ATM Forum Technical Committee
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Title : Necessity of an FEC Scheme for ATM Networks
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Abstract :

This contribution discusses the benefits of a cell-level forward error correction (FEC) scheme in the AAL. An FEC scheme will benefit real-time needs of multimedia applications as well as reliable data communications. An ATM network performance degrades rapidly with increasing cell loss or the bit error rate (BER) of the medium. The achievable throughput for reliable services also deteriorates with increasing packet or frame size. Further, when reliable multicast service is used, the packet throughput seriously degrades with the number of receivers.

An AAL-level FEC scheme would improve the end-to-end QoS in all these cases. FEC schemes would be very beneficial in cases where retransmissions by a higher layer protocol lead to low QoS and an inefficient use of network resources, or where delay requirements preclude the use of retransmissions. This contribution therefore proposes that the SA&A specify an AAL-level FEC scheme as an optional SSCS function.
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1 Introduction

This contribution discusses the potential benefits of an AAL-level forward error correction (FEC) scheme for reliable data transmission services in ATM networks to both correct bit errors and recover from cell losses.

Since the basic data-unit, the cell, in ATM networks is typically very small compared to application level data-units (e.g., IP packets in the Internet protocol suite), one data-unit at the application level corresponds to dozens or hundreds (or sometimes thousands) of cells. As discussed in [95-0150], it is expected that, either when the cell loss ratio is high or the packet length is large, the peer-to-peer throughput is severely limited.

As shown in [Rom95] and [94-0914], the loss rate of higher layer packets (e.g., TCP packets) grows linearly with the number of cells composing a packet. In [95-0151] it was shown that the average response time of IPX and TCP protocol stack also degrades rapidly with increasing cell loss. This problem is even more serious for large-scale reliable multicast service (e.g. in interactive games or conferences over the Internet). Also, in some environments, because of the lack of error correction capability in lower layer services (i.e., PHY), it cannot be expected that the bit error rate is sufficiently small.

This contribution therefore presents the rationale to provide an AAL- level FEC scheme, and proposes that the SA&A work on an AAL-level FEC scheme as an optional SSCS function.

2 Rationale for providing an AAL level FEC scheme

2.1 When do we need an AAL level FEC scheme ?

Some important requirements for a reliable data transmission service would include the following:

(a) throughput;
(b) latency:
(c) data-transmission reliability (i.e. robustness) which depends on the cell loss rate and the bit error rate (BER);
(d) data transmission costs, which will be determined by bandwidth, duration of call, and/or by the number of transmitted cells;
(e) protocol processing costs;
(f) scalability for high distances and a large number of receivers.

The transmission performance in terms of throughput and latency will degrade by cell loss and the BER in ATM networks. The effective cell loss ratio and BER will depend on the following:

1. The physical layer that is used below AAL/ATM.
   Some media may have a large BER, or BER characteristic of a highly bursty medium than the physical layers currently specified. For example, in wireless LANs, tolerance of BERs higher than those for physical layers of wired media allows a significant reduction in implementation costs.

2. The type of service class and QOS class.
   In ATM networks, QOS parameters associated with the cell loss ratio may be negotiable, and will also depend on the service type. For some service classes (e.g., UBR), a cell loss ratio sufficiently low to achieve a satisfactory application level QoS may not be possible.

3. The congestion status of the network.
   During the occurrence of congestions due to congestion in ATM networks, buffer overflows will result in cell losses. For certain applications, especially mission critical applications, it is desirable to limit the degradation of service quality, in terms of loss of data, during onset of congestion.

Reducing the effective BER and cell loss ratio for the upper layer process (e.g. IP) will significantly improve the overall service quality. This is especially true for applications that require the provision of a highly reliable service. A number of previous researchers [Sha90, Ohta91, Ayan93] have shown that the use of FEC will improve end-to-end ATM performance in terms of effective throughput and latency. In addition [Bie92] showed that an FEC scheme may be used advantageously for multiplexing VCs with different QoS requirements. If data streams with redundancy and without redundancy are multiplexed, different QoS requirements may be satisfied even for a switch that does not distinguish the data streams.

