A Multi-hopLocation-aware Directionalized Routing AlgorithmforMaximizing Probability of Successful Packet Delivery in Delay Tolerant Networks

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Abstract—Currently, delay tolerant networks (DTN) gainsgreat attention from academic as well as research communities in whichincessantconnectionfrom the sender node to the intended receiver node cannot be guaranteed.Therefore, traditional routing strategies fail, because these strategiesattempt to create contemporaneous connections before transmitting any packet.This worktargets to design a multi-hop routing algorithm, a location-aware directionalized routing algorithm (LDRA),to maximize the probability of successful packet delivery and minimize network overheads.It calculates the delivery probability of packets using its adjacenthosts and disseminatesreplicas of packets accordingly. The proposed LDRA predicts the location of the intended receiver (i.e., expected zone) and only forward the packet replicas from each nodethatfalls in the expected zone. Consequently, it directionalizes the packet delivery in line with the receiver position. Weaddressthe directional distribution of packets which leads tosendinga lesseramount of packet replicas.Extensive simulations have been carried outusing the Opportunistic Networking (ONE) simulator. The simulation results demonstrate that our LDRA algorithm outdoes the other routing protocols including Epidemic, PRoPHET, Spray and wait in terms of performance metrics including theprobability of successful delivery, and network overhead.

Keywords—delay tolerant networks; epidemic routing; location information;packet replicas; routing algorithms;

I. INTRODUCTION

Delay tolerant networks havetransformed from comparativelyambiguous research area into vigorous research activities appealing to both architectural and protocol designers [1], since the Internet architecture (i.e., Transmission Control Protocol/Internet Protocol (TCP/IP) model)relies onseveralintrinsic assumptions, such as the presence of anunceasingcommunication linkamonghosts, the symmetric channel bandwidth and the bit error rate, and the comparativelysmallercommunicationlatencies [2]. Indelay tolerant networks, these expectations aregenerallyruined to operate, which brought up the fact that the TCP/IPcommunication modelcannot operate in delay tolerant scenarios. Therefore, several protocols developed for the TCP/IP protocol stackcannot work well in the DTN applications including satellite communication, opportunistic experience sharing, opportunistic content sharing, and mobile data offloading.Besides, one morekey contributor to this development is the reflection that numerousexisting communication systemsshow delaytolerant characteristics, notwithstandingdiverseenvironments:from sparse mobile ad-hoc networks (MANETs) to wireless sensor networks (WSNs) to mobile Internet access. It is also observedthat delay tolerance is also considered a significantfeature to definethe transmissionpattern and to developalgorithmsappropriate for working indifficultcommunicationscenarios. Furthermore, the DTNs embrace the idea of sporadically linked networks that may be affected by repeated partitions.

Of late, the delay tolerant networks research group headed by the internet research task force developeda communication model with arouting mechanismcalled bundle communication strategy. In delay tolerant networks, a packet–based overlay (i.e., bundle) layer isincorporated [3]. This layer operateson top of the transport (or other) layers of the reference model and enables communication amongthem. The bundle layer decomposes the application data units into one or more blocks of information known as bundles. Then, these bundles are forwarded by hosts in delay tolerant networks using the bundle routing mechanism. The basic concept used in this protocol is to pack all the information essential for a particular transaction, reducing the number of contacts, which is beneficial when the communication latency is too high. In order to support scheduling and routing conclusions, the participating nodes employ store-carry-forward techniques.

In general, the bundle communication strategy does not offerpath information for messagesamong any twohostsin DTNs. It involves only the transmission phase. Meanwhile, providingcontinuousconnection between nodes in a particularcommunication system is animportant issue and requires to be solved by suitableforwardingalgorithms;consequently, innumerable studies have been performed for appropriate routing mechanisms based on avariety ofapproaches, includingdirect delivery, first contact, epidemic, spray-and-wait (SAW)approaches [4]. In direct delivery approach, the source host forwardsthe packets until it delivers them to its intendedreceiver. In the first contact approach, the hopstransmitpackets to the first host they meet, which leads to a random walk exploration for finding thedesignated receivinghost. The epidemic approachduplicatespackets to all encounterednodes that still do not have them [5]. If system storage capacity is infinite and encountersamonghostsare adequate, the epidemic approachreduces the communicationlatency and increases the packet delivery rate significantly. Conversely, those network resources are typicallyconstrained.This protocolconsumes more bandwidth and storage space related to other approaches.

