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Reputation and Incentive Based Detection of Selfish Nodes in Delay Tolerant Networks

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Abstract—

A Delay Tolerant Network (DTN) is a new approach to disconnected computer network architectures and also deals with issues in the heterogeneous networks that lack continuous network connectivity. DTN works to operate effectively over extreme distance. In real time applications nodes in DTN may behave with selfish behavior. Hence, many nodes do not always co-operate in packet forwarding in all applications. To address the selfish behavior issue in DTN, many techniques are available based on credit and incentive mechanisms. This suggests that it is mandatory to provide incentive to the selfish DTN nodes so that they can participate in the packet forwarding. In this paper, the proposed approach addresses the selfish-node forwarding problem in DTNs. To detect the selfish behavior of DTN nodes a basic detection algorithm is used along with the proposed incentive strategy. The proposed incentive strategy with selfish-node detection is evaluated using different DTN routing protocols to compare bundle delivery ratios across different DTN routing protocols. The proposed approach is evaluated across different DTN routing protocols, and among the evaluated protocols, Spray and Wait achieved the highest BDR (28.10%), followed by MaxProp (26.33%) at 10,000 s.

Keywords— DTN; selfish behavior; credit and incentive mechanisms; selfish-node; routing protocols.

I. INTRODUCTION

A Delay-Tolerant Network (DTN) is a network architecture designed to operate despite intermittent connectivity and long delays [1], [4]. The DakNet project of India is a typical example of DTN [2]. Such networks are characterized by intermittent connectivity, variable delays, and frequent disruptions, which make conventional end-to-end communication protocols unsuitable. The main characteristics of DTNs are explained below [1].

Intermittent Connectivity: DTN has no end-to-end connectivity like TCP/IP network and this is a main characteristic of DTN. Store-carry-and-forward protocol is implemented to handle intermittent connectivity.

Long or Variable Delay: DTN is operated over the long distance and there are opportunistic contacts and hence there is long and variable delay between the source and destination nodes.

Asymmetric Data Rates: Users with cable TV which uses Internet supports moderate asymmetric nature of full duplex links which has bi-directional data rate, if asymmetric nature is large, they can beat the conversational protocols.

High Error Rates: Long distance journey of bundles and different environmental conditions are the main cause of high error rates in DTN. Data rates of nodes in DTN are asymmetric as heterogeneous nodes are the part of the network.

Store-carry-and-forward Message Switching: Store-carry-and-forward protocol is implemented in DTN to deal with all the characteristics of DTN. This protocol stores the in-transit bundles with the respective node and opportunistically delivers the bundles to the destination DTN node. The bundle protocol (BP) is defined in RFC 5050 [3] and implements a bundle layer in the DTN architecture defined in RFC 4838 [4].

There are many nodes in the DTN which are selfish which drops the bundles intentionally or which refuses to store the in-transit bundles. Such selfish nodes are not co-operating in bundle forwarding. Incentive strategy is used to mitigate the selfishness problem of DTN which stimulate the nodes for bundle forwarding. Selfish nodes should be detected and punished to improve the bundle delivery and hence eventually improves the network performance [10].

The main research question motivating this study is how to effectively handle selfish behavior in DTN nodes. An important challenge is to stimulate selfish nodes to participate in message relaying. This issue has attracted considerable research attention, and incentive mechanisms have been proposed as a potential solution. Among these approaches, credit- or virtual-currency-based incentive mechanisms [5], [11] encourage DTN nodes to cooperate in packet forwarding by rewarding nodes that successfully participate in bundle delivery with virtual electronic currency. Nodes can use this accumulated virtual currency to participate in network communication; therefore, maintaining sufficient credit encourages continued cooperation and reduces the possibility of isolation from the DTN. Consequently, DTN nodes are motivated to earn additional credit by participating in packet forwarding, thereby sustaining their participation in the communication process [13].