2.2 Performance degradation due to BER

The current AAL types for data transfer (i.e., AAL5 and AAL3/4) do not provide any error correction scheme. They perform error detection only, and rely on the error correction capability of the transport layer protocol (e.g., TCP). When error correction is performed by TCP or any other transport layer protocol, complete AAL PDUs are discarded if a bit error or a cell loss is detected. The error correction capability of the transport layer is typically based on retransmissions from the sender (e.g., TCP uses a variant of the go-back-n retransmissions scheme).

In general, the transport layer (or the network layer, e.g. IP) does not have a cell-based error correction capability. Therefore, the complete packet must be retransmitted even if the received packet has only one bit in error. In go-back-n schemes, not only the packet in error, but a full transmission window has to be retransmitted. For example, for a data-unit of 65,535 bytes (the maximum data-unit size of AAL5), the probability that the received data-unit has any bit error is expected to be about 5×10^{-4}, for uncorrelated errors with a bit error ratio (BER) of 10^{-9}. For packets of 9,180 bytes (i.e. the default MTU size defined in [RFC1626]), the resulting packet error rate is approximately 1×10^{-4}. Moreover, in the case of reliable multicast service, the probability of packet error due to bit errors will linearly increase with the number of receivers. This means that for large-scale reliable multicast service (e.g., interactive games over the Internet), it is difficult to provide a service with satisfactory throughput and latency performance without an FEC scheme.

2.3 Performance degradation due to cell loss

In the ATM layer, the issue of cell loss due to congestion-related buffer overflows must be considered. Since the transmission service data-unit (e.g.IP packet) will be segmented into multiple cells, a complete packet is assumed to be in error even when only one cell within the received packet is missing. This packet must then be retransmitted from the sender process. For example, the default MTU size defined in [RFC1626] is 9,180 byte which corresponds to about 192 cells. The maximum size of an AAL5 CPCS-PDU corresponds to about 1,366 cells (= 65,535 bytes). The approximate packet error probability due to the cell loss was provided in [95-0150]. For example, for a 64 Kbyte data-unit (i.e. close to the maximum data-unit size of AAL 5), the probability that the received data-unit is erroneous is about 1.3×10^{-3}, when cell loss ratio (CLR) is 10^{-6}. For an 8 Kbyte data units, (i.e. the one page size of modern file system), the error probability is about 2×10^{-4}. Moreover, in the reliable multicast service, the expected packet error probability due to cell loss will linearly increase with the number of receivers. This means that for large-scale reliable multicast service we can not always expect sufficient performance in throughput and latency without an FEC scheme.

2.4 Relationship with other FEC Schemes

2.4.1 FEC scheme developed in ITU-T SG15 video expert group

ITU-T SG15 video expert group is developing an FEC scheme in the AAL for the purpose of audio-visual signal (e.g. MPEG or H.261) transmission over ATM networks. In other words, the target FEC scheme is for high quality services for real-time audio-visual signals, which are continuous bit streams, over the network. In addition, the FEC scheme to be developed should be independent of the AAL type and the physical media.

The goal and requirements of the FEC scheme to be developed by ITU-T SG15 can be summarized as follows:

1. It is assumed that the ATM network provides a sufficiently small cell ratio (e.g., 10^{-9}) for the audio-visual signal transmission, but can not provide a sufficiently small BER (e.g., $BER > 10^{-7}$). Audio-visual signal transmission will use a CBR service so that the expected cell loss ratio is sufficiently small. However, BER characteristics cannot be always be expected to be small enough, e.g. due to physical media's poor BER characteristics. Therefore, it is assumed that the error control required because of cell loss need not be taken into account by the FEC scheme, but the error control due to bit error(s) must be taken care of.

2. The transmission of audio-video signals, that the ITU-T SG15 is addressing, has much stricter quality requirements associated with latency (i.e., delay and delay jitter), than those required for general data transmission.