SAW is an alternative algorithm that confines packet duplication related to the epidemic approach. However, it producesmultiplereplicas of a packet. Duringthe normal mode of operation, a host delivers one replica to each encounter; in binary mode, 50% of the replicas are delivered to anencountered peer. Whenonly onereplica is available, it is dispatched only to the intendedreceiver [6]. The probabilistic routing protocol using history of encounters and transitivity (PRoPHET) [7] approachtransmits the packet to anadjacent node if it calculates that the adjacent node has a maximumprobability of being capable ofdistributing the packet to the intended receiveraccording topreviouscontactinformation.

Moreover, routing protocols are not only developed to resolve network partition issues. There are numeroussignificantreasons to develop routing strategies, includingpacket delivery ratios, communication latency between sender and receiver, bandwidth performance, energy consumption, etc. [8]. The application is also imperativesince no routing algorithm can meet all these requirements. Hence, themajority of developedalgorithms are intended for particular applications [9]. Conversely, these algorithms are not appropriate for applications having messages with diversepriorities and demands. To handle this problem, fewinvestigatorsproposed adaptive routing algorithms with variouscommunication measures [10].

In this work, we introducealocation-aware directionalized routing algorithm with the goal of maximizing packet delivery probability and minimizing communicationcost. It calculates the delivery probability of packets using its adjacent hosts and disseminates replicas of packets consequently. The proposed LDRA predicts the location of the intended receiver (i.e., expected zone) and only forward the packet replicas from each node that falls in the expected zone. The remaining sections of this article are structured as follows: Section 2 reviews the related works about routing protocols in DTNs. In Section 3, we take an in-depth look at the proposed method to explore precisely how each step works. Then the results are presented and related tothreepopularDTN routing approaches found in the literature in Section 4. To end, conclusions are drawn in Section 5.

II. LITERATURE REVIEW

This section details the summary of related worksto therouting protocols by differentresearchers in delay tolerant networks. The last few years have seen substantialworksdeveloped to solve the routing issues in delay tolerant network scenarios [11]. Jain et al. formulated the DTN routing problem, where packets are to be transferred across a connectivity graph that is time-varying however whose dynamics may be predictedearlier. The problem has the additionalrestraints of bounded buffers at everyhop and the commonaspect that no concomitantcomplete communicationlink may always exist [12]. Vahdat et al. introduced methods to distribute packets in a scenario where there is no end-to-end connectivity between a sender and intended receiver or when a network partition occurs during a packet is created [13]. Finally, the authors presented an epidemic approach, in which arbitrary pair-wise packet sharing among nodes guarantees final packet delivery. In this work, when two hosts come into the encounter, they sharepackets. In this manner, a packet is disseminated to each encountering host and eventually dispatched to its receiving host. The objectives of the epidemic approachare toi) increasepacket delivery ratio, ii) reducecommunication delay, and iii) reduce the overall resources consumed to deliver apacket successfully.

Likethe epidemic approach, Kang and Chung proposed PRoPHETrouting algorithm that uses probabilistic routing verdicts [14]. Eachhostpreservesdelivery expectedness for everyhostit meets. Hostthat encounterregularlyhasmaximum delivery expectedness, and it isreduced if hostsdo not meet each other for a moment. Epidemic style transmission of messagesbefalls only if the delivery expectedness of anadjacent host is greater than that of the host itself for a receiving node. Spyropoulos et al. introduced single-copy routing approachesin which each local movement will cause a message to its receiver [15]. They proposed two types of forwarding approaches. In the most fundamentalapproach(i.e., direct distribution), the senderdelivers the message only if it meets the intended receiver. In utility-based forwarding, hostsdeliver themessage only if an adjacenthost has a maximum utility value to the receiver. A newone-copy approach is developed by Conan et al. [16]. By exploitingonlythe value of meanencounter time among hosts, a two-hop forwardapproach is extended to a recursive multi-hop relay approach.