Taking into consideration all the challenges mentioned above, there is a need for innovation in DTN for well-designed incentive scheme along with routing protocol [14]. Detection of selfish nodes is also very critical issue in DTN. For incentive scheme and selfish node detection process the following issues should be considered:

i. Fair incentive model
ii. It is not mandatory for the intermediate DTN node to forward bundles
iii. All intermediate nodes in the DTN network can self-determine whether or not to participate in bundle forwarding

Hence, some selfish nodes may present (probability is low) in DTN even if incentive mechanism is implemented in DTN.

II. LITERATURE REVIEW

The existing work is discussed in this section with classification based on models as follows.

Network Model

Consider a DTN as a directed graph $G = (V, E)$, where V and E represent the set of DTN nodes and opportunistic contact edges respectively. In the DTN, a source node delivers the bundles to the destination through the movement of DTN nodes with contact edges.

Node Model

Consider a Vehicular ad-hoc network as a concrete DTN where, each DTN node is represented by a vehicle moving within an urban environment. All DTN nodes use Bluetooth interface for communication i.e. IEEE 802.15.1 protocol. Therefore, when two vehicles are within the transmission range (100 meters), they can exchange bundles. Velocity, transmission range and buffer size of each DTN node is same. Higher node velocity and longer bundle holding time increase the probability of contact with other DTN nodes, which can improve bundle delivery. Assuming two nodes are moving towards each other then bundle dropping event will not occur if and only if $(V_A + V_B) * T_h >= D$ [6]. Assuming one node is stationary and another node is moving towards stationary node then Bundle Dropping event will not occur if and only if $V_A * T_h >= D$ [6]. Assuming two nodes are moving away from each other then Bundle Dropping event will not occur if and only if $|V_A - V_B| * T_h >= D$ [6].

i. Implementation of incentive strategy to provide a fair incentives model [11,14,19]
ii. To detect the selfish nodes in DTN [12,16-18]
iii. Test the incentive strategy with different DTN routing protocols and determine which routing mechanism is best suited to the proposed approach [15]

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This approach provides fair incentive strategy which stimulates the DTN nodes in bundle forwarding and selfish node detection approach is used to identify the selfish DTN nodes in the network. Although several studies have investigated incentive mechanisms and selfish-node detection in DTNs and socially aware networks, comparatively limited attention has been given to integrating reputation-based incentive strategies with selfish-node detection and evaluating their performance across multiple DTN routing protocols [10]– [19].

Practical Incentive Protocol

The Practical Incentive Protocol (Pi) [7] provides a credit- and reputation-based incentive framework. The reputation-update and reward mechanisms adopted from the Pi framework [7] are given below. Reputation value decreases dynamically according to following equation and distributed by trusted authority (TA) according bundle delivery to the destination. Note that TA does not participate in bundle forwarding.

Where, $R_{IP(n)}$ = New Reputation of DTN node at time

$$R_{IP(n)} = e^{-\lambda T_i} R_{IP(n-1)} + C_{T_i}$$

T_n

$R_{IP(n-1)}$ = Reputation value of DTN node at time T_{n-1}

$T_i = T_n - T_{n-1}$

λ = Rate at which the reputation value would decrease

C_{Ti} = Reputation cumulative function, which is the summation of new gained reputation values in the time period T_i

According to successful and unsuccessful delivery of bundles to the destination DTN node, credit and reputation values given by TA to the intermediate nodes:

Where, Di_{si} = Distance for which Intermediate node Ni help in bundle forwarding

III. METHODOLOGY

The proposed algorithm uses the incentive strategy described below:

Proposed Incentive Strategy

The proposed algorithm builds on the reputation and reward framework of the Practical Incentive Protocol (Pi) [7]. The reputation-update and reward equations described above are adopted as the underlying incentive framework. The following threshold, penalty, and conditional incentive rules constitute the proposed modification for selfish-node handling.

Initial Parameters: Consider the initial Credit = 10,000, Reputation = 10,000, and Threshold Reputation R_{th}=5,000 (50% of the initial reputation).

Ti is measured in seconds in the proposed simulation.

Normal Forwarding Rule: For the proposed implementation, a reputation threshold R_{th} is introduced to determine eligibility for normal bundle forwarding.

If $R_{IP} \geq R_{th}$, the node is eligible for normal bundle forwarding.

