocols**. Routing can also be performed heuristically by storing inter-contact durations between any two nodes. The collection of these past durations can help in determining the estimated time left for a particular encounter to occur. In this section routing protocols that exploit past inter-meeting times between network nodes are discussed in brief.

Minimum Expected Encounter Delay (MEED) [25] is a shortest path routing protocol. Every node calculates its expected encounter delay towards rest of the nodes. It uses epidemic routing algorithm for spreading this information. If two node are in contact, their mutual MEED is zero else the average waiting time for a message to go from one node to another node is determined by the sum of their disconnection durations in a particular time period divided by the duration of time period. If disconnection duration and timings are not uniformly distributed, then MEED does not give accurate result.

The following figure shows message forwarding done upon the average inter-contact duration of a neighboring node and the destination entity. Message forwarding from node *S* to *D* is thus performed by the expected meeting delay, ED, towards destination of encountering node.

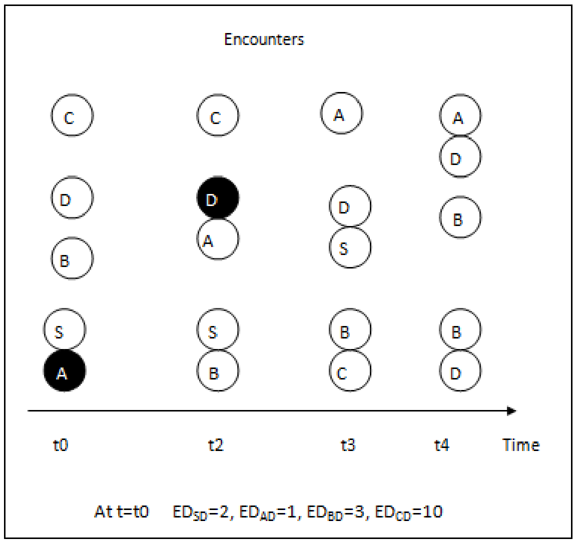

Figure 2. Message forwarding on the basis of expected delay to encounter destination

Unlike other history-based routing protocols, ARBR [28] not only takes into consideration the contact duration history of the encountered node towards destination, in a particular time window, but also the capacity of wireless link towards the encountered node (i.e. congestion and interference) and the buffer status of the encountered node (i.e. full or empty) for decision making in message forwarding. The protocol is adaptive to the changing situations in the network by constantly updating its history and claims to result in reduced message delivery delay and number of transmissions with increased delivery ratio. The protocol exchanges not only summary vectors of the buffered messages but also the contact history table along with the new status in current time window so that the protocol may work.

OPF [27] provides a delivery probability derivation formula by not only taking into account encountered node's inter-meeting times with destination but also remaining life time and hop count of the message. If full information about inter-meeting times between network nodes is known, and hops to be traversed are limited to H then 2^H message copies are generated. Message holding node increments the hop count value of the message by one, keeping a single copy with itself; it hands over a copy to that encountered node which has higher expectations to deliver the message to destination before its expiry. Hence there are a maximum of 2^H recipients. However if partial information is available then OPF switches to Spray and Wait Binary process.

In [28] H. Chen and W. Lou have proposed Expected Encounter-based Routing (EER); a multi-copy routing protocol that distributes message copies on the basis of expected encounter value (EEV) of the nodes. Every node maintains records of its past meeting durations with other nodes. EEV means the expected number of nodes a node may meet before expiry of the message. If a node has multiple message replicas, it divides the number of replicas proportionally according to its own EEV and encountered nodes' EEV. Encountered node is given its portion of messages. Once each node is left with a single message copy then the current node compares its Minimum Expected Meeting Delay (MEED) with that of the encountered node's. The one having smaller MEED value is handed over the message. MEED is calculated both with respect to single-hop and multi-hop. A community based structure is used to lower the burden of maintaining global information.

Conditional Shortest Path (CSP) [29] presents the idea of conditional intermeeting time metric. This metric measures inter-meeting time between two nodes relative to meeting with a third node. Let there be three nodes A, B and C and period is of 12 time units. A and B encounters every 12 time units (1, 13, 25 …) and B, C encounters every 6 time units (2, 8, 14 …). It can be deduced that whenever B encounters A, it encounters C one unit time later. In CSP, therefore, along with maintaining standard intermeeting times a node has also to maintain conditional intermeeting times leading to a complex processing mechanism. Moreover CSP may not select optimal path if destination is multiple hops away.

