DSG-PC: Dynamic Social Grouping Based Routing for Non-uniform Buffer Capacities in DTN Supported with Periodic Carriers

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Abstract. Routing a message in networks that are dynamic in nature with time varying partially connected topology has been a challenge. The heterogeneity of the types of contacts available in such a network also adds to complexity. In this paper we present an approach to transfer messages in disruption/delay tolerant network when there is only intermittent connectivity between the nodes. Most of the existing approaches exploit either the opportunistic contacts and transfer messages using the probabilities of delivering a message or use periodic contacts. In addition to opportunistic contacts, we also have scheduled carriers that are available periodically. Scheduled carriers guarantee delivery of the messages to the base station, however, it may have an added delay. If a message can tolerate the delay through the scheduled carrier, it waits else it may be forwarded to an opportunistic contact. We define a utility function for a node to decide whether to forward the message to an opportunistic contact or to a scheduled contact.

This is an improvement over routing through opportunistic contacts that exploits social behavior of the nodes as in [2]. We compare performance of our approach with [2] on message delivery ratio, message delay and message traffic ratio (number of messages forwarded / number of messages delivered) and found that our algorithm outperforms [2] on all the three metrics. We also studied the impact of initializing the probabilities of the nodes proportional to the varying buffer size in [2]. It was found that delivery ratio increased significantly without increasing the message traffic ratio and delay.

1 Introduction

MANETs (Mobile Ad hoc Networks) address challenges related to mobility and low battery life when there is no pre-existing communication infrastructure. In most of routing techniques for MANETs there is an underlying assumption that there always exists a connected path from source to destination. However, there are number of applications in which nodes need to exchange messages over partitioned MANETs called Delay Tolerant Networks. Research in the area of Delay Tolerant Networks (DTNs) has received considerable attention in the last few

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years owing to their widespread occurrence in a variety of applications such as– (a) InterPlaNetary(IPN) Internet project [3], (b) Wizzy digital courier service which provides asynchronous (disconnected) Internet access to schools in remote villages of South Africa [8], (c) A scenario where a hypothetical village is being served by digital courier service, a wired dial-up Internet connection and a store and forward LEO satellite. Route selection through any one of them depends upon the variety of factors including message source and destination, size, time of request, available connects or other factors like cost and delay etc. [8], and d) Transmission of information/ message during mission critical operations like natural disasters or battle zones.

Delay and Faults are usually tolerable in such aforementioned applications. In this work, we look at the problem of routing in a DTN [6]. A Delay-Tolerant Network is an occasionally connected network that may experience frequent, long-duration partitioning and may never have an end-to-end contemporaneous path. Thus, in contrast to the traditional routing techniques of MANET's where the aim is fast delivery of a message, here the aim is the delivery itself. Since the links are available intermittently, messages must be stored and forwarded later, delays are inevitable in such networks.

One of the earliest approaches proposed for routing in partitioned networks is *epidemic routing* [17]. However, it is very expensive in terms of message traffic and buffer space, which reduces life of the network. To overcome the problems of heavy traffic and high buffer requirement, probabilistic routing [11,19] and social routing [5,7,4] schemes were proposed. Both the approaches provide considerable improvement in delivery ratio under low buffer requirement. The probabilistic routing schemes are based on heuristic that if a node has interacted with a group of nodes in the past it will do so again in the future. On the other hand, the social routing assumes that nodes that are a part of same social network will interact more frequently with the members of that social group. Taking advantage of both the schemes, a dynamic social grouping (henceforth referred to as DSG) method was proposed by Cabaniss et al. in [2] that forms social groups based on contact patterns and use consistent routes to base stations based on delivery patterns to deliver the messages with high probability. However their work considers only the opportunistic contacts to deliver the messages. In practical scenarios, many times one or more scheduled carrier to the destination is also available. Work on scheduled contacts [8,18,16,21] relies on periodic/scheduled contacts to deliver the message. One advantage of the scheduled contacts is higher probability of delivery where as the delay may be more. Another advantage is that since the scheduled contacts are special nodes, they are equipped with better resources, say more buffer capacity.