3. Some (sufficiently small) error can be tolerated, as dictated by human interface requirements. The error ratio of the transmitted data to the application level must be sufficiently small, but this does not warrant error-free data transmission.

4. The optimization of the transmission performance of audio-visual data does not assume the operation of a transport protocol.

The following features provide the comparisons between the proposed FEC scheme (FEC-SSCS) and the FEC scheme developed by ITU-T SG15.

1. In the general data transmission with FEC-SSCS, we can not assume that the network can always provide a sufficiently small cell loss ratio. On the contrary, for the audio-visual signal transmission defined by ITU-T SG15, we can assume that the ATM network provides a sufficiently small cell loss ratio.

2. The latency requirement for the general data transmission could be less strict than that for the audio-video signal that ITU-T SG15 deals with.

3. In data transmission with FEC-SSCS, we assume that the application requires an error-free data transmission.

4. In order to optimize the data transmission by the transport layer, the FEC-SSCS interacts with the transport layer entity. Transport layer entity is generally needed to perform an error-free data transmission.

5. While a real-time audio-visual signal is a continuous bit stream data, the data transmission we consider is generally not a continuous bit stream but rather an asynchronous data stream. The data source is asynchronous and can produce short (e.g., less than 50 bytes) to long packets (e.g., 64 Kbytes).

As discussed above, the FEC scheme developed by ITU-T SG15 video expert group and the FEC-SSCS proposed in this contribution are not conflicting schemes, but rather complement each other nicely.

2.4.2 FEC schemes in the application level

FEC control provisions in the application level, rather than in AAL, appear to be an alternative solution to obtaining high quality data transmission. In these approaches, FEC control is performed at the application level, regardless whether the end-station attached to ATM network. This approach seems to be reasonable for communication over the heterogeneous Internet environment that includes many types of data link platforms (including ATM).

However, even when the application performs an FEC scheme, there are still benefits to having an AAL-level FEC control capability in ATM networks.

1. High throughput communication
   When the application requires a high throughput communication (e.g. 155 Mbps), it will be difficult to achieve such a high throughput with FEC control performed at the application process. An AAL-level FEC scheme can provide significant benefits when high-quality high-throughput communication is required. The implementation of an

SSCS-FEC scheme can be optimized for a specific network adapter and operating system to perform cell-level functions. It is possible to extend existing VLSI-based AAL implementations by FEC-SSCS, offering a high-performance cell-based FEC implementation to some (or all) applications. In comparison, an application-level FEC scheme typically has the following characteristics: available only for a single application, implemented in software, and operating on larger data units (i.e. packets or frames).

2. Retransmission latency
   The AAL (i.e., FEC-SSCS) can indicate the loss of or error in the received data to the application (i.e., through the transport protocol entity) much faster than the FEC scheme performed by the application. When the application is sensitive to quality degradation due to the latency of retransmission for lost or erroneous data, an FEC scheme performed by the application level is not appropriate.

3. High-quality pipe between routers
   Whether to use the FEC-SSCS to transfer the data flow over ATM cloud is a router's decision. Even when a resource reservation protocol (e.g., RSVP) is used, the router can drop packets. Therefore, to recover from such packet loss, applications may use an FEC scheme in the application process. However, since routers are usually entrusted to provide a secure and high-quality ATM pipe to transfer (IP) packets, they may choose to use a resource reservation protocol. In this case, an application-level FEC scheme and an AAL-level FEC scheme (i.e., FEC-SSCS) will co-exist.

As a result, even when the end-station has a application-level FEC control scheme, we can obtain some significant benefits by the provision of AAL-level FEC scheme (i.e. FEC-SSCS).

2.5 Interaction with frame-based control mechanisms in ATM networks

FEC-SSCS has many goals, some of which are shared by other proposed mechanisms. This section briefly explores the relationship between FEC-SSCS and a class of such mechanisms we term "frame-based" due to their objective of operating on entire frames rather than individual ATM cells.

