Confirmed Delivery Multicast Protocol in Delay-Tolerant and Disruptive Networks

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Abstract. This paper evaluates the performance of the NORM multicast transport protocol, when used in mobile satellite channels that behave as in delay-tolerant and disruptive networks (DTN). Comparisons are made between multicast transmissions with and without interleaver when NORM is used in "confirmed delivery" mode.

Keywords: DTN, mobile satellite channel, NORM multicast protocol, confirmed delivery, FEC, interleaver, performance evaluation.

1 Introduction

Communications in delay-tolerant networks (DTN) are characterized by intermittent connectivity (congested links or disrupted links), long and variable delays, unbalanced traffic, and high error rates [1]. A DTN is a network of regional networks, which bases its communications on the asynchronous message forwarding paradigm (called *bundle*) implemented by the Bundle protocol (BP) [2], which lies between the transport and upper layers, thus augmenting to eight the number of the OSI layers. DTN concepts, such as asynchronously connected nodes, store-and-forwarding principles, and routing for opportunistic connectivity-based networks, can be applied in scenarios where mobile satellite links are present.

An example of this type of scenarios is shown in Figure 1: a data server (the data source) has (directly or indirectly) access to a wide-area broadcast medium, such as a DVB geostationary satellite link, that covers the area where the final receivers (moving people) are located. It is unrealistic to assume that each final receiver has the capability to receive data directly from the broadcast medium. For reasons of cost-efficiency and power conservation, receivers on broadcast links would rather be established as routers (the vans or the helicopters, in Fig. 1) that store and forward data either towards other intermediate routing nodes, thus acting as bent pipe repeaters, or towards the final receivers (people) via a more efficient terrestrial wireless technology. This is an example of an application that operates in a group-based manner, thus requiring efficient network support for group communications (multicast transmissions).

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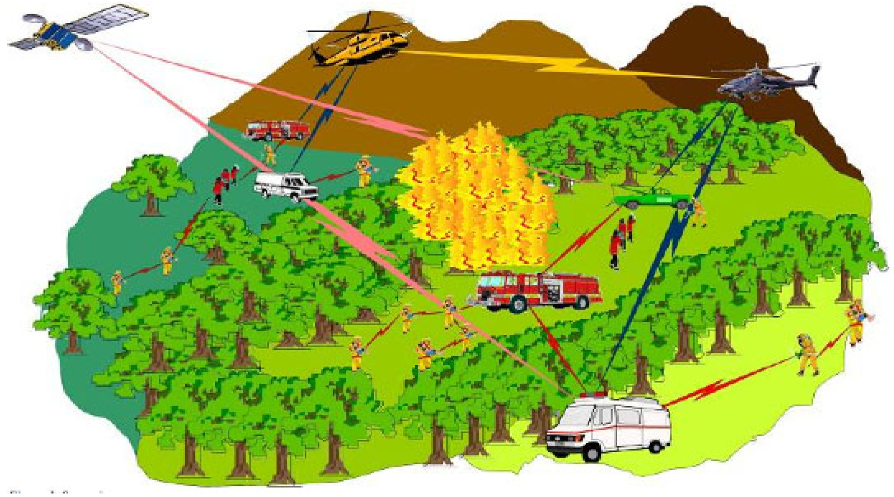

Fig. 1. An example of scenario where mobile satellite links behave as DTNs

While multicasting in the Internet and mobile ad hoc networks has been extensively studied, in DTNs it is a considerably different and challenging problem, due to the DTN unique characteristic of frequent partitioning. Therefore, traditional multicast methods proposed for the Internet (e.g., MOSPF [3] and DVMRP [4] or mobile ad hoc networks (e.g., AMRoute [5] and ODMRP [6] are not suitable for DTNs. First, it is difficult to maintain the connectivity of a source-rooted multicast tree (or mesh) during the lifetime of a multicast session. Second, data transmissions suffer from large end-to-end delays along the communication tree because of the repeated disruptions caused by periodically broken branches. Third, the traditional approaches may fail to deliver a message when the probability of link unavailability becomes high (e.g. ~80%). DTN bundle protocol accesses the underlying transport networks by using Convergence Layers (CL), which map existing protocol suites to a common set of functions.