We propose an approach that combines the advantages associated with social routing, probabilistic routing and scheduled contacts for routing a message. For routing we assume social groups among opportunistic nodes are formed in the network in a similar way as that in DSG. Periodic carriers do not participate in group formation and mergers. We update the individual probabilities even when two nodes meet and there are no messages to be exchanged. In contrast to DSG where the initial probabilities of the nodes are uniform, we assign the initial probabilities proportional to the buffer capacity of the nodes. We first show the impact of doing this on DSG and then extend the work of [2] to include scheduled carriers whose probability to deliver a message to the base station is very high as compared to the probability of other nodes. We define a utility function for a node to choose between an opportunistic carrier and a scheduled carrier. The buffer capacity of the scheduled carrier is higher than that of the other nodes. To be able to use groups to forward messages we make use of contact strength to define joint individual probabilities that are used to make routing decisions. We show through simulation that the message delivery ratio, message delay and the traffic ratio improve considerably over DSG when the time period of the carriers is not too big. We also show the impact of time period of the carrier nodes on the performance. It was observed that delivery ratio increased significantly without increase in the message traffic ratio and delay.

The paper is organized as follows: Section 2 presents the related work done in the area of routing in delay tolerant network. Section 3 describes the problem. Section 4 presents the proposed algorithm. Section 5 presents experimental setup and analysis of results generated after the implementation of the algorithm on ONE Simulator [10]. Section 6 presents conclusion and future work.

2 Related Work

One of the earliest approaches proposed for routing in partitioned networks is *epidemic routing* [17]. The goal of epidemic routing was to maximize the message delivery ratio while minimizing the message delivery time. It relies on replicating messages through buffer contents synchronization when two nodes come in contact until all nodes have a copy of every message. It operates without knowledge of the communication pattern and is well-suited for networks where contacts between the nodes are unpredictable. However, it is very expensive in terms of message traffic and buffer space, which reduces the life of the network. That is, the approach does not seem to scale as the number of messages in the network grows. An intelligent buffer management scheme can improve the delivery ratio over the simple FIFO scheme. Epidemic routing is sometimes useful in transferring control messages in a part of a network.

In [11,12,13,20] authors claim that mobility is mostly not random and there is a pattern in encounters. The Probabilistic Routing Schema is based on individual probabilities of nodes of successful delivery of a message. Delivery probabilities are computed using the history of encounters and transitivity to reflect that if a node has been encountered in the past, it is likely to be encountered again. When two nodes come in contact, the one with lower probability of delivery forwards its messages to the one with higher probability updating its own probability upward as it does so. If a node drops a message its probability is reduced to reflect the nodes inability to transfer. This algorithm shows a marked improvement in terms of message transmission rate while maintaining a high delivery probability under the resource (buffer capacity and bandwidth) constraints. The approach introduced by Wang et al. in [19] is also based on probabilities of nodes of successful delivery of a message to a base station. However the delivery probabilities are computed based on successful delivery of messages rather than regular contacts between the nodes.

The SimBet routing algorithm [5] borrows ideas from social networking and contact patterns to predict paths to destinations to improve delivery ratio and time. The algorithm assumes that the groups of frequently encountered nodes have been formed and calculates the Betweenness and Centrality metrics to make routing decisions. Bubble Rap [7] extends their work by allocating nodes into social groups based on direct and indirect contacts. Based on the global knowledge of the nodes contact, they construct k-cliques/clusters to define the groups. However, grouping is static in their approach. In [1,2] Cabaniss et al presents an approach that combines advantages of social grouping and message forwarding based on probabilities of delivery of message of a node. Groups are formed dynamically as nodes come in contact with each other.The message is either forwarded using individual delivery probability of the node, which is computed on the basis of message forwarded by the node, or using group probability of groups of which node is the member. In [2] the authors present an application of social grouping on network with single base station and in [1] approach for network with n message sources and sinks is presented.