SAWrouting approachtargets to integrate the benefits of single-copy and epidemic approaches by reducing the number of replicasof a message can have [17]. It minimizes the number of broadcasts as compared withthe epidemic approach and realizes animprovedpacket delivery rate than one-copy approaches. Spray-and-focus is considered as an advanced version of SAW. It has a “focus” phase instead of a wait phase, whereonereplicaistransferred to increasethe utility value [18]. Nelson et al. proposed a contact-based routing scheme as an additional alternate for routing problems, which employs encounter history when choosing hosts to spray [19]. Yen et al. designed a multicast routing approach based on the genetic algorithm [20]. The proposed approach is flooding-limited by exploiting the existing resources withlowerprocessingcomplexityin a real-time scenario. The authors employed a genetic algorithm to optimize the paths and to satisfy the quality of service (QoS) limitations of the communication system by choosing the suitablevaluesfor crossover, mutation, and population size.

Prodhan et al. introduced time-to-live-based routing (TBR) in opportunistic networks [21]. Toenhancethe buffering performance, it selectspacketsusing a measureand prioritizesthese packetsbased on theirminimum time-to-live (TTL), minimum hop count, and smaller dimension. Yang et al. examined the efficiency of buffering in detail using a systematic model based on a two-dimensional Markov chain model to assess the performance of delivery of block of information in intermediary hosts. [22]. Thus, a latency model and a packet delivery probability model for disseminating bundles indelay tolerant networks are also designed. These models are reliant closely on the sojourn time in buffers.

Merugu et al. discussed routing techniques with expectablemovement in delay tolerant networks [23]. Mobile hosts find a particular deterministic route that is expressed as a function of time. For a particularperiod, a space-time graph iscreatedusing the location information. The space-time graph is a single large graph where routing is carried. This graph is developedby integrating various network graphs at various periods. The authors also focused on scalability problems in DTN routing protocols. Usinga particularmovement model, the authorsdevelopeddelay tolerant hierarchical routing (DHR), which employsa hierarchical mechanism ina multilevel clustered network.

Liu and Wu examined the optimality problem for probabilistic routing protocols [24]. The authors defined a single-node delivery probability measure and convert it to K-hops. The transmissionprotocoldenotedby the measure is articulatedwithin an optimal termination rule problem to determine optimal paths. Lindgren et al. employed occurrence of encounters [25], Dvir and Vasilakosdeveloped a backpressure-based forwardingapproach [26], and Ferriere et al. employed elapsed time which is calculated fromthe time of previousencounter[27]. Bulut et al. designed a new conditional inter-contact time-based algorithm, called conditional shortest path routing (CSPR) that describes the time when two hops contact over an intermediate hop [28]. Hui et al. proposed analogoustechniques, estimatingconnectedness, social similarity, and centrality of hops as routing measures[29].

Ayub et al. employed collected information including the latestmeetings and the number of forwarded packets, discarded packets, and deliveredpackets to measuretheencounter quality point, which findstransmission and storageverdicts [30]. Youssef et al. reviewed thetechniques used to calculate the routing measures of cognitive radio networks [31]. The proposed model can be usedindelay tolerant networksfor analyzing the routing measures. Jones et al. discussed about real-worldimplementationsofrouting mechanisms in delay tolerantnetworks [31]. The proposedalgorithmis based ona metric of how far a packetdelays on a node until forward to the subsequentnode. The measure is estimated from encounterinformation, hence does not employoverallencounter statistics. Transmission is carried out when an adjacent node is measured to be nearer to the intended receiver than the present hop.

