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A New Approach for Improving the Performance of Delay Tolerant Networks

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ABSTRACT

Powerful personal devices provide the basis for Ad hoc networking among mobile users. Delay tolerant Networking (DTN) enables such communication in spite of low node density—to reach an infrastructure network as well as for direct information exchange between peers. Numerous DTN routing protocols have been developed, and their analysis has shown different performance depending on the (human) mobility assumed—ranging from simple to complex mobility models to a variety of real-world traces. Most of the routing protocols in DTN assume that the buffer size and bandwidth to be infinite but these resources are limited in realistic environment. In this paper, we propose a new approach for improving the performance of Delay Tolerant Networks that can optimize the average delivery ratio. our proposal derives utility value of the message for the given metric when decision on transmission is to be taken. Simulation results show that our approach significantly optimizes the performance of DTN for limited resources.

Keywords: *Delay Tolerant Networks, Optimization, Performance.*

1. INTRODUCTION

A mobile ad hoc network (MANET) is a set of wireless mobile nodes can be connected dynamically in an arbitrary manner. All nodes of these networks behave as routers and take part in discovery and maintenance of routes to other nodes in the network. Many routing protocols have been proposed. For all these protocols, it is implicitly assumed that the network is connected and there is a contemporaneous end to end path between any source and destination pair. However, in a physical ad hoc network this assumption may not be true. To enable such networks to operate a new network paradigm called Delay Tolerant network has been proposed. Delay Tolerant Networking is a technology which supports data transfer in a challenging environment where a fully connected end to end path never exists between a source and destination.

Delay Tolerant Network works on the principle of store, carry and forward. According to this principle, a node may store a message in its buffer and carry it along for long period of time until it can forward it further. A significant research has been performed in developing efficient routing algorithms for DTNs [1]-[4]. However, as these networks enable communication between wide range of devices, there are secondary problem that routing strategies may need to be aware of, is to deal with limited resources like buffer and bandwidth. Most of the routing protocols in DTN assume that the buffer size and bandwidth to be infinite. But in reality they are limited. In DTN, message transmission occurs only when nodes encounter each other. Moreover due to node mobility, the duration of the contact between them is small. Therefore, the decision has to be made on transmission of messages which improves the performance. Similarly decision has to be made on dropping of messages which affects the performance less. There are many routing protocols [1]-[10] differ in the knowledge that they use in making routing decisions and the number of replication they make. Some of these protocols are simple routing protocols which do not require any knowledge about the network but others use some extra information to make decisions on forwarding. Another classification of these protocols is based on the replication, some protocols replicate multiple copies but others forward only a single copy. Though replication based protocols waste resources, the consensus in [7] appears to be that replication can improve performance over forwarding. But they have the risk of degrading the performance when resources are limited.

Our approach attempt to improve the performance of replication based protocols when resources are limited. Performance optimization the of the network through appropriate selection of the messages to be transmitted is considered. The decision is based on the utility value of the message. At first, the utility value of the message is derived at the instant when transmission has to be carried out. We develop the theoretical framework which calculates per-message utility value which takes into account the number of nodes that have received the message, the number of copies of the message in the network at that instant and the remaining time. Markovian model is used here in the estimation of the above information. The optimization mainly depends on the number of nodes in the network that have received the message at that instant.

This paper is structured as follows: Section 2 presents the related work. Section 3 gives our proposed approach. Section 4 elaborates on the simulation environment and the experimental results, and in Section 5, we present our conclusions.

2. RELATED WORK

An efficient buffer management policy is required to decide at each step which of the messages to be dropped when buffer is full and which of the messages to be transmitted when bandwidth is limited irrespective of the routing algorithms used.

The replication based protocols like, MaxProp [10] and RAPID [11] protocol assumes the buffer and bandwidth as limited. MaxProp routing assigns priorities to the messages based on hop count and delivery likelihood. Estimation of delivery likelihood is done based on historical data. It forwards the messages. RAPID protocol derives the per-packet utility function from administrator- specified routing metric. It forwards the messages with highest utility value first.

Similarly, the Optimal policy presented in [12] and [13] derives per- message utility function from statistical learning and the message with smallest utility is dropped when the buffer is full. In Prioritized Epidemic Routing [14], each bundle is assigned a drop priority and transmit priority which is based on hop count. i.e., the number of hops the bundles has traversed thus far. The transmission and dropping is done based on the priority with high priorities when a contact arises.

Though a number of scheduling policies [15] and [16], FCFS is the simple policy which is easy to implement. As long as the contact duration is long enough to transmit all messages a node has, FCFS is a very reasonable policy. However if the contact duration is limited, FCFS is sub-optimal as it does not provide any mechanism for preferential delivering or storing of high priority messages. Considering the above said problems, the proposed policy attempts to find per-message utility value and the messages are scheduled in the order of their utility with smallest value first. The proposed policy is more advantages in the environment when bandwidth is limited and duration of the contact is small.