Jain et al. [8] proposed an approach for routing in DTN using modified Dijkstra. They assumed that DTN nodes posses knowledge about time and duration of contact. On the basis of this knowledge a node may create number of routing metrics. Their results show that the efficiency and performance increases with the amount of information used for the metric. In DTN determining futuristic knowledge of opportunistic contacts is extremely difficult and therefore the approach presented in [8] may only exploit the scheduled contacts for message transfer and opportunistic contact may not be used.

Jones et al. in [9] presented an approach that is using link state routing protocol. The link state packets are exchanged using epidemic approach that leads to overhead. Whenever a node has a message to transfer, it forwards it to the node that is closest to the message destination. The approach is good in the sense that it requires very small buffer space and is therefore scalable. But the approach may not be practical in the scenario wherein the nodes have sparse connectivity.

The concept of using carrier nodes to transfer data to nearest access point in sensor networks is used in [16]. The carrier nodes acting as data mules follow a random walk and come in contact with sensor nodes. The movement of the data mules generates opportunistic contacts that are exploited to deliver the message. The concept of using a ferry for carrying the messages to the destination was introduced by Zhao et al [21]. A ferry following a fixed schedule moves along a fixed trajectory. Two different approaches have been presented. Firstly, a node may adjust its own path so that it comes in contact with ferry node, when it has a message to be delivered. In the other approach a node calls up a ferry on demand. The ferry adjusts its path so as to come in contact with the node requiring its services. The approach relies on direct contact between the ferry and the sender/receiver nodes. It fails to exploit the mobility and the contacts between the nodes to deliver or receive messages to/from the ferry.

3 Problem Definition

Consider a scenario where people (showing social behavior) living in remote villages have to transfer mails/ messages to a central office (fixed base station) located at an urban area far away from the village. Periodically a postman visits the villages. The people in the village are well aware about the day and the time of visit of the postman. Occasionally people from the village may also visit the urban area and may deliver the message to the central office. A villager, wanting to send a message to the central office, needs to take a decision as to whether he should give his message to another villager, planning to visit the city, whose probability of visiting the central office is low or to wait for the postman to arrive. Thus, we require a routing approach that exploits availability of the postman (acting as periodic carrier) and the movement of village people (acting as opportunistic contact) to maximize the number of messages delivered without much delay. In this paper we present an approach that maximizes the message delivery in a DTN having opportunistic as well as periodic contacts.

4 Preliminaries

In this section we briefly explain the DSG based algorithm of Cabaniss et al. [2]; The nodes having common interest tend to meet frequently. Groups are formed in DSG so that good contact strength between nodes of the common interest can be exploited to route messages. A group consists of at least two nodes. First time a group is formed when the contact strength between two nodes exceeds the threshold (ψ). The contact strength $\lambda_{A,B}$ between two nodes $Node_A$ and $Node_B$ is computed as in [2] i.e. $\lambda_{A,B}$ is initialized to zero and is updated as follows:

$$\lambda_{A,B} = (1-\alpha)\lambda_{A,B} + \alpha \frac{time_{contact}}{time_{contact} + time_{nocontact}} \tag{1}$$

where α is a control parameter. The nodes common to two groups may initiate the process of enlarging the group by mergers. Mergers are initiated when the ratio of overlapping members of the group to the unique members of the union is above threshold (τ). The updated information regarding the group is maintained by the cluster-heads or the group heads. Any node which does not want to be a part of the group may resign from it and the group dynamism is maintained. The nodes of same group coming in contact updates the group information on the basis of group versions. Group formation, group merger, node resignation and group updates are done in the same manner as in [1].

Besides contact strength with other nodes in the network, each node maintains a probability of delivery σ_A to the base station. Initially all the nodes except the base station are assigned uniform probabilities with base station having probability 1. Probabilities are updated as the messages are forwarded. Each cluster head also maintains group's probability of delivering a message to the base station. Group's probability is the average of individual probabilities of its members. Besides individual probabilities, each node maintains a list β_A of the group probabilities of all the groups $Node_A$ is a member.

