Utilizing Public Transportation System as a Delay Tolerant Network

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Abstract

Delay Tolerant Networks (DTN) enable data communication in sparse regions, where long delay and intermittent connectivity can be tolerated. In DTNs, end to end path may not be existed, therefore, packets may be stored in nodes and be forwarded in appropriate conditions. Public transportation system has some characteristics that can be useful in DTNs. In this system, routes are predefined and system agents (such as buses, taxies, trams etc...) pass on their specific routes. Having this knowledge about transportation routes, we can determine optimal relay node that ensures delay tolerant connectivity. In this paper, we model optimal network configuration problem using integer linear programming (ILP). The proposed model minimizes network cost and routing delay, simultaneously. Based on the proposed ILP model we use a DTN routing mechanism in which packets are stored, carried and forwarded to their destinations. Simulation results show the performance of the defined method.

Key words: Delay Tolerant Networks, Public Transportation System, Routing, Relay Nodes

1. Introduction

Delay Tolerant Networks are made based on store-carry-and-forward strategy to provide communication facilities in controversial environments. In such environments, connections are intermittent, delay is high and variable, rate of data transmission is asymmetrical, rate of loss is high, network topology is sparse and there may be no end-to-end connection. A particular class of DTN is vehicle-based or vehicular DTN (VDTN). In this network, vehicles transmit data between static nodes. One application of VDTN is providing asynchronous internet access to rural and distant areas. This architecture also used for monitoring the traffic situation of the transportation system, avoiding collision, and emergency message propagation. There are several projects that allocated to investigate connection challenges using VDTN architecture in rural areas. For example, A. Seth, ?… (2006) developed a framework to provide a low cost communication system called Rural Internet Kiosk. As an another example, W. Zhao and M. H. Ammar (2003) proposed a mobility model for special nodes called message ferries to transmit data in distant villages.

Each one of the above projects addresses specific network issues and problems under certain service request and network assumptions such as topology, node architecture, capabilities, mobility patterns, and available knowledge about the network to provide the requested delay-tolerant connectivity. For example, the Rural Internet kiosk project focuses on hardware and software architecture of nodes. The main idea in MF is designing mobility pattern of message ferries such that network performance be improved.

Public transportation system covers a large part of a city. This system, because of almost complete coverage of city, can be used to exchange data traffic between various points in a city. Using this backbone for network is important, because it is secure and reliable, and also needs low cost.

Public transportation system has specific characteristics that can be considered in data traffic exchange. In this system, vehicles move in predefined routes and in some cases, vehicles move based on time tables. Benefiting from this information can improve data network design.

As we mentioned, in the public transportation system, time tables are specified and movement routes are also predefined. Studies in this field have applied this information in various ways. M. Sede, ?… (2008) proposed a routing algorithm based on predefined movement routes, in which the algorithm performance has been measured in the public transportation system of Shanghai. M. Doering, T. Pögel, and L. Wolf. (2010) proposed a routing algorithm based on time tables in public transportation system.