ICR [32] presents a multi-copy routing protocol. The number of message copies handed over to an encountered node depends upon its inter-contact delay towards a destination. Every node consists of two types of tables i.e. a single inter-contact delay table and multiple routing tables. An inter-contact delay table consists of average and variance of time left to encounter a particular destination while routing table is actually an inter-contact delay table of a previously met node. With the help of these tables a node selects forwarders who have high chances to meet destination before message expiry.

S. Medjiah and T. Ahmed [33] claim a procedure that finds out that when and for how long next contact will happen. They assume that each communicating device is equipped with location hardware that helps in selecting the neighbor who is closest to destination. If such a node is not available, forwarder node looks for most advancing connected neighbor towards destination. Even if such a neighbor is not found then ORION [33] uses Auto-Regression Moving Average (ARMA (2, 1)) scheme for predicting the duration of next connection and disconnection of neighbors with destination node. A neighbor who is expected to have left least time to meet destination is handed over the message.

M. Y. S. Uddin et al [32] present a routing strategy that uses local contact information of a node for message forwarding. Each node keeps contact history in the form <event, time, node ID >, where *event* is either *contact_start* or *contact_end*, *time* is the time at which event occurred and *node ID* is the identifier of the node with which the event occurred. Expected waiting time is represented as the average length of the disconnection interval minus time passed since the last contact ended. Each node keeps a routing table. Each entry of the routing table is of the form <destination, probability to reach destination, delay to reach destination, next hop>, initially when there is no contact trace available, the probability of delivering message to any node is zero and the estimated delay is infinity. On an encounter every node updates and shares its routing table with its neighbor(s). Therefore the routing table of a node is either updated by a node using its own contact-trace or by the better information received from the routing tables of neighboring nodes. Source node sends message directly to destination if it is in contact; otherwise the routing table is referred. If next hop is currently in neighbor list, message is forwarded to the next-hop else it is kept in buffer till the routing

Routing Protocol	Message Copies	Knowledge Oracle	Delivery Ratio	Delivery Delay	Message Discard Policy	Chances of Congestion

table updates. If buffer is full and there is no space for new messages then those messages are discarded first which have suffered largest delay.

MEED	Single	Summarized	Medium	Medium	No	Medium
ARBR	Multiple (variable)	Summarized	Medium	Medium	No	Medium
OPF	Multiple (fixed)	Summarized	High	Medium	No	Medium
EER	Multiple (pre-defined)	Summarized	High	Low	No	High
CSP	Single	Summarized	Low	High	No	Low
ICR	Multiple	Detailed	High	Low	No	Medium
ORION	Single	Summarized	Medium	Medium	No	Low
Social Structure based Routing [35]	Single	Detailed	Medium	Medium	Yes	Low

Table 2. Characteristics of contact duration based routing protocols

4. **Recency of Encounters based Routing Protocols**. Third category of heuristic routing protocols gives priority to recent encounters by considering that a node has higher chances of encountering again if it has come in contact a few minutes ago than the one that has met a few hours ago.

J. Burgess et al. implemented MaxProp[34] in a network of fast moving nodes. In order to better utilize the limited storage capacity of mobile nodes and short links; the nodes in MaxProp prefer to pass those messages to the encountered node first that are new and have higher delivery probability towards destination. In case of full buffers, messages are discarded on the basis of their old age and low delivery probability. In this scheme delivery predictability towards different destinations is calculated by keeping a vector $F_i=(f_{0i}, f_{1i}, . . . , f_{(j-1)i})$, where i is current node and j are total number of the nodes in system. Sum of all elements of vector F_i is always equal to 1. Whenever a node k encounters a node i, the value f_{ki} is incremented by 1. The result of the vector sum F_i and the value of each element in F_i is divided by 2. This is done to normalize the value of F_i again to 1. MaxProp considers that a node met in near past has higher chances to meet soon again than those met in far past.

H. Dubios et al [34] defined FRESH. In this technique each node keeps a table that maintains the most recent encounter times, called encounter age, of current node with the rest of the nodes in the system.