If $R_{IP} < R_{th}$, the node is not eligible for normal forwarding.

However, when only selfish nodes are available in the contacted list, Case 3 is invoked and a selected selfish node may be conditionally encouraged to forward through the proposed incentive mechanism.

Case 1: Normal Node – A forwarding charge of 50 credit units is assigned in the proposed implementation, with λ=0.01.

Case 2: Selfish Node – The node's reputation is reduced by 1000 points, and λ= 0.3 is assigned in the proposed implementation.

The values λ=0.01 and λ= 0.3 were selected as experimental parameters to provide slow reputation decay for normal nodes and accelerated decay for detected selfish nodes.

Case 3: Only selfish nodes are present in the contacted list of the forwarding node.

For Case 3, only selfish nodes with $1000 \leq R_{IP} < R_{th}$ are

$$Reward_i = \begin{cases} D_{i,s}(C_{IP} + R_{IP}), & \text{if bundle arrives at } D \\ D_{i,s} R_{IP}, & \text{otherwise} \end{cases}$$

considered for incentive-based forwarding.

i. Classify the contacted selfish nodes into the reputation ranges [1000, 2000), [2000, 3000), [3000, 4000), and [4000, 5000).
ii. Determine the number of selfish nodes present in each reputation range.
iii. Select the selfish node(s) from the highest available reputation range.

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iv. Offer a forwarding incentive of 500 credit units to the selected selfish node(s) to encourage bundle forwarding.

The following steps in the proposed incentive strategy are important in the communication process, as illustrated in Fig. I.

Network Creation: DTN is created in the ONE simulator with 66 nodes. The simulation parameters are configured as listed in Table I.

Registration Process: When new DTN node is created and wants to join network, it should register with the trusted authority (TA) to obtain a personal credit account (PCA) and a personal reputation account (PRA) to store credit and reputation values.

Establishment of connection: When a source node comes into contact with other DTN nodes or roadside units (RSUs), a connection is established to forward the bundles. The intermediate DTN nodes store and opportunistically forward the bundles toward the destination.

Reporting: The forwarding outcome is reported to the TA. For successful bundle delivery, the destination node generates an acknowledgment (ACK). The relevant intermediate forwarding node then reports the successful or unsuccessful forwarding outcome to the TA when connectivity is available.

Credit and Reputation Clearance: When the trusted authority receives a report, it performs credit and reputation clearance for the intermediate nodes according to the incentive mechanism.

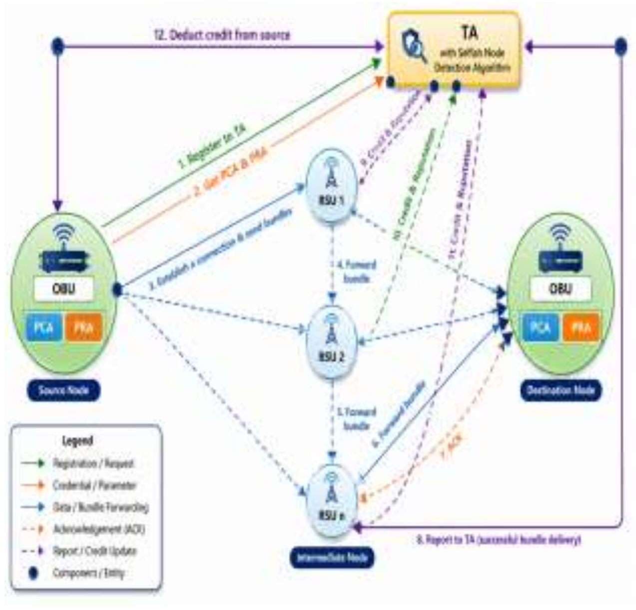


Figure I (a). Proposed incentive strategy with selfish node detection approach (successful delivery)

Parameters	Values
Simulation Area	6,000 m * 15,000 m
Number of DTN nodes	66
Duration of Simulation	1,000 s–10,000 s
Router	Direct Delivery / Epidemic / Spray and Wait / PRoPHET / MaxProp
Velocity of DTN nodes	12 m/s
Transmission range	100 m
Buffer size	5 MB
Bundle size	500 KB–1 MB
Holding time	0–120 s
Bundle TTL	300 s