Let $\Delta_A = max\{\beta_A, \sigma_A\}$. When two nodes $Node_A$ and $Node_B$ come in contact, they compare their probabilities of delivering a message to the base station individually or through one of its groups. $Node_A$ forwards its messages to$Node_B$ if $\Delta_B > \Delta_A$. $Node_A$ also increments its probability as per the following formula:

$$\sigma_A = (1 - \phi)\sigma_A + \phi\Delta_B \tag{2}$$

where ϕ defines the weight factor.

In [1], 'joint individual probability' (γ_A) instead of individual probability is used to make the routing decisions. Joint individual probability signifies the node's capability to deliver the message to the destination through itself or through any of its groups. The joint individual probability of $Node_A$ is computed as follows:

$$\gamma_A = 1 - \{\{1 - \sigma_A\} \times \Pi_{i=1}^{|GroupsofA|}(1 - \beta_{Gp_i})\} \tag{3}$$

where β_{Gp_i} is the group probability of $Group_i$. When two nodes say $Node_A$ and $Node_B$ meet they exchange their joint individual probability and $Node_A$ forwards its messages to $Node_B$ if $\gamma_B > \gamma_A$. $Node_A$ with lower joint individual probability updates its individual probability as follows:

$$\sigma_A = (1 - \phi)\sigma_A + \phi \cdot \gamma_B \tag{4}$$

When a node drops a message due to ttl expiry or buffer overflow its delivery probability is decreased as follows: $\sigma_A = (1 - \phi)\sigma_A$ to indicate node's inability to forward it.

5 Improvements Proposed in DSG for DSG Supported with Periodic Carriers (DSG-PC)

As mentioned in previous section, DSG uses social group formation and probability of delivery to take routing decision for a message in a network of nodes with uniform buffer capacities. In this section, we propose improvements in procedures of initialization, evaluation and updation of individual probabilities by considering node's bufferspace as a part of their capability to deliver message.

5.1 Individual Probability and Initialization of Individual Probabilities

In contrast to DSG where the individual probabilities are initially assigned uniformly to all the nodes, we assign the individual probabilities proportional to buffer space of a node based on the theory that a node with larger buffer space is a better candidate to deliver the message, by virtue of retaining the message for longer duration, than the one having less buffer space. In our approach we have assigned the initial delivery probability to all the nodes on the basis of their buffer space which is different from the one presented in DSG wherein all nodes are assigned equal probability initially. We compute initial probability of $Node_A$ as follows:

$$\sigma_A = \frac{BufferSpace_A}{MaxBufferSpace} \tag{5}$$

where $MaxBufferSpace$ is a network wide parameter. Probabilities are updated from time to time as explained in next section.

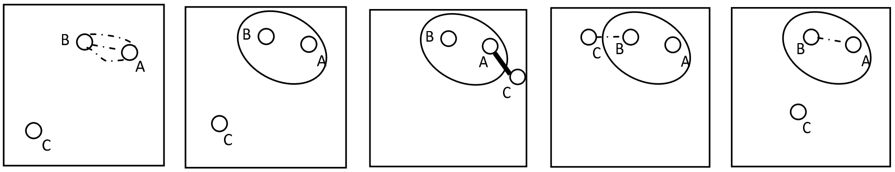
5.2 Delivery Probabilities

Joint individual probability as defined in [1] allows a node with low individual probability and weak contact, with other group members, to accept messages which it is less likely to deliver. Consider the situation when node's average contact strength with its group members is low say 0.2 but above the threshold of resigning. A message should not be forwarded to such a node just because its group probability is high. For example, consider $Node_A$ with $\sigma_A = .1$ member of two groups G1 and G2 with group probability as P(G1)=.7 and P(G2)=.8. Using the approach used in [1], the $\gamma_A = 0.946$. This means $Node_A$ will receive the messages but is less likely to forward it to other members of group due to low average contact strength. We have used the measure of average contact strength in determining the joint individual probability of a node. We propose to compute the joint individual probability of $Node_A$ as follows:

$$\gamma_A = 1 - \{\{1 - \sigma_A\} \times \Pi_{i=1}^{|GroupsofA|} 1 - \lambda_{A,Gp_i} \cdot \beta_{Gp_i}\} \tag{6}$$

where λ_{A,Gp_i} is the average contact strength of $Node_A$ in $Group_i$ and β_{Gp_i} is the group probability of $Group_i$. Now the joint individual probability of $Node_A$ with weak average contact strength i.e (0.2) with this group member is 0.35. Clearly λ_A as defined above is a better measure to capture the node's capability to deliver the messages.

