# APPLICATIONS OF BLIND EQUALIZATION IN WIRELESS ATM NETWORK

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**Abstract**

*We investigated the feasibility of applying blind equalization to wireless ATM networks. Making use of the information exploited from the wireless ATM cell structure and Medium Access Control(MAC), blind channel estimation together with a Non-linear Data Directed Estimator achieve good equalization performance without transmitting extra preamble. Simulation results are presented for ATM CBR and ABR traffic.*

## 1. INTRODUCTION

Since it was proposed in 1993 as a possible solution for next generation wireless networks, wireless ATM (Asynchronous Transfer Mode) has attracted world wide research interest. In deed if wireless ATM could be successfully implemented, major advantages, such as high speed wireless multimedia communications, seamless connection to wired ATM networks and user mobility would be obtained. However applying ATM technology which was designed for high quality and bandwidth sufficient physical links like optical fiber to wireless networks is not straightforward. Besides the issues of mobility and location management, the time varying nature of wireless channels poses major challenge to the research of wireless ATM.

One important technique to meet the challenge is equalization. Though equalization has been studied for a long time, wireless ATM networks have more strict requirements. Wireless ATM network is a high speed multimedia network with bursty traffic which makes the equalization technique have to have good performance while at the same time have high bandwidth efficiency ( least overhead ) and be fast convergent. As is pointed out in [1], in order to achieve good performance, the time varying channel shared by many users needs to be learned often. For training based techniques, this means frequent transmission of training symbols which results in the lower efficiency of bandwidth and this large overhead could become the bottle neck of the effective data rate of the network. An alternative is blind equalization which could potentially eliminate all the overhead, an example is Constant Modulus Algorithm (CMA) which has been suggestted in [2]. However for CMA, the lack of convergence speed makes it not suitable for Constant Bit Rate (CBR) traffic with short packet. Fast blind equalization techniques [9, 10, 5, 8] that exploit both time and space diversities are suitable for short data packet transmissions. But they may be sensitive to channel conditions. With the importance of channel equalization in wireless ATM well known, few details are reported in literature.

Our approach is based on the idea that wireless ATM protocols and the special cell structure contain certain information that can be exploited. Together with the blind channel estimation methods, our approach makes use of the ATM protocol information and cell structre and achieves no extra overhead for most data cells on up link and maintains good Symbol Error Rate (SER) performance.

## 2. EQUALIZATION IN WIRELESS ATM

Wireless ATM network is often structured as a cellular network with micro or pico cells.There is a base station in each cell (a base station's coverage area) which communicates with mobiles within its coverage via a high speed wireless link. Mobiles send information to the base station on up link and base station broadcasts information to mobiles by down link. Since up link equalization is more complicated than down link, this paper will mainly deal with up link.

### 2.1. What information can be exploited from wireless ATM

ATM transmits information in packet format, each packet or so called cell, has a fixed size (standard ATM data cell is 53 bytes, wireless ATM cell may have a few bytes more due to sequencing and error correction coding). For each cell, 48 bytes are payload and 5 bytes are header which contains information about the virtual connection, the type of information in payload and some quality parameters. For the same virtual connection, the header part of all the cells is the same.

There is a Medium Access Control (MAC) in each mobile and the base station to coordinate the access of the common up link among all the mobile users within the same coverage. There are 3 general types of traffic on the link, Constant Bit Rate (CBR), Variable Bit Rate (VBR) and Available Bit Rate (ABR). CBR corresponds to real time communications like telephone which has a constant data rate, VBR represents the communications with varying data rate like a video conference and ABR traffic is the general data communications like computer files or emails. In order for different traffic to share the limited bandwidth efficiently, most MAC schemes [4, 6] are reservation assignment based which means each mobile will make requests to the base station for each of its on-going virtual connection and the base station will assign bandwidth to them accordingly. Because of this request and assignment process and the fact that the cells of the same virtual connection will have the same header, the receiver at the base station will know all the cell's header on up link.

Another important feature of the wireless ATM up link is the existance of guard time between the cells of different users. Since the up link is shared by all users, guard time will play an important role of separating the interference from one user to another and it is at least as long as the channel.