Frame-based control mechanisms rely on two factors:

1. Cells passing over the associated connection(s), are the result of the segmentation of larger "frames".

2. The boundaries of such frames can be determined by examining the cell headers.

Given that these conditions hold, frame-based controls have been shown [Rom95] to improve application layer throughput by reducing the transport of "dead" cells; and by reducing the total number of frames discarded in times of congestion. The former is achieved by Partial Packet Discard (PPD) and is invoked after a switch drops a cell, while the latter is achieved by Early Packet Discard (EPD) which drop complete frames when the onset of congestion is indicated by the queue occupancy.

Both FEC-SSCS and the various frame-based control mechanisms, are or would be, optional features selected on a per-connection basis.

Our opinion is that frame-based control mechanisms and FEC-SSCS can constructively co-exist; but that they do have impacts on each other, and this interaction requires further study. For example, consider the following:

- FEC-SSCS is able to recover a CPCS-PDU, if a few cells were lost (for example, due to buffer overflow caused by congestion). For connections utilizing frame-based controls, however, the likelihood is that either no cells are discarded, or most (PPD) or all (EPD) are discarded. FEC-SSCS is thus likely to be able to recover fewer frames, on a connection utilizing frame-based controls.

- Frame-based controls may be negatively affected by the use of segmentation at the FEC-SSCS layer. For example, consider a packet broken in half by FEC-SSCS. This results in 2 CPCS-PDU's, which are discernable "frame"s to the frame-based controls.

  Should such controls be activated, they may discard one of the CPCS-PDU's but not the other. The CPCS-PDU which successfully reaches the destination, may nonetheless be discarded by the application (e.g., due to packet-level checksum failure).

  In this case, the frame-based control's objective of reducing the transport of "dead" cells, was partly negated by the use of FEC-SSCS segmentation.

Several questions require further study. They include:

1. How best to utilize both frame-based controls and FEC-SSCS, on the same connection? Under what conditions does this make sense? How are appropriate options selected?

2. How best to utilize a mixture of connections over the same link or VP? Are there interactions between the two types of connections?

3. How and when should one choose between the following per-connection options?

   - use of FEC-SSCS only
   - use of frame-based mechanisms only
   - use of both FEC-SSCS and frame-based mechanisms
   - use of neither FEC-SSCS nor frame-based mechanisms

4. How should one choose parameters appropriately?

   - size of CPCS-PDU
   - amount of redundancy of FEC-SSCS per frame
   - dimensioning of parameters for frame-based control schemes

5. Which approach is appropriate for heterogeneous network scenarios (i.e. not all switches/end systems in a networks have identical functionality)?

3 Requirements and Goals for an AAL level FEC scheme

In the following, a list of requirements and goals for an AAL-level FEC scheme is presented.

1. Compatibility with existing AAL type 5 is the first priority. The provision of FEC using AAL3/4 is not precluded.

2. It should be possible to adjust and negotiate the parameters of the FEC algorithm. These parameters should be negotiable during a session, as well during the connection establishment phase. Here, the parameter of the FEC would be the size of the appended redundant information, and the maximum size of cells in the FEC frame. The purpose of this requirement is to allow optimization of the transmission efficiency (i.e., minimize redundant data transmission for a given effective packet error rate), and to achieve a media/service independency.

3. Adjustment of actually transmitted redundant data length should be allowed for the source entity. The length of redundant data length is usually negotiated by the FEC parameter negotiation procedure. However, the source entity can decide how much redundant data is actually transmitted to the destination entity. In other words, the FEC parameter negotiation procedure only specifies the maximum length of redundant data unit to be transmitted to the destination entity. This operation is completely localized in the source entity, and there is no need for negotiation between the source and destination entities. The information that source entity must indicate to the destination entity is how much redundant data is actually sent to the destination entity. This information will be explicitly indicated either by the LI (length indicator) of CPCS trailer or by the Number of Redundant data field in the CPCS-UU of CPCS trailer.

