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Random Walk-Driven Encounter Routing for Enhanced Delivery Efficiency in DTNs

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ABSTRACT

Traditional networks face challenges in delivering messages when no direct path exists between the nodes. Delay Tolerant Networks address this issue through specialised algorithms, many of which leverage social metrics to select optimal relay nodes. While these approaches improve message delivery, they often incur high overhead costs. This paper introduces the routing protocol for DTNs, which aims to balance efficiency and performance by using three social metrics: Degree Centrality, Social Activeness, and Random Walk Encounter. Degree Centrality and Social Activeness both are already used in literature but we introduce a new social attribute called as Random Walk Encounter. The philosophy behind this protocol is to prioritise nodes that exhibit higher social connectivity and activity, ensuring that messages are forwarded through nodes with the best potential to enhance delivery performance while minimising the overhead associated with more traditional methods. The message is forwarded to the node with the highest Degree Centrality, Social Activeness, and Random Walk Encounter value, and this process continues until the message reaches its destination. The design philosophy behind this approach is to use social metrics that correlate with real-world human behaviours, optimising the selection of relay nodes for efficient data forwarding. We run the simulations with all three social attributes individually with same set parameters and simulation results show that proposed social attribute named as Random Walk Encounter outperforms Degree Centrality and Social Activeness, improving the Packet Delivery Ratio, with fewer hops and reduced overhead, at the expense of increased average latency.

Keywords: Intermittent Connected Networks, Naive Replication, Utility Forwarding, Delay Tolerant Networks, Social Attributes, Random Walk Encounter

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Introduction

Wired computer networks are high-speed networks due to the provisioning of guided media. In a wired communication environment, data is transmitted over a cable-based communication technology. Wired networks are comparatively more preferred because of their high speed, lack of interference, long-distance system connectivity and high security [1]. Although, traditional networks ultimately provide high throughput and low latency but have few associated limitations in terms of expensive cabling and mobility. To overcome the cost of cabling and more importantly the provision of mobility, in recent times, wireless networks have been preferred. Although, the wireless medium (unguided) is more error-prone [2] and suffers unreliable low-speed connectivity. Wireless networks are of different types and concerning mobility, wireless networks cover the entire spectrum of mobility from very low to very high as shown in Figure 1.



Figure 1: Spectrum of Mobility in Wireless Networks

In disrupted connectivity, a message is forwarded whenever a node encounters with other neighbouring nodes. However, when a node fails to find a more social node, then this node buffers the message and carries itself until it comes across an appropriate social node [3][4]. This approach leads us to another subdomain of Ad hoc Networks called Delay Tolerant Networks (DTNs). Networks in which nodes are interconnected intermittently are termed as DTNs. A DTN is an overlay network of Intermittent Connected Networks (ICN). The DTN architecture provides a promising platform which improves the efficiency of routing data forwarding either in partitioned opportunistic networks (i.e.; Mobile Adhoc Networks (MANETs), deep space, Vehicular Adhoc Networks (VANETs)) or sparse network where no end-to end path exists between source and destination to deliver a message. Hence, there is a need to exploit DTNs in which message is disseminated to the destination in a store-carry-forward fashion.

In DTN environment, no direct link exists between sender and receiver. Therefore, when a sender node fails to relay a message, it stores the message in its custody until it finds an appropriate relay node to forward the message. Due to dynamic topology and network partitioning, DTN may be used in a variety of applications. It can be implemented to deal with post-disaster situations e.g. earthquakes, flood affected areas and emergency/rescue scenarios, where traditional networks fail to provide reliable communication between nodes, mostly because the infrastructure is itself destroyed. In DTN, each node forwards a received packet to one hop node because no end-to-end path exists between a source and destination node. When a source node or intermediate node fails to find the appropriate node, source/intermediate node buffers the message and carry it until it encounters the suitable relay node in a store-carry-forward fashion [5-6]. As a result, only the next hop needs to be available when using

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DTN. However, DTN-based routing protocols are required to deal with the following challenges like dynamic topology, intermittent connectivity, network partitioning, long delays, no end-to-end path exists, sparse density, frequent packet drops, data dissemination in congestion-free route, security provisioning, routing in DTN.

Many routing protocols have already been developed to send the message in DTN. However, recent research in routing reveals that after sometime, the social relations between nodes become more stable. In recent times, many routing protocols [7-34] have been developed which utilize social metrics to identify more social and influential relay nodes. These protocols are considered as socially aware routing protocols. However, selection of a most suitable relay node and when to transmit a message is still a challenge. Inspite of location, speed and other attributes, social ties and behaviour among nodes tend to be more stable over time which are more helpful in identifying the most appropriate relay node. To address these issues, there is need to have a plenty of information about the dynamic network (i.e. location information, encounter information and traffic information) and network knowledge (i.e; social relation among nodes) to support diverse range of applications in various extreme environments. Considering different opportunities, a number of routing protocols have been proposed in literature that consider different metrics to find the most influential node to disseminate the message.

In order to further improve the packet delivery ratio (PDR) and reduce overhead, we introduced a routing scheme that utilizes a novel social metric, Random Walk Encounter to find more social/forwarder node in the entire network. The Random Walk Encounter value remains stable and incremented each time, a node encounters other nodes with in the network as compare to existing social attributes e.g. Social Activeness and Degree Centrality. In this routing protocol, each node computes its Random Walk Encounter value, Social Activeness and Degree Centrality, updates, and shares with neighbouring nodes after a set interval. A source node or intermediate node forwards the message to a one-hop relay node using all three social attribute values individually which holds the higher social attribute value than the source node/intermediate node. This process continues till the message reached the destination. In order to evaluate the proposed routing scheme, we used the evaluation metrics like packet delivery ratio, overhead, hop-count and end-to-end average delay and simulations are run with different social attributes e.g. Random Walk Encounter, Social Activeness and Degree Centrality using random set of simulation parameters. The simulation results proved that our proposed social attribute Random Walk Encounter improves packet delivery ratio, hop-count and reduce overhead ratio when comparing with Social Activeness and Degree Centrality but at the cost of increase in average end-to-end delay.