3. A PROPOSED APPROACH

It is observed from the previous studies that the process of scheduling and dropping has an impact on the performance of the system. Most of them fail to consider some important information such as number of nodes that have received the messages and the meeting rate which sufficiently affects the DTN performance. A theoretical framework based on epidemic message dissemination is developed. Based on this theory, per-message utility is derived. The messages are transmitted and dropped based on this utility value. The per-message utility is a function of number of copies of the messages, the number of nodes that have received the messages at the instant t and the remaining time. In the context of DTN, it is very difficult to know the global information about number of copies of the messages in the network and number of nodes that have received the messages at any particular instant. Therefore in the proposed approach, Markovian model is used for estimating the value of above parameters. In our proposed approach, the utility value of each message is derived for the popular metric of performance measurement such as delivery ratio.

3.1 Problem Description

Assume that there is L number of total nodes in the network. The nodes in the network are mobile nodes which move according to random mobility model. The message transmission occurs only when nodes encounter each other. Therefore two nodes exchange messages when they come within transmission range of each other. It is observed from [17], that many popular mobility models like Random Walk, Random Way Point and Random direction have a property that the meeting rate is exponentially distributed or has at least an exponential tail. Therefore the inter-meeting time of any pair of nodes is considered as exponentially distributed with meeting rate λ . As the node density is low, the interference among the nodes is ignored. When two nodes meet, the transmission between them succeeds instantaneously. Each of these nodes has a buffer, which can store 10 messages in transit, either message belonging to other nodes or messages generated by itself. Consider a node which acts as an intermittent to several flows. That is the messages from several senders enter the node at various instances. Since node mobility is assumed, the node may accept message either from other routing nodes or directly from senders. In the first case, the messages arrive back to back with constant inter arrival times and in the second case in a stochastic manner. The node then has to keep them until a connection opportunity occurs or until its storage space is full. Each message is destined to one of the nodes in the network and has a Time-To-Live (TTL) value. Once the TTL value expires, the message is no more useful to the application and it is dropped from the buffer.
In Table 1, we summarize the various quantities and notations that are used in estimation.

Table 1. Best results

Variable	Description
L	**No. of nodes in the Network**
$K(t)$	**No of distinct messages in the Network at time t.**

TTL_i	**Initial time to live for message i**
R_i	**Remaining time to live for message i**
$T_i = TTL_i - R_i$	**Elapsed time for message i**
$n_i(T_i)$	**No of copies of the message i in the Network after elapsed time T_i**
$m_i(T_i)$	**No of nodes (excluding source) that have received message i since its creation until elapsed time T_i**
λ	**Meeting rate between two nodes under the given mobility model λ = 1/E[U] when E[U] is the average meeting time.**

3.2 Performance Optimization

3.2.1 Theorem

It is assumed that a number of messages are propagated in the network using replication. Each of the messages has a finite TTL value. It is considered that there are K distinct messages in the network at an instant t when decision is to be taken. For each message i $\in$[1, K], let $n_i(T_i)$ be number of copies of the message i in the network and $m_i(T_i)$ be the number of nodes that have received the message i excluding the source and those who have a copy of it at this instant t such that $n_i(T_i) \le m_i(T_i)$. The proposed policy for optimizing the delivery ratio is that to transmit the messages with smallest utility value first.

3.2.2 Proof

This section gives the proof that the proposed policy leads to optimization of performance of delay tolerant network. Given that all nodes including destination have the same chance to receive the message i, then the probability that a message i has been already delivered given by

$$\text{P\{message i already delivered\}} = \frac{m_i(T_i)}{L-1} \qquad (1)$$

Then the probability that a message i has not delivered given by

$$\text{P\{message i not delivered yet\}} = 1-\frac{m_i(T_i)}{L-1} \qquad (2)$$

The probability that a message i will get delivered before its TTL expires is given by the probability that a message i itself will not get delivered and the message i has already been delivered. It can be written as

P_i = P{message i not delivered yet}* P{message i will get delivered}+ P{message i already delivered}

The probability that a copy of a message i will not be delivered by a node is then given by the probability that the next meeting time with the destination is greater than the remaining time R_i. This is equal to $\exp(-\lambda R_i)$. Given that the message i has $n_i(T_i)$(equivalent to number of nodes that have received the message) copies in the network and assuming that the message i has not been delivered, the probability that the message itself will not be delivered (i.e. non of the n_i copies gets delivered)

$$\prod_{i=1}^{n_i(T_i)} \exp(-\lambda R_i) = \exp(-\lambda n_i(T_i) R_i) \qquad (3)$$