DSG updates the delivery probability only when the message is delivered; however even when two nodes come in contact but they have no message to exchange, their individual probabilities should be updated. Consider an example wherein there are three nodes in a network, $Node_A$, $Node_B$ and $Node_C$ (see figure 1). Suppose $Node_A$ is a base station with probability P(A)=1.0. Initially the delivery probability of other nodes is 0.0 i.e. P(B)=0.0 and P(C)=0.0. Suppose $Node_B$ comes in contact with $Node_A$ frequently thereby increasing their contact strength but have no messages to exchange. So B and A form a group Gp_1 with probability of B as P(B)=0.0, and group probability say $P(Gp_1)$=0.50. Now C meets A and delivers 10 messages thereby increasing probability of C to say P(C)=0.55. Next, C moves close to B and meets B. C has a message for A. Now C will not forward the message to B. Next B meets A (they are in the same group). Message of C could have been delivered to A through B if we had



(a) Base station ($Node_A$), and $Node_B$ meet frequently. $Node_B$ has no messages to transfer

(b) $Node_B$ and $Node_A$ form a group

(c) $Node_A$ and $Node_C$ meet and $Node_C$ delivers messages to $Node_A$ and increases its probability

(d) $Node_C$ meets $Node_B$, a good node for delivering the message, but $Node_C$ does not forwards the message to $Node_B$

(e) $Node_B$ meets $Node_A$. $Node_C$'s message could have been delivered

Fig. 1. A scenario of message exchange and updation of probabilities in DSG

forwarded the message to B. We update the probabilities when the connection between two nodes terminates, even though they do not have a message to exchange. However, we do so at the time of connection removal and only when the contact duration is sufficient to transfer at least one message. In the above example the contact between $Node_A$ and $Node_B$ would lead to increase in probability of $Node_B$ to say P(B)=0.40 and then the group probability will become $P(Gp_1)=0.70$. In this scenario $Node_C$ would forward the message to $Node_B$ and the message would be delivered.

6 Proposed Algorithm

The proposed algorithm, DSG-PC, uses scheduled carriers to transfer messages in an intermittently connected network, running delay tolerant applications, equipped with periodic carriers and has advantages over probabilistic routing and social grouping behavior. The model of periodic carrier is somewhat similar to the DAKNet [14] but DAKNet does not take advantage of the opportunistic contacts and regular movement patterns to deliver messages. DSG-PC exploits availability of opportunistic contacts as well as periodic carriers.

We propose a periodic carrier node that is an especially designed drop- in node following a fixed trajectory over fixed time interval and has large buffer capacity. The schedule (time and place where periodic carrier would meet the DTN nodes) of the periodic carrier is known in advance to all the DTN nodes in the network. For example at time say 9'o clock a periodic carrier starts its schedule from its office and meets a node say $Node_A$ between 10.00 to 10.30. It meets the $Node_B$ between 12.00 to 12.30 and then delivers its messages to base station between 1.00 to 1.30. Next day again it follows the same schedule to collect and deliver messages. $Node_A$ and $Node_B$ knows in advance that they can meet periodic carrier at particular fixed schedules and also for fixed duration. In

DSG-PC, periodic carriers do not generate any messages and are used to improve timely delivery of messages in the scenario like delay tolerant network with opportunistic nodes. A periodic carrier does not participate in group formation and mergers.