Currently, the bundle communication protocol supports the FLUTE [7] multicast transport protocol thanks to the Uni-DTN [8] convergence layer, while it does not support the NORM multicast transport protocol [9]. The main difference between FLUTE and NORM is that NORM can operate in both the “confirmed delivery” and “silent” mode, the last one being the equivalent to the unidirectional modality supported by NORM. In [10], we defined a convergence layer, named DT-NORM, which allows the bundle protocol to support the NORM transport protocol. NORM protocol, as defined in the RFC 5740, supports the FEC (forward error correction) coding but it does not implement the interleaving, which is another powerful tool (when used together with FEC) to reduce the probability of error packets in channels like the ones we consider.

In this paper, we present the results of the performance of NORM when used with and without the interleaving technique. When used with interleaving, it is shown a dramatic reduction in the residual (after decoding and de-interleaving) packet loss

(RPL), over a mobile satellite channel in rural and suburban environments, which behaves as in a DTN. We stress that reducing the residual packet loss implies reducing the number of retransmission requests to the sender; as a consequence, the end-to-end delivery delay of a file is reduced.

2 The Channel Model Assumed

The mobile satellite channel has been modelled as a two-state Gilbert channel [11], by means of a discrete time Markov chain (DTMC) model, defined by a transition matrix:

$$\mathbf{T}=\begin{pmatrix} 1-b & b \\ g & 1-g \end{pmatrix}.$$

The stationary probability vector $\mathbf{P}^{\infty}$ is a normalized eigenvector relative to the dominant eigenvalue λ=1, which characterizes the matrix **T**; we have:

$$\mathbf{P}^{\infty}=\left[\frac{g}{b+g},\frac{b}{b+g}\right].$$

In [11], the mobile satellite channel has been modelled for four environments: urban, suburban, rural, and highway. We selected mobile suburban and highway environments only since rural mobile channel has fading characteristics close to the suburban one, while urban fading is too adverse and other wireless technologies (like WIFI, WIMAX or HSDPA) are reasonably preferable in fully connected cities. The numeric values of the elements of the transition matrix **T** are reported in Table 1 for the two different types of environment considered.

Table 1. Channel parameters of the DTMC model in suburban and highway environments

Environment	Transition matrix		Stationary probabilities
Suburban	0.995671	0.004329	0.799308
	0.017241	0.982759	0.200692
Highway	0.998069	0.001931	0.899306
	0.017241	0.982759	0.100694

3 The Advantage of Using the Interleaver

The sender segments NORM data into symbols and transforms them in FEC coding blocks before transmission. In NORM, a FEC encoding symbol directly corresponds to the payload of a "segment". When systematic FEC codes are used, data symbols are sent in the first portion of a FEC encoding block and are followed by parity symbols generated by the encoder. These parity symbols are generally sent in response to repair requests, but some of them may be sent proactively in each encoding block in order to reduce the volume of feedback messages. When non-systematic FEC codes are used, all symbols sent consist of FEC encoding parities. In this case, the receiver needs to receive a sufficient number of symbols to reconstruct the original user data for the given block (FEC decoding).

Interleaving is an additional feature necessary to reduce the correlation between loss events, as in disruptive channels characterized by memory and high loss rates. Figure 2 shows how the interleaver works: the sub-matrix *k* x *n* contains the allocation for each segment of data. Each row *i* {*i*=1...*m}* is a Reed Solomon Erasure (RSE) codeword constituted by *k* information segments and *r* parity segments; each column *j* {*j*=1...*n}* is fragmented into *m* units that are the payload of as many NORM segments.

Figure 3 shows how a finite interleaver can almost perform as an ideal interleaver, in terms of RPL in the two chosen (rural and suburban) environments. The two parameters characterizing the mobile satellite channel model for each environment are the average packet loss (PL) and the channel correlation factor ρ=1-*b*-*g* [12]. These two parameters are sufficient to define the DTMC process, which models the channel behavior, as presented in [11], [12], [13], [14].