Combining (1), (2) and (3), the probability that a message i will get delivered before its TTL Expires

$$P_i = \left(1-\frac{m_i(T_i)}{L-1}\right) * \left(1-\exp(-\lambda n_i(T_i) R_i)\right) + \frac{m(T_i)}{L-1}$$

After an elapsed time, the global delivery ratio (DR) for the whole network will be $\sum P_i$ which is given by

$$DR = \sum_{i=1}^{K(t)} \left[\left(1-\frac{m_i(T_i)}{L-1}\right) * \left(1-\exp(-\lambda n_i(T_i) R_i)\right) + \frac{m(T_i)}{L-1} \right] \qquad (4)$$

When nodes encounter each other, they should decide on a message to be transmitted that increases the delivery ratio. To find the message to be transmitted the delivery ratio is differentiated with respect to $m_i(T_i)$ (i.e. number of nodes that have received the message i in the network) which can be expressed as

$$\Delta(DR) = \sum_{i=1}^{K(t)} \frac{1}{L-1} \left(\exp(-\lambda n_i(T_i) R_i) \right) * \Delta m_i(T_i) \qquad (5)$$

To maximize DR, it is known that $m_i(T_i)$ = 1 if the message i was not received by the encountered node previously and hence transmitted, $m_i(T_i)$ = 0 if the message was already received by the encountered node. The proposed policy is that the performance with respect to delivery ratio can be maximized if the message i transmitted is with smallest value of the following metric

$$\left(\frac{1}{L-1}\right)\left(\exp(-\lambda n_i(T_i) R_i)\right) \qquad (6)$$

From equation (4), it is understood that delivery ratio is a function of meeting rate, number of copies of the message and the remaining time. To prove that DR can be optimized by the parameter $m_i(T_i)$, DR given by the equation (5) is further differentiated with respect to $m_i(T_i)$to check for negative definite. Considering that number of copies of the messages in the network at the instant t is equal to the number of nodes that have received the message (i.e. $n_i(T_i)$ = $m_i(T_i)$),

$$\Delta^2(DR) = \sum_{i=1}^{K(t)} -\frac{\lambda R_i}{L-1}\left(\exp(-\lambda m_i(T_i)R_i) \right) * \Delta^2 m_i(T_i) \quad (7)$$

It is observed that the resultant equation (7) is negative. As the parameters like meeting rate, remaining time, number of nodes cannot be negative value, the equation (7) will result only in negative value. So as per the optimization theory, the negative value shows that the DR can be maximized by the parameter $m_i(T_i)$ which is number of nodes that have received the message at the instant t. Hence it is proved that the proposed policy optimizes the performance of DTN. The estimation of m_i is discussed in the following section.

3.2.3 Estimation of m_i

The number of nodes that have received the message and the number of copies of the message in the network can be modeled as finite state Markov chain. The Markov chain takes its value in {1,2,...,N}. The Markov chain is in state j=1,2,...,N-1 when there are j copies of the message in the network including the original message. It is in state N when the message has been delivered to the destination node. To calculate the utility value of a message, the value of $n_i(T_i)$ and $m_i(T_i)$ should be known. In the context of DTN, it is very difficult to find the global value of $n_i(T_i)$ and $m_i(T_i)$ due to long duration partition of the network. One possibility is to use current value of $n_i(T_i)$ and $m_i(T_i)$ which is collected by the node through flooding. But this information approximates the value of $n_i(T_i)$ and $m_i(T_i)$ poorly. So the proposed approach uses Markovian model for modeling and estimating the value of $n_i(T_i)$ and $m_i(T_i)$. According to epidemic routing protocol, each node which has a copy of the message replicates it to other node which comes within its transmission range and does not have a copy yet. Therefore when there are j copies of the message in the network, a new copy is sent to (N-j) nodes which do not have a copy at the rate $\lambda j(N-j)$ (i.e. transition from state j to j+1) and one of these j copies reaches the destination at the rate λj (i.e. transition from state j to N) which is given by

$$J'(t) = \lambda J(N-J) \quad (8)$$

The number of copies of the message coincides with average number of nodes that have received the message in the network. Therefore the average number of nodes that have received the message at time t converges to $J(t)$ from [18]. The equation for J(t) can be derived as follows : Solving for equation (8) by integrating with initial condition $J(0)=1$, the following expression is obtained for number of nodes that have received the message at time t

$$J(t) = \frac{N}{1-(N-1)\exp(-\lambda Nt)} \quad (9)$$

4 SIMULATION AND RESULTS

4.1 Experimental setup

To evaluate our new scheme, we have added an implementation of the DTN architecture to the Network Simulator NS-2. This implementation includes:

- Epidemic routing protocol with *FIFO* and *drop-tail* for scheduling and message drop in case of congestion, respectively.
- RAPID routing protocol based on flooding (i.e. no side-channel).
- Epidemic routing protocol enhanced with our proposed approach.

