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Control of coding in DTN's for progressive packet arrivals dynamically"

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Abstract: *In Delay Tolerant Networks (DTNs) the core challenge is to cope with lack of persistent connectivity and yet be able to deliver messages from source to destination. In particular, routing schemes that leverage relays' memory and mobility area customary solution in order to improve message delivery delay. When large files need to be transferred from source to destination, not all packets may be available at the source prior to the first transmission. This motivates us to study general packet arrivals at the source, derive performance analysis of replication based routing policies and study their optimization under two-hop routing. In particular, we determine the conditions for optimality in terms of probability of successful delivery and mean delay and we devise optimal policies, so-called piecewise-threshold policies. We account for linear block-codes and rateless random linear coding to efficiently generate red undancy, as well as for an energy constraint in the optimization. We numerically assess the higher efficiency of piecewise-threshold policies compared with other policies by developing heuristic optimization of the thresholds for all flavors of coding considered.*
Keywords: *Delay tolerant networks, mobile ad hoc networks, optimal scheduling, rateless codes, network coding.*

I. Introduction

Delay Tolerant Networks (DTNs), also called as intermittently connected mobile networks, are wireless networks in which a fully connected path from source to destination is unlikely to exist. However, effective forwarding based on a limited knowledge of contact behavior of nodes is challenging. When large files need to be transferred from source to destination make all the packets available at the source and transfer the file as small packets. Study of the packets arrival at source and analysis of their performance is done. It is considered that the linear blocks and rateless linear coding to generate redundancy and also for energy constraint . Scheduling the large file into small packets and delivering through multipath to destination, for this we use optimal user centric allocation and scheduling the packets in the receiver side.

DELAY Tolerant Networks (DTNs) leverage contacts between mobile nodes and sustain end-to-end communication even between nodes that do not have end-to-end connectivity at any given instant. In this context, contacts between

DTN nodes may be rare, for instance due to low densities of active nodes, so that the design of routing strategies is a core step to permit timely delivery of information to a certain destination with high probability. When mobility is random, i.e., cannot be known before hand, this is obtained at the cost of many replicas of the original information, a process which consumes energy and memory resources. Since many relay nodes (and thus network resources) may be involved in ensuring successful delivery, it becomes crucial to design efficient resource allocation and data storage protocols. The basic questions are then, sorted in the same order by which we tackle the problem:

(i) **Transmission policy:** when the source meets a relay node, should it transmit a packet?
(ii) **Scheduling:** if yes, which packet should a source transfer?
(iii) **Coding:** should the packets composing the message be encoded according to a specific scheme? If so, what is the resulting joint coding and scheduling?

In the basic scenario, the source has initially all the packets. Under this assumption the transmission policy has a threshold structure: it is optimal to use all opportunities to spread packets till some time _ depending on the energy constraint, and then stop. This policy resembles the well-known "Spray-and-Wait" policy [3]. In this work we assume a more general arrival process of packets: they need not to be simultaneously available for transmission initially, i.e., when forwarding starts, as assumed in [2]. This is the case when large multimedia files are recorded at the source node (from, e.g., a cellular base station) that sends them out (in a DTN fashion) without waiting for the whole file reception. This paper focuses on general packet arrivals at the source and two-hop routing.

We distinguish two cases: when the source can overwrite its own packets in the relay nodes, and when it cannot. The contributions are fourfold:

• For work-conserving policies (i.e., the source sends systematically before stopping completely), we derive the conditions for optimality in terms of probability of successful delivery and mean delay.
• In the case of non-overwriting, we prove that the best policies, in terms of delivery probability, are piecewise threshold. For the overwriting case, work-conserving policies are the best without energy constraint, but are Out performed by piecewise-threshold policies when there is an energy constraint.
• We extend the above analysis to the case where copies are coded packets, generated both with linear blockcodes and rateless coding. We also account for an energy constraint in the optimization.
• We illustrate numerically, in the non-overwriting case, the higher efficiency of piecewise-threshold policies compared with work-conserving policies by developing a heuristic optimization of the thresholds for all flavors of coding considered. As well, in the overwriting case, we show that work-conserving policies are the best without any energy constraint.

II. Related work

[1] E. Altman, F. De Pellegrini, and L. Sassatelli **"Dynamic control of coding in delay tolerant networks"**. The authors study replication mechanisms that include Reed-Solomon type codes as well as network coding in order to improve the probability of successful delivery within a given time limit. They propose an analytical approach to compute these and study the effect of coding on the performance of the network while optimizing parameters that govern routing. The memory of a DTN node is assumed to be limited to the size of a single frame. They study adding coding in order to improve the storage efficiency. They consider Reed-Solomon type codes as well as network coding.