### 2.2. The role of blind equalization

In fact if we try to eliminate the training symbols, blind equalization becomes a natural choice. Even with the availability of header information, when channel length is longer than the header or under network error conditions which could cause wrong header information exchange, blind method is superior than standard training based equalization. [7] has investigated the channel identifibility conditions for different wireless ATM models and shown that given a channel with order $L$; if standard training based schemes are used, when guard time is presented, the header has to be at least $L+1$ to identify the channel, and when there is no guard time the header has to be $2L+1$ long; however if blind channel estimation is applied, without guard time the whole cell only needs to be $4L+1$ long while with guard time, almost any size of the cell will do. Specifically as shown in Table 1, we assume a single ATM cell of 54 bytes with 6 bytes of header is transmitted and compare the standard training based equalization with blind equalization with respect to the maximum identifiable channel length. It is very clear blind equalization can handle much longer channel than standard schemes and if with guard time, almost any size of the channel can be identified. Therefore blind equalization is very desirable and in fact as is shown below blind equalization is feasible in new applications like wireless ATM networks.

## 3. BLIND CHANNEL ESTIMATION AND EQUALIZATION

We present one possible approach of using blind equalization together with the header and guard time information as following to achieve the elimination of extra overhead.

1. obtain first channel estimation $\tilde{\mathbf{h}}$ using blind method
2. NDDE[3] is used to yield the tentative detected symbol $\tilde{\mathbf{s}_p}$
3. based on $\tilde{\mathbf{s}_p}$,obtain the re-estimated channel $\hat{\mathbf{h}}$

| | QPSK | 8-PSK | 16QAM | 64 QAM |
|---|---|---|---|---|
| S. w/o GT | 11 | 7 | 5 | 3 |
| B. w/o GT | 53 | 35 | 26 | 17 |
| S. w GT | 23 | 15 | 11 | 7 |
| B. w GT | any | any | any | any |

Table 1: Maximum identifiable channel length for different modulation, units are in symbol interval. S: standard equalization, B: Blind equalization, GT: Guard Time, w: with, w/o: without

4. using $\hat{\mathbf{h}}$ in NDDE again to produce the final detection of $\hat{\mathbf{s}}$

### 3.1. Blind channel estimation with channel basis

We have the following system equations in the time domain

$$\mathbf{x}_k = \sum_{i=0}^{L} \mathbf{h}_i s_{k-i} + \mathbf{n}_k, \tag{1}$$

where $\mathbf{x}_k$ is the recieved (noisy) signal and $\mathbf{n}_k$ is the noise. The least square blind channel estimation [10, 11] is obtained as

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

where $\hat{\mathbf{Q}}$ is constructed from $\mathbf{x}_k$.

However the above method requires that $\hat{\mathbf{Q}}$ is rank deficient by one so that $\mathbf{h}$ which is in the null space of $\hat{\mathbf{Q}}$ can be idenitified. Since we can not guarantee $\hat{\mathbf{Q}}$ always satisfies the condition, we introduce channel basis to avoid the problem. For multipath fading channels, it is often possible to obtain the channel basis. Specifically, the multipath channel can be modeled as scaled and delayed *known* pulses (*e.g.*,the square-root raised cosine pulse)

$$h_c(t) = \sum_i \alpha_i b(t-\tau_i), \tag{3}$$

where pulse shaping waveform $b(t)$ is known. Further, although $\alpha_i$ vary considerablely with time, the variation in delay $\tau_i$ is not significant. Therefore, channels during one session may be considered as a vector in the space spanned by fixed basis $\{b(t-\tau_i)\}$ which can be estimated during call set-up. As explained in Figure 1, on the left when $\mathcal{N}(\hat{\mathbf{Q}})$ has only one dimention, $\mathbf{h}$ can be identified uniquely, but as shown on the right when $\mathcal{N}(\hat{\mathbf{Q}})$ has more than one dimention, if without basis space $\mathcal{H}$ channel can not be identified, fortunately $\mathcal{H}$ introduces another constraint and the intersection of $\mathcal{H}$ and $\mathcal{N}(\hat{\mathbf{Q}})$ still uniquely identified the channel. So instead of estimating $\mathbf{h}$, we estimate $\mathbf{g}$

$$\hat{\mathbf{g}} = \arg \min_{||\mathbf{g}||=1} \mathbf{g}^H \mathbf{B}^H \hat{\mathbf{Q}} \mathbf{B} \mathbf{g} \tag{4}$$

$$\hat{\mathbf{h}} = \mathbf{B}\hat{\mathbf{g}} \tag{5}$$

where $\mathbf{B}$ is channel basis which is estiamted during call setup.

