

# Deadline Aware Hybrid Data Forwarding Scheme in Delay Tolerant Networks

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## Abstract

*Even though long delay is permitted in Delay Tolerant Networks (DTNs), some applications explicitly demand an upper bound imposed on message delivery delay for the application specific purpose. Despite some researcher have proposed to meet new requirement, their approaches have weakness in the point of implementation since infinite buffer space on a node or the knowledge prior the moment regarding mobility and connectivity are assumed. To remove dependency on buffer and mobility pattern for bounded delay, we propose how to extend the epidemic routing protocol through delay estimation with inter meeting times record. Moreover, utility based forwarding to decide the adequate next hop while preserving an upper bound imposed on message delivery delay is introduced. Finally the simulation results will be given to prove the guarantee of delay bounded under the same simulation scenarios as comparative well-known protocol, RAPID. As the result, the proposed scheme shows the delivery in upper bound with less resource usages.*

**Keywords:** *Delay-tolerant networks (DTNs), Bounded delay, Packet delivery delay, limited buffer space, Inter meeting times*

## 1. Introduction

Delay tolerant networks (DTNs) are a kind of challenging network characterized by frequent and long partitions. In DTN it is usually not possible to maintain complete path between source and destination, or such a path is highly unstable and may only exist for a short period of time. Examples scenario, where DTNs have been employed include wildlife tracking sensor network, military network, emergency ad hoc networks, vehicular ad-hoc networks, and deep space inter-planetary networks, *etc.* [1]. To deal with this paradigm, researchers have suggested using the principal of store-carry and forward routing. Based on this principal, a node is allowed to buffer a message, carry them while moving and forward them to the other node when encounter it. Such a process repeats until the destination is arrived. In most DTNs scenarios, communication is achieved by the movement of mobile nodes and the ability to store, carry and forward the messages since contacts in this network occur opportunistically.

One of the most popular routing protocols in this context is epidemic routing [2] which disseminate multiple copies of identical message to every node in order to reduce the delivery delay and to improve delivery rate. Epidemic routing achieves optimal delivery delay under no buffer and bandwidth constraint as it uses message flooding method which replicates the message throughout the network, it is extreme usage of network resources. Furthermore, under resource constraint scenario epidemic routing result in extreme overheads such as message transmission, bandwidth and buffer usage, battery consumption as these resources

are strictly limited in such situation. A number of routing protocols have been proposed to reduce these overhead and improve the performance of epidemic routing [3, 4 and 5]. Despite of their low transmission delay these protocols consume a high amount of bandwidth and buffer space which are crucial to DTN network. A significant research has been performed to develop efficient routing algorithm for DTNs. Most of these researches emphasize on improving the delivery ratio and to balance the overheads with redundant copies for successful delivery. However, the design of DTN routing algorithms can be application specific. In this work, we emphasize the need for delivering messages to the destination within the threshold of user defined delay and minimizing the usage of resources. Thus, our goal is to develop algorithm based on the delivery delay constraints to deliver packets within user defined delays threshold while using as little resources as possible. To do so, our proposed routing doesn't require any special knowledge about the network.

To deal with this dilemma, there has been some recent work which can provide customized bounded delay and consider the delay requirements in DTNs [1, 6, 7 and 8]. However, these routing algorithms assume infinite resources or some level of knowledge regarding node mobility and connectivity. We will briefly discuss the most related work in Section 2, and will also differentiate our algorithm from them. In most of these protocols, either partial information of the node contacts mobility patterns are assumed in advance or they include some special nodes for routing assistance including message ferries [9], trowboxes [10] and data mules [11]. Although prior knowledge about the node connectivity is useful for making routing decisions but such information may not be available to the nodes in the network. In contrast our approach assumes no knowledge of node connectivity or mobility patterns. To solve current issues on this research area, in this paper, we propose a new routing protocol by extending current epidemic routing protocol. To achieve this goal, analytic suite approximation using ordinary differential equations (ODEs) that describe the probability of successful delivery of messages as a function of time parameter is used. Addition to this model, time-varying utility based forwarding is presented to decide the appropriate node for the destination. Fundamental benefits of this scheme are to optimize the performance of epidemic routing in term of threshold delay associated with buffer space and the number of transmissions. Simulation has been carried out to evaluate the performance of our scheme. The simulation confirms that our proposed scheme achieves high throughput in term of message delay, buffer space and the number of transmissions than other flooding-based schemes.

