A Novel Mechanism for Controlling Packet Coding Rate Dynamically in Delay Tolerant Networks

Saragadam Ramu [#1], Dr.Koduganti Venkata Rao [*2]

M.Tech Scholar [#1], Professor & HOD [*2]

Department of Computer Science & Engineering,
Vignan Institute of Information Technology,
Visakhapatnam, AP, India.

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Abstract

Delay-tolerant network (DTN's) is an approach to computer network architecture that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity. Examples of such networks are those operating in mobile or extreme terrestrial environments, or planned networks in space. The main characteristic of DTN is by their lack of connectivity, resulting in a lack of instantaneous end-to-end paths. In particular, routing schemes that leverage relays' memory and mobility are a 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. 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 rate less random linear coding to efficiently generate redundancy, 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, Optimal Scheduling, Rateless Codes, Network Coding, Mobile Ad Hoc Networks

1. Introduction

Delay-tolerant network (DTN's) is an approach to computer network architecture that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity [1]. Examples of such networks are those operating in mobile or extreme terrestrial environments, or planned networks in space. The main characteristic of DTN is by their lack of connectivity, resulting in a lack of instantaneous end-to-end paths. DTN's 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 an certain destination with high probability. When mobility is random, i.e., cannot be known beforehand, 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.

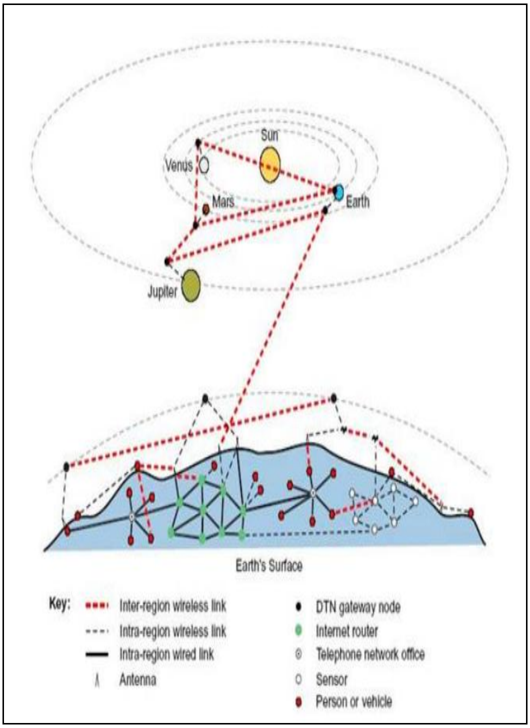


Figure 1. Represents a DTN Network as an Earth Surface

The basic questions are then, sorted in the same order by which we tackle the problem:

- **A. Transmission Policy:** when the source meets a relay node, should it transmit a packet?
- **B. Scheduling:** if yes, which packet should a source transfer?
- **C. Coding:** should the packets composing the message be encoded according to a specific scheme? If so, what is the resulting joint coding and scheduling?

n the basic scenario, the source has initially all the packets. Under this assumption it was shown in [2] that the transmission policy has a threshold structure: it is optimal to use all opportunities to spread packets till some time σ 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.

2. Background Knowledge

In this section we will describe the assumptions and background knowledge that is used for developing the new dynamic control of coding for progressive arrivals in DTN Networks.

2.1 Main Contributions

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:

1. **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.

2. **In the case of non-overwriting**, we prove that the best policies, in terms of delivery probability, are piece wise 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.

3. **We extend the above analysis** to the case where copies are coded packets,

generated both with linear block codes and rateless coding. We also account for an energy constraint in the optimization.

4. **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.

2.2 Related Work

The original idea of packet level encoding for multicast was proposed first by [4], [5] dealing with packet level forward error correction (FEC). Several satellites need to receive several data packets, that may need retransmission due to channel errors. Because many sites may need retransmissions, the problem is to avoid the phenomenon of *ACK implosion* due to several sites requesting repairs. [5] builds on Reed– Solomon codes, to transmit *H* additional packets, so that upon receiving any *K* of the *K*+*H* packets, all stations are able to decode correctly the *K* information packets. This scheme, and this intuition, do prove useful also in our context. This seminal idea was employed later by several works to combine FEC and acknowledgment-based retransmission protocols, such as [6].