We define a utility function that helps a node to choose among opportunistic contacts or periodic carriers. The decision of forwarding a message to an opportunistic contact or to a scheduled carrier depends upon the delay tolerance capabilities of the message. Each node at the time of contact with any other node checks delay tolerance capabilities of all the messages in the buffer using their creation time (m_{toc}) and time to live (TTL_m) parameters. The messages which can tolerate the delay of at least one scheduled carrier are kept in buffer. On the other hand for the messages which cannot tolerate the delay the utility value of the encountering node say i for the message m ($U_i(m)$) is computed. The node in contact forwards the messages only if its utility is less than the encountering node. The utility value of an encountered node is computed as follows:

$$U_i(m) = jointIndProbability_i \times \begin{cases} f(m)\ when\ Node_i\ is\ opportunistic\ carrier \\ !f(m)\ when\ Node_i\ is\ scheduled\ carrier \end{cases} \tag{7}$$

where

$$f(m) = \begin{cases} 1\ when\ (m_{toc} + TTL_m - CurrTime) \leq min(CD_j) \\ 0\ when\ (m_{toc} + TTL_m - CurrTime) > min(CD_j) \end{cases} \tag{8}$$

$CurrTime-$ Current Time and CD_j-Delay introduced byj^{th} carrier for $j = 1 \ldots n$ and $n =$number of carriers. Intuitively $f(m) = 1$ means that the message cannot tolerate the delay by one of the scheduled carriers and hence the utility value of any $Node_B$ for m is 0. $f(m) = 0$ means that the message can tolerate the delay by any of the scheduled carriers and hence the utility value of any $Node_B$ for m is nothing but its joint probability of delivering a message to the base station.

Thus if message can tolerate delay introduced by a periodic carrier it waits for the periodic carrier to arrive since it will guarantee delivery of the message, else it uses DSG like approach to forward message to an opportunistic contact i.e. the message is forwarded to an opportunistic contact with higher probability. For example, consider a node $Node_A$ having message m comes in contact with $Node_B$ at current time say 100 sec. Now suppose message m can tolerate the delay according to its TTL requirement say for 50 sec. Now, if any of schedule carrier delivers before 50 sec (i.e. message can tolerate the delay) then f(m) evaluates to 0 and $U_B(m)$ also evaluates to 0. Hence $Node_A$ does not forward the message to opportunistic contact $Node_B$. In case message is not able to tolerate the delay then $U_B(m)$ evaluates equal to $Node_B$'s joint individual probability. Now like DSG, if $U_B(m) > U_A(m)$, $Node_A$ forwards message to $Node_B$ otherwise not.

We assume that groups along with the individual and group probabilities of the nodes have already been computed using an algorithm like DSG.

When $Node_A$ comes in contact with $Node_B$, it makes a decision whether to transmit a message to $Node_B$ or not. The decision of the node is based on the following factors :- a) If $Node_B$ is a destination node the node A transfers all its messages. b) If $Node_B$ is any of the carrier nodes, then $Node_A$ transfers only those messages to $Node_B$ which can sustain the delay of $Node_B$ reaching the destination . c) If $Node_B$ is an opportunistic contact, it determines if any carrier is scheduled shortly whose delay it can sustain. If so, it waits for the carrier to arrive as it guarantees the delivery of message where as the opportunistic contact would deliver the message only with some probability. Otherwise, the two nodes exchange the joint individual probability and if the probability of $Node_B$ is higher than $Node_A$ it forwards the message to opportunistic contact.

Algorithm 1. DSG-PC Routing Algorithm

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Notation
$jointIndProbability_A -$ Joint individual Probability of A
$jointIndProbability_B -$ Joint individual Probability of B
$message_i -$ Message in DTN
$Dm_i -$Delay sustained by message
$S_i -$Carrier Node
$Dest -$ Message Destination