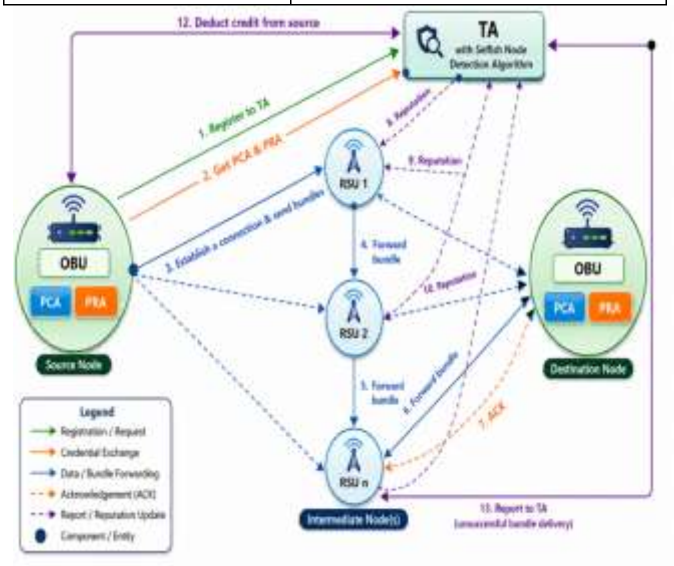


Figure I (b). Proposed incentive strategy with selfish node detection approach (unsuccessful delivery)

Selfish Node Detection Algorithm

The forwarding-behavior conditions used in the basic detection procedure are adapted from [8] for detecting selfish nodes in the DTN. The first two conditions of the basic detection algorithm are used in the proposed incentive strategy.

Let, m = Message S_t = Set of messages

forwarding requests R = Set of contacted Nodes

S_f = Set of messages forwarded

$N_k(m)$ = Set of next hop node chosen for message forwarding Procedure Selfish_Node_Detection

for each m belongs_to S_t do

if m is_not_belongs_to S_f and R! =0 then return 1

else if m_is_belongs_to S_f and $N_k(m)$ is_not_a_subset_of R then return 1

end if end for return 0

end Procedure

When the detection procedure returns 1, the corresponding forwarding node is recorded as a selfish node. The number of unique detected selfish nodes is then used to calculate the Selfish Ratio (SR).

IV. RESULTS AND DISCUSSION

In this research work, an approach for incentive strategy and selfish node detection is proposed. This work will be validated by using simulation of DTN by using ONE simulator [9]. The following subsections present experimental setup, performance analysis and scenarios for testing. For each routing protocol and simulation duration, one independent simulation run was performed. During each run, both the bundle delivery ratio (BDR) and the number of unique selfish nodes detected were recorded.

$$BDR(\%) = \frac{\text{Number of Bundles Delivered}}{\text{Number of Bundles Generated}} \times 100$$

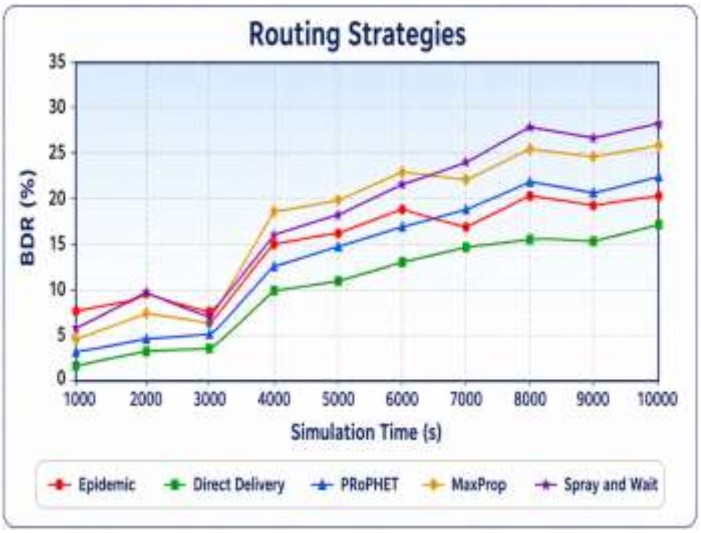
Table I. ONE Simulation Setting

Different Scenarios of Implementation and Testing

Scenario 1: Perform the simulation from 1,000 – 10,000 s for Direct Delivery Routing and do the analysis for bundle delivery ratio and the number of unique selfish nodes detected.