The effort there was to improve timeliness of packet delivery in multicasting multimedia streams which are subject to hard delay constraints. In DTNs the framework is different since the challenge is to overcome frequent disconnections. Papers [7] and [8] propose a technique to erasure code a file and distribute the generated code-blocks over a large number of relays in DTNs, so as to increase the efficiency of DTNs under uncertain mobility patterns. In [8] the performance gain of the coding scheme is compared with simple replication. The benefit of coding is assessed by extensive simulations and for different routing protocols, including two hop routing. In [7], the authors address the case of non-uniform encounter patterns, and they demonstrate strong dependence of the optimal successful delivery probability on the way replicas are distributed over different paths. The authors evaluate several allocation techniques; also, the problem is proved to be NP–hard. The paper [9] addresses the design of stateless routing protocols based on network coding, under intermittent end-to-end connectivity, and the advantage over plain probabilistic routing is proven. In [10] ODE-based models are employed under epidemic routing; in that work, semi-analytical numerical results are reported describing the effect of finite buffers and contact times. The same authors in [11] investigate the use of network coding using the Spray-and-Wait algorithm and analyze the performance in terms of the bandwidth of contacts, the energy constraint and the buffer size.

Table I
Main Notation Used Throughout the Paper

Symbol	*Meaning*
N	number of nodes (excluding the destination)
K	number of packets composing the file
H	number of redundant packets
λ	inter-meeting intensity
τ	timeout value
$X_i(t)$	fraction of nodes (excluding the destination) having packet i at time t
$X(t)$	summation $\sum_i X_i(t)$
$\widehat{X}_i, \widehat{X}$	corresponding sample paths
z	$:=X(0)$ will be taken 0 unless otherwise stated.
$u_i(t)$	forwarding policy for packet i; $\mathbf{u} = (u_1, u_2, \ldots, u_K)$
u	sum of the u_is
$Z_i(t)$,Z_i	$Z_i(t) = \int_0^T X_i(u)du$, $Z_i = Z_i(\tau)$, $\mathbf{Z}(t) = (Z_1(t), Z_2(t), \ldots)$, $\mathbf{Z} = \mathbf{Z}(\tau)$, $Z = \sum Z_i$
$D_i(\tau)$	probability of successful delivery of packet i by time τ
$P_s(\tau)$	probability of successful delivery of the file by time τ; $P_s(\tau, K, H)$ is used to stress the dependence on K and H
$\mathbb{R}_+$	nonnegative real numbers

The above table clearly defines what the notations that are used are in our proposed algorithm for dynamic control of coding for progressive arrival of packets in delay tolerant networks. The main symbols used in the paper are reported in Tab. I.

Consider a network that contains $N + 1$ mobile nodes. We assume that two nodes are able to communicate when they come within reciprocal radio range, that communications are bidirectional and that the duration of such contacts is sufficient to one packet in each direction, and that the node buffer size is one packet. Also, let the time between contacts of pairs of nodes be exponentially distributed. The validity of this model has been discussed in [12], and its accuracy has been shown for a number of mobility models (Random Walk, Random Direction, Random Waypoint).

3. Proposed Algorithm

The following is the main optimal control algorithm that we have proposed in this paper for dynamic control of coding for progressive arrival of packets in Delay Tolerant Networks.

3.1 Constructing an Optimal WC Policy

We propose an algorithm that has the property to generate a policy **u** which is optimal not just for the given horizon $\boldsymbol{\tau}$, but also for any horizon shorter than τ. Yet optimality here is only claimed with respect to WC policies. We need some auxiliary definitions that we list in order:

$Z_j(t) := \int_{t_1}^{t} X_j(r)dr$. We call $Z_j(t)$ the cumulative contact intensity (CCI) of class j.
$I(t,A) := \min_{j\in A}(Z_j, Z_j > 0)$. This is the minimum non zero CCI over j in a set A at time t.

Let $J(t, A)$ be the subset of elements of A that achieve the minimum $I(t, A)$.

• Let $S(i,A) := \sup(t : i \,/\!\in J(t,A))$ for i in A.

• Define *ei* to be the policy that sends packets of type I with probability 1 at time t and does not send packets of other types.

A1	Use $\mathbf{p}_t = e_1$ at time $t \in [t_1, t_2)$.
A2	Use $\mathbf{p}_t = e_2$ from time t_2 till $s(1,2) = \min(S(2,\{1,2\}), t_3)$. If $s(1,2) < t_3$ then switch to $\mathbf{p}_t = \frac{1}{2}(e_1 + e_2)$ till time t_3.
A3	Define $t_{K+1} = \tau$. Repeat the following for $i = 3, ..., K$:
A3.1	Set $j = i$. Set $s(i,j) = t_i$
A3.2	Use $\mathbf{p}_t = \frac{1}{i+1-j}\sum_{k=j}^{i} e_k$ from time $s(i,j)$ till $s(i,j-1) := \min(S(j,\{1,2,...,i\}), t_{i+1})$. If $j = 1$ then end.
A3.3	If $s(i,j-1) < t_{i+1}$ then take $j = \min(j : j \in J(t,\{1,...,i\}))$ and go to step [A3.2].