The rest of the paper is organized as follows. In Section 2, we review and discuss the previous work done in the related area. Section 3, introduces the system model with problem statement. This section also includes delay estimation calculation with forwarding policy. Simulation results and performance evaluations are presented in Section 4. The paper concludes with Section 5.

## 2. Related Work

Epidemic routing [2] extends the concept of flooding in delay tolerant networks. It is used when path from the source to the destination is rarely available. A random pair-wise exchange of messages among nodes ensures ultimate delivery. The flooding like transmission achieves high delivery rates and very low delivery delay at the cost of high resources consumption and causes congestion in loaded network. The reason of such congestion is it explores all available communication paths to deliver message. If the network resources are unconstrained, the Epidemic routing can be the best choice to reliably disseminate data across the network. But network resources such as buffer, nodes battery power and bandwidth are generally

limited so Epidemic routing is not applicable under the constrained situation which causes contentions leading to dropping of messages.

To address these weakness of epidemic routing different routing schemes based on selective flooding [3, 4, 5, 12 and 13] have been proposed in order to tradeoff delivery delay at the cost of bandwidth utilization. These replication based algorithms differ from each other in assumptions they make about the network. The main differences among these protocols also come from the type of information they consider to make routing decisions (*e.g.*, node mobility pattern, location information) and their forwarding and replication strategy. Each of these routing schemes has its own strengths according to their specific application scenario.

Recently, a few routing protocols have been proposed that explore and focuses on characterizing, specifically on the packet delivery delay in DTNs. Antonios [6] proposed two algorithms (greedy and the centralized) for the delay bounded routing in vehicular network (VDTN), which satisfy the user defined delay requirements and at the same time maintaining a low level of channel utilization. In the greedy algorithm the message is delivered along the shortest path, while in centralized algorithm the message is delivered along the minimum number of relay nodes. This algorithm assumes local and global traffic information in a city to achieve the constrained delay time. According to the global traffic information, the map is preloaded with historical traffic statistics about the street. In [1] Eyuphan's propose routing algorithm, which assumes zero knowledge about the network (node meeting, contact duration). In this algorithm, number of message copies are varied in such a way that the predefined percentage of all messages to be delivered to the destination before the given delivery deadline. This scheme follows the assumptions of standard Spray and Wait algorithm, which assume the buffer space in a node to be infinite. Wei *et al.*, [9] also considers the delay requirements in DTNs and used some special nodes called message ferries deployed in the network. Message ferries are mobile robots or vehicles move between different sites periodically, following a pre-planned route. Message ferries have larger buffer space, better processing capabilities than regular nodes to guarantee the delay constraint requirements. This approach assumes the knowledge prior the moment of the potential ferries. Md Yusuf *et al.*, [8] uses delay decomposition algebra for computing end-to-end delay bound for prioritized data flow in DTNs. By knowing the end-to-end delay bounds helps in planning resource provision. This approach provides meaningful estimation of end-to-end delay under the recurrent mobility patterns.

All the above work tried their best to the delivery of a message with bounded delay, however they are lacking practical assumption like node (ferry, infinite storage, location visiting probabilities, motion pattern information, and schedule contact). Since such powerful nodes may be impractical or unnecessary in some network scenarios. With the strong points and weak points of existing DTNs routing protocols in mind, we modify and extend epidemic routing in our context for the threshold bounded delay under time and buffer constraint, which may exists as part of routing scheme or as an application requirement.

### 3. System Model and Problem Statement

In this section, we present the system model with the assumptions used in our network scenario and then we formally define the problem and subsequently address it. Let  $N$  be the total number of nodes in the network, all moving according to specific mobility model in a finite area. All nodes are equipped with wireless communication capability with transmission range of  $r$ . The network is assumed to be sparse, and the message transmission occurs only when two nodes get within communication range of each other. The inter contact time of any pair of nodes is nearly exponentially distributed with a meeting rate of  $\beta$ . Furthermore, we also assume the buffer size in a node is limited and message forwarding is done in a store-

carry and forward routing manner. As the node density is sparse, we ignore the impact of interference and channel collision between nodes. Therefore, we also assume that any communicating pair of nodes does not interfere with any other simultaneous communication.