The rest of the paper is organized as follows. A literature review based on thorough analysis is given in second section. In third section, we describe our proposed scheme of routing including the algorithm. In fourth section, we discuss the simulation parameters and their set values to simulate the proposed routing scheme. Section V demonstrates the result of the simulation. Finally, we conclude the outcome of our proposed technique and future work in Section VI.

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Literature review

In a DTN, a sender node and a receiver node may not have a direct physical path. Therefore, forwarding a message from the sender to the destination is a challenge in DTN. In these environments, data is transmitted using intermediate nodes to forward a message towards the destination. Many routing schemes introduced in the past which used social attributes to identify the more social relay node. In DTNs, messages are disseminated either by using a replication approach or by forwarding based on some criteria. Following is a brief description of routing techniques already introduced in DTN.

Vahdat and Becker [17] introduced a replication-based routing technique which ensures a better packet delivery ratio but a high overhead was observed. In this routing scheme, each node floods the message (except those messages which are possessed by that node) to all neighbouring nodes and then these nodes forward the message to all their neighbouring nodes. Each forwarder node follows the same approach even a complete message was received by the targeted node.

Spray and Wait [18] technique utilizes the features of two routing techniques (e.g. Epidemic and Direct transmission). This routing technique keeps the half copies with itself, and half of the copies are forwarded to the nodes in an entire network. Each node follows the same process even a single copy is left and a node waits till a node encounters the desired target node. The simulation results demonstrate that the Spray and Wait routing technique shows better performance with the reduced number of transmissions.

In [19], a bundle is forwarded by selecting an intermediate node based on criteria in contrast with Epidemic routing in which messages are flooded which consumes more network resources. The proposed routing protocol exploited delivery predictability which is calculated keeping in mind the transitivity and encounter history of nodes. A forwarder node selects and relays messages to encountered nodes which have higher delivery predictability and transitivity regardless of the distance. In PRoPHET, data is disseminated in two steps. In the first step, the neighbouring nodes sync their summary vector using a control packet and update their internal delivery predictability vector. In the second phase, bundles are forwarded to the node having highest delivery predictability (DP). They also used transitivity which is also an important factor in selecting the forwarder node. A node having larger DP will be selected as an intermediate node to transmit data packets. Experimental results demonstrate that the proposed PRoPHET has shown improvement in delivery ratio and latency.

In People rank [20], whenever two nodes encounter each other, share their People rank value with neighbouring nodes and collect the People rank value of neighbouring nodes. A node is considered to be a high-ranked node which encounters frequently with other nodes. In this routing approach, a message is relayed from a low People rank value to a high People rank value. The same process continues even a complete message is delivered to the destination. People rank routing technique reduced retransmissions by up to 50% while having a delivery rate close to the epidemic.

In [21], Matthias proposed a Social-based Relaying Strategy (SRS) where social metrics information is utilized to select a suitable forwarder node. SRS exploits the Localized Clustering Co-efficient (LCC) and lobby index to target the most active

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node having a high degree of centrality to increase the coverage of the Service Channel (SCH). The author proposed to distribute the load fairly on service channels to maximize the throughput in a highly mobile multi-channel network. To achieve this objective, a node having a high lobby index value has more potential to find the central node and the nodes on the border of subgraphs. For each area, the best relay nodes are selected to rebroadcast the SCH state lists between neighbours. Simulation results using NS-3 demonstrate that multi-channel social-based routing outperforms GPSR-MA in terms of network throughput.

Friendship [22], introduced a new social metric named as 'friendship' which is calculated based on a node's encounter frequency and encounter duration. The authors also used indirect friendship relationships to send a message to a forwarder node. Messages are transmitted to a forwarder node having high friendship value directly or indirectly. The results showed that the routing technique improves packet delivery but at high overhead to form a community.

FCSA [23], used three common social attributes (i.e. Social Activeness, Centrality and Similarity) to calculate the influential node in its neighbours. In this routing scheme, each node computes its neighbour's priority using Fuzzy logic instead of a utility function. They used the calculated priority partially only on intersections. This routing scheme improved the packet delivery ratio and overcame average latency.

SARP [24], used the knowledge of both communities' e.g. local community and global community which not only reduce overhead and hop count but also improve the packet delivery ratio. In this routing technique, each node calculates the priority of a node summing up social attributes value of social acquaintance, social activeness, and degree centrality. In this routing technique, a forwarder node is selected by considering the local and global knowledge of a node.

Chang et al. [25] introduced a new technique which analyses node trajectories and social relationships at different set periods. This routing technique protocol designs two graphs to enhance the packet delivery. At first, it designs the node encounter graph and then based on this node encounter graph, constructs the packet relay path graph. SATR splits a day into several time intervals and to deduce their social relationship, constructs a node encounter graph by analysing the past trajectory movements of nodes. SATR predicts the future locations to the encounter nodes by comparing node encounter graphs. SATR calculates popularity values of all locations based on trajectory information which enhances the choice of routes to forward a packet, reduces forwarding delay and increases the delivery ratio.

The bubble Rap algorithm [26], also utilizes two social metrics (i.e., centrality and community) to find more popular forwarder nodes for message transmission. The results demonstrate that the routing technique improves overhead but produces the same delivery ratio as PROPHET and SimBet.

