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Encounter-History Based Fast Routing for Post-Disaster Communication in DTNs

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***Abstract*—Delay Tolerant Networks (DTNs) are characterized by the absence of end-to-end path. One potential application of such networks is post-disaster environment, where conventional network infrastructure is fully or partially destroyed. Routing is a challenging issue in DTNs because of intermittent connectivity. Most of the traditional DTN routing schemes do not consider the contact history of the nodes for data delivery. The history of encounter of a node with the other nodes gives valuable information about the network topology. In this paper, a set of potential relay nodes is primarily chosen based on available buffer space and residual energy of the nodes in the network. Among the potential relays, one is selected considering the value of a metric which is designed based on the encounter history and residual energy. The node with the highest value of this metric is finally selected as a relay. The performance of our proposed scheme is evaluated in ONE simulator considering a post-disaster situation analysis application. In this application, messages need to be delivered to the destination as fast as possible which implies to keep delay as low as possible. Comparative results show that the proposed scheme delivers significantly faster, i.e. lower delay than the existing state-of-the-art competing schemes while keeping an acceptable delivery ratio.**

***Keywords*—Delay/disruption tolerant networks, encounter history, residual energy, relay selection**

I. Introduction

A delay tolerant network (DTN) is a sparse dynamic wireless network where mobile nodes work on adhoc mode and forward data opportunistically upon contacts [1]. An end-to-end path rarely exists because of opportunistic contacts between the nodes. DTN architecture aims to address the technical issues in heterogeneous wireless networks that experience lack of continuous network connectivity [2]. A DTN has a useful application in challenging environments like wild life monitoring, post-disaster scenario etc.

Characteristics of DTNs make the routing challenging in this network. Limitation of resources like battery power of the nodes also exists in DTNs [3]. Due to lack of consistent connectivity, DTN routing follows store-carry-forward mechanism. It implies that after receiving the data, a node carries them until it contacts another node to forward the data. In DTNs, most of the routing protocols suffer from the problem of efficient relay selection for data delivery. Since DTN routing relies on mobile nodes to forward packets for each other, the routing performance depends on the opportunity of getting contact with other nodes.

Many works are so far reported on DTN routing. One such routing protocol is Epidemic [4], where nodes transfer copies of all the packets to all the other nodes in the network. Epidemic achieves high message delivery through huge resource consumption. The Spray-and-Wait [5] modifies epidemic routing by bounding the total number of message copies to spread in DTNs. When no more spreading is allowed the carrying node keeps the packet until it either meets the destination or the packet is dropped. Another standard protocol is Prophet [6] which makes routing decisions based on the encountered nodes' delivery predictability. But computation overhead is high in this scheme. In MaxProp [7] protocol maximum probability of message to be delivered is calculated. MaxProp prioritizes the packets and uses Dijkstra's algorithm to ensure that the lowest cost path is chosen for delivering data. Another recently reported work is EDR [8] where forwarding strategy is based on context information of nodes. The forwarding parameter is calculated by the number of encounters with the destination and the distance of each node from the destination in the network. The messages are forwarded only to the nodes having forwarding parameter value greater than or equal to a predefined threshold. In another work [9], the proposed scheme relies on the mean frequency of past encounter with the base station. It aims to reduce computational overhead while maintaining high performance.

From the above discussion, we observe that though some of the existing DTN routing protocols consider past encounter rate but they do not consider buffer capacity and energy constraints together while taking routing decisions. Existing schemes suffer from high average latency and high resource consumptions which are hardly acceptable in post-disaster scenarios. The history of encounters of a node with other nodes gives important information about the relative locations of the nodes in the network. From the past encounter history, future contact can be predicted. This motivates us to propose a routing scheme that considers past encounter history of a node and available buffer space for data forwarding towards reducing delay while maintaining an acceptable delivery ratio.

The rest of the paper is organized as follows. Section II describes the network model. Section III illustrates the proposed encounter-based scheme. Performance evaluation is shown in Section IV. Finally, conclusion is drawn with some mention of future work in Section V.