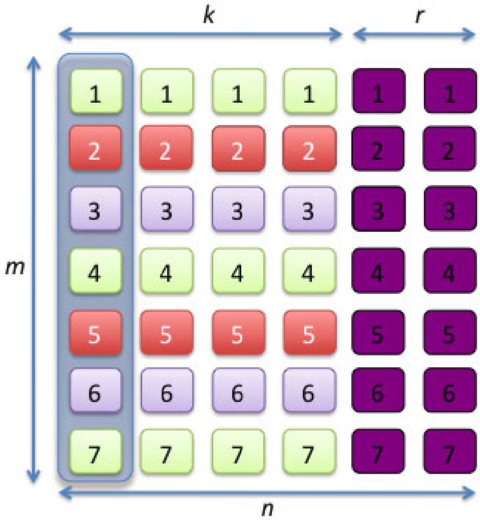

Fig. 2. RSE FEC with interleaver: m=7, n=6, k=4, r=2

Results reported in Fig. 3 have been obtained with the analytical model developed in [14] and applied to a DVB-S2 satellite network with mobile users. The satellite mobile environment has the same characteristics of a DTN network (unpredictable delays, intermittent connectivity, unbalanced traffic, and high error rates).

We assumed a packet size of 1024B, which includes the NORM header of 48B. 40B for UDP/IP has to be considered for the IP multicast addressing. The transmission rate is 256Kbps, which results in a sampling time of 0.03325s (one packet per sample) for DTMC process. For what concerns NORM features, we have assumed, likely to NORM, a proactive redundancy, by choosing an RSE (42, 32) and an RSE (42, 37) code in suburban and highway environments, respectively. In Fig. 3, *uncRPL* stands for "uncorrelated residual packet loss", i.e. the residual packet loss after RSE decoding in a channel where errors are totally uncorrelated, while RPL stands for "residual packet loss" after decoding, in case of a correlation factor ρ between channel losses.

The choice of the optimal proactive redundancy as a function of the channel error process would allow providing, a priori, the resource demand (in terms of bandwidth and processing power) and the scalability limit of a multicast distribution satellite system for disruptive channels.

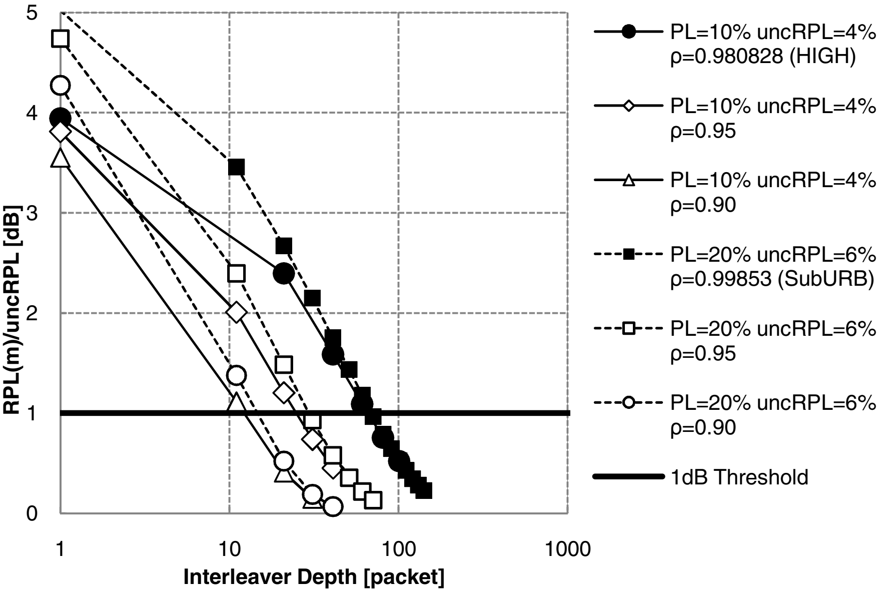

Fig. 3. Performance of a finite interleaver depth, in terms of residual packet loss relative to an ideal interleaver, for different values of the channel correlation factor ρ and for different values of the average channel packet loss (PL)

In details, the scalability, in terms of the maximum number of users within a multicast group, is severely limited by the RPL, which impacts on each receiver and reduces the performance of the whole group [15]. In fact, reliable multicast protocols adapt both the delivery rate and the error recovery parameters according to the receiver that experiences the worst channel conditions in terms of packet loss. That is, the residual packet loss is harsh to the scalability of a multicast distribution system, since the "equivalent packet loss", seen by the sender, is given by the overlap of loss events experienced by each receiver.