Table II
Represents the Algorithm A

Algorithm A in Table II strives for equalizing the less populated packets at each point in time: it first increases the CCI of the latest arrived packet, trying to increase it to the minimum CCI which was attained over all the packets existing before the last one arrived (step A3.2). If the minimum is reached (at some threshold s), then it increases the fraction of all packets currently having minimum CCI, seeking now to equalize towards the second smallest CCI, sharing equally the forwarding probability among all such packets. The process is repeated until the packet arrives: hence, the same procedure is applied over the novel interval.

3.2 System Architecture

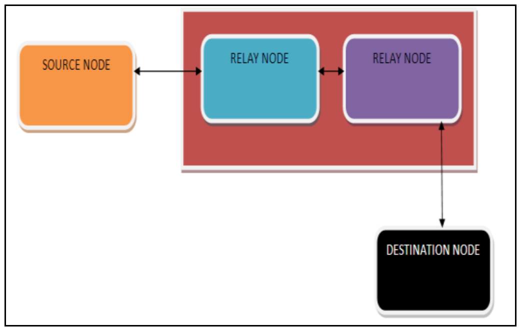


Figure 2. Represents the proposed System Architecture Diagram

In the above system architecture we can clearly see that this is a delay tolerant networks which uses relay nodes in the intermediate for sending data from source to destination without getting any delay and for successful sending of packets without any failure occur during transmission.

4. Implementation Modules

Implementation is the stage where the theoretical design is automatically converted into practically by dividing this into various modules. We have implemented the current application in Java Programming language with Front End as java Swings with network simulation code using RMI. Our proposed application is divided into following 4 modules. They are as follows:

A. Network Model
B. Routing Module
C. Simulation Module
D. Evaluation Module

A. Network Model

In this module, first we construct our network model, where it consists of Source, Router and Destination. In Router part, we assume that two nodes are able to communicate when they come within reciprocal radio range, that communications are bidirectional and that the duration of such contacts is sufficient to one packet in each direction, and that the node buffer size is one packet. Also, let the time between contacts of pairs of nodes be exponentially distributed.

B. Routing Module

In this module, we consider two-hop routing: a packet can go only through one relay. We distinguish two cases: when the source can overwrite its own packets in the relay nodes, and when it cannot. The possible reason for the source not to be allowed to overwrite its own packets would be to prevent source spoofing in case no authentication system is used between the nodes and an adversarial node would try to impede the transmission.

C. Simulation Module

In this module we do the following operations:

- Generating node movement using different movement models.
- Routing messages between nodes with various DTN routing algorithms and sender and receiver types.
- Visualizing both mobility and message passing in real time in its graphical user interface.

D. Evaluation Module

In this module, we evaluate our system using Graph. We show the performance evaluation using Energy constraint. Traces generated by ONE's connectivity report modules are suitable to control the link status between dtnd instances. This requires an external DTN Controller that reads the contact trace files produced by the ONE simulator and controls the dtnds through their console interfaces. The connectivity traces report each event of a link between two nodes going up or down and the time instance when it occurred. The controller reads these events sequentially and instructs the corresponding dtnd instances to open or close the specified link. Real-time operation is achieved by scheduling issuing the control commands according to the trace file's timestamps.

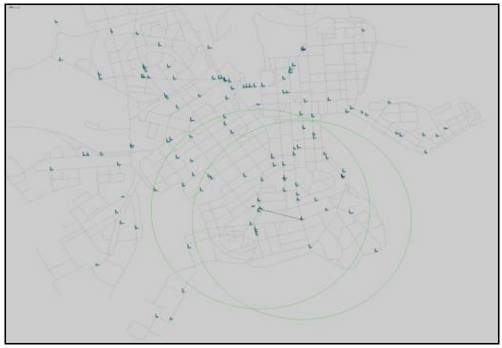
5. Enhancement Results in Simulation Manner

