A NEW ADAPTIVE FEC SCHEME FOR WIRELESS ATM NETWORKS

Ian F. Akyildiz and Inwhee Joe, ECE, Georgia Tech

Henry Driver and Y. L. Ho, Lucent Technologies

ABSTRACT

This paper describes the design and performance of a new adaptive FEC scheme (Yurie FEC) for wireless ATM. The wireless channel is characterized by higher error rates and burstier error patterns in comparison with fiber-based links for which ATM was designed initially. The purpose of Yurie FEC scheme is to provide a capability to dynamically support ATM-based communications over noisy wireless channels. The Yurie FEC scheme is based on Reed-Solomon coding to protect the ATM cell payload and PTI/ CLP fields in the ATM header. In order to enhance error tolerance in terms of framing and correct delivery, the Yurie FEC scheme functions within our existing LANET framing and addressing protection protocols. The proposed Yurie FEC scheme has been validated using a software emulator based on the simulation setup for an ATM network with low-speed wireless links. From the simulation results, the performance of Yurie FEC scheme agrees with the benchmark results using a random BER injector when the wireless terminal is stationary. At the channel BER of 10^{-3}*, the final BER after FEC correction is about* 10^{-6}*, low enough for TCP/IP operation.*

1. INTRODUCTION

In recent years, wireless ATM has emerged as a solution for mobile multimedia by supporting ATM-based transport in a seamless manner [6]. The attempt of ATM over wireless links immediately identifies a fundamental difference in the way that ATM will be used. That is, ATM will be subject to transmission links that are unreliable radio or satellite links. Because of the fading effects and interference, the wireless link is characterized by burstier error patterns, and a higher and time-varying error rate in comparison with the reliable fiber links for which ATM was designed. As a result, such difference leads to error control schemes such as FEC (Forward Error Control) to insulate the ATM network layer from wireless channel impairments.

The Yurie FEC scheme is designed to provide ATM QoS (Quality of Service) in a noisy environment. While maximizing performance, the design achieves maximum flexibility, bandwidth efficiency, and low costs of implementation. To these ends, the key requirement is "Per Virtual Circuit FEC." Thus, for example, voice traffic might use a low performance and short interleave scheme, since they are error-tolerant and sensitive to delay. Data cells, however, utilizes high performance and high overhead FEC with long interleave chains for maximum random and burst error tolerance. To further maximize efficiency, the FEC rate in each channel can dynamically adapt to the noise level. Where feasible, lower cost implementation options are included in the specification.

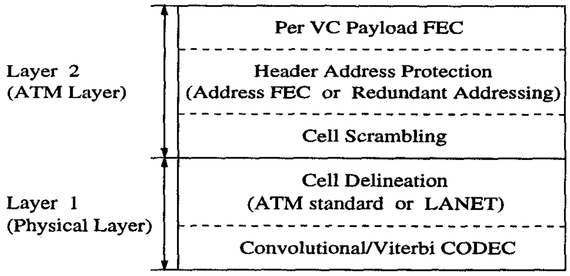


Figure 1: Structure of the Yurie FEC Scheme

As shown in Figure 1, the Yurie FEC scheme utilizes a multi-layered structure. At the upper part of the physical layer lies *LANET*. *Cell Scrambling* and *Header Address Protection* are collectively active at the lower part of the OSI layer 2, also known as the ATM layer. *Payload FEC*, the highest layer in the Yurie FEC scheme, operates at the upper part of the OSI layer 2.

The Yurie FEC scheme uses Reed-Solomon codes to protect nibbles in the header and bytes in the payload. Interleaving is also used to enhance burst error tolerance without impacting random error performance. This approach is known to couple well with convolution coding at the lowest layer. The Yurie FEC scheme thus recommends the use of radio modems with Viterbi CODECs built in. The recommended rates are 7/8 or 3/4.

In this paper, we propose a novel adaptive FEC scheme, *Yurie FEC*, using Reed-Solomon (RS) coding to protect the ATM cell payload and PTI/CLP (Payload Type Indicator/ Cell Loss Priority) fields in the ATM cell header over noisy wireless channels. In the next section, we present a detailed coding procedure of payload FEC, followed by a description of LANET framing. In Section 4 we discuss the simulation models and performance evaluation results from a software emulator based on the UNIX implementation. Finally, we conclude the paper by highlighting our contribution.