III. LOCATION-AWARE DIRECTIONALIZED ROUTING ALGORITHM

In this section, we first present the key tenet of the LDRA and then discuss its comprehensive design. To evade the shortcomings of existing routing approaches that exploit more than single-hop adjacent node data, we develop a novel algorithm that is based only on the locationstatistics of its single-hopadjacent nodes for every host. The key objective of LDRA is to increase the delivery probability of packets. Furthermore, although optimizing the overall communication latency is not vital emergency;maximum packet delivery probability can be promoted from rapid transfer in delay tolerant network scenarios, as hosts need not preserve the replica of a dispatched packet, consequently preserving the bounded storage space and the limited power. We agree with the researchers in [32] who witnessed that packet replication, first, enhances the delivery probability and, then again, reduces the communication latency. Nevertheless, the simpleduplication approachpresentsmaximumcommunication costs into networks. Hence,an additionalobjective is to applyreplication strategycautiouslyto achieve a trade-off between better efficiency and tolerableoverheads.

3.1 Network Model

Everyhop upholds a group of adjacent nodesin itscontact list. The proposed approach employs intermeeting graph rather than an encounter graph. In intermeeting graph, vertex denotes acontact between two hostsand alink denotes communication latencyamong two contacts. Every edge $uv \rightarrow uw$consists of two parameters $\delta(uv \rightarrow uw), (\sigma^2 \rightarrow uw)$, in which$\delta(uv \rightarrow uw)$ is the mean latency elapsed on host$u$amongencounteredhosts$v$ and w, and $(\sigma^2 \rightarrow uw)$ is the equivalent latency variance. The communication link in intermeeting graph is signified as (contact⇝node), for instance, $(uv \rightsquigarrow \mathrm{r})$ is a communication link from host uv to r where r is the receiving host. Linklatency denotes δ $(uv \rightsquigarrow \mathrm{r})$ and communication link variance as $\sigma^2(uv \rightsquigarrow \mathrm{r})$. These are an aggregation of communicationlatencies and variances correspondingly [33].

3.2 Location calculation

The parameter for receiving node r at vertex uv contains the communication link latency and variance. This parameter is diverse from traditional networks(eg., wired networks) parameters, where we have a single value per receiving node. In LDRA, both values are measured as a summary of the latency dissemination. The latency dissemination is applied to find the packetdissemination probability. The communication cost (i.e., overhead) of packettransmission is expressed as given in Equation (1).

$$C_{path} = r_u(uv \rightsquigarrow k) + 1.65\sqrt{\sigma^2}(uv \to k) \quad (1)$$

The definedoverhead shows favortocommunication linksthathavethe minimumlatency and the minimum latency variance. Everyuv in intermeeting graph related to 2 routing tables, one at host u and the other at host v. Ifencounter between 2hosts u and $v$befall, they appraise each other's routing table for uv. Assumes a host$v$encountershost u. Now, host$v$calculates its ideallinks to everyreceiving nodeonce again and shares it with host u. For eachadjacent node$n \in N_j$, (N_j is a group of adjacent nodes of v) the meanlatency (d_n), variance (V_n), and cost of the path(C^n_{path})are calculated as given in the following equations.

$$d_n = \delta(vu \to un) + r_v(vn \to d^*_n) \quad (2)$$

$$V_n = \sigma^2(vu \to un) + \sigma^2_b(vn \to k) \quad (3)$$

$$C^n_{path} = d_n + i.65\sqrt{V_n} \quad (4)$$

Now, the overhead is calculated as shown in Equation (5).

$$n^* = \arg min_{n \in N_j, n \neq u} C^n_{path} \quad (5)$$

Host v now transmits the value of d^*_n and V^*_n to host$u$ as average latency and variance of the intended receiver$k$through$v$(ideallink). Host$u$apprise its routing table with $r(uv \to r) = d_n$and $\sigma^2(uv \to r) = V_n$. In the same way, host$u$apprisesthe routing table of host$v$[34].Ifhost $u$encountersa host other than the designated receiver it transmitsfewreplicas to the meetinghosts. Considerhost u has a packet with βreplicas to transferto k, and it encounters with its adjacent node v. The host appraises itsTTLportion of the packet header. Then, it calculates the probability of successful deliveryρusing each of its adjacent nodes a using the following equations.

$$\rho_a = \rho\{0 < d \leq TTL/d > 0\} \quad (6)$$

$$\rho_a \frac{= \emptyset\left(\frac{TTL-d_a}{\sqrt{V_a}}\right) - \emptyset\left(\frac{-d_a}{\sqrt{V_a}}\right)}{1 - \emptyset\left(\frac{-d_a}{\sqrt{V_a}}\right)} \quad (7)$$

here$\emptyset(.)$ is the equivalent distribution function of normal distribution. Besides, adjacent nodes are rationallyorganizedaccording to theprobability of successful delivery ρ_a in decreasing order.