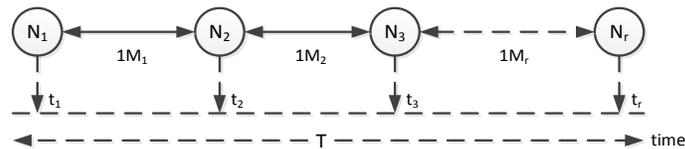
In this network, there is a source node which generates message destined to one of the node in the network with its TH threshold allowable delivery delay or deadline, eventually with L copies. It means that, after this threshold time all the nodes in the network will discard the message. Therefore, the goal of our routing scheme is to try to deliver the message to the destination before time TH using ordinary differential equations (ODEs).

### 3.1 Delay Bounded Routing Scheme

This section presents the main idea of the proposed scheme. We start off by describing the proposed approach with its strategy to achieve the aforementioned goals. Given the inter contact rate and the message threshold allowable delay time in our model, we calculate the expected delivery delay to achieve the bounded delay for any pair of nodes. Through contact rate each node locally calculates inter meeting times between the nodes and every other node under the assumption that the mobility real objects are nondeterministic but periodic. In this work, we take advantage of such knowledge which is used to predict average delay as it estimates how long it will take to encounter other node. Larger inter meeting times leads to larger expected delay. In this way, we can reduce the overheads of existing epidemic routing and can achieve better trade-off between delivery delay and its overheads. The proposed scheme employs L copies of a message which are distributed from source node to a number of distinct relay node, which are entirely based on the inter meeting times record and the threshold delay of the message. Furthermore, the relay nodes which carry the message forward its copy to a potentially more appropriate relay node using designed utility information, specified in the forwarding policy. This process is repeated until one of the message copy reach the destination. In the last, each node maintains a list of delivered messages in the summary vector that it does know has been delivered to the destination. By encounter time these summary vectors are exchanged between nodes when they meet and delete those delivered messages from their buffers.

### 3.2 Delay Estimation from Inter meeting Time Records

The goal of this section is how to use the inter meeting times record for the estimation of expected delivery delay for a pair of node. Our focus is on the inter meeting record between two pair of nodes. First we define the intermeeting time between two nodes, is the time separation between two consecutive contacts or the time elapsed between two successive contacts as shown blow in Figure 1. For simplicity the contact time is not considered when calculating the inter meeting times.



**Figure 1. An example of inter meeting times between nodes**

Each node keep a record of consecutive inter meeting times from itself to other nodes ever meet in the network. Consequently each node can take advantage of its inter meeting times record to predict delay to other nodes and to estimate delay between any source and

destination. Then the message source decides the number of message copies  $L$  to be spread to forward the message to be delivered before its deadline. Suppose a source node  $S$  with a message for a given time constraint  $TH$  is in contact with a set of encounter nodes with pairwise meeting rate  $\beta$ . The formula used for estimating inter meeting of nodes is  $\beta \approx 2\omega rE[V^*] / A$  [14]. Where  $r$  is the transmission range of each node which is very small compared to the network area  $A$ ,  $E[V^*]$  is the mean average relative speed between nodes of the network, where  $\omega$  is constant specific to the mobility models. Suppose the inter meeting times recorded between  $S$  and other encounter nodes is  $S = \{IM_1, IM_2, IM_3, \dots, IM_r\}$ . When the destination  $D$  inter meeting time is in the source set  $S$ , then at any time to predict the next meeting time can be calculated as  $T_{M=D} = t - IM_D$ . Where  $t$  is the current time and  $IM_D$  is the recent inter meeting time to destination. When a series of inter meeting time record for a pair of source and destination is already available on the source node we use the average inter meeting time as the estimation for expected delay. The objective of expected delay estimation is minimize the number of message copies  $L$  required for a message to meet the given threshold time constraint. Each mobile node in the network can obtained the inter meeting times between itself to the destination through information exchange when they encounter each other. So when two nodes meets the inter meeting times of two of these nodes are updated and exchanges with other encounter through which we can get expected delay information for any pair of nodes in the network.