Trigger$-$ $Node_A$ contacts $Node_B$
In $Node_A$
if Node$_B$ $= Dest$ then    Deliver message to $Node_B$
else if $Node_B = S_i$ then
    for all $message_i$
        $CarrierDelay = Compute\_Carrier\_Delay()$
        if $Dm_i > CarrierDelay$ then
            Deliver Message to $Node_B$
        end if
    end for
else
Transmit $jointIndProbability_A$ to $Node_B$
Receive $jointIndProbability_B$ from $Node_B$
if $jointIndProbability_B > jointIndProbability_A$ then
    $CarrierDelay = Compute\_Carrier\_Delay()$
    for all $message_i$
        if $Dm_i > CarrierDelay$ then
            Wait for the Carrier
        else
            Transmit messages to $Node_B$
        end if
    end for
else
```

```
    Receive messages from $Node_B$
end if
Compute_Carrier_Delay()
Notation
$C-$ set of carrier nodes
$T_i-$ Delay in reaching to $Node_A$ in $i^{th}$ cycle for $j_{th}$ carrier
$T_{Dest}-$ Delay in reaching destination from $Node_A$ for $j_{th}$ carrier
$Delay_j-$ Delay for $j_{th}$ carrier
In $Node_A$
    $Delay_j = T_i + T_{Dest}$
    $CarrierDelay = min(Delay_j)$ where $j = 1$ to $j \leq |C|$
return $CarrierDelay$
```

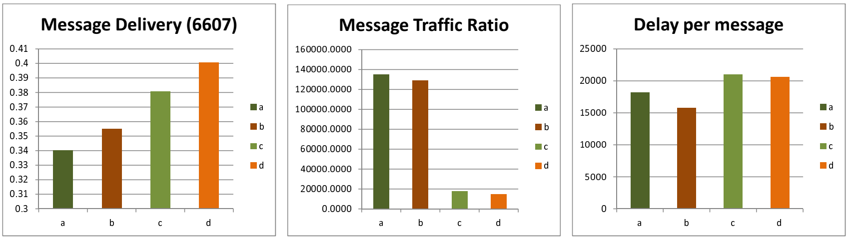
7 Analysis

7.1 Experimental Setup

The Opportunistic Network Environment(ONE) simulator [10] implemented in Java and available as open source has been used to evaluate the algorithms. The ONE simulating environment is capable of simulating the mobility pattern of the nodes and the message exchange between them. Many of the routing algorithms applicable to DTN environment are pre-implemented in the simulator. We implemented the routing as used in our algorithm and the one used in DSG by extending the functionalities available in ONE. Three metrics viz message delivery ratio, message traffic ratio and delay per message were used to compare the performance of DSG and DSG-PC. The simulator generated the message delivery ratio and the message traffic but the functionality for generating delay per delivered message was added to the simulator. The experimental setup was also slightly modified to study the impact of assigning initial delivery probabilities proportional to the buffer space of the DTN nodes on three metrics. The simulation was repeated for both replicated and non-replicated message forwarding.

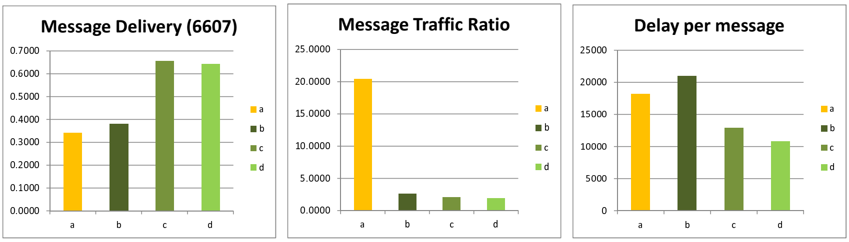
7.2 Data Source and Simulation Parameter

In order to objectively compare the results of DSG-PC with DSG extensive simulations were carried out on the data obtained from an experiment conducted at University of Cambridge at the 2005 Grand Hyatt Miami IEEE Infocom conference as used in DSG [15]. We also added the contact pattern of two periodic carrier nodes, following a fixed trajectory and a fixed time period, with other nodes in the data. For simulation purpose one of the node, as mentioned in the data, was considered to be a sink/base station. The simulation was run on the whole data set. Total number of messages generated were 6607. Message size was varied between 512 KB to 1MB. The transmission speed of nodes was 256kBps. The buffer space for carrier node was 2000MB and for DTN nodes it



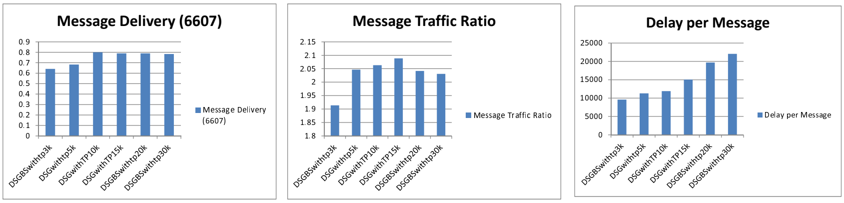
(a) Message delivery ratio (b) Message traffic (c) Delay per message

Fig. 2. Comparison of Impact of initial equal individual probability and initial individual probability proportional to buffer space. where ‘a’is DSG Replicate, ‘b ’is DSG Replicate with probability proportional to buffer space, ‘c’is DSG Non Replicate and ‘d’is DSG Non Replicate with probability proportional to buffer space



