PROTOCOL-AIDED CHANNEL EQUALIZATION FOR HF ATM NETWORKS

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ABSTRACT

In this paper we investigate the problem of equalization in High Frequency (HF) ATM networks. Aiming at minimizing the overhead associated with equalization, we exploit ATM protocol information for equalization. Specifically, Medium Access Control (MAC) protocol is exploited to provide known cell headers in a data burst. As a result, data bursts can be converted into a block structure that is widely used in current HF modem design without inserting extra training symbols. A new algorithm is developed which utilizes the blind channel estimation and the knowledge of ATM cell header. Simulation results show the new approach achieves good performance without training symbols.

1. INTRODUCTION

Wireless ATM has attracted worldwide research interest because of such advantages as providing Quality of Services (QoS)-based multimedia services to mobile users and the seemless connectivity to wireline ATM networks. In civilian wireless networks, wireless ATM has been proven feasible in cellular-type PCS systems by different prototypes [12, 4, 11]. In military wireless systems, interconnecting remote wireline ATM networks into a WAN via satellite links has been successfully tested by COMSAT [2]. Because HF remains to be an important alternative to satellite systems in military communications, and because of the trend that future wireline networks will be ATM-based, it is desirable to have a HF network which can support ATM-based traffics.

Due to the limited bandwidth in HF band, it is not possible for HF ATM to support applications with too high data rate. However, a HF link with moderate data rate, e.g. $128Kbps$, is enough to support applications like voice and E-mail. An envisioned HF ATM network is that several nodes, such as ships, aircrafts and land units, exchange low speed multimedia traffics over a HF link. Such a HF ATM network is quite different from a cellular-type wireless ATM network. For example, because of the broadcast nature of HF transmission, the concepts of uplink and downlink do not exist and there is no user mobility and location management issues. Complete network design of a HF ATM network is beyond the scope of this paper. We assume a proper high layer design has been made and concentrate on physical layer issues.

HF links are notorious for their poor quality. We consider TDMA systems with linear modulations such as $8PSK$. In such systems, severe Inter-Symbol-Interference (ISI) and the constantly changing HF channel are two challenges to the receiver design. Equalization has long be introduced into HF modem design to deal with the ISI. Conventional equalization techniques rely on the channel estimate obtained from the training period when known symbols are transmitted. In addition to the training symbols used for channel estimation, in order to keep track of the varying channel, a so-called block transmission structure is employed in HF modem in which unknown data blocks and known training blocks are transmitted alternatively. A typical example is the MIL-STD-188 [1] HF modem specification. However the training process consumes too much bandwidth. In MIL-STD-188 specification, about 50% of the bandwidth is used to transmit training. Since bandwidth is so precious in HF band, the challenge for equalization is to achieve good performance without training.

In this paper, aiming at minimizing the overhead associated with equalization, we propose a protocol-aided channel equalization approach. Besides utilizing unknown data in blind channel estimation, we exploit HF ATM protocol information to improve the equalization performance. Specifically, Medium Access Control (MAC) protocol is exploited to provide known ATM cell headers in data bursts. As a result every data burst on the HF link can be converted into a block transmission structure without inserting extra training symbols. This converted structure can be taken advantage of by equalizers to deal with time-varying channels. A new algorithm based on blind channel estimation and the knowledge of ATM cell header is devel-

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oped to provide robust performance for data bursts transmission over fast fading HF channels without training.

2. PROTOCOL-AIDED CHANNEL EQUALIZATION FOR HF ATM

In this section, we shall explain the protocol-aided channel equalization approach. First we describe briefly a HF ATM frame structure and a MAC protocol that will be taken advantage of in equalization. Then we explain how to exploit the MAC protocol for equalization.

2.1. HF ATM frame structure and MAC protocol

HF ATM is a new network concept, however the medium access control is not fundamentally different from a packet satellite system which support voice and data services. Many principle of the medium access control of packet satellite systems can be carried over to HF ATM networks. Now we describe a possible HF MAC principle based on the Priority-Oriented-Demand-Assignment (PODA) protocol [6]. Detailed design of a HF ATM MAC protocol is beyond the scope of this paper.

HF ATM transmit ATM cells in time slots over the HF link with each time slot carrying an ATM cell (control or data). Time slots are formed into MAC frames with a frame format shown in Figure 1. The whole MAC frame is divided into a data and a control subframe. In data subframe, different users send a burst of time slots. In control subframe, users transmit control cells in a contention mode. The principle of the MAC is the demand-assignment, just like many other proposed wireless ATM MAC protocols [7, 8, 3, 10]. There is a 'Master Node' among all the users and it is responsible for assigning time slots to different virtual connections. Every user, except the Master node, will have to request time slots from the Master node by either sending a control cell during current frame's control subframe in a contention mode or piggy-backing in previous data slots. Since each virtual connection's QoS has to be satisfied, the Master node assign time slots on a per virtual connection basis, considering each user's request and their virtual connections' QoS requirements. Then the Master node will announce the time slot assignment for the next frame in the beginning of that frame. Every user listen to the assignment and transmit cells in the designated time slots.