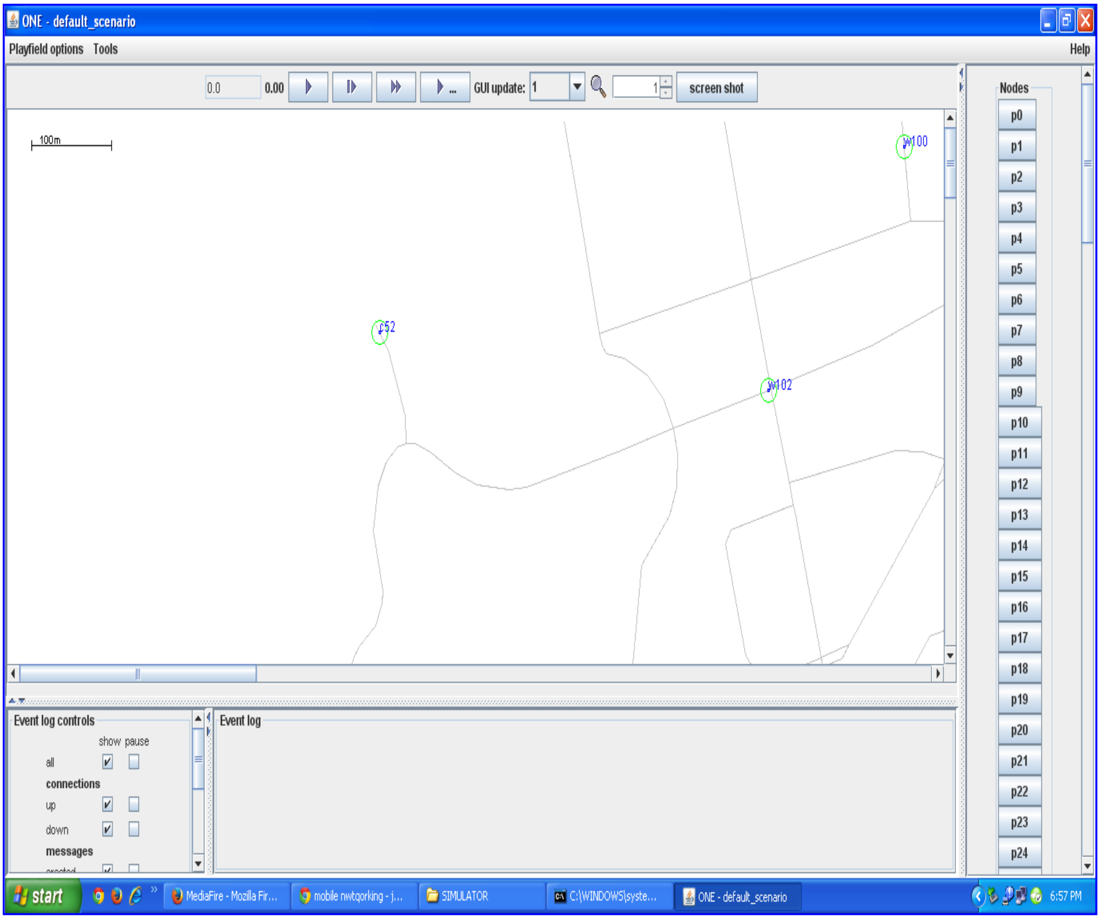
In this paper, we have proposed a new dynamic control of coding model for reducing packets dropping and delay time of packets during arrival from source to destination. For this we have shown the application in an network simulator using RMI concept in Java for showing the data transfer rates in DTN networks .By this simulation chart we can clearly show that there was no packet losses in this proposed model when sending data from source to destination.

Now let us see the following two windows which clearly state the efficiency of DTN networks in finding the delay rate of successful transmitted packets with no packet loss.

Main Window

In this window we will find some set of nodes in the right hand side with labeled as **po,p1…..Pn.**There was some lines just like Google maps road ways lines which indicates the connectivity links for each and every nodes. We can also find some buttons like start/ stop and fast play buttons below the menu bar which clearly tells that they are used for starting and stopping of the nodes action. In the bottom we come to see that there was a event log for each and every packet arrival information is stored in that location.





6. Conclusion

In this paper, 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.

As an enhancement we have also shown the data transfer in a simulation manner which clearly tells that there was no packet loss during the transmission of packets from source to destination in DTN Networks.

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8. About the Authors

Saragadam Ramu is currently pursuing his 2 Years M.Tech (CSE) in Department of Computer Science and Engineering at Vignan Institute of Information Technology, Visakhapatnam. His area of interests includes Networks and Information Security.

Dr.Koduganti Venkata Rao is currently working as Professor and Head of the Department in Department of Computer Science and Engineering at Vignan Institute of Information Technology, Visakhapatnam. His research interests include Security and Cryptography, Parallel Computing & Grid Computing