For these reasons, counteracting disruptive error processes is a very challenging issue in multicast mobile satellite networks.

4 Performance of NORM with and without Interleaving

The results of this section have been obtained by using the same environment types and the same considerations done for getting results reported in Fig. 3; the confidence interval is 5% at 95% level. NS2 2.34 has been adopted as a simulation environment and it has been patched (v. 1.4b3) by adding the NORM protocol developed by the US Naval Research Laboratory, which is downloadable from [16]. We assumed the sender has to transmit 10 files of 2.5MB each. An intermediate node acts as a multi-spot satellite, which realizes a multicast distribution by replicating the incoming data flow toward the spots that cover the subscribing mobile receivers. The NORM sender adopts no congestion control mechanism, and an information bundle of 32 and 37 packets for suburban and highway environments, respectively. A pre-computed redundancy of 10 and 5 packets, respectively, is proactively appended to the information bundle transmitted. The resulting codeword is a block of 42 packets in both cases. The coding rates, corresponding to *n-k/n* ratios, are just greater than the respective values of packet loss in the two environments. Such a condition would be sufficient to conveniently reduce the RPL, if the errors were uncorrelated; in case of correlated errors, instead, the parity length has to face the burst error length. In order to compensate for such a deficiency, our results show how a near-ideal interleaver works; in fact, such an interleaver allows to benefit from few parities and

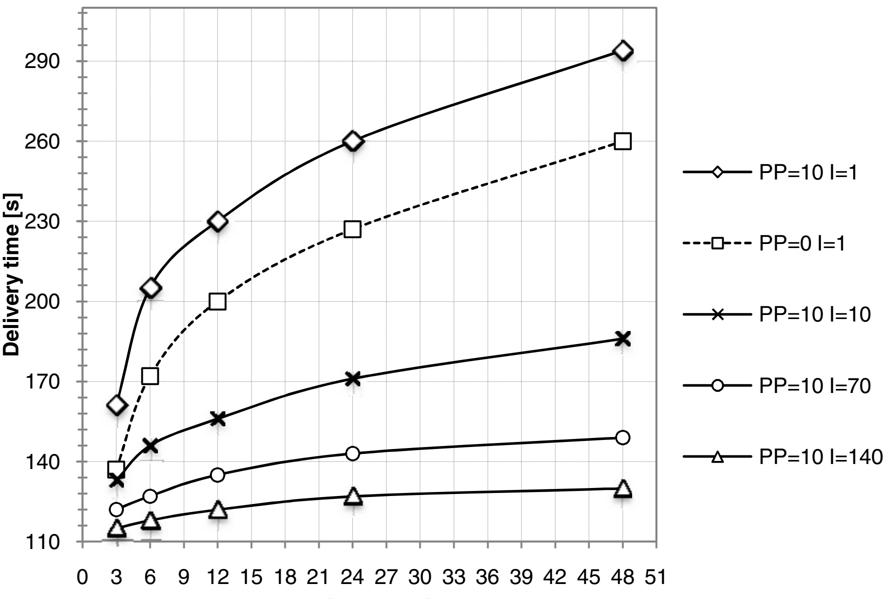

Fig. 4. NORM performance with and without proactive parity (PP) RSE (42, 32), in terms of delivery time, for different values of both the interleaver depth (I) and the number of multicast receivers in suburban environment

short coding blocks, which limit the number of recovery cycles of the NORM error recovery algorithm. In case of no NACK reception, i.e. a silent delivery, the proactive parity probably produces a waste of bandwidth (may be too much redundancy used), even if it minimizes the delivery time. Instead, just few recovery cycles (ideally one only) can represent a good tradeoff between delivery time and bandwidth overhead.

Simulation results reported in Figures 4 and 5 show the combined performance of interleaving, proactive parity, and reactive error recovery adopted in NORM, in suburban and highway environments, respectively. The term of comparison is the average delivery time, i.e. the interval between the reception of the first and the last packet of a file by all receivers.