2. PAYLOAD FEC FOR DATA TRAFFIC

The scheme described here is applicable for data traffic. Voice traffic protection, emphasizing compression with FEC and interoperability with current voice circuit emulation standard, is not yet developed.

0-7803-4506-1/98/$10.00 © 1998 IEEE.

	1 bit	2 bits	1 bit	4 bits
Block 1	Res.	Rate Request	Dummy	ATM Cell 1 PTI/CLP
Block 2	ATM Cell 2 PTI/CLP			ATM Cell 3 PTI/CLP
Block 3	ATM Cell 4 PTI/CLP			ATM Cell 5 PTI/CLP
Block 4	ATM Cell 6 PTI/CLP			ATM Cell 7 PTI/CLP
Block 5	0x00			
Block 6	0x00			

Figure 2: Header Format for Six Payload Blocks

2.1. Cell Encoding Procedure

1. Accumulate a sufficient number of cells to form a group depending on the current encoding rate of the virtual circuit (VC). Default rate for dynamic encoding is 3/4 rate.
   - 1/2 rate: 1 cell/group
   - 3/4 rate: 3 cells/group
   - 7/8 rate: 7 cells/group

   Time out if the group is not complete and no cell arrives in 1/4 seconds. If timed-out, pad with dummy cells to complete the group. This time-out period works for link at 2400 baud or faster. Below 2400 baud, user should only use 1/2 rate encoding. In the future, the time-out period may depend on link speed.
   Dummy cell format: the last byte of the last cell in the group of dummy cells indicates the number of dummy cells in the group, rest of the payloads are 0x6A, same header, PTI/CLP nibble = 0x0.
2. Extract payload and segment into 6 blocks. Allocate space for 1 extra byte at the head of each block.
   - 1/2 rate: 8 bytes/block
   - 3/4 rate: 24 bytes/block
   - 7/8 rate: 56 bytes/block
3. Add one piggyback byte to the head of each of the 6 payload blocks, as shown in Figure 2. PTI/CLP nibbles for cells 2 through 3 are applicable at the 3/4 rate encoding. PTI/CLP nibbles for cells 4 through 7 are applicable at the 7/8 rate encoding.
   Rate request indicates the desired encoding rate to the other side, based on errors detected during decoding. It does not reflect the encoding rate used for this side's output. The rates indications are 0 → No Change, 1 → 7/8 rate, 2 → 3/4 rate, 3 → 1/2 rate. The dummy cell bit, if set to 1, indicates that dummy cells are present in the group.
4. Reed-Solomon encode.
   - 1/2 rate: 9 bytes → 15 bytes.
   - 3/4 rate: 25 bytes → 31 bytes.
   - 7/8 rate: 57 bytes → 63 bytes.

   Use the 3-byte correcting RS(n=255,k=249) code shortened to k = 9,25, or 57 depending on the code rate in use. The code is shortened by implicit zero filling. The zeros are assumed to occupy the front positions in the message stream. The output of the encoder is in reversed ordering, i.e., the parity bytes are output first followed by the last message byte. The piggyback bytes are the last to output.
5. Prepare FEC encoded cell group for output. Same header for all cells.
   - 1/2 rate: 2 cells.
   - 3/4 rate: 4 cells.
   - 7/8 rate: 8 cells.
6. Load delineation byte in 1st byte location of each output cell in a group. The period of the delineation byte pattern is used by the receiving side to determine the code rate.
   - 1/2 rate: 0x5A, 0xA5.
   - 3/4 rate: 0x5A, 0xA5, 0x0F, 0x0F.
   - 7/8 rate: 0x5A, 0xA5, 0x0F, 0x0F, 0x0F, 0x0F, 0x0F, 0x0F.
7. Load payload.
   - Optionally, the PTI and CLP bits can be overwritten with user defined messages.
   - Load the remaining payload part of each cell in the group. Interleave data from the 6 blocks: block 1 byte 1, block 2 byte 1, block 3 byte 1, block 4 byte 1, block 5 byte 1, block 6 bytes 1, block 1 byte 2, ... Since the RS decoder returns data in reversed ordering, the 1st bytes loaded are the parity bytes. The last bytes loaded are the piggyback bytes. For the 7/8 rate case, there is no room for the last 2 piggyback bytes (blocks 5 and 6). They were defined as 0x00 and are to be discarded.
   - Disregard unused bytes (4 bytes at 1/2 rate, 2 bytes at 3/4 rate, none at 7/8 rate).
8. Swap least significant nibble between delineation byte and byte 25 in the payload (delineation byte is byte 1).
9. Output cell group starting with cell 1 (one with delineation byte 0x5A).