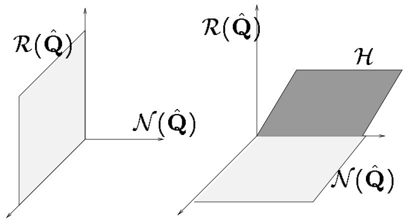


Figure 1: Channel basis

### 3.2. NDDE and its variation in wireless ATM

Given the received signal $\mathbf{x}$ and the fact that original input composed of 3 parts $\mathbf{s}_a$,$\mathbf{s}_b$ and $\mathbf{s}_c$ with $\mathbf{s}_a$ and $\mathbf{s}_c$ are known header part or guard time and $\mathbf{s}_b$ is the unknown data part, we can partition the channel matrix $\mathbf{H}$ into corresponding $\mathbf{H}_a$ $\mathbf{H}_b$ and $\mathbf{H}_c$ and obtain the following

$$\mathbf{x} = \mathbf{H}_a\mathbf{s}_a + \mathbf{H}_b\mathbf{s}_b + \mathbf{H}_c\mathbf{s}_c + \mathbf{n} \quad (6)$$

where $\mathbf{n}$ is the noise. We can subtract the known data part

$$\tilde{\mathbf{x}} = \mathbf{x} - \mathbf{H}_a\mathbf{s}_a - \mathbf{H}_c\mathbf{s}_c + \mathbf{N} \quad (7)$$

and use $\tilde{\mathbf{x}}$ to detected the two unknown symbols(top and the bottom of $\mathbf{s}_b$ by linear estimation such as MMSE or Zero Forcing. Add detected symbols to $\mathbf{s}_a$ and $\mathbf{s}_c$ and repeat until all unknowns are detected.

*Applications to CBR traffic:*

For CBR traffic on up link there are always guard time before and after each burst( we consider the worst case where there is only one cell in a burst) and the header is known, so $\mathbf{s}_a$ corresponds to the guard time after the cell and $\mathbf{s}_c$ is the header or the guard time. When header is longer than the channel, we just need to use the header, if not ,guard time is used to make up the channel length. Since $\mathbf{s}_a$ is pure guard time which is all zeros, we actually just detect one symbol( top one just after the header).

*Applications to ABR traffic:*

ABR is a burst of cells (usually longer than CBR burst)with guard time before and after the burst,not within the burst. For first and the last cell, the guard time can still help, but the rest of the cells we only have header. So we treat the following cell's header as $\mathbf{s}_a$ and make $\mathbf{s}_c$ as long as the channel by borrowing the previous detected symbols. We can either detect from one side or both ends.

## 4. APPLICATION TO HF ATM NETWORK AND SIMULATIONS

High Frequency(HF) band has perhaps one of the worst channels for data communications. Interestingly, the MIL-STD-188-110A modem standard specifies a channel probe of the size equal to that of an ATM cell. This prompts the design of a HF ATM network protocol that allows the transmission of ATM cell 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 network topology mimics a bus because of the full connectivity of the HF link. The access to the common HF link is coordinated by a Medium Access Control (MAC) protocol resides at every node in a distributed way. The MAC in our simulation is a central controlled Priority Oriented Demand Assigned (PODA) 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. Because of the possible header compression, we tested the possibility of using headers with different length.

### 4.2. CBR traffic simulation

CBR traffics usually take the form of periodic burst due to its traffic characteristics and we tested the worst case with single in each burst. The size of the cell is 54 bytes with 6 bytes of header. No preamble was transmitted before each cell and there was guard time between cells.

We tested our approach for different header size and compared with non-blind channel estimation which used the header to obtain the initial channel estimation( when header is not sufficient long, guard time was used to make up the channel length which basically padding zeros before header). Both approaches used the header in NDDE part as described above. Figure 2 shows the performance.

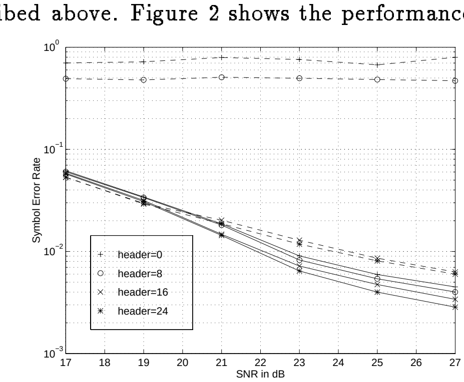


Figure 2: Symbol Error Rate vs. SNR. Solid lines:Using blind channel estimation. Dashed lines: Using header-aided channel estimation.

It is interesting to observe the effects of header size on our approach. Since blind channel estimation does not explicitly use the header information, the performance is relatively insensitive to the header length though longer header gives slightly better performance. In contrast, the header-aided non-blind channel estimator is affected greatly by the header. We can observe that for header length of 0( we borrow prvious cell's estimation) and 8 the performance is rather poor due to channel estimation. In paticular, Figure 3 shows the instantenous channel vs. blind and non-blind channel estimation for the same test conditions. It is clear blind channel estimation is superior to non-blind one especially when header length is not long enough. However when header length is sufficient long, both method performs well and blind one has a marginal advantage due to the reason that it used the whole cell data while non blind one only used the header part.