Dotted lines refer to the NORM usage with no proactivity parity and no interleaving (I) add-on. In case of a few packets of proactive parity PP=10, PP=5 and average error burst length of 58 packets in both the environments, the delivery time is even underperforming, since error bursts are longer than the parity length, on average. However, the combination of PP with interleaving is outperforming the case without PP and in case of quasi-ideal interleaving (i.e. I=140 packets in suburban and 70 packets in highway) NORM robustly behaves even when the number of multicast receivers scales.

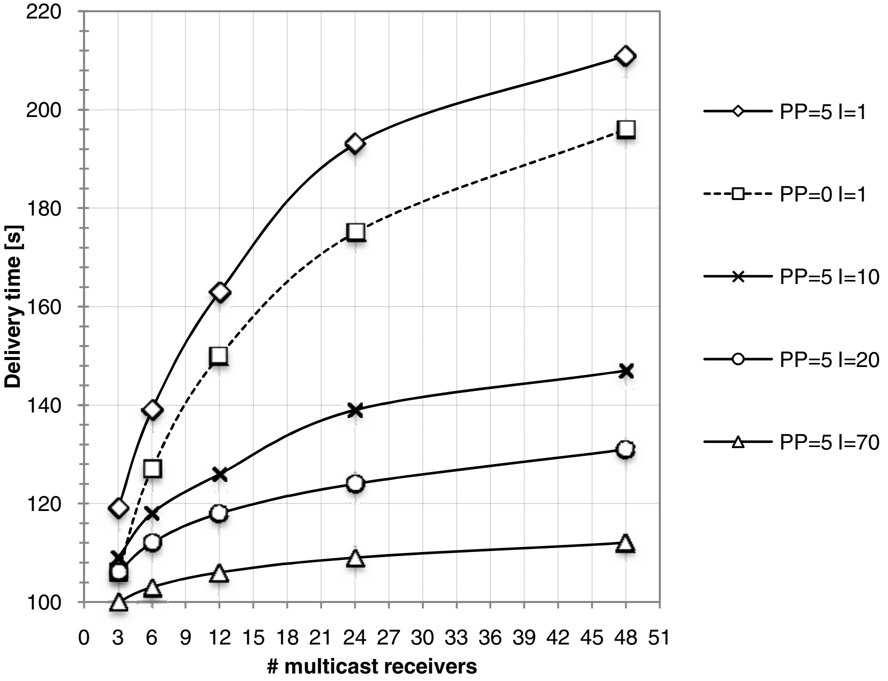

Fig. 5. NORM performance with and without proactive parity (PP) RSE (42, 37), in terms of delivery time, for different values of both the interleaver depth (I) and the number of multicast receivers in highway environment

In all the interleaved cases, an extra buffering time has to be accounted for, since the interleaver must be fulfilled before starting the decoding process. This time interval, in practice, occurs between the subscription of the file and the reception of the first packet. Interleaving delay is given by *I(n-1)pt,* where *pt* is the packet time equal to 0.03325s in our simulations. The interleaver delay may rise up to 191s, referring to the worst case in suburban PP=10 and I=140 of Fig. 4. Thus, the download time, i.e. the time between the notification of the file transmission (notified by the sender through a command message and acknowledged by the receivers) and the end of the file delivery, is given by the delivery time and the interleaving delay.

5 Conclusions and Future Works

The combined adoption of FEC and interleaving fosters the NORM's performance in terms of scalability and delivery time, in land mobile satellite environments. Interleaving allows limiting the packet error rate on the channel by means of a small amount of proactive parity. However, the interleaver depth is closely related to the channel correlation factor, which is responsible for bursts of errors. Scaling on the transmission rate results in longer error bursts, which require a deeper interleaver. In delay-tolerant networks, interruptions due to unpredictable obstacles, fading events, or, more generally, channel interruptions can last for unpredictable times; to counteract blockages that overcome a certain threshold, the interleaver may be so long to be no more convenient, as it reduces the transmission time but it may sensibly increase the user's perceived downloading time, because the adoption of the interleaver implies a pre-buffering time. This consideration encourages deepening our studies in order to optimize the tradeoff among bandwidth, end-to-end delivery time, and required computing power.

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