When a message within time constraint arrived at source node whose destinations inter meeting times is not recorded yet then we use utilize [15] average cumulative contact probability (CCP),  $C_i$  which show that a randomly chosen node  $N_j$  in the network is contacted by  $N_i$  within time  $TH$ . When the contact rate between node  $N_i$  and  $N_j$  is  $\beta_{ij}$ .

$$C_i = 1 - \frac{1}{N-1} \sum_{j=1, j \neq i}^N e^{-\beta_{ij}TH} \quad (1)$$

In order to decrease the delivery delay and the chances of message delivery we use multiple copies of each message, so that at least one copy will be delivered. The number of message copies  $L$  is depending on the network size and the number of nodes in the network. These copy count is much smaller than the total number of node in the network ( $L \ll N$ ). For a message source to know the exact number of message copies that is needed to be distributed in the network can be calculated as

$$L_{min} = \frac{-\ln(1-p_d)}{\beta TH} > \text{desired threshold rate} \quad (2)$$

Where  $p_d$  the expected delivery probability of the message can be calculated  $p_d = 1 - e^{-\beta LTH}$  within a given time constraint.

### 3.3 Message Forwarding Policy

In this section, we introduce our message forwarding policy and a method for calculating the utility value. The policy that has been used for message forwarding is based on the use of the time-varying utility function that is calculated from an evaluation of context information, which indicates the quality of link in delivering a message to a given destination. The context information we have considered for calculating the utility value, basis on the encounter frequency and contact duration of previous contacts between two nodes in a time interval  $T$ .

During the message forwarding phase the node with highest utility value is selected as the best message forwarder, within the given time constraint. We employ time varying contact information by dividing time into a period of 30 minutes, half an hour of the simulation time. This classification of time exploits more regular nodes for more accurate contact capability within given time constraint. Since these regular nodes enable nodes to exchange messages more often. Each node holds a utility value table which is used to store its utilities values with other nodes. Table 1 shows an example of calculating utility value for a particular node.

**Table 1. An example of utility value calculation**

Time period (T)	Contact duration (Ψ)	Encounter frequency (K)	Utility Value
01:00-01:30	3.5	2	5.875
01:30-02:00	1.0	1	
02:00-02:30	4.5	3	
02:30-03:00	2	1	
.....	.....	.....	

We have divided the time into type of half an hour of the simulation time to know more regular node for more accurate prediction of node contact capability. The utility value for the duration [01:00, 03:00], we have

$$\sum_{i=1}^n T_i \cdot \Psi_i \cdot K_i / \sum_{i=1}^n T_i \quad (3)$$

Based on this strategy the relay node forward the message to the neighbors node whose time dependent utility value is higher than itself among all of its neighbors. In our setting, every node in the network can take advantage of this utility table to predict expected delay to other nodes.

#### 4. Performance Evaluation

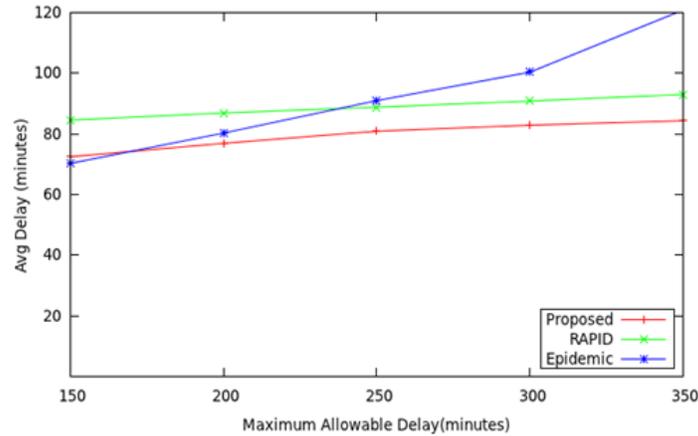
We used (ONE) Opportunistic Network Environment simulator with Helsinki city scenario to evaluate the performance of the proposed routing scheme. A detailed description of the simulator is available in [16]. To show the accuracy of our proposed scheme, we compare our simulation results with RAPID and original epidemic routing protocols given by Ref [1, 17]. RAPID is a DTN network protocol designed to optimize the worst-case delivery delay. The default and varied parameters for the simulation are listed in Table 2. The metrics we use to compare the performance of the proposed scheme include average delay and delivery rate.