Scenario 2: Perform the simulation from 1,000 – 10,000 s for Epidemic Routing and do the analysis for bundle delivery ratio and the number of unique selfish nodes detected.

Scenario 3: Perform the simulation from 1,000 – 10,000 s for Spray and Wait Routing and do the analysis for bundle delivery ratio and the number of unique selfish nodes detected.



Scenario 4: Perform the simulation from 1,000 – 10,000 s for PRoPHET Routing and do the analysis for bundle delivery ratio and the number of unique selfish nodes detected.

Scenario 5: Perform the simulation from 1,000 – 10,000 s for MaxProp Routing and do the analysis for bundle delivery ratio and the number of unique selfish nodes detected.

Parameters for Comparison

Bundle Delivery Ratio (BDR): The percentage of total number of bundles successfully delivered to the destination relative to the total number of bundles generated.

Selfish Ratio (SR): The percentage of unique detected selfish DTN nodes relative to the total number of DTN nodes.

$$SR(\%) = \frac{\text{Total number of unique selfish DTN nodes}}{\text{Total number of DTN nodes}} \times 100$$

For each simulation duration, the same number of unique selfish nodes was identified across the evaluated routing protocols. Therefore, Table II presents the common selfish-node count for each simulation duration.

Table II. Selfish Ratio for Different Simulation Time

Simulation Time (s)	**Unique Selfish nodes detected**	**Selfish Ratio (%) (Rounded off)**
1000	4	6
2000	4	6
3000	5	8
4000	2	3
5000	7	11
6000	2	3
7000	5	8
8000	8	12
9000	2	3
10000	4	6

Figure II. Comparative analysis of different routing strategies with the proposed incentive mechanism

Table III. Bundle Delivery Ratio for Different Routing Strategies

Simulation Time (s)	**Bundle Delivery Ratio (BDR) (%)**				
	Direct Delivery Routing	**Epidemic Routing**	**Spray and Wait Routing**	**PRoPHT Routing**	**Max Prop Routing**
1000	2.85	8.57	5.75	2.85	8.57
2000	2.89	7.24	10.14	4.34	7.24
3000	3.88	7.76	7.76	5.82	9.7
4000	10.21	16.78	13.86	15.32	19.7
5000	11.17	16.47	17.64	18.23	20
6000	14.21	19.6	22.05	18.13	23.03
7000	15.96	16.8	22.68	20.58	21.42
8000	16.54	22	26.1	21.69	23.89
9000	16.39	19.67	25.24	20.98	24.91
10000	17.75	21.3	28.10	22.48	26.33

Figure II presents the bundle delivery ratio (BDR) as a function of simulation time. The ONE simulator is used to perform the simulations from 1,000 s to 10,000 s for different routing strategies, including Epidemic, Direct Delivery, PRoPHET, MaxProp, and Spray and Wait routing. These routing protocols exhibit different performance when combined with the proposed incentive strategy and selfish-node detection approach. Among the evaluated routing protocols, Spray and Wait achieved the highest bundle delivery ratio. Direct Delivery routing has the lowest bundle delivery ratio among the evaluated protocols and therefore shows the lowest performance with the proposed incentive scheme.

V. CONCLUSION

In this research work, a fair incentive strategy is proposed along with the selfish node detection approach. The incentive strategy was evaluated with different DTN routing protocols. Among the evaluated protocols, Spray and Wait achieved the highest BDR of 28.10% at 10,000 s, followed by MaxProp with 26.33%. The selfish-node detection approach identifies selfish nodes in the simulated DTN environment. Security and energy of DTN nodes are two major areas that require further research.

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