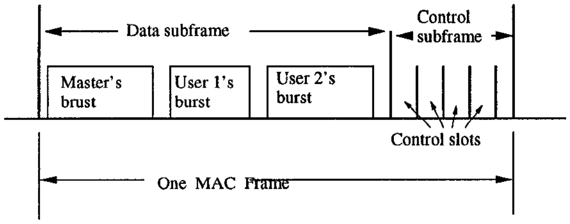

Figure 1: One MAC frame in HF ATM

2.2. Exploiting protocol information for equalization

Our objective is to achieve good equalization performance without training. Because block transmission structure is a very effective structure to deal with the fast varying HF channel, to keep this structure without training symbols require we exploit protocol information. We notice that in ATM networks, cells from a virtual connection have the same header. If headers of a user's data burst can be known to the receiving end, the burst will have a block transmission structure with known headers between cells. Indeed it is the case in HF ATM.

The reason that cell headers of a user's data burst can be known is closely related to the MAC. A possible cell format is shown in Figure 2 [12]. Recall the MAC described before, the time slots within a frame is assigned by the Master station on a per virtual connection basis and the assignment is broadcast to all the users. Therefore, every user will know the Virtual Connection Identifier (VCI) field of every cell in the frame. Once the VCI field of a cell's header is known, other related fields in a header like Type and Pay Load Type (PLT) can be known immediately. Because each user knows which virtual connection is for itself, the sequence number of that particular virtual connection's cells can be obtained from the Data Link Control (DLC) associated with that virtual connection. Therefore, the majority fields of a cell's header in the frame can be known to the receiving end.

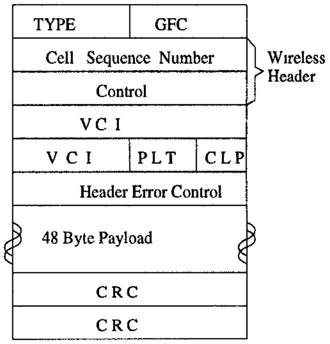

Figure 2: Data cell format in NEC's prototype

As a result, data bursts in a frame will have a block structure for the receiving end. Figure 3 illustrate such a block structure.

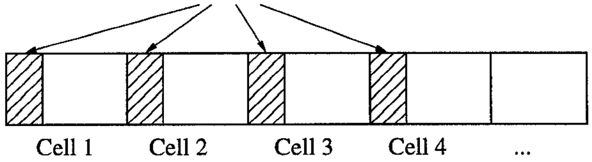

Figure 3: One data burst in HF ATM

3. ALGORITHM DESCRIPTION

3.1. Algorithm development

Since the protocol information can converted the data bursts into a block structure to the receiving end, our algorithm development is motivated by a conventional block equalization algorithm shown in the left side of Figure 4. It is a iterative process. With a initial channel estimate $\tilde{h}$, the tentative detection of $\tilde{s}$ is obtained by a detection scheme like DFE. Then the decision is used to reestimate the channel again. The final detection $\hat{s}$ is obtained from DFE with the reestimated channel $\hat{h}$. The last step is to estimate the channel using the final symbol detection for next cell. Since the detected symbols are used to estimate the channel, we refer this method as Decision Directed Channel Estimation (DDCE-DFE). Although DFE is used in this algorithm, other detection schemes, especially those block detection scheme discussed in [5] are also applicable.

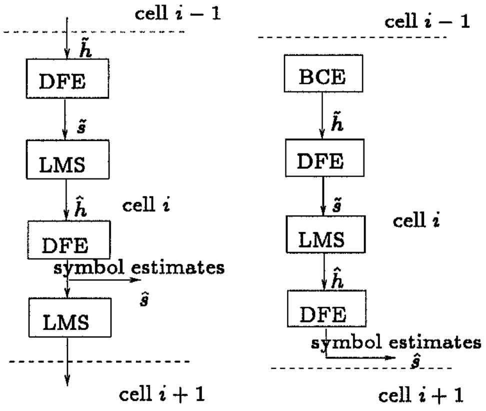

Figure 4: Left: DDCE-DFE, Right: BCE-DFE

There are two problems if DDCE-DFE is applied to HF ATM. One is the how to obtain the initial channel estimate for the first cell in a burst because there is no training symbols before each burst and it is not possible to pass channel estimation from that user's previous burst. Another is the channel estimation error propagation problem. The reason is that previous cell's channel estimate may not be accurate for the current cell. An inaccurate channel estimation may cause more detection errors for current cell and a worse initial channel estimate for the next cell. We need to develop an algorithm to resolve these two problems, that is why we introduce Blind Channel Estimation (BCE) into our algorithm. One reason of using BCE for each cell is that even we know cell headers, the length of each header is not enough for channel estimation. Another advantage of using BCE is that channel estimation depends on current cell only, therefore the channel estimation error propagation problem can be avoided. The new algorithm is referred to as BCE-DFE and is shown in the right side in Figure 4. The most important difference between BCE-DFE and DDCE-DFE is that the initial channel estimation, BCE-DFE obtains initial channel estimation from current cell, DDCE-DFE obtains it from previous cell.