Sok et al. [27] introduced a new routing technique named "Distance-based PRoPHET Routing Protocol in DTN". They introduced a new metric "distance" which is used along with the node's DP value. They proposed that a forwarder node sends a message to that node which is close to the target node using a distance metric. The simulation results show an improvement in packet delivery as compared to PRoPHET.

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Borrego et al. [28], introduced a new routing technique to deliver a message to a highly influential node. An influential node is calculated based on the virtual interaction (i.e., message exchanged between nodes) and physical interaction. A message is delivered in two steps. In the first step, nodes possessing the highest virtual centrality are kept (explore) but the message is not delivered. In the second step, a message is delivered to the most influential node which holds the highest virtual centrality. This technique improves overhead, the delivery ratio and latency as compared to the state-of-the-art routing protocols.

Ligang Cong et al. [29] designed a spatial delay-tolerant algorithm to resolve the problems of high overhead and complexity in a space DTN. An algorithm is designed by combining the social attributes related to satellites in space and node clustering. The proposed algorithm comprises of three major parts like community division, extracting characteristics of social attributes and finally routing the message. According to the designed algorithm, the most active satellite node in the community will receive the message and forward it either within the community or between the communities. The value of the social attributes is calculated whenever satellite nodes interconnect to one another and divides the community using Circle-k-means algorithm. For simulation, they used ten sending stations and ten receiving stations which cover end-to-end communication within the same hemisphere and even in different hemispheres. The performance of the proposed algorithm is much better than Epidemic and PRoPHET in terms of packet delivery ratio, average delay, and network overhead especially in a large satellite network.

EL MASTAPHA SAMMOU [30] introduced a social-based routing technique named Social Spray-and-Wait to address the inefficiency of DTN routing protocols especially the Spray and Wait without social attribute. They designed this protocol by utilizing the social and mobile similarity along with the visit and delivery probability to reduce the delivery delay and improve delivery rate. The proposed routing protocol also utilizes less DTN resources. The proposed routing technique introduced a new strategy to select the most appropriate forwarder node to ensure maximum packet delivery successfully during the Wait stage. In order to relay a message towards the targeted node, a forwarder node is selected which possesses high social and mobile similarity along with high visit and delivery probability. The selection criteria of a relay node enhance the probability of high delivery because the forwarder node is selected which has more opportunities to interact with other nodes and share messages with them. The simulation results demonstrate that the proposed routing technique outperforms Spray and Wait in terms of delivery rate, utilized fewer resources, and overcome the latency.

Erika Rosas et al. [31] presented a strategy to control congestion for a smooth flow of traffic by prioritizing the messages. To control congestion in disaster scenarios, congestion is measured by keeping in mind the available space in the buffer, adjusting the TTL value and counting the number of deleted messages from a buffer in a specific period. The main objective of the proposed routing protocol is to transmit high-priority messages as fast as possible like messages that can save lives. After the simulation, a significant improvement was observed in terms of message latency. 50% time was reduced in some simulations which is a noticeable performance, especially in disaster scenarios. Consequently, a high-priority message delivery rate increases

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which was the main objective of the proposed routing protocol

Srivastava et al. [32] designed a location-based routing protocol to provide a far better solution which addresses the problems incurred in Vehicular adhoc Networks like frequently disruptions, local optimum problem, broadcasting overhead etc. This paper critically analyze the above-mentioned problems and compares its results with the existing routing protocols. Another challenge which is addressed in this paper, resolve the issue of reliability and robustness in VANET by introducing an efficient routing strategy which overcomes the accidents, increase packet delivery ratio in both sparse and dense environment with low overhead. It also highlights the upcoming technology like WAVE+LTE which can be further improved in future to introduce more efficient location-based routing protocols.

Domingues et al. [33] proposed an opportunistic routing algorithm which considers a forwarder node based on individual social links in order to transmit data packets to the target node. Although, degree centrality and betweenness centrality are mostly used to identify the most popular node in the network. However, theses social metrics very simply to operate in human mobile networks Therefore, this routing approach evaluate its performance by utilizing dissemination profile which is selected based on the priority and content of the message by deploying static relay nodes at popular locations. Furthermore, this routing method may transfer data at cheap computational cost, both for getting the social characteristics and for disseminating overhead. Lastly, we evaluated our suggested routing algorithm using two real mobility traces from NCCU and Dartmouth, and the outcomes are contrasted with four cutting-edge routing methods. The outcomes of the simulation show that the suggested routing algorithm achieves better delivery ratios with a smaller amount of overhead.

Bine et al. [34] presented a routing technique which not only fill in communication gap between vehicles in internet of drones (IoD) but also integrate it into Intelligent Transport System. As IoD applications are about to be very common in smart cities very soon, this will make the airspace very much busy. Moreover, end-to-end path may not exist in some scenario due to high sparsity and high mobility. Therefore, the communication between IoD's and other devices can be improved by collaborating many network devices like vehicular networks, bicycle networks, public transport networks etc. A consistent communication is required between internet of drones and other network devices for many reasons like to keep update about weather information, network control and emergency messages. Therefore, there is need to develop a routing protocol for drones to promote collaboration between VANET and other networks and also considers the characteristics of each network in collaboration like node speed and communication range. The proposed drone routing technique IoDMix calculates message delivery expected time of a current node and also traverse the neighboring node for the same reason. Finally, it selects the forwarder node which has less message delivery time than the current node. This process continues till a complete message is delivered to the destination node. The experimental results demonstrate that IoDMix protocol improves the delivery rate when compared with competitive protocols.