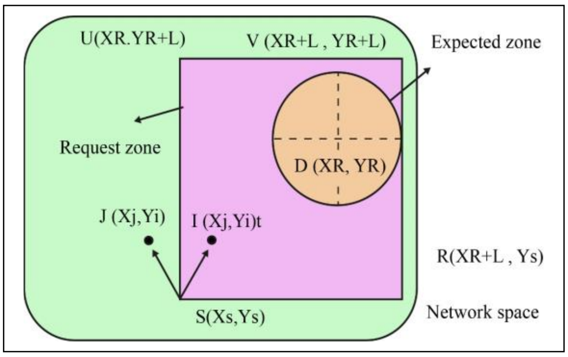

Figure 1: Estimation of the location of destination [34]

Every adjacent node a is assigned $\rho_a\beta$ replicas and these allocations are deducted from β. This endures until all adjacent nodes have been taken into account or β expires. Our LDRA employs the directional distribution of messages to the intended receiver. It determines the position of the intended receiver and then transmits the replicas of the packet to those who are near to the receiver. The integration of position data in the aforementioned technique and further decreases the energy consumption in transmission. The LDRA realized directional transmission of packets which leads to the transmission of the minimum amount of packets.Based on the position of the designated receiver, the LDRA predicts the request zone as shown in Figure 1 [35]. The hosts used in this zone have higher delivery probabilities. Consequently, the proposed LDRA transmits the replicas from the hosts which fall in this zone. This decreases the number of replicas in the communication system and also the transmission energy consumption.

IV. PERFORMANCE EVALUATION

We assess the effectiveness of ourLDRA with Opportunistic Networking (ONE) simulator, which is extensively employed for the assessment of delay tolerant algorithms[36], and relate it to three similar multiple replicaforwardingapproaches including the SAW [17], the PRoPHET [25], and the Epidemic [37]. ONE is a clock-step-basedsimulation tool. This means that the accuracy of the numericaloutcomedepends on the time-step used for simulation. The minimum time-step typicallycauses a quicker simulation process. In most of the experiments, we fix the time-step as 0.1 seconds, whereas in fewcomputational-centricoperations, we select to marginally increasedtime-step to acquire a suitable simulation time. Also, to reimburse the imprecisionproduced by reducing the time-step, everytrail is performed10 times. By averaging the results, we ultimatelyprovide the final results.

4.1 Simulation environment and parameter settings

In ourexperiments, the hostscomprisedtrams, taxis, and pedestrians.We initializethe control parametersasχ = 0:1, α =0:5, β = 0:5, and γ =0:5; the value of theseparameters can be variedbased on various environments. The speed of trams, taxis, and pedestrians are [7, 10] m/s, [2.7, 13.9] m/s, and [0.5, 1.5] m/s respectively; the coverage region of trams is [22, 30] m, while those of pedestrians and taxis are [3, 6] m and [15, 20] m correspondingly. To achieve appropriate real-time simulation environments, we considercollege, auditorium, and park-likepublic zones in the simulation map. Toachieve exactresultsinsimulation, we set the parametersas given in Table 2.

Table 2: Simulation parameters

Parameters	Setting
Simulation scenario	Helsinki
Number of nodes	60
Node types	trams, taxis, pedestrians
Buffer size (MB)	5–50
Message TTL (min)	300
Message size	500 KB –1 MB
Node wait time (min)	0–120
Simulation scenario size	4500 m × 3400 m
Simulation time (sec)	10000
Movement model	Map-based movement model

4.2 Performance metrics

We considered the two performance measures for evaluating the effectiveness of LDRA including the delivery probability and the overhead for different node densities, buffer size, and the number of initial replicas.