II. Network Model

In this work, we consider a post-disaster scenario as shown in Fig. 1, where conventional network infrastructure is fully or partially destroyed due to flood (e.g. Chennai flood [10] in India, 2015). There is one control station and some relief camps. In this case, volunteers/ relief workers with DTN/DTN-like mode enabled mobile devices exchange messages and eventually form a DTN. The connection between two nodes exists, when they stay in the communication range of each other. But when they move

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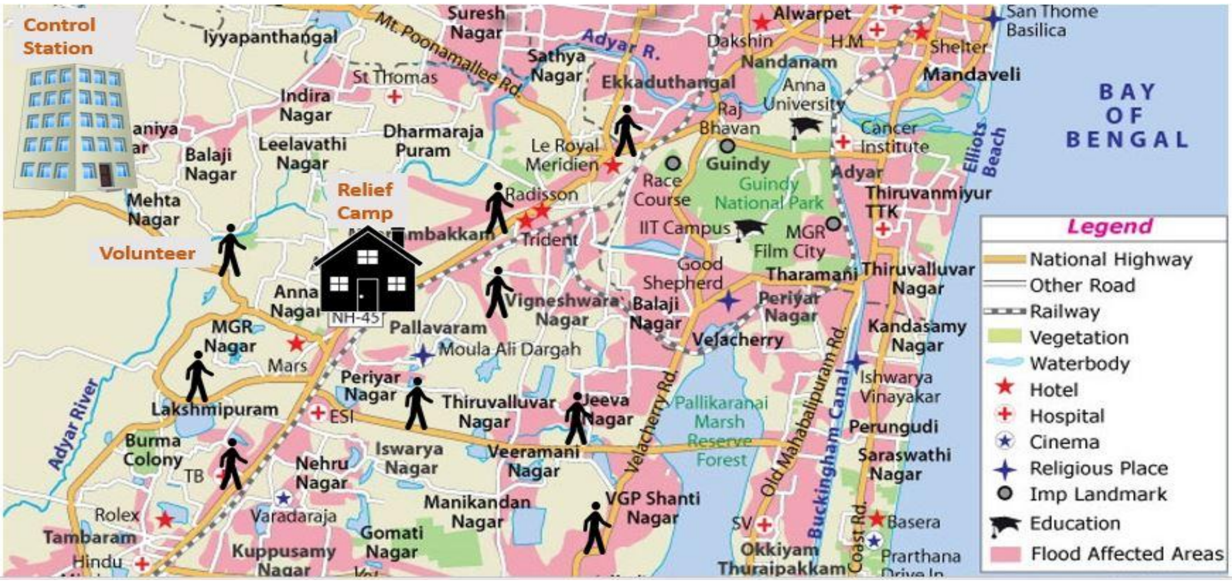

Figure 1: A DTN Scenario

out of the communication range, the connection is disrupted, which makes the end-to-end path difficult to maintain. Due to the unpredictable movement of the nodes (volunteers with mobile devices), the network topology becomes dynamic in DTNs. Here, the delivery of data is dependent on the employed DTN routing strategy. Moreover, in post-disaster scenario, each node has resource limitations like battery, storage etc. Data may not be delivered successfully, if residual energy of a node becomes low.

In absence of conventional communication infrastructure, whenever the volunteers come in close proximity (within communication range) of another volunteers, they communicate via bluetooth or high-speed interface (WiFi Adhoc). We assume that all the nodes cooperate with each other and no malicious nodes are present. We also assume that all the messages in the network have the same priority. A source node delivers the message to its destination in multi-hop through relay nodes.

III. Proposed Encounter-History Based Routing Scheme

This section presents our proposed energy-aware encounter-history based routing (EHR) scheme along with the corresponding algorithm and illustrative example.

A. *Proposed Scheme*

In this scheme, whenever a source node (S) intends to send a message, S broadcasts hello message towards all of its neighbors. As soon as S receives reply messages containing node-id from all of its neighbors, it checks whether the destination node (D) is present in its neighbor nodes. If D is present in its radio range, it sends the message to D. Otherwise, S first checks available buffer space (B_s) and residual energy of each of its neighbor nodes. The neighbor nodes which have B_s more than the size of the message and also energy ratio (EN_r) more than a pre-defined threshold (E_{th}) are considered for relay selection. Here, EN_r of a node is defined as the ratio of residual energy and the initial energy. It is observed that a node like smartphone cannot function properly, if the residual energy is less than 20%. So, we set the value of parameter E_{th} to 0.2. Among the potential relay nodes, S finally decides the most suitable relay based on the forwarding metric (FM) which is defined as follows.

$$FM = \frac{1}{2}(EN_r + E_r)$$

where E_r is the encounter ratio which is obtained from the encounter-history of the nodes. It is specified as the ratio of the number of encounters of a node with the destination to the total number of encounters of the neighbor nodes with the destination. After calculating FM, S opts for maximum value of FM for choosing the relay. The relay with the maximum FM becomes the next forwarder of the message. The relay selection algorithm of EHR is as follows.