Hasan et al. [35] proposed a routing technique for Delay Tolerant Networks (DTN's) in which no of copies are controlled because a limited number of resources are available mostly in DTN. This routing technique adjusts the number of copies to be

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sent according to the dissemination ability of a node. The dissemination ability of a node is decided based on the factors like number of current connections, buffer size, encounter history, time to live value and energy. The suggested routing method was used by the authors with three different routing strategies: Spray and Wait, Encounter-based Routing, and Destination-based Routing Protocol. The Opportunistic Network Environment (ONE) simulator was utilized to assess the suggested routing method. In terms of overhead ratio, latency, and delivery ratio, the simulation results beat the Spray and Wait, Encounter-based Routing, and Destination-based Routing Protocols. Since a source node can create the initial number of messages based on their buffer size rather than a predetermined number of replicas for each message, it is also observed during the simulation that the suggested routing technique exhibited substantial improvement when the number of nodes exceeds 50. Comparing the suggested routing technique to the aforementioned competitive routing protocols, the delivery probability is improved by 13%, 8%, and 10%, respectively.

Space networks are high reliable, wide coverage and provide high speed transmission as compared to terrestrial networks. However, the specificity of space networks demands an in-depth research related to theory and technology due to high mobility and sparse networks. To address the problem of high network overhead, high complexity of algorithm and latency in space delay tolerant network, Cong et al. [36] proposed a node clustering algorithm m (CD-SDTN) which utilizes the social attributes of satellite nodes. The proposed algorithm calculated the social attribute value based on the connection frequency of satellite nodes and their connection with the ground stations, used Circle-k means algorithm to divide a community and finally, an active social node is used as relay node to forward the message with in a community or between the communities. The whole network is divided into four communities based on characteristics of nodes. In each community, the center satellite node is used to forward the message either with in the community, if the destination node is within the same community otherwise, send to other community. The same process of forwarding a message is carried out until the message is reached to the destination node. This paper uses 10 sending and 10 receiving stations forming 100 pairs of communication connections which covers the whole space networks. The simulation results demonstrates that CD-SDTN improves delivery rate, overhead ratio as compared to Epidemic and PRoPHET.

[37] Proposed a network routing algorithm ST-ProPhet based on the stability of a node's connection and energy recovery. ST-ProPhet considers the duration of average connection, node's encounter probability and the energy consumed during frequent message forwarding. This routing protocol works in three phases. Firstly, a probability prediction model is developed which fuses the average connection duration. Secondly, an energy recovery model is designed which recovers node's energy in a wireless network. Lastly, the ST-ProPhet used both the energy recovery model and the probability prediction model to build a message forwarding mechanism. According to the simulation results, the average message energy consumption of the ST-ProPhet algorithm is 5066.27mAh lower than that of the ProPhet.

This paper [38] proposes an optimised version of the PROPHET protocol that refines the calculation of delivery predictability values by enhancing the representation of

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direct and transitive links. The new model reduces the propagation of stale information and improves routing decisions. Simulations demonstrate that the proposed protocol achieves a higher delivery ratio and lower hop count compared to PROPHET and PROPHETV2, optimising data transmission in DTNs while maintaining resource efficiency.

The paper [39] presents a comprehensive survey of routing protocols designed for disaster management, emphasising the importance of robust communication systems during emergencies. Disasters, both natural and man-made, often lead to failures in conventional communication infrastructure, necessitating alternative solutions such as wireless ad-hoc networks. Traditional communication systems (e.g., cellular networks) fail in disaster scenarios due to infrastructure damage. The study highlights wireless ad-hoc networks, Mobile Ad-Hoc Networks (MANETs), Delay-Tolerant Networks (DTNs), Vehicular Ad-Hoc Networks (VANETs), Flying Ad-Hoc Networks (FANETs), and Wireless Sensor Networks (WSNs) as viable alternatives. It reviews routing challenges in disaster settings, including energy efficiency, latency, packet loss, and scalability. Several novel protocols are analysed, such as Motif-Centric Routing (MCR), Proximity Services (ProSe), and Epidemic Routing, focusing on their advantages and limitations. These protocols are designed to improve message delivery in disrupted networks with minimal energy consumption. The paper highlights gaps in current routing technologies, emphasising the need for adaptive algorithms that can operate efficiently in dynamic and resource-scarce disaster scenarios. Future research should focus on AI-driven routing, energy-efficient protocols, and integration with IoT-based disaster response systems.

After a thorough study of literature, it is observed that all DTN routing protocols related to naive replication routing protocols improve the delivery ratio but with high overhead cost. On the other hand, the DTN routing protocols are related to forwarding, which utilizes some criteria to select a forwarder node to transmit data towards the destination. The criteria-based routing protocols used some important social (centrality, social activeness, friendship etc.) or non-social attributes (location, distance etc.) to find a popular node(s) in an entire network. It has been analysed that DTN routing protocols with social attributes produced better output than routing protocols with non-social attributes as mentioned below in Table 1. Although many social attributes are used in literature to design a DTN routing protocol, they did not use all available social attributes. We are using a new social attribute named “Random Walk Encounter” and a forwarder node will be selected which possesses the highest Random Walk Encounter value.