   Using the above operation, we can optimize the data transmission efficiency through reduction (and optimization) of the actually transmitted redundant data length, without need for the FEC parameter negotiation procedure. The benefits of this operation are as follows:

   (a) Reduction of redundant data transmission overhead
   This option will work well when the end-station must transmit various length of packets, e.g., from 100 bytes to 64 Kbytes. For larger packets, a larger number of redundant data units must be appended. When the end-station does not want to renegotiate FEC parameter for the case of small size packet transmission, the transmission overhead due to the redundant data will be large. Using this operation, the length of appended redundant data can be reduced for small size packet transmission.

   (b) Avoiding FEC parameter renegotiation overhead
   In some cases, the FEC parameter renegotiation procedure would be costly. Moreover, when the generated packet size is frequently changed, the end-station may have to perform frequent FEC parameter renegotiations to reduce the transmission performance (i.e., latency and throughput). By using this operation, the frequency of FEC parameter renegotiation can be reduced.

(c) Low-cost implementation
Some interface cards may support only one (or few) FEC parameters set(s). This would be happen for low-cost FEC-SSCS implementation. It could be generally said that the implementation of this operation will be easier and simpler than the implementation with FEC parameter renegotiation.

4. AAL-SDUs of variable length (e.g., IP packets) should be supported.

5. It should be possible to segment large AAL-SDUs into several smaller CPCS-PDUs, and to protect individual CPCS-PDUs by the FEC scheme. The source FEC-SSCS entity can transfer FEC-SSCS-PDUs by pipelining. By the use of pipelining, the buffer resources in the source FEC-SSCS entity can be used more efficiently, and the transmission latency at the source FEC-SSCS can be reduced. Both the pipelining of AAL-SDU transmission and the pipelining of FEC frame transmission should be supported to reduce the peer-to-peer data delivery latency. The fragmentation of AAL-SDU into multiple FEC-SSCS-PDU will be performed for the large size AAL-SDU transmission. In pipelining mode, the received FEC-SSCS-PDU will be transmitted to the upper layer before whole of the AAL-SDU is completely received by FEC-SSCS entity. This operation mode is similar to the streaming mode defined in I.363. The benefits of this pipelining mode are:

   (a) Reduction of required receiving buffer space
   Some end-stations may not be able to allocate a sufficiently large buffer space to receive a large AAL-SDU. This will typically occur when the product of "number of VCCs" and "Maximum AAL-SDU size" becomes large. By using the pipelining operation (i.e., AAL-SDU fragmentation), buffer space to be allocated to the VCC can be reduced.

   (b) Reduction of control latency
   Since the error in the received AAL-SDU (e.g., IP packet) will be indicated by the FEC-SSCS entity earlier than in the non-pipelining operation, the upper layer entity can perform the end-to-end control (e.g., fast retransmission) earlier. As a result, the performance (i.e. latency and throughput) of the end-to-end data transmission will be improved.

6. The processing costs of the FEC scheme in lossless state (i.e., without cell loss or bit error) should be as small as possible. When there is no loss or error in the CPCS-PDUs carrying the user data, no FEC decoding should be required. Similarly, re-ordering of data should be avoided in the lossless state.

7. The FEC method should have the following three modes of operation, while avoiding an increased implementation complexity :
   (a) Error recovery in case of cell loss and bit errors;
   (b) Error recovery only in case of cell loss;
   (c) Error recovery only in case of bit errors.

8. In order to support transport layer protocols like TCP with a rate control scheme that is based on the detection of losses in the network, it should be possible to indicate to the higher layer whether the transmission service data-unit has experienced congestion and cell loss.

4 Conclusion

We propose that SA&A should work on an AAL level FEC scheme for reliable data transmission, as an optional function for the SSCS of AAL type 5 and type 3/4.

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Annex A : List of acronyms

AAL : ATM Adaptation Layer
AUU : ATM User-to-User Indication
BER : Bit Error Ratio
EPD : Early Packet Discard
FEC : Forward Error Correction
PPD : Partial Packet Discard
FEC-SSCS : FEC Service Specific Convergence Sublayer