- Probability of successful delivery: It is the measure of successful delivery of packetswithin a deadlinewhich is employed to measure the hop's forwarding ability for that message. It can be defined as the ratio of all effectively delivered messages at the receiver hostand totalmessages produced at the sender.
- Overhead: We exploitthis metric to assess the packet scheduling performance of the method. It calculatesthe number of "additional"packetsis required for each effective delivery.

4.3 Result and discussion

We carry out three sets of experiments with the variablenumber of nodes, size of the buffer used, and the number of initial replicas of packets. First, we discuss the comparative results of various routing approaches with variable node density. For this simulation, we select the buffer dimension as 5 to 50 MB. The number of initial replicas of packets is 35.

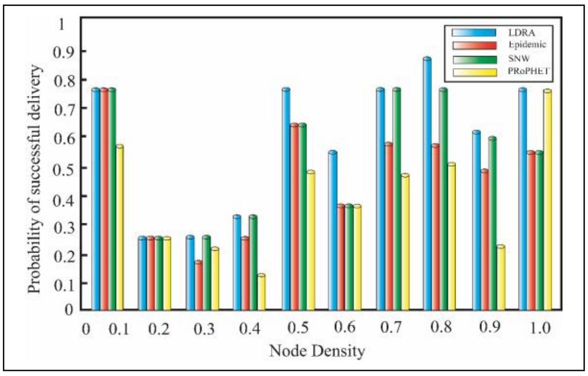

Figure 2: Node density versus Probability of successful delivery

The first scenario, node density versus probability of successful delivery, is verified and the results are given in Figure 2. Our proposed LDRA performs better than other approaches in terms of the probability of successful delivery.

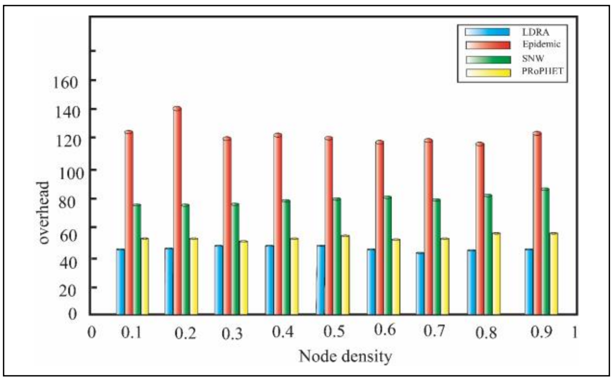

Figure 3: Node density versus overhead

From the results illustrated in Figure 3, it is observed that there has been a reduction in the communication costs of LDRA except for PRoPHET for different node densities 0.1, 0.2, 0.3, 0.4, 0.6, and 0.7 as illustrated in Figure 3, which implies that for dense network scenarios our LDRA outperforms all other approaches. This ensues owing to the minimum amount of copies in the network for packets. The presented algorithm forwards packets only to selectedhosts.

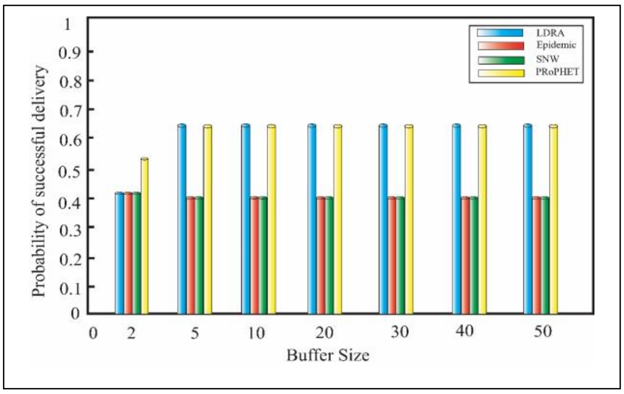

Figure 4: Buffer size versus probability of successful delivery

The second simulation provides the results with the variable dimension of the buffer. In this simulation, we employ 100 nodes and 35 initial replicas for the packet. From the result, it is observed that there has been a reduction in the communication cost of our algorithm in all the cases as displayed in Figure 4. The figure displays the probability of successful delivery against the buffer dimension. The proposed algorithm has identical or abridged delivery probability with the same explanations as conferred above. Similarly, it is found that there has been a considerable reduction in the communication costs of our LDRA as given in Figure 5.