Table 1: Comparisons of DTN routing protocols

Research Paper	Methodology	Strength	Weakness
Epidemic [17]	Send a message to all neighbouring nodes (one hop)	High delivery ratio	High overhead cost

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PRoPHET [19]	Select a relay node having a high DP and transitivity value	Better delivery ratio than Epidemic Low overhead ratio	Unable to decide to which node forward a message when two or more nodes have the same DP and transitivity value
FCSA [23]	A node having high priority is used to forward messages to the next hop	Improve delivery ratio Reduce latency	use social attributes only on intersections
Hye Influencer! [28]	Used virtual centrality and electronic centrality to select a forwarder node. A message is forwarded using explore phase and wait phase	Improve delivery ratio and latency	
IoDMix [34]	IoDMix selects the forwarder node having low delivery time than the current node.	Address the problem of DTIoD to deal with communication gaps.	Unable to predict network connectivity to switch between protocols for sparse and dense scenarios.
Hasan et al. [35]	Control the message replica based on encounter history, current encounter, buffer size, TTL value and energy	Improves the delivery probability Latency is reduced	Less efficient with low number of nodes
CD-SDTN [36]	An active social node is used as relay node to forward the message with in a community or between the communities.	Improve delivery rate Improve Overhead ratio	Algorithm does not consider constraints like cache, and deployment challenges.
ST-ProPhet [37]	This routing protocol works in three phases. Developed probability prediction model. Secondly, an energy recovery model is designed which recovers node's energy. Finally, forwarding message using both	Effectively address the connectivity problem	Consider only the energy factor not the cache.

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models

Proposed Routing Protocol

The primary purpose of the routing technique is to increase the packet delivery ratio, reduce hop count and reduce overhead in DTN by selecting a more social relay node. The Random Walk Encounter routing scheme utilizes Random Walk Encounter to calculate the Random Walk Encounter value of nodes and then select the more influential node possessing the highest Random Walk Encounter.

Random Waypoint Mobility model is utilized in which nodes move around randomly. When a node reaches the destination, it pauses and then starts its travelling towards another random destination. The flow of selecting a forwarder node to disseminate messages to the receiver is divided into three phases as shown below in Figure 2.

In the first phase, A node when joins the network, recalculate their Random Walk Encounter value, Social Activeness and Degree Centrality. A source/intermediate node with a message will share these values with its one-hop nodes. Secondly, a source node or an intermediate forwarder node compares its Random Walk Encounter, Social Activeness and Degree Centrality value with all one-hop nodes. The nodes which have more social attribute value from the source/intermediate node, are shortlisted. Finally, the forwarder node forwards all messages to the selected nodes first using Degree Centrality, Social Activeness and then Random Walk Encounter. This process continues until all messages are forwarded to the receiver.

Random Walk Encounter (RWE)

Random walk-based routing is probabilistic in which each node starts its walk randomly [40[41]. Whenever a node encounters another node, its random walk encounter value is incremented by 1. The walk goes on until the simulation time ends. Fig. 2 demonstrates a time-evolving DTN in which no end-to-end path exists between a sender (S) and a receiver (D). The sender intends to send messages to a target node which is not in its radio range. Moreover, a message can be relayed to the next node which may carry a message and pass it to the next intermediate node. The same process continues till the message reaches to the target node. At time t0, the node ‘S’ generates a message which is about to send to the target node ‘D’. A sender node can't send a message to the receiver directly because no physical path is established between a sender and a receiver. In Figure 2, we can see that node ‘A’ and node ‘B’ are in the range of source node ‘S’ but the source node forwards a message to node ‘A’ based on applied criteria. At time t1 (t1 > t0), A enters in radio range of node C, and A will forward the packet to C. Node C stores the received packet in its buffer and at time t2 (t2 > t1), C comes in the range of target node and hence, node C successfully delivered the message to the target node ‘D’.

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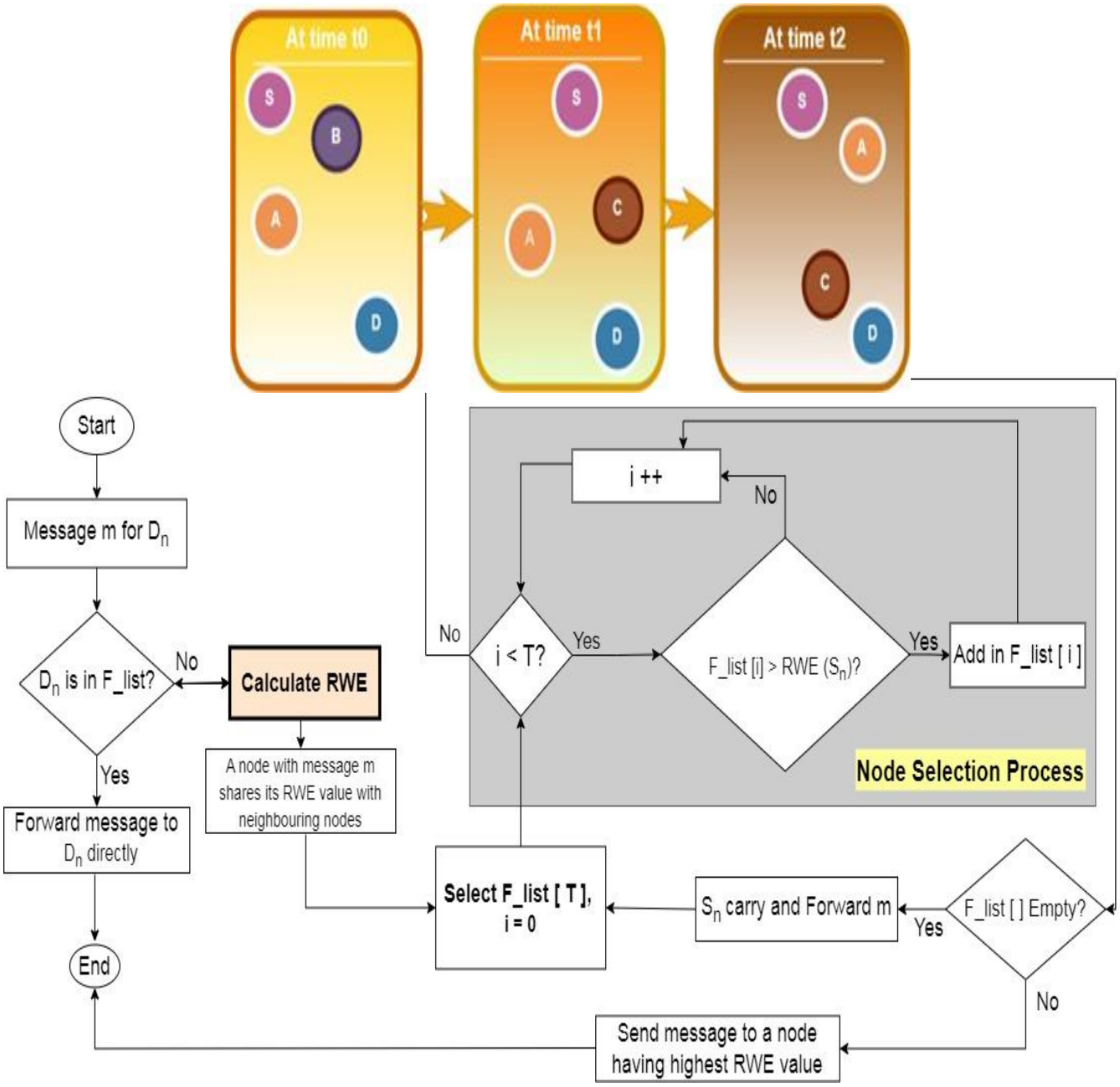


