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Towards efficient and practical network coding in delay tolerant networks☆

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ABSTRACT

Network coding techniques offer an emerging solution to efficient data transmission in Delay Tolerant Networks (DTN). To date, abundant techniques have been developed on exploiting network coding in DTN, however, most of them bring additional overhead due to the extra coded message redundancy. In this paper, we analyze the coded message redundancy issue, and then propose NTC, an efficient network coding scheme for DTN. In NTC, a novel metric named "redundancy ratio" is introduced within the anti-entropy message exchange process. We also discuss the design and implementation of practical NTC in detail. To evaluate the performance of our proposed NTC scheme, we implement NTC in ONE, the current state-of-the-art simulator for DTN. Simulation results show that, comparing with existing schemes, our proposed NTC scheme has significant advantages in enhancing the message delivery ratio and reducing the transmission overhead.

1. Introduction

Over the past few years, Delay Tolerant Networking (DTN) [1,2] has attracted a lot of research effort since it provides a feasible solution to efficient communication in delay/disruption environments. In DTN, the efficiency of data transmission is one of the most critical issues. Towards this issue, several schemes were proposed. In general, these schemes can be classified into two categories, i.e., the schemes with network coding and without network coding. Meanwhile, it is worth noting that network coding based approaches were more efficient and thus attracted more attention.

To enable practical network coding in delay tolerant networks, random linear network coding plays an important role due to its simplicity and efficiency. For the sake of convenience, in this paper, we use the term "network coding" to indicate the term "random linear network coding".

However, although most current network coding schemes are very helpful in data transmission, they also bring high transmission overheads due to redundant coded messages. In this paper, we analyze the problem of redundant coded messages, and propose a novel network coding-based data Transmission Control scheme (NTC) to reduce the overhead. In general, the contribution of this paper can be summarized as follows,

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- We identify the packet redundancy problem for practical network coding in delay tolerant networks, and propose a novel metric of "code generation redundancy ratio" to indicate coded message redundancy. To the best of our knowledge, we are the first to study such a problem.
- We propose NTC, a novel Network coding-based data Transmission Control scheme to exploit the metric of code generation redundancy ratio.
- We also implement the NTC scheme within the ONE simulator, and evaluate its performance. Simulation results show the efficiency of our proposed NTC scheme.

The remainder of this paper is organized as follows. In Section 2, we provide an overview of related work. In Section 3, we analyze the problem of coded message redundancy for random linear network coding in DTN. Thereafter, we propose the NTC scheme along with its design details in Section 4. The performance of the NTC scheme is evaluated in Section 5. Finally, we conclude the paper in Section 6.

2. Related work

Early work on data transmission in DTNs does not use network coding methods. Well-known algorithms include Epidemic Routing (ER) [3], Spary and Wait [4], Spray and Focus [5], and so forth. The Epidemic Routing (ER) scheme is a flooding-based algorithm in which a network node will exchange every message in its buffer with the node it meets until they have the same messages in their buffers. ER can achieve a high message delivery ratio but is very resource-consuming, which is not practical in real applications. Spray and Wait, Spray and Focus use limited message copies to eliminate the high message overhead in ER. In the two algorithms, a limited number of message copies are injected into the network and delivered to other nodes until only one message is left. The left message will be transferred to the destination directly. A similar algorithm named SMART [6] only sprays messages to the so-called companions of the destination node so that the message delivery ratio can be improved. PROPHET (Probabilistic ROuting Protocol using History of Encounters and Transitivity) [7], and Advanced PROPHET [8] make their routing decisions according to the characteristics of recursiveness and locality in node movements.

Recently, stimulated by the efficiency and promising benefits of network coding, people has devised some schemes with network coding for data transmission in DTNs. It is believed that the network coding based algorithms will be more efficient that those without network coding in DTNs because such schemes are more resilient to the challenging conditions in DTNs, like intermittent connections, long transfer delays, etc. The erasure codes [9,10] and rateless codes [11] are evaluated using traditional end-to-end encoding techniques in communication theory. At present, data transmissions in DTNs using network coding have got exciting results [12,5,13,14].

Although many schemes with network coding have been proposed to improve the efficiency of data transmission, most of them focus on encoding and decoding techniques. An important problem has not been thoroughly studied. That is, the number of messages using network coding will increase quickly with the spreading of messages in DTNs, which always causes serious redundant coded messages. Therefore, it is very crucial to handle the redundant coded message problem. In the remainder part of this paper, we will analyze this problem in the context of random linear coding, and propose an efficient and practical scheme named NTC to tackle this problem.

3. The coded message redundancy problem

3.1. Preliminaries of network coding

Network Coding was firstly proposed in 1999 [15]. Since then, it has been widely investigated in numerous applications. We would like to review some mathematical fundamentals as follows.

Assume $G = (V, E)$ represents a communication network, where V and E denote the node set and edge (or called channel) set respectively. For each node $T \in V$, let $\text{In}(T)$ and $\text{Out}(T)$ denote the incoming channel set and outgoing channel set respectively. $|\text{In}(T)|$ and $|\text{Out}(T)|$ represent the size of set $\text{In}(T)$ and $\text{Out}(T)$. In network coding, a data unit is always represented by an element of a base field F, consequently, a message consisting of ω data units can be represented by an ω-dimensional row vector $x \in F^{\omega}$.

Network coding is always specified as encoding mapping, where the mapping function usually maps the symbols received from all the incoming channels to a symbol of each outing channel. These mappings include local encoding mapping, global encoding mapping, etc.

Definition 1 (*Local Encoding Mapping*)**.** Let F be an infinite field and ω be a positive number, for each channel $e \in \text{Out}(T)$ of node T in $G = (V, E)$, its local encoding mapping can be denoted as,

$$\tilde{k}_e : F^{|In(T)|} \rightarrow F. \tag{1}$$

The local encoding mapping represents an ω-dimensional mapping function for node T, where $\omega = |\text{In}(T)|$ incoming messages will be mapped to a new message on the channel e.