The VAC- CINE mechanism described in [19] is used with all solutions to “clean up” the network after message delivery.

In our simulations, each node uses a wireless communication channel 802.11b of range 100 meters and of bandwidth capacity of 1Mbits/s. Our simulations are based on two mobility patterns, a synthetic one based on the Random Waypoint model, and a real-world mobility trace that tracks San Francisco’s Yellow Cab taxis [20]. Many cab companies outfit their cabs with *GPS* to aid in rapidly dispatching cabs to their costumers. The Cabspotting system [20] talks to the Yellow Cab server and stores the data in a database. We used an API provided by the Cabspotting system to extract the taxi mobility trace then we converted it into a format readable by the NS-2 simulator. Note that this trace describes taxis’ positions according to the *GPS* cylindrical coordinates (*Longitude*, *Latitude*). In order to use it as input to the NS-2 simulator, we had to implement a tool based on the Mercator [21] cylindrical map projection that permits to convert cylindrical coordinates into plane coordinates.

To each source node, we have associated a CBR (Constant Bit Rate) application, which chooses randomly from $[0, TTL]$ the time to start generating messages of 85KB for a randomly chosen destination. Other message sizes were also considered but for lack of space we only show results for this value. Unless otherwise stated, we associate to each node a buffer with a capacity of 10 messages.
We compare the performance of the various routing protocols using the average delivery ratio of messages in the case of infinite TTL.

As a final note, we have chosen to compare all policies in the context of Epidemic routing, which uses up the largest amount of resources. However, we believe that similar conclusions could be drawn if the various policies were applied in other routing protocols, as well, operated in a regime of limited bandwidth or buffer space.

4.2 Performance evaluation

First, we compare the delivery ratio of all protocols for the two scenarios shown in Table II. Figures 2 and Figures 3 show the delivery ratio for the Taxi trace for the case of both limited bandwidth and buffer, and the case of limited bandwidth and unlimited buffer, respectively. The number of sources is changed to cover different congestion levels.

Table 2. Simulation Parameters

Mobility pattern	RWP	Taxi Trace
Simulation's Duration (s)	5000	36000
Simulation' Area (m^2)	1500x1500	-
Number of Nodes	40	40
Average Speed (Km/H)	6	-
TTL(s)	750	7200
CBR Interval (s)	200	2100

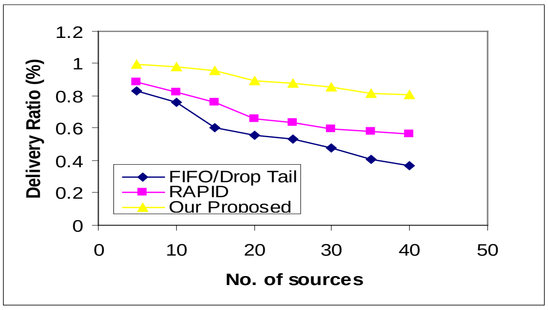

Figure 1. Average delivery ratio for limited buffer and limited bandwidth

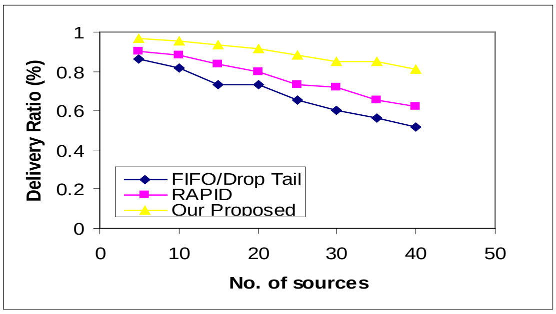

Figure 2. . Average delivery ratio for unlimited buffer and limited bandwidth

From these Figures, it can be seen that: our proposed approach plugged into Epidemic routing gives the best performance for all numbers of sources. When congestion-level decreases, so does the difference between our proposal and other protocols, as expected. Moreover, our proposed policy also outperforms existing protocols (RAPID and Epidemic based on FIFO/drop-tail). For example, for 40 sources, and in the case of limited bandwidth and buffer, our proposed delivery ratio is 24% higher than RAPID.

5. CONCLUSION

The approach presented in this paper optimizes the performance of DTN in terms of delivery ratio. Optimization done here is with respect to the number of nodes that have received the message at the instant t. The utility value of each message is estimated which is used in making decision at the instant t when transmission is to be done. The numerical results prove the improvement in performance by the proposed policy. Moreover, most of the DTN routing protocols operate with the assumption of infinite buffer and bandwidth. But these resources are limited in a realistic environment. Therefore the proposed approach is more suitable when there is no prior knowledge about the network. It is advantageous in strict resource constrained and highly mobile environment with emergency applications.

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