Figure 3: Flow of RWE- SAAD

Overview of Flow diagram

The objective of our proposed routing protocol is to find the more appropriate forwarder node(s) which minimizes the resource utilization in DTN. In this routing technique, the process of routing a message from source node to destination node is categorized into three steps as shown in Figure 3. In first step, each node in the network is required to compute its RWE value. When nodes encountered each other,

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they exchange Random Walk Encounter value using Hello message. This Random Walk Encounter value of a node keep on increasing as much as it encountered other nodes with in a simulation time This Random Walk Encounter value will be used in the next phase for the selection of the forwarder node. In second step, source node S check the destination node D in its radio range, if D exists, S directly forward message m to D. Otherwise, upon receiving list of sorted ranked nodes, S check for their Random Walk Encounter value should be greater than S. In third step, message m will be forwarded to a node possessing highest Random Walk Encounter value. This process will continue for a given time period t. At the end of simulation period, a statistical report is generated which contains message delivery, overhead ratio, hop count, average end-to-end latency etc. The algorithm of the flow diagram is also given on the next page which forwards the messages to the destination using Random Walk Encounter value.

Algorithm 1 Message Forwarding Algorithm

```
function MessageForward(S, m, D)
    // Check D_n in the previously calculated F_list[]
    if D_n is in F_list[] then
        Directly send message m to D_n
        return
    end if
    // Calculate Random Encounter value of each node
    rwe_S ← Calculate.RandomWalkEncounter(S)
    share_list[] ← GetConnectedNodes(S)
    // Compare RWE values with its own RWE value
    for each node N in share_list[] do
        rwe_N ← Calculate.RandomWalkEncounter(N)
        if rwe_N > rwe_S then
            Add N to F_list[]
        end if
    end for
    // Check whether final list is empty or not
    if IsEmpty(F_list[]) then
        S carries message m
        return
    end if
    // Select the node with the highest RWE value
    sorted_list[] ← SortDesc(F_list[])
    selected_node ← sorted_list[0]
    Forward message m to selected_node
end function
```

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Experiment and Simulation Setup

To experiment and simulate the proposed methodology, the following performance evaluation metrics are exploited in order to evaluate the performance of the proposed routing scheme with its competing routing techniques.

Performance Evaluation Metrics:

Packet Delivery Ratio (PDR):

Packet Delivery Ratio (PDR) is commonly used in the evaluation of routing protocols. PDR is calculated by dividing the total number of messages received successfully by the total number of messages forwarded by a source node.

Overhead Ratio:

The overhead ratio is calculated by measuring the ratio between the total numbers of messages delivered to the total number of messages transmissions required for delivery.

Average end-to-end Delay:

This is the delay or average time, utilized by the nodes to propagate all messages from a sender to a receiver successfully.

Average Hop Count:

Hop count is the average number of nodes involved in delivering all messages from a sender to a receiver node successfully.

Simulation Setup

ONE simulator [42] is used to assess the efficiency of social attributes-based routing schemes. The simulation is run using all three social attributes value one by one. A commonly used mobility model Random Waypoint is used to evaluate the proposed DTN routing scheme. Random Waypoint is used to track the mobility of pedestrians [43]. In Random Waypoint, each node starts its movement by selecting a random destination. After reaching the destination node, the node pauses for a while and then starts its movement by selecting another random destination. The nodes keep on moving randomly till the simulation time ends. For simulation, an area of 3000 x 1500 m^2 is taken in the disaster site. The simulations with different buffer sizes are run from 5MB to 25MB and with different random seed values from 30 to 200. We use different buffer sizes just to observe the change in the results of simulation.

Each simulation is run for 12 hours keeping all the parameter values the same except the random seed value. We get different simulation results for each simulation with different random seed values. A high-speed interface is used so that nodes can encounter each other in the range of 100 m and can transmit messages at the speed of 2Mbps. The time to live value so that a packet can move for a limited time and after that, it should be discarded itself. For our simulation, we set a 500-second warm-up period to ensure that the simulator may initialize the process of computing Random Walk Encounter, Social Activeness, Degree Centrality and the message generation process starts. The details about the simulation parameters and their corresponding values, used in our simulation are given in Table 2.