2.2. Cell Decoding Procedure

1. Cell group delineation.
   - For each cell, swap least significant nibble between delineation byte and byte 25 in the payload (delineation byte is byte 1).
   - Wait for next cell's arrival.

- Overwrite bits 7, 5, 3, and 1 of delineation byte with corresponding bits from the next cell's delineation byte. Thus, if the 1st delineation byte is 0x5A and the next one is 0xA5, the 1st delineation byte will become 0xF0. Assuming the link is error free, the delineation byte sequence becomes:
    - 1/2 rate: 0xF0, 0x0F, 0xF0, 0x0F, 0xF0, 0x0F, ... (repeats every 2 cells)
    - 3/4 rate: 0xF0, 0x0F, 0x0F, 0x0F, 0xF0, 0x0F, ... (repeats every 4 cells)
    - 7/8 rate: 0xF0, 0x0F, 0x0F, 0x0F, 0x0F, 0x0F, 0x0F, 0x0F. (8 cell period)

  This method of interleaving doubles the burst error tolerance of the delineation bytes.
- Using table lookup (256 byte table), look for start of group. Start of group is signaled by the delineation byte as 0xF0 and all other bytes equal or less than 3 bits difference from 0xF0. There are 8 possible bytes that are 1 bit different, 28 bytes that are 2 bits off, and 56 bytes that differs by 3 bits. In other words, a total of 93 entries in the lookup table should indicate a match for the start of group byte.
- If cell arrives for fixed rate port, completion of a group is indicated as follows: If the delineation byte indicates 0xF0, terminate current group and save new cell as 1st cell of the next group; Or if with new cell, current group size reached 2 for 1/2 rate, 4 cells for 3/4 rate, and 8 cells for 7/8 rate, terminate current group with new cell (next group has no cells); Otherwise, save new cell as part of current group.
  Terminate group also if no cell arrives in 1 sec. Discard group whose length does not match configuration.
- If cell arrives for dynamic rate port, completion of a group is indicated by finding delineation byte indicating 0xF0 or if no cell arrives in 1/4 secs. Discard group if length is not 2 cells, 4 cells, or 8 cells. Group length is used to set the decoding rate. In the future, the time-out period may depend on link speed.

2. Extract payload.
    - Extract the 6 data blocks by de-interleaving. For the 7/8 rate, add a byte of 0x00 at the end of blocks 5 and 6 to complete the 6 data blocks.
    - Optionally, pull out inserted messages from piggyback byte locations and re-insert PTI and CLP bits.
3. Decode.
4. Rate adjustment for dynamic links.
    - Target for standard: At 10^{-3} BER, self adapt to 1/2 rate encoding. At 10^{-4} BER, self adapt to 3/4 rate encoding. At 10^{-5} BER, self adapt to 7/8 rate encoding.
    - Target for HiQ: Thresholds set at 3 times lower error rate.
    - Target for LoQ: Thresholds set at 3 times higher error rate.

   On each return from RS decoder, let *Bucket* be a 32 bit floating point variable, *scalefac* be an integer. *mess* and *errcode* are in the argument list for RS decoder.
   scalefac = 84000 for standard adaptation, 252000 for HiQ, 26000 for LoQ.
   $Bucket = Bucket + errcode - mess * Bucket / scalefac$
    - Currently at 1/2 rate: If *Bucket* < 100, goto 3/4 rate.
    - Currently at 3/4 rate: If *Bucket* > 200, goto 1/2 rate. If *Bucket* < 10, goto 7/8 rate.
    - Currently at 7/8 rate: If *Bucket* > 20, goto 3/4 rate.
5. Regenerate original cells.
    - Fill payload.
    - Pull PTI/CLP nibbles from the piggyback bytes.
    - If dummy cell present bit is set, read last byte of the last cell in the group to determine the number of dummy cell for discard.
    - Read rate request bits to determine encoding rate for traffic going the opposite direction.