INPUT: B_s, EN_r, E_r of the contacted neighbor nodes

OUTPUT: Selected relay node

// $R_1, R_2, \ldots, R_n$ are the neighbor nodes.

// Forward(m,N) indicates, message m is forwarded to N.

// k[ ] contains the potential relay nodes.

// max(k[ ]) returns the node with the highest FM.

// $R_{selected}$ is the selected relay node.

for i=1 to n

//Destination node checking

if($D=R_i$)

Forward(m,D)

//When destination is not in the contacted neighbors of the source

else

j← 0

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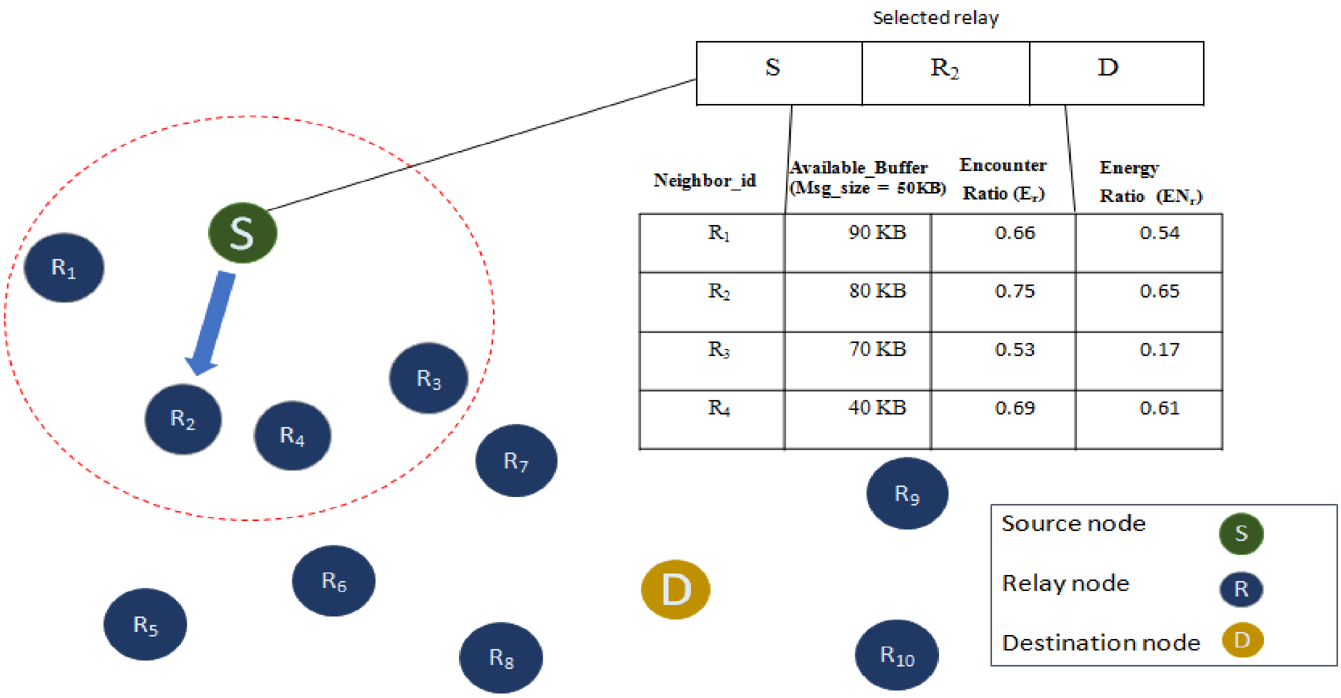

Figure 2: Relay selection following EHR

```
        if Ri.Bs >= message size & Ri.ENr >= Eth
              k[j++]=Ri
        end if
        Calculate FM values of k[1…j]
        Rselected=max(k[1…j])
        Forward(m,Rselected)
    end for
```

B. ***Complexity***

The complexity of the scheme depends on number of contacted neighbor nodes of the sender. The proposed scheme, in the first phase, checks the parameters Bs and residual energy of the neighbor nodes. So if there are n number of neighbors, it takes O(n) time. In the second phase, sender computes FM for those nodes that are considered for relay selection after the first phase. It selects the relay node with the highest value of FM. This task may also take maximum of O(n) time. So, in the worst case, the total time taken by EHR is [O(n) + O(n)] = O(n).