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Table 2: Simulation Parameter

Parameters	Value
Simulator	ONE
Time duration	12 hours.
No of hosts	50
Area	3000 x 1500 m^2
Interface	High-Speed Interface
Traffic	Random movement and random selection
Mobility model	Random Waypoint
Buffer capacity	Between 5MB to 25MB
Range of Speed	0 m/sec to 20 m/sec
Message size	500Kb, 1MB
Message creation	After 25 to 35 sec
Time To Live value	300 mins
Random Seed	30, 50, 100, 150 and 200
Transmission range	100 m
Transmission speed	250 KBps
Warm-up	500c

Results

With the set parameter values mentioned in Table 2, Simulations run to evaluate the performance of three social attributes-based e.g. proposed social attributes Random Walk Encounter, Social Activeness and Degree Centrality. Simulation results are compared in terms of PDR, overhead ratio, hop count and average latency.

Packet Delivery Ratio (PDR)

The graph shown in Figure 4 shows the packet delivery ratio. We use different values for buffer size to run the simulation. The simulations are run five times (12 hours each) for each buffer size by keeping all the parameter values the same except the random seed value. Then, take the average of these five simulations and the average value is presented below in Figure 4.

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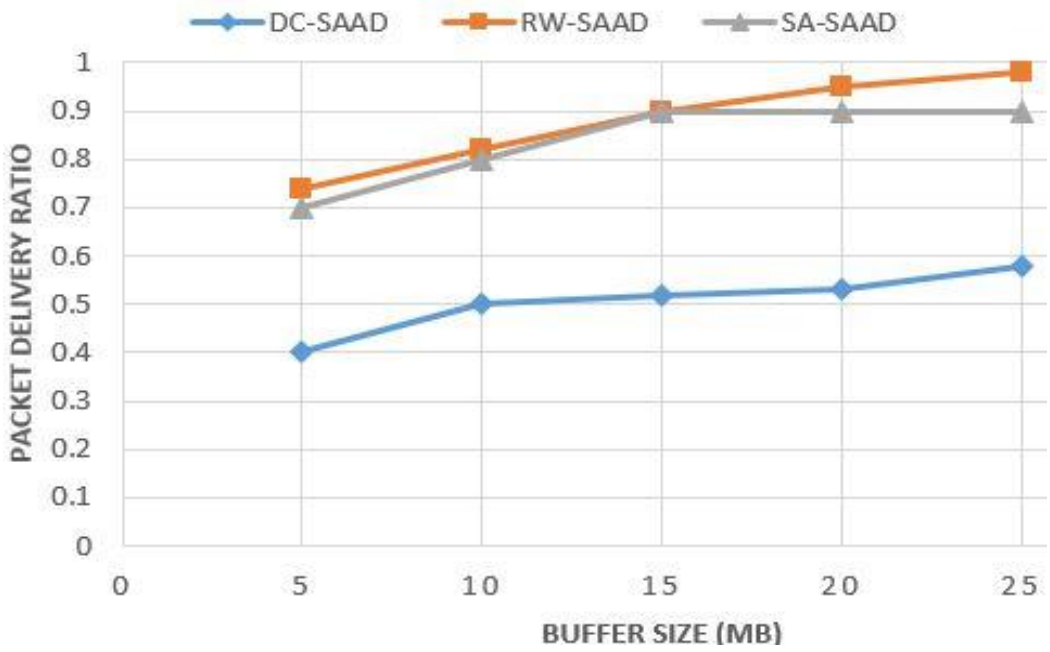


Figure 4: Packet Delivery Ratio with varying buffer size

The simulation results demonstrate that the proposed routing technique Random Walk Encounter (RW-SAAD) improves PDR than Social Activeness (SA-SAAD) and Degree Centrality (DC-SAAD) as shown in Figure 4. When a buffer size is increased, a node can hold more messages and increased the packet delivery ratio. By increasing the size of a buffer from 5 MB to 10 MB, delivery of packets also increases but when we set the size of a buffer to 15MB, 20MB, and 25MB, we observed a low increase in packet delivery.
Secondly, the value of our social attribute named Random Walk Encounter is stable as compared to Degree Centrality which we used in the previous routing scheme. Random Walk Encounter value keeps on increasing as the simulation carries on while the Degree Centrality value and Social Activeness value of a node can vary on different occasions. This stability also enhances the performance of the proposed routing technique Random Walk Encounter.

Overhead Ratio

The graph shown in Figure 5 shows that the proposed routing technique Random Walk Encounter delivered more packets than SA-SAAD and DC-SAAD with low overhead.

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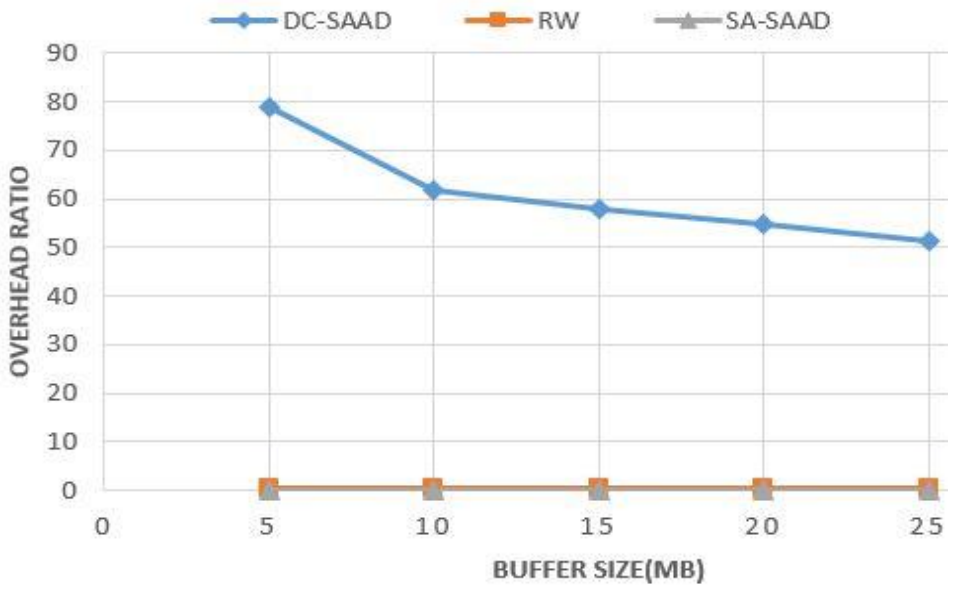