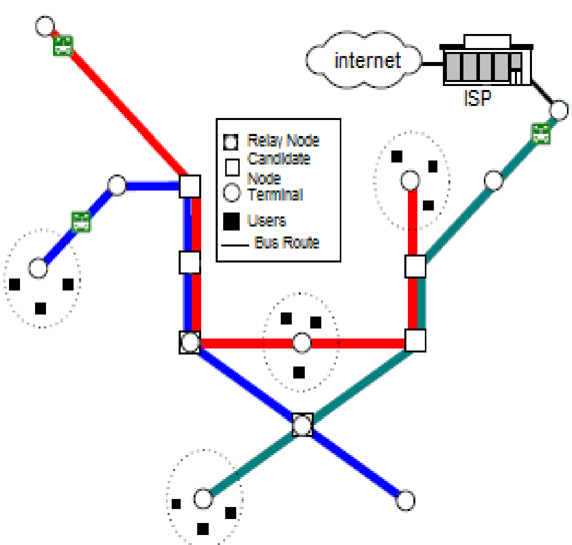

Fig. 1 An example of a VDTN

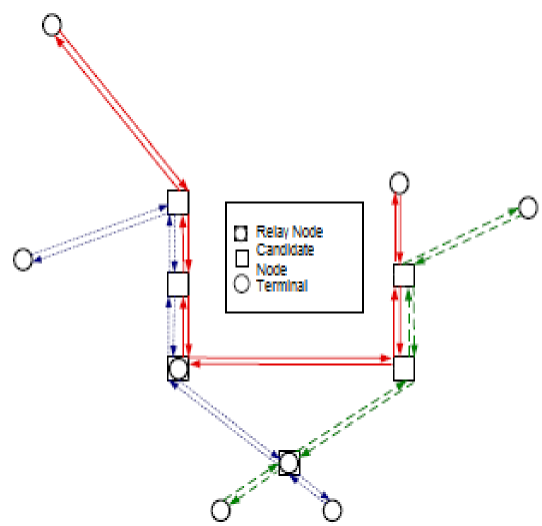

Fig. 2 Network graph obtained from Fig.1

VDTN divided into two class, infrastructure-based and infrastructure-less. In infrastructure-less VDTN, the communications simply carry out between vehicles and there is no static station, but in infrastructure-based case, static stations amplify the VDTN. It is obvious that application of static stations improve the performance criteria of VDTN, however, they impose some costs on network. F. Farahmand, ?… (2009) studied the relay node placement problem in VDTN in order to reduce the cost of the network. However, network performance criteria, such as routing criteria haven't been considered, only the number of relay nodes has been reduced. Our aim is optimal routing with minimum relay nodes. In this paper, we consider a VDTN architecture including vehicles that acts as mobile nodes and transport data traffic between terminal nodes within isolated areas. We assume the public transportation system as the backbone. but, because of reasons, e.g, congestion and facing red light, vehicles may not follow the time tables. In this paper, firstly, the problem of placing relay nodes in order to minimize both the cost and the delay of network will be discussed. We consider that the cost is proportional to the number of relay nodes. In network designing, we attempt to provide the necessary connections between users in isolated areas in a delayed manner. Two users in separate areas with access possibility to a vehicles that move between users corresponding areas, have been considered connective. In areas without direct route between them, the connection will be provided by relay nodes. Then we address the performance of the proposed model via simulation.

2. Assumptions

The given VDTN uses the public transportation system as a backbone. In this network, vehicles move in predefined routes, as showed in Fig.1, each route connects two or several end stations.

There are three types of nodes in this network: (a) terminal nodes which are origin and destination of data traffic, (b) relay nodes that provide data exchange possibility between vehicles and (c) mobile nodes that are mounted on vehicles and transmit data traffic between terminal nodes and relay nodes. Terminal nodes are access points to the VDTN. End users through the short-range and low-power frequency signals such as IEEE 802.11 connect to terminal nodes. The main role of terminal nodes is collecting IP packets of end users and making messages. In modeling, we assume that there is no possibility of message exchange between mobile nodes but in simulation, eliminate this assumption. Relay nodes are also store-and-forward devices that receive messages from mobile nodes and store them until they can be sent to another mobile node.

3. System Model

In this section, we formulate the problem of optimal network configuration. A VDTN network can be represented as a weighted graph $G = (V, E)$. The V set consists of the set of terminal nodes which are origin and destination of the traffic, V_t, and the set of terminal nodes which sit at routes intersections (i.e., candidate nodes), V_c. Thus, $V \subseteq V_t \cup V_c$. A directed link exists between two nodes *s* and *d*, if there is a vehicle route *i* that passes both nodes in sequence. Fig. 2 shows the graph obtained from the VDTN network in Fig. 1. Each node in V_c is a candidate node for placing a relay node. The *optimal network configuration problem* can be defined as follows. Given a VDTN graph and the requested connectivity between source and destination nodes, the *optimal network configuration problem* aims at finding the placement of the minimum number of relay nodes that minimize routing delay, in order to satisfy the requested connectivity. The *optimal network configuration problem* can be described with an integer linear programming formulation, as presented next.