C. ***Illustrative Example***

Fig. 2 portrays a network scenario where S and D are source node and destination node respectively. Nodes R_1 to R_{10} are the DTN nodes. The neighbor nodes of S are R_1, R_2, R_3 and R_4. Node R_4 does not have enough available buffer space as it has B_s less than the message size (50KB). On the other hand, R_3 has insufficient residual energy as EN_r of R_3 is less than the E_{th} (0.2). So, R_3 and R_4 are not considered for further process of relay selection. Each of R_1 and R_2 has sufficient available buffer space and residual energy. Now, between R_1 (FM=0.60) and R_2 (FM=0.70), R_2 is finally selected as the relay as FM value of R_2 is the highest.

IV. Performance Evaluation

The ONE simulator [11] is used for implementing our proposed scheme to evaluate the performance.

A. ***Simulation Setup***

In our simulation, we consider disaster crisis map of Nepal Earthquake [12] as shown in Fig. 3. We also consider 45-150 number of mobile nodes. Here, two types of mobile nodes are used to represent mobile users with different speed within an area of 4500×3400 square meters. The two such types of mobile users are pedestrians and cars. Also, 80% of the mobile users communicate using bluetooth interface, while 20% of them use high-speed interface. The values of other simulation parameters are provided in TABLE I.

TABLE I: Simulation parameters

Simulation time	43200s
Movement model	Map-based movement
Transmission range	10m (BT interface), 250m (high-speed interface)
Message generation interval	25-35s
Message size	100-500 kB
Node speed	Pedestrians: 0.5-1.5 m/s, Cars: 2.5-9 m/s
Message TTL	300 min
Transmit speed	250 kBps (BT interface), 10 Mbps (high-speed interface)
Buffer size	5M
Initial energy	20500J

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Figure 3: Disaster crisis map for Nepal earthquake

B. *Simulation Metrics*

Our scheme is evaluated based on the following performance metrics [13].

$$\text{Average Latency} = \frac{\text{Sum of delivery time of the data}}{\text{No. of the delivered data}}$$

Average Buffer time – The average buffer time is the average time that a message stays in the buffer of a node.

$$\text{Delivery Ratio} = \frac{\text{No. of data delivered to the destination}}{\text{No. of data generated by the sources}}$$

Two of the above parameters such as average latency and delivery ratio are measured within a fixed period of time.

C. *Results and Discussion*

Performance of EHR is evaluated with three standard DTN routing protocols, namely Spray-and-Wait [5], Prophet [6] and MaxProp [7]. In the first set of experiments, impact of number of nodes on the average latency time is studied. The results are shown in the Fig.4. It is observed from the figure that average latency of EHR is significantly lower than Prophet, Spray-and-Wait and MaxProp for any number of nodes. For example, when the number of nodes is 90, EHR performs 35%, 25% and 11% better than Prophet, MaxProp and Spray-and-Wait respectively.

In the second set of experiments, impact of number of nodes on average buffer time is studied and the results are shown in Fig.5. If efficient relay nodes are chosen, average buffer time becomes lower. We observe that average buffer time is the lowest in Prophet among all the competing schemes. However, it is significantly lower in EHR than Spray-and-Wait and MaxProp for any number of nodes. For example, for 90 nodes, EHR performs 49% and 90% better than MaxProp and Spray-and-Wait respectively.