Since techniques like DFE and LMS are fairly standard, we will not discuss them. Next we describe the blind channel estimator we used and discuss some implementation issues.

3.2. Blind channel estimation

Because we want to estimate the channel for each cell, the blind channel estimator must be able to converge within a cell. We chose the least square method [13, 14] for blind channel estimation.

With a $\frac{2}{T}$ oversampling of the received data, we can have a equivalent multichannel model shown in Figure 5, where T is the symbol interval, $h_k^{(1)}$ and $h_k^{(2)}$ are even and odd samples of the continuous time channel impulse response, respectively.

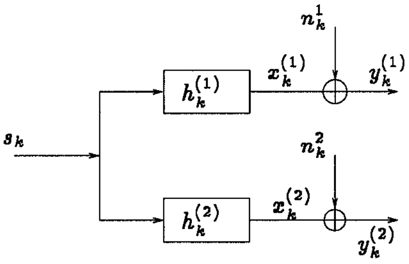

Figure 5: A multichannel model.

The discrete time baseband model is given by

$$\mathbf{y}_k^{(j)} = \sum_{i=0}^{L} \mathbf{h}_i^{(j)} s_{k-i} + \mathbf{n}_k^{(j)}, j = 1, 2 \tag{1}$$

where $\mathbf{y}_k^{(j)}$ and $\mathbf{n}_k^{(j)}$ are the received (noisy) signal and noise of jth subchannel.

Follow [13], the least square blind channel estimation is obtained as

$$\hat{\mathbf{h}} = \arg \min_{||\mathbf{h}||=1} \mathbf{h}^H \mathbf{Q} \mathbf{h} \tag{2}$$

where $\mathbf{Q}$ is constructed from $\mathbf{y}_k^{(i)}$, $i = 1, 2$.

3.3. Implementation issues

Now we discuss some implementation issues of the algorithm.

- Channel basis utilization and updating

  The optimization of Equation 2 requires $\mathbf{Q}$ to have a one dimensional null space to identify the channel, but practical communication problems often do not satisfy this condition. Therefore we introduce the idea of channel basis to overcome this problem. Detailed discussion about channel basis can be found in [15, 9]. Essentially if we can found a subspace $\mathbf{B}$ in which the channel lies, i.e. $\mathbf{h} = \mathbf{B}\mathbf{g}$ with $\mathbf{g}$ being the gain, we can estimate the channel by estimate the gain

$$\hat{\mathbf{g}} = \arg \min_{||\mathbf{g}||=1} \mathbf{g}^H \mathbf{B}^H \mathbf{Q} \mathbf{B} \mathbf{g} \tag{3}$$

$$\hat{\mathbf{h}} = \mathbf{B}\hat{\mathbf{g}} \tag{4}$$

.

The basis can be obtained from the initial connection setup messages and updated from the following request messages sent through the control subframe.

- Utilization of header and guard time in DFE

  Since we know headers, we can use them as the initial feedback in the DFE. When header is not long enough, we borrow previous detected symbols or using guard time if the cell is the first one in a burst. The advantage of using header in DFE is that we can block detection errors from one cell to another.

4. SIMULATIONS

In the MIL-STD-188-110A modem standard, a channel probe has the size equal to that of an ATM cell header. This prompts the design of a HF ATM network that allows the transmission of ATM cells without additional overhead.

4.1. Simulation setup

The HF ATM network being considered consists of nodes interconnected by the HF link such as the navy tactical HF communication network. The access to the common HF link is coordinated by a Medium Access Control (MAC) protocol resides at every node. The MAC in our simulation is a central controlled Priority Oriented Demand Assigned (PODA) [6]as used in satellite networks. Using the Watterson model, we considered a two-ray multipath HF channel with both paths having equal power. Square-root raised cosine filtering with rolloff factor of 0.25 was employed at both the transmitter and the receiver sides. The received signal was fractionally sampled at a rate twice of the symbol rate. The modulation is $8PSK$ and other parameters are the same as specified in MIL-STD-188-110A.

4.2. Simulation results

In our simulation, we considered a burst of 10 ATM cells and there are guard time before and after each burst.