Figure 5: Overhead ratio with varying buffer size

Degree Centrality-based routing technique although produced good packet delivery ratio but at the high overhead cost than Social Activeness-based and Random Walk Encounter-based routing techniques

Average Hop-count

Figure 6 demonstrates that the proposed routing scheme utilized minimum average hops to transmit messages from a sender/forwarder node to a destination node. The proposed routing scheme uses almost one hop as an average to send a message to the target node which is better as compare to Degree Centrality-based and Social Activeness-based routing techniques. This reflects the significance of the social attribute Random Walk Encounter used in the proposed routing scheme.

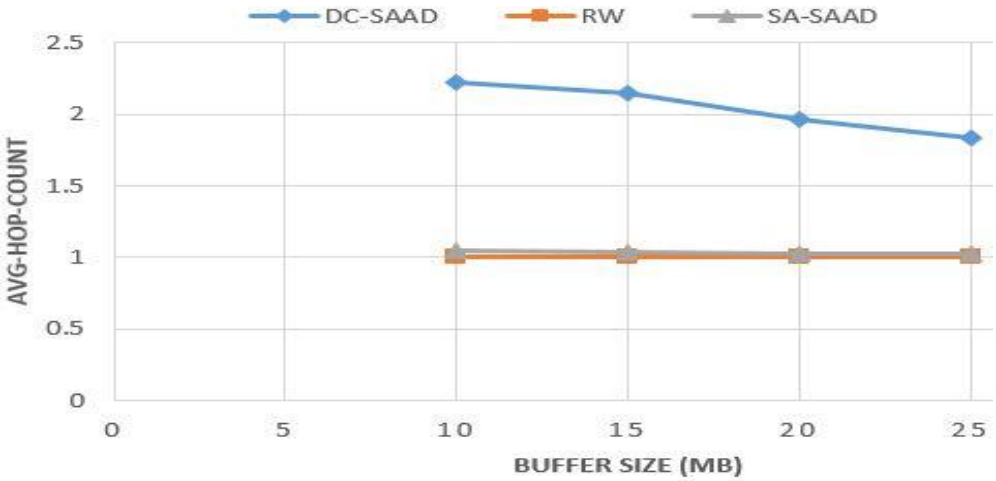


Figure 6: Average Hop-count with varying buffer size

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Average end-to-end Delay

The proposed routing scheme graphs shown in Figure 4-6 demonstrate that our proposed routing scheme Random Walk Encounter has shown a better packet delivery ratio, average hop count and reduced overhead ratio as compare to Degree Centrality-based and Social Activeness-based routing techniques but at the cost increased average latency as shown in Figure 7.

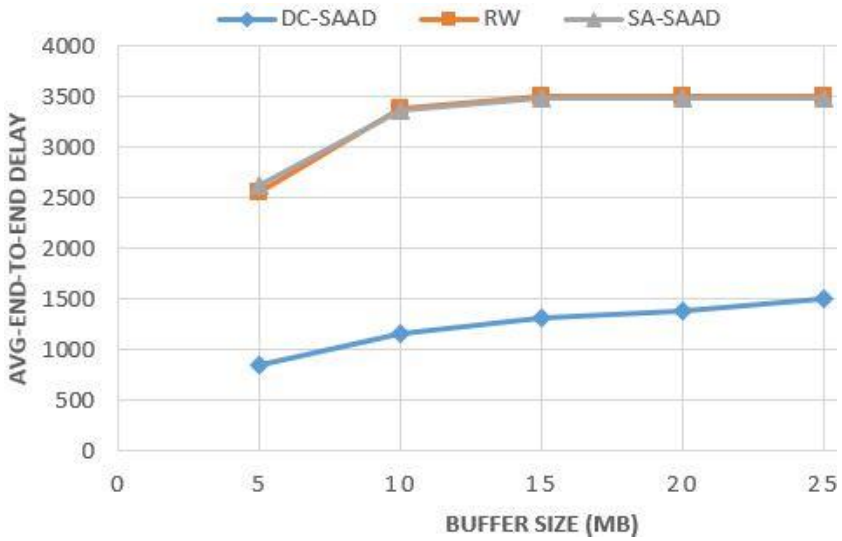


Figure 7: Average latency with varying buffer size

The above results demonstrate that our proposed routing scheme performed well with the set simulation parameters and outperformed Degree Centrality-based and Social Activeness-based routing techniques in terms of delivery ratio, overhead ratio, average hop count and average end-to-end delay.

Conclusion and Future work

The proposed routing technique uses ONE simulator, a Random Waypoint mobility model, and a social attribute (i.e. Random Walk Encounter) to compute the Random Walk Encounter value of each node. Each node in one hop shares its Random Walk Encounter value. Then a forwarder node shortlists relay node having highest Random Walk Encounter value than the forwarder node. Finally, forwards the message to the node possessing highest Random Walk Encounter value. The same process continues even the complete message reached to the target node. The simulation results demonstrate that the proposed routing technique Random Walk Encounter improves hop-count, packet delivery ratio and overhead ratio but average latency increased when comparing with Degree Centrality-based and Random Walk Encounter-based routing. In future, we aim to apply the proposed routing technique to other mobility models to further improve the results.

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