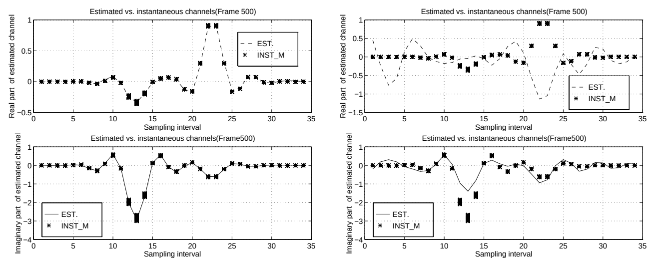


Figure 3: Instantenous channel vs. estimated channel for header length 8 (left: blind channel estimation,right: header-aided non-blind channel estimation)

### 4.3. ABR traffic simulation

We considered in our simulation ABR traffic of a burst of 10 cells. There are guard times before and after each burst but there is not guard time within a burst. There is no preamble transmitted before each and within each burst and we assume channel changes within a burst.

We tested our approach for different header length and also compared with the non-blind emthod as in CBR simulation. Figure 4 shows the performance.

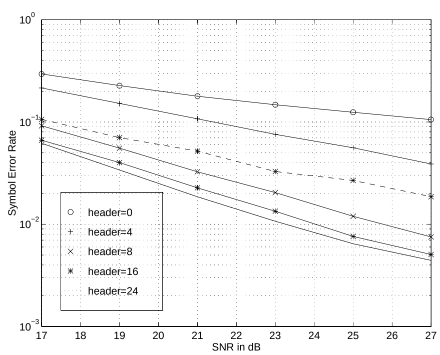


Figure 4: Symbol Error Rate vs. SNR. Solid lines:Using blind channel estimation. Dashed lines: Using non-blind channel estimation.

We can observe clearly the importance of header information in our approach. When header length is longer than 8, the performance is much better than header is shorter than 8 symbols.( the optimum header length which gives reasonable good performance is still under research) However when header is longer than 16 symbols, the performance gain is very slight. We also tested the non blind method with header 16 ( shorter header obviously will have worse performance). In our test we borrowed previous cell's channel estimaton as initial and use the header in detection. Clearly it performance is worse than our approach with the same header length.

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## REFERENCES

[1] E. Ayanoglu, Kai Y. Eng, and M. Karol. "Wireless ATM: Limits,Challenges,and Proposals". *IEEE Personal Communications*, pages 18–34, August 1996.

[2] D.C. Cox. "Wireless Personal Communications: What is it?". *IEEE Personal Communications*, 2(1):22–35, Feb 1995.

[3] F.M.Hsu. "Data directed estimation techniques for single-tone HF modems' '. In *Proc. IEEE MILCOM'85*, pages 12.4.1–12.4.10, 1985.

[4] M. Karol, Z. Liu, and K. Eng. "Distributed Queuing Request Update Multiple Access (DQRUMA) for Wireless Packet (ATM) Networks". In *Proc of International Conference on Communications*, pages 1224–1231, Seattle, USA, June 1995.

[5] E. Moulines, P. Duhamel, J.F. Cardoso, and S. Mayrargue. "Subspace-Methods for the Blind Identification of Multichannel FIR Filters". *IEEE Trans. SP*, SP-43(2):516–525, Feb. 1995.

[6] D. Raychaudhuri and et. al. "WATMnet: A Prototype Wireless ATM System for Multimedia Personal Communication". *IEEE J. Selected Areas in Communications*, 15(1):83–95, January 1997.

[7] L. Tong and J. Bao. "Equalization in Wireless ATM". In *Proc. 35th Allerton Conference on Communication, Control, and Computing*, Allerton, IL, Oct. 1997.

[8] L. Tong and S. Perreau. "Multichannel blind channel estimation: From subspace to maximum likelihood methods". *to appear in IEEE Proceedings, 1998.*

[9] L. Tong, G. Xu, and T. Kailath. "Blind identification and equalization based on second-order statistics: A time domain approach". *IEEE Trans. Information Theory*, 40(2):340–349, March 1994.

[10] G. Xu, H. Liu, L. Tong, and T. Kailath. "A Least-Squares Approach to Blind Channel Identification". *IEEE Trans. Signal Processing*, SP-43(12):2982–2993, December 1995.

[11] H. Zeng and L. Tong. "Connections between the Least-Squares and and subspace approaches to blind channel estimation". *IEEE Trans. Signal Processing*, 44(6):1593–1596, June 1996.