[2] E. Altman and F. De Pellegrini **"Forward correction and Fountain codes in delay tolerant networks".** Delay-tolerant ad hoc networks leverage the mobility of relay nodes to compensate for lack of permanent connectivity and thus enable communication between nodes that are out of range of each other. To decrease delivery delay, the information to be delivered is replicated in the network. Their objective in this paper is to study a class of replication mechanisms that include coding in order to improve the probability of successful delivery within a given time limit. They propose an analytical approach that allows to quantify tradeoffs between resources and performance measures (energy and delay). They study the effect of coding on the performance of the network while optimizing parameters that govern routing. Their results, based on fluid approximations, are compared to simulations that validate the model. A native approach is to forward a file to the destination is by epidemic routing in which any mobile that has the message keeps on relaying it to any other mobile that falls within its radio range. This would minimize the delivery delay at the cost of inefficient use of network resources (e.g. in terms of the energy used for flooding the network). The need for more efficient use of network resources motivated the use of less costly forwarding schemes such as the two-hops routing protocols. In two-hops routing the source transmits copies of its message to all mobiles it encounters; relays transmit the message only if they come in contact with the destination.

[3] T. Spyropoulos, K. Psounis, and C. Raghavendra **"Efficient routing in intermittently connected mobile networks: the multi-copy case".** Intermittently connected mobile networks are wireless networks where most of the time there does not exist a complete path from the source to the destination. There are many real networks that follow this model, for example, wildlife tracking sensor networks, military networks, vehicular ad hoc networks, etc. In this context, conventional routing schemes fail, because they try to establish complete end-to-end paths, before any data is sent.

To deal with such networks researchers have suggested to use flooding-based routing schemes. While flooding-based schemes have a high probability of delivery, they waste a lot of energy and suffer from severe contention which can significantly degrade their performance. Furthermore, proposed efforts to reduce the overhead of flooding-based schemes have often been plagued by large delays. With this in mind, they introduce a new family routing schemes that "spray" a few message copies into the network, and then route each copy independently towards the destination. They show that, if carefully designed, spray routing not only performs significantly fewer transmissions per message, but also has lower average delivery delays than existing schemes; furthermore, it is highly scalable and retains good performance under a large range of scenarios.

Finally, they use their theoretical framework proposed in their 2004 paper to analyze the performance of spray routing. They also use this theory to show how to choose the number of copies to be sprayed and how to optimally distribute these copies to relays.

[4] E. Altman, T. Bas¸ar, and F. De Pellegrini**, "Optimal monotone forwarding policies in delay tolerant mobile ad-hoc networks".** In this paper they describe a framework for the optimal control of delay tolerant mobile ad hoc networks where multiple classes of nodes co-exist. They specialize the description of the energy-delay tradeoffs as an optimization problem based on a fluid approximation. They then adopt two product forms to model message diffusion and show that optimal controls are of bang-bang type. Under this general framework, they analyze some specific cases of interest for applications. In the paper, they study the problem of optimal control of routing. To this respect, in view of the use of battery operated mobile terminals, a mobile DTN depends on its overall energy budget. The energy budget has to accommodate the cost of energy expended on message forwarding. Intuitively, the higher the number of message copies, the smaller the message delay. This gain comes at a price of higher energy expenditure. More precisely, a finite energy cost accrues every time a message is transmitted and received. In the following it is assumed that the energy expenditure is linear in the number of released copies; this is a viable approximation especially for sparse networks where the impact of interference and collisions can be neglected.

[6] J. Nonnenmacher, E. Biersack, and D. Towsley **"Parity-based loss recovery for reliable multicast transmission".** The authors investigate how forward error correction (FEC) can be combined with automatic repeat request (ARQ) to achieve scalable reliable multicast transmission. They consider the two scenarios where FEC is introduced as a transparent layer underneath a reliable multicast layer that uses ARQ, and where FEC and ARQ are both integrated into a single layer that uses the retransmission of parity data to recover from the loss of original data packets. To evaluate the performance improvements due to FEC, they consider different loss rates and different types of loss behavior (spatially or temporally correlated loss, homogeneous or heterogeneous loss) for up to 10^6 receivers. Their results show that introducing FEC as a transparent layer below ARQ can improve multicast transmission efficiency and scalability. However, there are substantial additional improvements when FEC and ARQ are integrated.