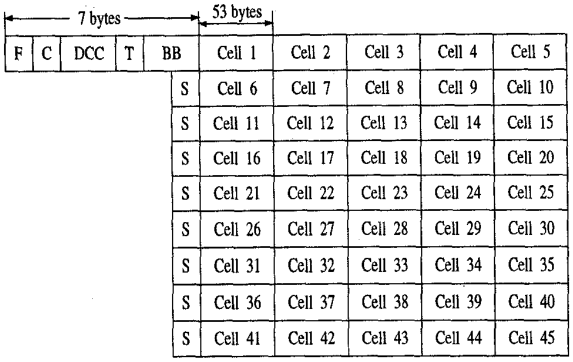
3. LANET FRAMING

While the upper layers of the Yurie FEC scheme can function with standard HEC delineation specified by the ATM Forum, LANET offers significant performance gains in noisy environments. Indeed, LANET cell delineation functions at BER as high as 10^{-2}. However, standard delineation is still required for interoperability when FEC is not needed. The Yurie FEC thus specifies that both delineation methods be provided and be selectable.

LANET's design emphasis is on noise tolerance and the possibility of low cost firmware implementation. Yet, its structure is similar to SONET. The ATM cells are packed in a framing structure with frame headers and sub-frame headers as shown in Figure 3. By inserting predictable header patterns, the extra information helps to delineate the cells in a noisy environment. A LANET frame has the following features:

- A LANET frame consists of a byte-oriented serial data stream. The frame size is 2400 bytes.
- The 2400 bytes are subdivided into 45 ATM cells (2385 bytes) with a 15-byte overhead. The LANET overhead therefore is about 0.63% of the bandwidth.
- The 2400-byte LANET frame is subdivided into 9 subframes.

As for the overhead bytes, a LANET frame starts with one-byte frame header of 0x96 (*F*). The *C* field is a checksum byte computed over the previous frame except *F*. The



7 bytes					53 bytes				
F	C	DCC	T	BB	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
				S	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
				S	Cell 11	Cell 12	Cell 13	Cell 14	Cell 15
				S	Cell 16	Cell 17	Cell 18	Cell 19	Cell 20
				S	Cell 21	Cell 22	Cell 23	Cell 24	Cell 25
				S	Cell 26	Cell 27	Cell 28	Cell 29	Cell 30
				S	Cell 31	Cell 32	Cell 33	Cell 34	Cell 35
				S	Cell 36	Cell 37	Cell 38	Cell 39	Cell 40
				S	Cell 41	Cell 42	Cell 43	Cell 44	Cell 45

Figure 3: LANET Frame Structure

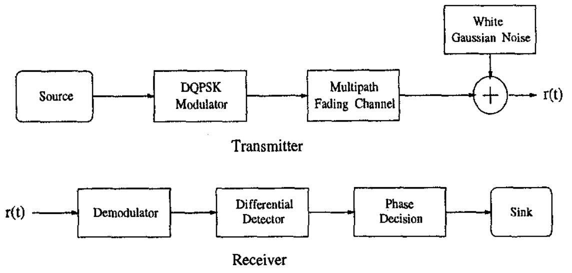


Figure 4: Physical Wireless Channel Model

2-byte data communication channel (*DCC*) is used to provide for operation, administration, and maintenance of the communication link. After this field, there is one byte reserved for the transport layer control channel (*T*) whose usage is yet to be defined. In addition, there are two types of special header patterns: 0xF628 (*BB*) for byte stuffing control and 0xE8 (*S*) for the subframe header.

4. PERFORMANCE EVALUATION

The objective of our simulation is to evaluate the performance of the Yurie FEC scheme over wireless ATM channels for stationary and mobile wireless terminals.

4.1. Simulation Model

In order to evaluate the Yurie FEC scheme with the LANET framing over wireless ATM channels, we developed two simulation models as follows:

- *Configuration 1*: Yurie FEC scheme without LANET over the wireless ATM channel.
- *Configuration 2*: Yurie FEC scheme with the LANET framing over the wireless ATM channel.

