Ad Hoc Networks 20 (2014) 132–149

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Economy driven content dissemination in Delay Tolerant Networks ☆

Faezeh Hajiaghajani *, Yogesh Piolet Thulasidharan, Mahmoud Taghizadeh, Subir Biswas

Electrical and Computer Engineering, Michigan State University, East Lansing, USA

ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form 4 April 2014
Accepted 6 April 2014
Available online 18 April 2014

Keywords:
Delay Tolerant Network
Routing protocols
Economic gain of dissemination

ABSTRACT

Majority of the existing Delay Tolerant Network (DTN) routing protocols attempt to minimize the message delay, forwarding count, or required storage. However, for many DTN applications such as distributing commercial content, targeting the best performance for only one index and neglecting the others is insufficient. A more practical solution would be to strike a balance between multiple of those performance indices. This paper introduces a Gain-aware Dissemination Protocol (GDP) which attempts to reach the maximum economic gain of content delivery by maintaining a balance between the value achieved via message delivery and the involved forwarding costs given out as user rebates. Economic gain from disseminating content is defined as the generated value upon content delivery minus its forwarding costs. The key concept behind the proposed protocol is to adaptively balance between dissemination latency and forwarding costs in order to maximize the economic gain. Using the DTN simulation software ONE, we characterize the GDP protocol with varying mobility models, content sources, and content generation times.

1. Introduction

Routing in Delay Tolerant Networks [1] addresses the technical issues in delivering single or multiple content in heterogeneous networks that may lack continuous network connectivity. When no end-to-end path is present, intermediate nodes take custody of the data being transferred whenever opportunity rises. To choose the most appropriate content forwarders, majority of routing protocols attempt to explicitly minimize one of the DTN routing indices such as message delay [2], forwarding cost [3], or storage [4]. Those protocols attempt to explicitly minimize any one of the above three indices at a time.

From an operational standpoint, it is often necessary to strike a balance between multiple of those indices instead of targeting the best performance for a single index while neglecting the others. For instance, a routing protocol that offers excellent delay performance may require an unacceptably large number of forwarding (e.g. flooding), thus causing impractical amount of energy burden on the intermediate forwarding nodes. Similar practical problems also exist for the protocols that attempt to minimize forwarding-count or storage without considering the primary application requirement, namely, delay. Therefore, a desired DTN routing protocol should be able to strike an operational balance between the different objectives.

As a first step toward this goal, we develop a composite delay-forwarding cost index, and design a DTN routing protocol around that index. Many practical mobile applications would benefit from DTN routing based on such a composite cost index that combines the effects of delay, forwarding cost, and sometimes storage.

There are many applications of DTNs ranging across education, healthcare, government, interplanetary networks [5,6], vehicular networks [7] and marketing services

☆ This work was partially supported by a grant (NeTS 1017477) from U.S. National Science Foundation.

* Corresponding author.
E-mail address: hajiagh1@msu.edu (F. Hajiaghajani).

http://dx.doi.org/10.1016/j.adhoc.2014.04.001
1570-8705/

[8]. As a marketing strategy, consider a coupon distributing application which distributes time-constrained coupons through the wireless network using users' mobile devices. Let the *value* of a coupon be the amount of discount its recipient gets when she or he redeems the coupon at the store. And the economic gain of the store from disseminating the coupon is defined as the generated value upon delivery minus the forwarding costs. Therefore, for a *value* function that linearly decreases with time, it is desirable to deliver the coupon as early as possible with the minimum possible forwarding cost, i.e., through the fewest number of intermediate hops. In other words, the goal would be to find the right combination of delivery delay and number of forwards so that the economic gain of dissemination is maximized.

In self-organizing unmanaged networks nodes cannot be expected to forward messages without considering their own energy-cost of forwarding. This may require the content distributor to pay a *rebate* (i.e., contributing to the forwarding cost) to each user whenever he/she forwards the content. The concept of *rebate* is particularly important in self-organizing social settings in which there is no central authority that can enforce nodes to store and forward content without incentives. In addition to the coupon example above, the concepts of *value*, *rebate*, and *economic gain* apply to a number of other contents such as advertisements and event notifications.