(a) Message delivery ratio (b) Message traffic (c) Delay per message

Fig. 3. A comparison of DSG based Routing in DTN with Opportunistic contacts and Periodic contact where ‘a’is DSG Replicate, ‘b’is DSG Non Replicate, ‘c’is DSG-PC with Periodic Carrier(10k Time Period), and ‘d’is DSG-PC with Periodic Carrier(3k Time Period)



(a) Message delivery ratio (b) Message traffic (c) Delay per message

Fig. 4. Impact of Variation in Periodicity of Carriers

was varied from 100MB to 30MB. The message TTL(time to live) was set as one day(1440 min). The threshold used for group formation (ψ) is 0.004 and for group merger(τ) is 0.300 as used in DSG. The probability decay rate (ϕ) is 0.075 and that of contact decay ratio (α) is 0.300.

7.3 Comparison of Results

We conducted two sets of experiment. The results were compared for replicated as well as non replicated message forwarding. In the first experiment, we compared and analyzed the results of assigning the initial individual probabilities proportional to the node's buffer space. The results (see figure 2) show that the DSG with initial individual probabilities proportional to the buffer space (say A) performed better than DSG with nodes assigned equal probabilities (say B) for all the metrics namely message delivery ratio, message traffic ratio and message delay.

For the second experiment we compared our results i.e. the results of DSG-PC with that of DSG i.e. the initial individual probabilities were assigned proportional to the buffer space and periodic carriers were added. The review of results (see figure 3) indicates DSG-PC (exploiting both the scheduled as well as opportunistic contacts) outperforms DSG (exploiting only opportunistic contacts) on all the three metrics. The message delivery ratio for DSG-PC shows (see figure 3a) an improvement of 85-94% over DSG with replicated forwarding and 65-73% with non-replicated forwarding. Also the message traffic ratio (see figure 3b) for replicated forwarding reduced by 89-90% and that for non-replicated forwarding it reduced by 22-28% and the delay suffered by a message (see figure 3c) reduced by 29-40% for replicated forwarding and 38-50% for non replicated forwarding.

7.4 Impact of Periodicity of Scheduled Contact

The experiments for DSG-PC were repeated with periodic carriers having time periods 3k, 5k,10k, 15k, 20k and 30k sec (see figure 4). It was observed that the message delivery ratio (see figure 4a) increased when the periodicity of the carriers was varied from 3k sec to 10k sec. Beyond 10k sec i.e. for 20k and 30k sec the delay per message (see figure 4c) also increased considerably as was expected.

8 Conclusion and Future Work

The proposed algorithm improved message delivery ratio, message traffic ratio, and delay significantly by using buffer capacity to assign initial probabilities and exploitation of periodic contacts along with opportunistic contacts. While the cost of setting up this type of network will increase marginally due to cost of introducing a carrier, but since improvements in terms of outcome are substantial so cost will not be an issue. Further, as future work, an application of DSG may be widened by attaching communities to social groups. Attaching communities to the social groups may be useful to ensure that messages from one community do not travel through another.

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