FEC by itself cannot provide full reliability. Therefore, when coupled with ARQ, FEC can produce inherently scalable reliable multicast transport protocols. If introduced as a separate layer beneath the ARQ layer, it has the effect of substantially reducing the packet loss probability and, thus, reducing the number of packet retransmissions and network bandwidth requirements. If integrated with ARQ, then FEC introduces the following:

- A single parity packet can repair the loss of different data packets at different receivers.
- Using parity packets for loss repair, the sender needs to know only the maximum number of packets lost by any receiver but not their sequence numbers. Feedback from a single receiver is reduced to a single number for a group of packets

[7] Sushant Jain, Michael Demmer, Rabin Patra, Kevin Fall on "**Using Redundancy to Cope with Failures in a Delay Tolerant Network".** The authors consider the problem of routing in a delay tolerant network (DTN) in the presence of path failures. Previous work on DTN routing has focused on using precisely known network dynamics, which does not account for message losses due to link failures, buffer overruns, path selection errors, unscheduled delays, or other problems. They show how to split, replicate, and erasure code message fragments over multiple delivery paths to optimize the probability of successful message delivery. They provide a formulation of this problem and solve it for two cases: a 0/1 (Bernoulli) path delivery model where messages are either fully lost or delivered, and a Gaussian path delivery model where only a fraction of a message may be delivered. Ideas from the modern portfolio theory literature are borrowed to solve the underlying optimization problem. Their approach is directly relevant to solving similar problems that arise in replica placement in distributed file systems and virtual node placement in DHTs. In three different simulated DTN scenarios covering a wide range of applications, they show the effectiveness of our approach in handling failures.

[8] Yong Wang, Sushant Jain†, Margaret Martonosi, Kevin Fall On "**Erasure-Coding Based Routing for Opportunistic Networks"** Routing in Delay Tolerant Networks (DTN) with unpredictable node mobility is a challenging problem because disconnections are prevalent and lack of knowledge about network dynamics hinders good decision making. Current approaches are primarily based on redundant transmissions. They have either high overhead due to excessive transmissions or long delays due to the possibility of making wrong choices when forwarding a few redundant copies. In this paper, the authors propose a novel forwarding algorithm based on the idea of erasure codes. Erasure coding allows use of a large number of relays while maintaining a constant overhead, which results in fewer cases of long delays.

They use simulation to compare the routing performance of using erasure codes in DTN with four other categories of forwarding algorithms proposed in the literature. Their simulations are based on a real-world mobility trace collected in a large outdoor wild-life environment. The results show that the erasure-coding based algorithm provides the best worst-case delay performance with a fixed amount of overhead. They also present a simple analytical model to capture the delay characteristics of erasure-coding based forwarding, which provides insights on the potential of their approach

[9] Jorg Widmer, JeanYves Le Boudec on "**Network Coding for Efficient Communication in Extreme Networks"** Some forms of ad-hoc networks need to operate in extremely performance-challenged environments where end-to-end connectivity is rare. Such environments can be found for example in very sparse mobile networks where nodes "meet" only occasionally and are able to exchange information, or in wireless sensor networks where nodes sleep most of the time to conserve energy. Forwarding mechanisms in such networks usually resort to some form of intelligent flooding, as for example in probabilistic routing.

They propose a communication algorithm that significantly reduces the overhead of probabilistic routing algorithms, making it a suitable building block for a delay-tolerant network architecture. Their forwarding scheme is based on network coding. Nodes do not simply forward packets they overhear but may send out information that is coded over the contents of several packets they received. They show by simulation that this algorithm achieves the reliability and robustness of flooding at a small fraction of the overhead.

[10] Yunfeng Lin, Ben Liang, and Baochun Li on "**Performance Modeling of Network Coding in Epidemic Routing"** Epidemic routing has been proposed to reduce the data transmission delay in opportunistic networks, in which data can be either replicated or network coded along the opportunistic multiple paths. In this paper, the authors introduce an analytical framework to study the performance of network coding based epidemic routing, in comparison with replication based epidemic routing. With extensive simulations, they show that their model successfully characterizes these two protocols and demonstrates the superiority of network coding in opportunistic networks when bandwidth and node buffers are limited. They then propose a priority variant of the network coding based protocol, which has the salient feature that the destination can decode a high priority subset of the data much earlier than it can decode any data without the priority scheme. Their analytical results provide insights into how network coding based epidemic routing with priority can reduce the data transmission delay while inducing low overhead.