3.1 Problem Formulation

Given

- $G = (V, E)$: VDTN network graph as defined above;

- Λ: the binary matrix that represents the requested connectivity among terminal nodes, $\Lambda_{sd} = 0$, if there is no traffic from source node $s \in V_t$, to destination node $d \in V_t$, otherwise $\Lambda_{sd} = 1$;
- W: the set of routes in the transportation system;
- π_i: ith route (i.e., sequence of nodes in V);
- d_{mn}: delay of directed link (m,n);
- R_T: maximum number of relay nodes, e.g., $R_T = |V_c|$;
- D_T: maximum delay, *e.g.*, $D_T = \sum_{s\in V_t}\sum_{d\in V_t}\sum_{i\in W}\sum_{(m,n)\in\pi_i} d_{mn}\times\Lambda_{s,d}$

Variables:

- R_m denotes whether node m is a relay node.

$$R_m = \begin{cases} 1 & \text{if candidate node } m \in V_c \text{ is a relay node} \\ 0 & \text{if } m \in V_t \text{ or if } m \in V_c \text{ is not a relay node} \end{cases} \quad (1)$$

- $\lambda_{mn}^{sd,i}$ is a binary variable that denotes whether the traffic from s to d passing on directed link (m,n) of G, uses route i. The end-to-end connectivity Λ_{sd} may be satisfied using one route i or multiple routes thanks to the store-and-forward capabilities of relaying nodes

Objective Function:

$$\text{Minimize: } \left(\sum d_{mn}\times\lambda_{mn}^{sd,i}\right)/D_T + \left(\sum_{m\in V_c} R_m\right)/R_T \quad (2)$$

Constraints:

$$\sum_{i\in W}\sum_{m:(s,m)\in\pi_i}\lambda_{sm}^{sd,i} = \Lambda_{sd} \quad \forall s,d \quad (3)$$

$$\sum_{i\in W}\sum_{m:(m,s)\in\pi_i}\lambda_{ms}^{sd,i} = 0 \quad \forall s,d \quad (4)$$

$$\sum_{i\in W}\sum_{m:(m,d)\in\pi_i}\lambda_{md}^{sd,i} = \Lambda_{sd} \quad \forall s,d \quad (5)$$

$$\sum_{i\in W}\sum_{m:(d,m)\in\pi_i}\lambda_{dm}^{sd,i} = 0 \quad \forall s,d \quad (6)$$

$$\sum_{i\in W}\sum_{m:(m,k)\in\pi_i}\lambda_{mk}^{sd,i} = \sum_{i\in W}\sum_{n:(k,n)\in\pi_i}\lambda_{kn}^{sd,i} \quad \forall s,d\ \forall k\in V \quad (7)$$

$$\sum_{m:(m,k)\in\pi_i}\lambda_{mk}^{sd,i} - \sum_{n:(k,n)\in\pi_i}\lambda_{kn}^{sd,i} \le R_k \quad \forall s,d\ \forall k\in V \quad (8)$$

Eq. 3-7 are flow conservation constraints, i.e., the requested s to d connectivity should be satisfied, using one or multiple routes. Eq. 8 forces to use the previous route to satisfy requested connectivity if node k lacks relaying capabilities. In other words, the combination of Eq. 7 and 8 allows the relaying of requested connectivity on a different route at relay nodes, while it forces not to change route in the intermediate nodes without relaying capabilities to satisfy requested connectivity.

4. Results and Analysis

In this section, we evaluate the performance of the proposed optimization method by simulation. We use the Lingo slower to generate a relay node deployment and specify the minimum delay routes. We use the Milan transportation map depicted in Fig. 3 in our evaluation. Evaluation methodology is as follow: first, the model feed to Lingo slower which generates the optimal network deployment specifying the relay nodes locations and routing method. Then, the Lingo results used to extract routing file which used by the ONE simulator.

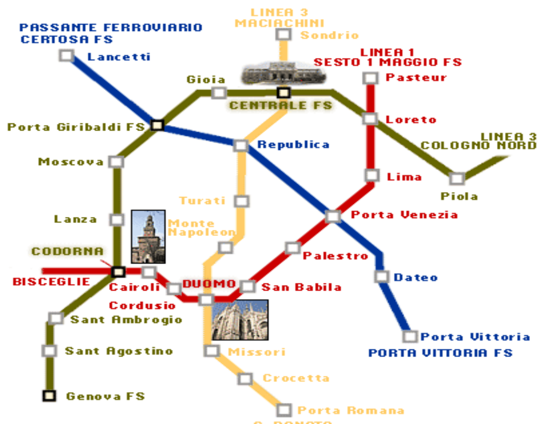

Fig. 3 Milan transportation map

For the evaluation, various performance criteria are used to compare the deferent routing protocols. First, the delivery probability, that is the number of successfully delivered messages to the total number of created messages, versus node buffer size is investigated. The next criterion is the message average buffer time. As you know node buffer size is limited and this limited buffer should be used effectively. If message buffer time be short, more messages can utilize it. Finally, the effect of car to car communication on average delay is of concern.