The wireless channel model for the physical layer is shown in Figure 4. For modulation, $\pi/4$-shifted DQPSK is used because it was adopted as the Standard for the digital cellular system in the US. This modulation scheme is particularly useful for fast fading environments due to differential encoding. Moreover, differential detectors are simpler to implement than coherent detectors.

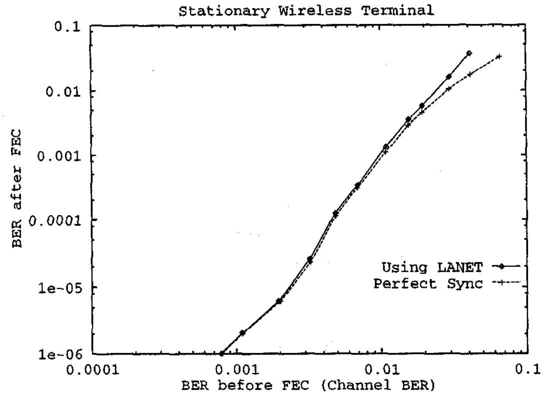


Figure 5: FEC Performance for Stationary Wireless Terminal

The wireless channel suffers from various impairments, such as multipath fading, co-channel interference, and delay spread. The most important of these is multipath fading due to the reception of multiple paths that is caused by reflections or scattering of the transmitted signal from various objects. Each path can be modeled with random amplitudes and phases. Furthermore, the motion of wireless workstations introduces a Doppler shift for each path. The combined effect of these events is that the magnitude of the received signal becomes Rayleigh distributed. Such channels are closely approximated by Jakes model [3].

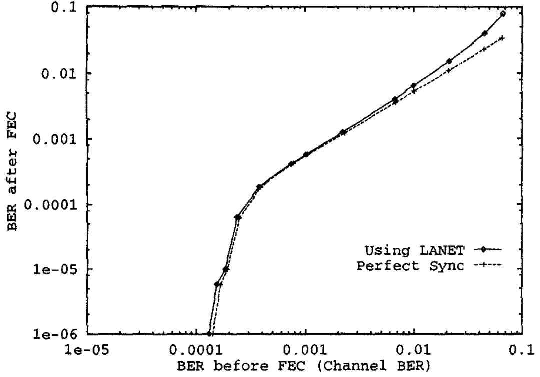
4.2. Simulation Results

We consider a simulation setup for an ATM network with low-speed wireless links. For simulation parameters, the carrier frequency is 2.4 GHz ISM band, the data rate is 128 kbits/s, and wireless terminals are stationary or moving at 5 mph and 55 mph, respectively. Each wireless terminal has a wireless link with an ATM switch, which works as a base station. At the 2.4 GHz band and normal mobile speeds, the Doppler shift is limited up to 200 Hz. For example, the Doppler shift is about 18 Hz for pedestrians at 5 mph and 197 Hz for the mobile terminal speed of 55 mph. Since two source bits are mapped into one channel symbol at a time in $\pi/4$-DQPSK, the symbol interval is about 15.6 μsec at 128 kbits/s.

The implementation of Yurie FEC was carried out on a Sun Sparcstation. For simulation results, we measure the following performance parameters as a function of channel BER for stationary and mobile wireless terminals on a simulated wireless ATM channel by adjusting the SNR value and Doppler shift.

- *Cell Sync Error Rate (%):* The percentage of the number of ATM cells in sync error based on the cell delineation byte in the ATM payload to the total number of ATM cells transmitted.

(a) Mobile Wireless Terminal: v = 5 mph



(b) Mobile Wireless Terminal: v = 55 mph

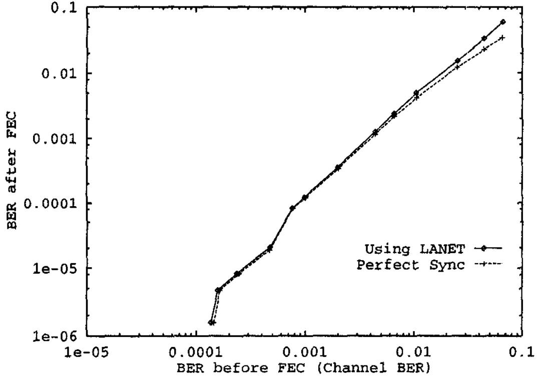


Figure 6: FEC Performance for Mobile Wireless Terminal

- *BER Performance after FEC Correction:* The final BER values after FEC correction with the LANET framing.