III. Statement of Problem

For work-conserving policies (i.e., the source sends systematically before stopping completely), derive the conditions for optimality in terms of probability of successful delivery and mean delay.

- In the case of non-overwriting, prove that the best policies, in terms of delivery probability, are piecewise threshold. For the overwriting case, work-conserving policies are the best without energy constraint, but are outperformed by piecewise-threshold policies when there is an energy constraint.
- Extend the above analysis to the case where copies are coded packets, generated both with linear block codes and rate less coding. Also account for an energy constraint in the optimization.
- Illustrate numerically, in the non-overwriting case, the higher efficiency of piecewise-threshold policies compared with work-conserving policies by developing a heuristic optimization of the thresholds for all flavors of coding considered. As well, in the overwriting case, we show that work-conserving policies are the best without any energy constraint.

IV. Proposed System

This report focuses on general packet arrivals at the source and two-hop routing. This distinguish two cases: when the source can overwrite its own packets in the relay nodes, and when it cannot. The contributions are fourfold:

- ❖ For work-conserving policies (i.e., the source sends systematically before stopping completely), derive the conditions for optimality in terms of probability of successful delivery and mean delay.
- ❖ In the case of non-overwriting, report prove that the best policies, in terms of delivery probability, are piecewisethreshold. For the overwriting case, work-conserving policies are the best without energy constraint, but are outperformed by piecewise-threshold policies when there is an energy constraint.
- ❖ This extend the above analysis to the case where copies are coded packets, generated both with linear blockcodes and rateless coding. Also account for an energy constraint in the optimization.
- ❖ This illustrate numerically, in the non-overwriting case, the higher efficiency of piecewise-threshold policies compared with work-conserving policies by developing a heuristic optimization of the thresholds for all flavors of coding considered. As well, in the overwriting case, it shows that work-conserving policies are the best without any energy constraint.

V. Algorithm Used

Algorithm 1: Constructing an optimal WC policy

Step 1 Use pt = e_1 at time t □ (t_1, t_2)

Step 2 Use pt = e_2 from time t_2 till s (1,2) = min (S (2, {1,2}), t_3). If s (1,2) < t_3 then$_1$ switch to p_t = –2
(e_1 + e_2) till time t_3

Step 3 Define t_{K+1} = □. Repeat the following for i = 3, …., K:

Step 3.1 Set j = i. Set s (i, j) = t_i

1 i

t ∑

Step 3.2 Use p = ——— e
i □ 1 □ j ^{k} k

t_{i+1}). If j = 1 then end.
from tiem s (i,j) till s (i, j – 1): = min (S (j, {1,2,...i}),

Step 3.3 If s (i, j – 1) < t_{i+1} then take j = min (j : j □ J (t, {1,…,i})) and go to step

Algorithm 2: Rateless coding after tK

Step 1 Use p_t = e_1 at time t □ (t_1, t_2).

Step 2 Use p_t = e_2 from time t_2 till s (1,2) = min (S(2,{1,2}), t_3). If s (1,2) < t_3 then$_1$ switch to p_t = 2 (e_1 + e_2) till time t_3.

Step 3 Repeat the following for i = 3,…, K – 1: Step 3.1 Set j = i. Set s (i, j) = t_i
1 i

t ∑ k

Step 3.2 Use p = ——— e
i □ 1 □ j $^{k □ j}$
from time s (i, j) till s (i, j – 1): = min (S(j, {1,2,….,i}),ti+1). If j=1 then end.

Step 3.3 If s (i, j – 1) < t_{i+1} then take j = min (j : j □ J (t, {1,…,i})) and go to step 3.2

Step 4 From t = t_K to t = □, use all transmission opportunities to send an RLC of information packets, with coefficients picked uniformly at random in F_q.

VI. Conclusion

We have addressed the problem of optimal transmission and scheduling policies in DTN with two-hop routing under memory and energy constraints, when the packets of the file to be transmitted get available at the source progressively. We solved this problem when the source can or cannot overwrite its own packets, and for WC and non WC policies. We extended the theory to the case of fixed rate systematic erasure codes and rateless random linear codes. Our model includes both the case when coding is performed after all the packets are available at the source, and also the important case of random linear codes, that allows for dynamic runtime coding of packets as soon as they become available at the source.

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