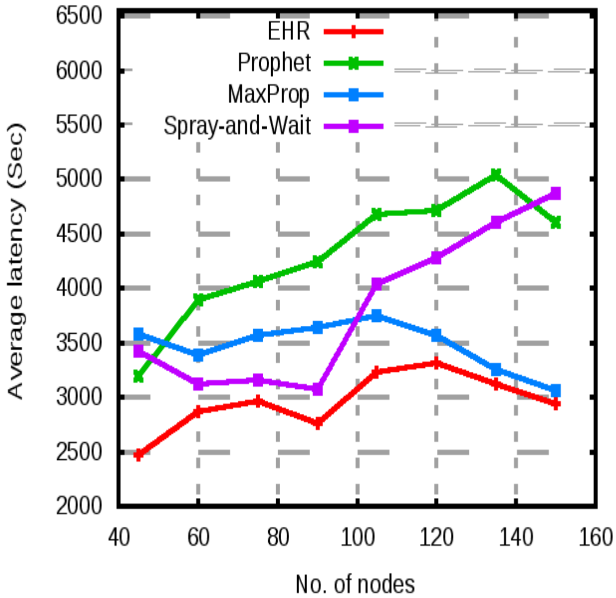

Figure 4: Comparison of average latency

In the third set of experiments, the study focuses on the variation of delivery ratio with the number of nodes. The results are shown in Fig.6. It is observed that delivery ratio of EHR is always better than Prophet. Also, for lesser number of nodes, EHR performs better than MaxProp, while for more number of nodes, MaxProp marginally performs better. On the other hand, for more number of nodes, EHR is better than Spray-and-Wait, while for less number of nodes, it is worse than Spray-and-Wait. For example, for 90 nodes, EHR performs 21% better than Prophet, 9% better than MaxProp, where Spray-and-Wait performs 8% better than EHR. Precisely, when number of nodes is below 110, EHR performs better than others excluding Spray-and-Wait.

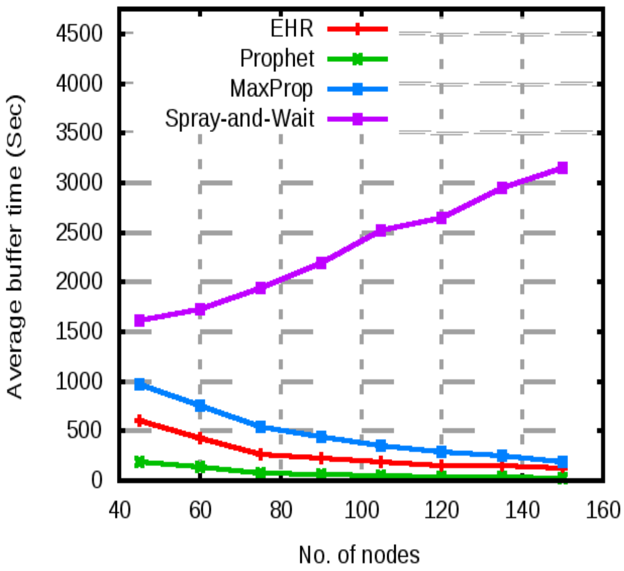

Figure 5: Comparison of average buffer time

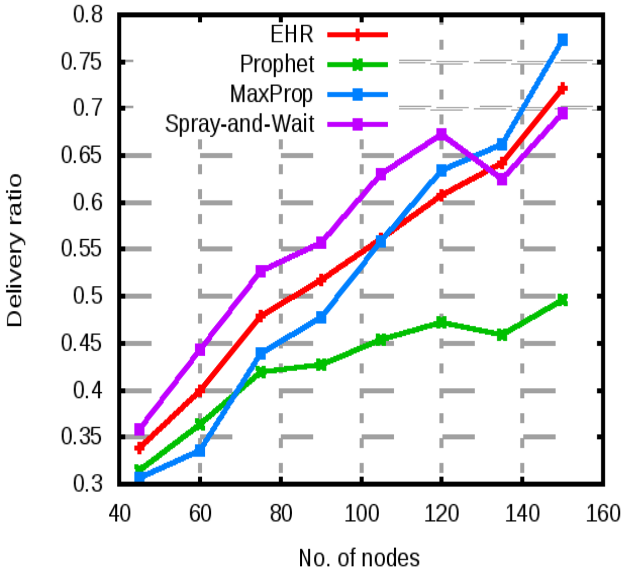

Figure 6: Comparison of delivery ratio

V. Conclusion

DTNs emerge as the potential solution for communication in challenging environments like post-disaster scenario, where traditional network infrastructure is fully or partially absent. Most of the DTN routing schemes do not consider the contact history of the nodes for relay selection. In DTNs, the encounter history of a node with the other nodes gives important information about the relative locations of the nodes in the network. In this paper, primarily a set of potential relay nodes are selected considering available buffer space and residual energy of the neighbors of a source node. Then out of these potential relays, one is selected based on a newly designed forwarding metric value. This forwarding metric is designed considering the encounter history and residual energy of the potential relays. The node with the highest forwarding metric value is finally selected as a relay. Considering the disaster scenario after Nepal earthquake (2015), we evaluate the performance of our proposed scheme in ONE simulator. Comparative results show that the proposed scheme outperforms other popular schemes in terms of delay, while keeping delivery ratio within an acceptable limit. In future, we intend to develop smartphone based test-bed for analyzing robustness of the proposed scheme.

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