Figure 5 shows the performance of Yurie FEC with the LANET framing for the stationary wireless terminal over the wireless channel model. Final BER values after FEC correction are presented as a function of channel BER values. For comparison, the performance of Yurie FEC with perfect sync is also given in Figure 5. The performance of Yurie FEC with LANET is almost identical to the perfect sync case before the channel BER of 10^{-2}. Beyond this point, however, the performance of Yurie FEC with LANET degrades gradually compared to the perfect sync case, while the performance degrades significantly after LOS (Loss of Sync) declaration around the channel BER of 3.0×10^{-2}. Figure 6 shows the performance of Yurie FEC with LANET for the mobile wireless terminal at 5 mph and 55 mph each over the wireless channel model.

Since the AWGN (Additive White Gaussian Noise) portion is dominant in case of the stationary wireless terminal, these values agree with the results of the benchmark experiments in which random bit errors are injected to generate an error situation [9]. At the channel BER of 10^{-3}, the final BER after FEC correction is about 10^{-6}, low enough for TCP/IP operation. However, as the channel BER becomes higher beyond the point of 10^{-2}, the performance of Yurie FEC with LANET framing degrades gradually compared to the perfect sync case, while it degrades significantly in the event of LOS. To make it worse, as the wireless terminal is moving, the performance of Yurie FEC degrades severely even before the channel BER of 10^{-2} due to the Doppler shift. For example, the final BER after FEC correction is about 10^{-4} at the channel BER of 10^{-3}, as compared to 10^{-6} in the stationary case.

5. CONCLUSIONS

In this paper, we have discussed the design and performance of a novel adaptive FEC scheme, *Yurie FEC*, for wireless ATM networks. The Yurie FEC scheme is based on the Reed-Solomon coding to protect the ATM cell payload and PTI/CLP fields in the ATM header. In order to enhance error tolerance in terms of framing and correct delivery, the Yurie FEC scheme functions within our existing LANET framing and addressing protection protocols. We have also presented simulation results from a software emulator based on the UNIX implementation. When the wireless terminal is stationary, the performance of Yurie FEC with LANET framing agrees with the benchmark experiments in which random bit errors are injected [9]. At the channel BER of 10^{-3}, the final BER after FEC correction is about 10^{-6}, low enough for TCP/IP operation.

6. REFERENCES

[1] E. Ayanoglu *et al*, "Forward Error Control for MPEG-2 Video Transport in a Wireless ATM LAN," ***Mobile Networks and Applications***, pp. 245-257, 1996.

[2] J. B. Cain and D. N. McGregor, "A Recommended Error Control Architecture for ATM Networks with Wireless Links," *IEEE Journal on Selected in Communications*, Vol. 15, No. 1, pp. 16-28, January 1997

[3] W. C. Jakes, "Microwave Mobile Communications," *Wiley*, 1974 (Reissued by IEEE Press, 1994).

[4] I. Joe, "An Adaptive Hybrid ARQ Scheme with Concatenated FEC Codes for Wireless ATM," *ACM/IEEE MobiCom'97*, pp. 131-138, September 1997.

[5] Y. Nakayama and S. Aikawa, "Cell Discard and TDMA Synchronization Using FEC in Wireless ATM Systems," *IEEE Journal on Selected Areas in Communications*, Vol. 15, No. 1, pp. 29-34, January 1997.

[6] D. Raychaudhuri, "ATM Based Transport Architecture for Multiservices Wireless Personal Communications Networks," *IEEE Journal on Selected Areas in Communications*, October 1994.

[7] J. B. Scholz *et al*, "Experimental Investigation of Multimedia Communications Over Degraded ATM Links," *Submitted to IEE Electronics Letters*, 1995.

[8] Y. A. Tesfai and S. G. Wilson, "FEC Schemes for ATM Traffic over Wireless Links," *IEEE International Conference on Communications*, pp. 948-953, August 1996.

[9] Yurie Systems, "LANET with Adaptive Payload FEC," *Technical Report*, 1997.