**Table 2. Simulation Parameters**

Parameters	Default	Range
Simulation area	4500 m x 3400 m	-
Simulation time	43200 = 12 Hours	-
No of nodes	150	150-350
Node buffer size	5 Mb	-
Transmission range	5 meters	-
Delay threshold	300 min	150-350
Message creation rate	15-40 min	-
Message size	500 Kb	-

We assume three node group pedestrians, tram and cars in the considered scenario by assigning 50 node element to each group. The speed of pedestrian varies from 0.5 to 1.5 m/s, cars run at speed of 2.7-13.9 m/s where trams run at speed of 7-10 m/s. The sum of all nodes equal to 150 nodes. All the nodes we considered are mobile with Bluetooth interfaces, communication range of 5 meters, message size of 500KB and buffer capacity of 5MB. Figure 2 shows the average delay of each protocol as the maximum allowable delay varies from 150- 350 minutes.

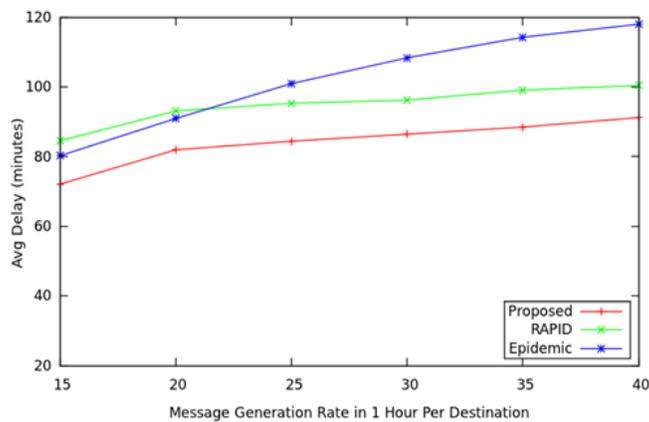
We can observe that the average delay increases as the maximum allowable delay increases. The reason for this as a large delay bound allows a message to exists for long time in the buffer before it is delivered to the destination, thus increase its average delay too. However, successful deliveries of the message are not affected with the large delay bound. The average delay is higher in epidemic protocol the reason for this is the limited buffer and too much duplicate copies of the message. We can notice the proposed scheme has better delay performance most of the time. The reason for this the proposed scheme initially spreads limited number of message copies and then chooses time dependent utility value according to their delivery deadline. In comparison delay occurred in RAPID is a result of local forwarding decision made by each forwarding node first whether to forward a message to a given node or not. In real, RAPID avoids forwarding of message copies in order to look for better forwarding node, so the average delivery delay increase. Thus proposed scheme lead to better delay performance than RAPID.



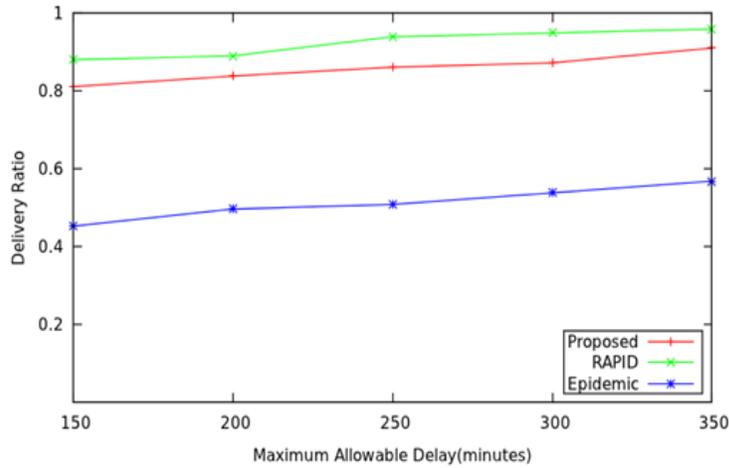
**Figure 2. Average Delay vs. Maximum Allowable Delay**