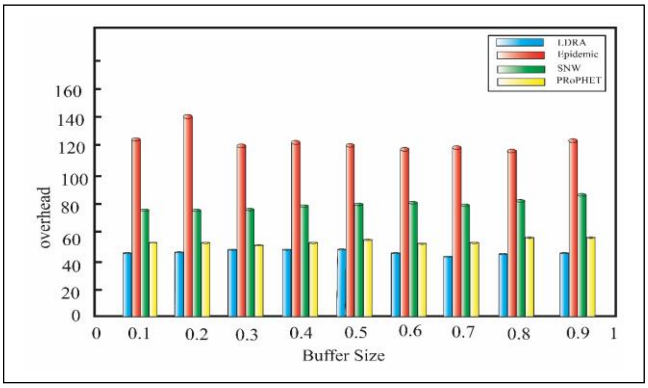

Figure 5: Buffer size versus probability of successful delivery

Our third simulation provides the results with the variable number of replicas. In this scenario, we employ 100 hops and a 5MB buffer size. The impact of the initial amount of the replicas of the packet on probability of successful delivery is analyzed and the results are given in Figure 6. Similarly, it is found that there has been a reduction in the communication costs of our LDRA except for PRoPHET in the case of the number of initial replicas 15 and 70 as given in Figure 6.

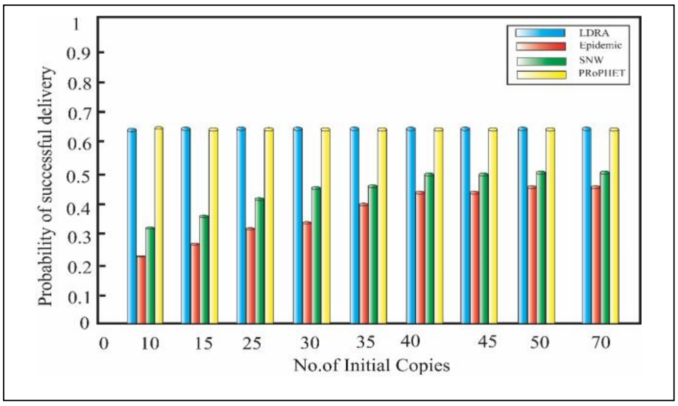

Figure 6: Number of initial copies versus Probability of successful delivery

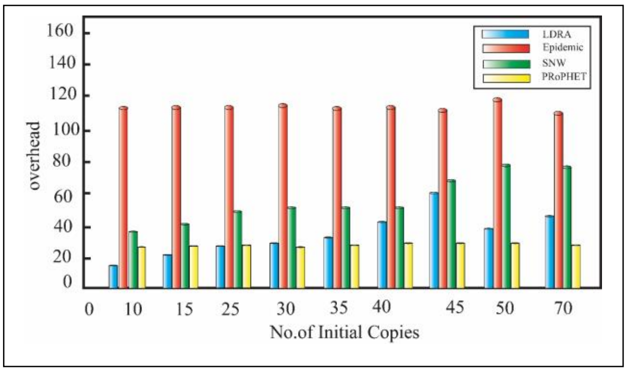

Figure 7: Number of initial copies versus communication cost

V. CONCLUSION

Despitewidespread research in the field of DTNs, it still experiencesnumerouscomplications. The majorstimulatingproblem among them is the needformaximum packet delivery probability. Some routing approaches focused on reducingcommunication costs and end-to-end delay. The algorithmintended in this worktargetsincreasing the packet delivery probability inthe DTNs by minimizing the communicationcosts. It finds the probability of successful packet deliveryvia each of its adjacent nodes and distributesreplicas of the packet accordingly by exploiting the location statistics of the intended receiver. In order to simulate DTN scenario and evaluate the effectiveness of the proposed algorithm by considering delivery probability and cost as performance metrics, we have employed the ONE simulator. It is demonstrated thatthepresented algorithm achieves maximum delivery probability and minimum communication cost as compared with other existing routing approaches.

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