Symbol Error Performance and Header length effect:

We compared the Symbol Error Rate (SER) performance of BCE-DFE with DDCE-DFE. We added a sufficient long preamble for every data burst so that the first cell in a burst can have a good initial channel estimation. Figure 6 shows the SER performance vs SNR for BCE-DFE with different known header length and for DDCE-DFE. It is clear that for BCE-DFE, no matter we know the whole header, half of the header or not knowing any header, the performance is much better than DDCE-DFE.

Taking into account of possible unknown fields in the header, we tested BCE-DFE for three different known header length: known header length = 0 symbols, corresponding to not knowing any header; known header length = 8 symbols, corresponding to only knowing half of the header; known header length=16 symbols, corresponding to knowing the whole header. We also tested the DDCE-DFE for header = 16 symbols and header = 0 symbols. We can observe that for BCE-DFE, at lower SNR, there is not much difference in performance. However, as SNR goes higher, the header effect starts to show up in the performance. We can see that longer the known header length, better the SER performance. It is interesting to observe that knowing half of the header (length of 8) in our algorithm actually has just slightly worse performance than knowing the whole header (length of 16). This suggests that our algorithm is not very sensitive to header length as long as known header is longer than certain threshold which remains to be investigated.

As for the DDCE-DFE, knowing header does not improve the performance. The reason is that the channel estimation error propagation which will be illustrated soon is so severe, knowing some symbols can not correct the large amount of errors caused by the bad channel estimation.

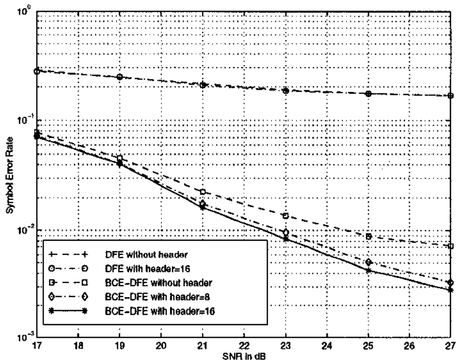

Figure 6: SER vs SNR for BCE-DFE with different header length and DDCE-DFE

Channel estimation error propagation:

The channel estimation error propagation effect discussed before can be clearly observed in the simulation. Figure 7 shows the symbol error patterns for 1000 cells. The top one is the pattern of DDCE-DFE, the second one is BCE-DFE without known header, the third one is BCE-DFE with whole known header. The last one shows channel variations for the 1000 cells duration. We can observe that errors are in long bursts for DDCE-DFE. While in BCE-DFE, even without cell header knowledge, the errors are still isolated. In fact, we can see most of the errors happened when there were severe channel variations.

Next let's exam one data burst of cell $81 - -89$ which is shown in Figure 8. We can see for the DDCE-DFE, (the

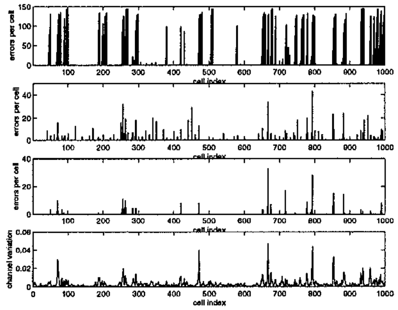

Figure 7: Error pattern comparison, SNR=27dB

top one is the symbol error distribution for these 9 cells and bottom one shows the normalized channel estimation error), from cell 81 − −86, the channel does not change too much, the channel estimation error is small, and the detection is good. Once the channel startes to vary from cell 87, previous channel estimation becomes inaccurate, thus more detection errors occur. As a result, channel estimation becomes worse and this error propagates along cells. This effect can be observed from both the symbol error distribution plot and the channel estimation error plot (the solid line is the error for initial estimation error, the dashed and the dotted lines are errors for channel estimation before final detection and for next cell). But for BCE-DFE, even after channel varies, the estimation error remains the same and the symbol errors are isolated.

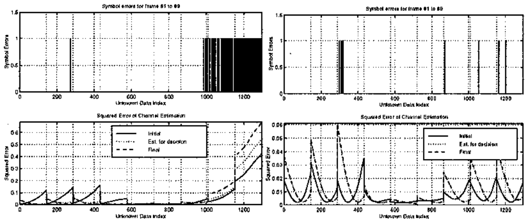

Figure 8: Symbol error vs normalized channel estimation error for cell 81 − 89 (left: DDCE-DFE , right:BCE-DFE)

5. CONCLUSION AND ACKNOWLEDGEMENT

We have investigated the problem of equalization in HF ATM networks and presented the approach of protocol-aided channel equalization. A new algorithm has been developed which utilize blind channel estimation and the knowledge of ATM cell headers. Simulation results show our approach has good performance without extra training symbols.

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