Figure 3 shows the assessment of average delay according to message generation rate. We varied the message generation rate from 15 to 40 messages per hour per destination to evaluate the performance of each protocol. With the increase in message generation rate the performance of all schemes degrades, because of the buffer limitation constraint. Epidemic routing shows a sharp increase as it produces many message copies, which result to buffer exhaustion. In contrast RAPID and proposed scheme only need a limited buffer for control limited replication. We observed that the proposed scheme obtain better results since the time varying utility metric reflects regular node more accurately for the destination. RAPID are more sensitive to the traffic load the reason lies in fact that the meta-data over heads which becomes more significant when the load increase. As a result the average delay grows.

Figure 4 shows the delivery ratio performance according to the maximum allowable delay. As the maximum allowable delay increases from 150-350 minutes the increase in delivery ratio occurs. With the increase in maximum allowable delay, a message stays for a longer duration increases its chances to reach destination during long delay bound. The increase in delivery ratio of the proposed scheme is comparatively small than RAPID is due to the initial random distribution of replicas. While RAPID initially uses more focused local decisions for the distribution of replicas. Therefore, it benefits the good delivery results in delivery ratio.

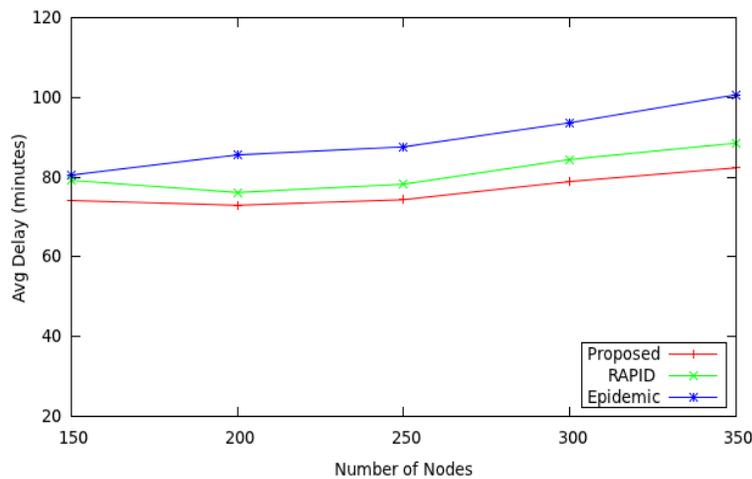


**Figure 3. Average Delay vs. Message Generation Rate**



**Figure 4. Delivery Ratio vs. Maximum Allowable Delay**

Figure 5 describes the average delay of each routing protocol with different node density. The average delay of RAPID and proposed scheme decreasing up to certain threshold, compared to epidemic. Two factors account for it. First, by increasing number of node encounter opportunities increase. Second total network buffer space increase as well and we need more relay node to store message. This improvement comes up to certain threshold because more number of nodes increases messages copies too lead to congestion further leads to message drop which increase delay. Figure 5 also indicates that the proposed scheme has better delay performance most of the time. The reason is that proposed scheme uses utility information based forwarding which is more likely to meet the destination, through number of relay nodes that share similar pattern with destination.



**Figure 5. Average Delay vs. Number of Nodes**

## 5. Conclusions

In this paper, we have introduced a delay bounded routing protocol for delay tolerant network (DTN), with aim to distribute message copies depending on the threshold delay deadline. Our algorithm manages to overcome the shortcomings of Epidemic and other flooding based routing scheme and provides comparable performance. Furthermore extensive simulation has been carried out for performance evaluation. Our results indicate that the proposed algorithm performs better than other routing scheme in term of packet delivery delay and packet delivery ability while keeping the buffer overhead low. Finally, we discuss results of simulation of our proposed algorithm confirming that our scheme are very robust to network size by varying number of the nodes.

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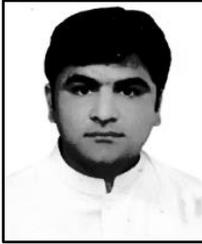
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