In this paper we propose an economic gain-aware DTN routing protocol that automatically adapts itself to different combinations of value functions and forwarding costs without requiring any explicit parameter tuning. Specific contributions of the paper are as follows. First, we design and parameterize a composite *gain* function that combines the effects of delay (via *value*) and forwarding-cost (via *rebate*) during unicast DTN routing. Second, we develop a unicast routing mechanism that yields the best possible *gain* for a given network and mobility pattern. Third, we develop a unicast DTN routing protocol *Gain-aware Dissemination Protocol* (GDP) that utilizes the time-dependent *gain* function as a forwarding decision metric in both direct and transitive manners, to route content from a mobile source to a mobile destination. Finally, using DTN simulator ONE [9,10], the proposed protocol is extensively characterized along with few other existing unicast DTN routing protocols. It should be noted that the proposed mechanisms in this paper assumes full node cooperation. In other words, it does not address issues raised in the presence of non-cooperative and colluding selfish nodes, and attacks such as Sybil [11] and whitewashing attacks [12].

2. Related work

A large amount of work on DTN routing exists in the literature [2–8,13–32,34–37]. Most approaches work based on a store and forward strategy. We categorize these methods in three classes [13], namely, naïve flooding, utility-based forwarding, and hybrid of the two. The naïve replication/flooding protocols [2] achieve delivery by forwarding multiple copies of a message and without any prior network information such as node mobility and interaction statistics both local or global. *Epidemic Routing* [2] is a basic naïve flooding protocol whose primary aim is to minimize message delivery delay in the presence of network disconnections. Each node keeps track of the contents stored in its buffer through a *summary vector*. When two nodes meet, they exchange their summary vectors, and then request for those messages that are not in their respective buffers. In order to minimize system resource consumption (i.e., memory, network bandwidth, and energy), a *hop count* field in each content limits the number of hops it can be forwarded. Epidemic Routing guarantees minimum content delivery delay because all nodes in the network eventually act as carriers for each content. The content forwarding count and replication overhead, however, are not minimized, because the number of simultaneous content copies in the network is directly dependent on the number of nodes in the network. Thus, Epidemic, despite ensuring shortest delivery delay does not address the objective of minimizing gain (as defined in Section 1) which is a composite metric combining delivery delay and forwarding cost.

Direct Delivery [3] is a forwarding strategy in the other extreme compared to *Epidemic*, in the following sense. Instead of flooding a packet, source of a content holds it until it meets the destination directly. While minimizing the number of forwarded and replicated copies, this approach can suffer from very large delivery delay, thus not ensuring the maximum composite metric, gain. In fact, depending on the specific mobility pattern, the source may never directly meet the destination. A source node following this protocol does not leverage any specific knowledge about the network topology and nodes' interactions.

Spray and Wait [14–16], as a flooding method, combines the low latency of *Epidemic Routing* with the simplicity and thriftiness of *Direct Contact*. This is accomplished by decreasing the overhead of flooding, while keeping the delay short. *Spray and Wait* sprays a number of copies into the network and then "waits" till one of those "sprayed" nodes meets the destination directly. In *Two-Hop-Relay* [17], another naïve flooding algorithm, a node forwards the packet to the first T nodes it encounters. Consequently, each of the carriers can deliver the packet to destination using two extra hops. Both *Spray and Wait* and *Two-Hop-Relay* attempt to minimize delay using their initial spraying phase. The wait phase in *Spray and Wait* and the two-hop relay to the destination in the *Two-Hop-Relay* protocol try to limit forwarding cost in a heuristic manner. None of these approaches, however, can explicitly maximize the composite metric gain as formulated in this paper.

In utility based DTN routing methods, a single message copy is forwarded to a node which is qualified based on a defined utility. Utility based methods usually leverage topology and/or node information to choose a forwarder which has the highest utility among the forwarding candidates. *Motion Vector* (*MOVE*) [18] is a utility based routing method which uses movement direction of vehicles in a vehicular network as the utility. Nodes running *MOVE* are encouraged to forward packets to neighbors which are in the process of moving toward the destination. *Bubble* [19], as another utility based method, detects inter-node