The protocol uses relative times for storing encounter ages therefore synchronization between nodes' clocks is not required. Source node prefers to hand over message to that node which has more recently met with destination node. The process is repeated until message reaches destination. It is a simple procedure as a node has never to update its routing table on the basis of information in the routing table of encountered node. Due to periodic nature of the network it may happen that currently encountered nodes may not meet until the same point in time approaches again.

A. Makke et al [36] recommended Time-Aware Opportunistic (TAO) routing scheme where each node maintains a neighbor list, the IDs of the non-neighbor nodes which this node has encountered some time ago along with their last contact timings and the IDs of nodes with which its neighboring nodes have encountered along with their last contact timings. A message copy is forwarded to a good node that has recently met with destination node so that to move the message closer towards the destination. In case a carrier node has no good neighbor then message copies are distributed among bad neighbors with the expectation that good node(s) might meet the bad node(s).

Figure 3 presents message forwarding process from node *S* to node *D* using encounter age (EA) of neighboring node with destination node.

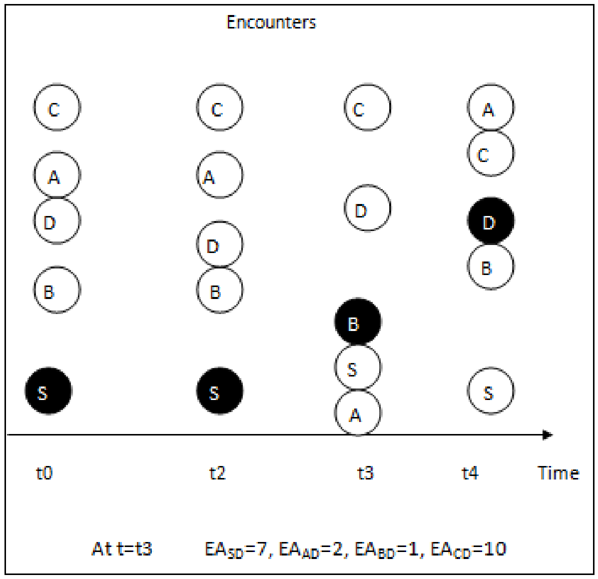

Figure 3. Message forwarding on the basis of encounter age of the neighboring node with the destination node

Spray and Focus [38] has two phases; a spraying and a forwarding phase. Spray phase exploits Spray and Wait Binary [6] for distribution of message copies to the nodes that have not previously received a copy. This method speeds up the process of spreading the message copies in the network. After a node is left with a single copy, unlike Spray and Wait [6], the copy is transmitted to the encountered node having greater utility where utility of two nodes towards each other is high if they have encountered recently. Spray and Focus also incorporates transitivity that finds utility towards a rarely encountered node via mutual friends. Nevertheless currently encountered node does not guarantee its encounter in near future.

In another recency-based routing protocol EASE [32] each node maintains a table that stores two pieces of information about rest of the network nodes i.e. last encounter time and location of the node with which this node has encountered. Whenever a node has a message, it searches for a node that has recently encountered destination, once such a node is found, the location information stored with it about destination is used to forward message in that particular direction.

Table 3. Characteristics of recency based routing protocol

5. **Conclusion.** The survey paper provides a brief overview of the routing schemes for periodic and scheduled disconnected wireless networks. These routing protocols exploit past history of a node's mobility pattern for future routing decisions.

The history is maintained in the form of meeting frequency of two nodes within a time period, their inter-meeting durations or their last encounter timings. All of the history based routing schemes either use one or a combination of above history based metrics. These routing schemes are more intelligent compared to zero-knowledge based routing schemes and therefore results in better utilization of the scarce resources in the disconnected wireless networks.

Routing Protocol	Message Copies	Knowledge Oracle	Delivery Ratio	Delivery Delay	Message Discard Policy	Chances of Congestion
MaxProp	Multiple	Summarized	Medium	Medium	Yes	Medium
FRESH	Single	Limited	Low	High	No	No
TAO	Multiple	Summarized	Medium	Medium	Yes	Medium
Spray and Focus	Multiple	Limited	Medium	Medium	No	Medium
EASE	Single copy	Limited	Low	High	No	No

Apart from briefly discussing the routing mechanism of each of the history-based communication protocol, the paper also highlights their different characteristics such as average delivery ratio and delay, burden on system in terms of knowledge base required and message copies generated for early delivery of messages. Depending upon available scenario and affordable resources one can choose an appropriate routing scheme according to its inherent characteristics.

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