In Fig. 4 delivery probability is depicted versus buffer size limitation. LpSourceRouting is a single copy protocol which has the highest delivery probability among used routing protocols for a typical buffer size. Fig. 5 shows the average message buffer time. The figure suggests that, utilizing LpSourceRouting algorithm, results in lower message buffer time. In Fig. 6, the effect of car to car communication on average latency is showed. We used 3 cars per each line for the simulation. As inferred from the figure, car to car communication decreases the average latency of message delivery.

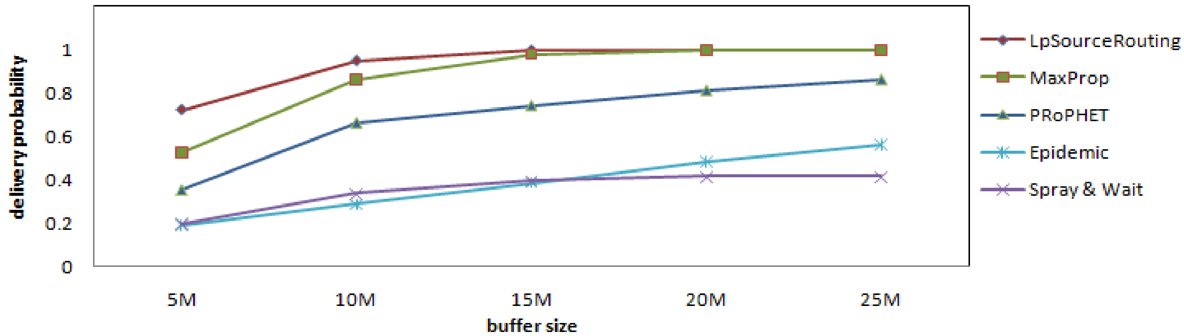

Fig. 4 Delivery probability

5. *Conclusions*

In this paper, we formulated the optimal network configuration problem in terms of minimum relay node location and minimum delay routing. Using relay nodes improve the network connectivity but it imposes new cost to the network. So, we want to benefit more from the relay nodes by reducing the routing delay. The performance of the proposed model was investigated on Milan transportation map.

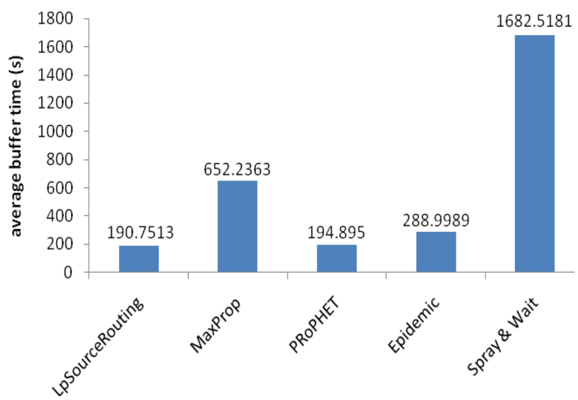

Fig. 5 Average message buffer time

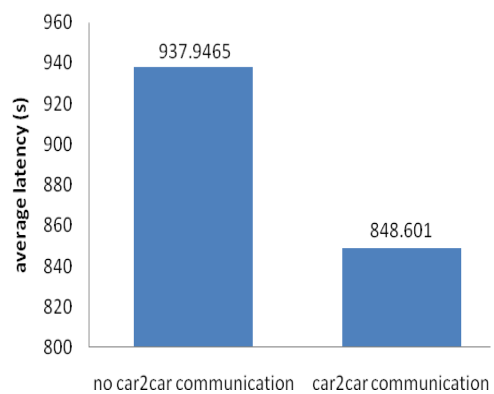

Fig. 6 Car2car communication effect

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