

Preamble Design for 802.16a/b SISO and MIMO OFDM Systems

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Apurva N. Mody
Georgia Institute of Technology
250, 14th Street NW, #549
Atlanta, GA 30318.

Voice: 404-894-9370
Fax: 404-894-7883
E-mail: apurva@ece.gatech.edu

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Preamble Design for 802.16 SISO and MIMO OFDM Systems (TG 3/4)

Apurva N. Mody

*Georgia Institute of Technology
Atlanta, Georgia, U. S. A.
apurva@ece.gatech.edu*

Efficient Preamble Design for OFDM Systems

- Good correlation properties,
- Low PAPR,
- Suitable for parameter estimation,
- Suitable for frequency offset estimation over a wide range,
- Low computational complexity and low overhead.

Use of Short Periodic Sequences

- Short sequences have following advantages
 - They help in rapid synchronization because of shorter length,
 - They increase the frequency offset estimation range,
 - If length of the channel is less than the short sequences, they can be used to estimate the channel.
- Disadvantages of the short sequences
 - They increase the system overhead,
 - Susceptible to multipath and noise.

Length of the Sequence Needed for Channel Estimation

- Two back to back similar sequences of length greater than or equal to the length of the channel are sufficient for any DFT based channel estimation. [4 (Tellambura), 5 (Manton)]



T = Sample time, G = Number of taps in the guard

N = OFDM Blocksize

- Linear convolution becomes a circular convolution and DFT based techniques can be applied

Expected Channel Lengths for the Proposed System

	Number of taps	
	BW=3.5 MHz $f_s=4.0832$ MHz	BW=7 MHz $f_s=8.1664$ MHz
SUI-4	17	34
SUI-5	42	83
SUI-6	83	164

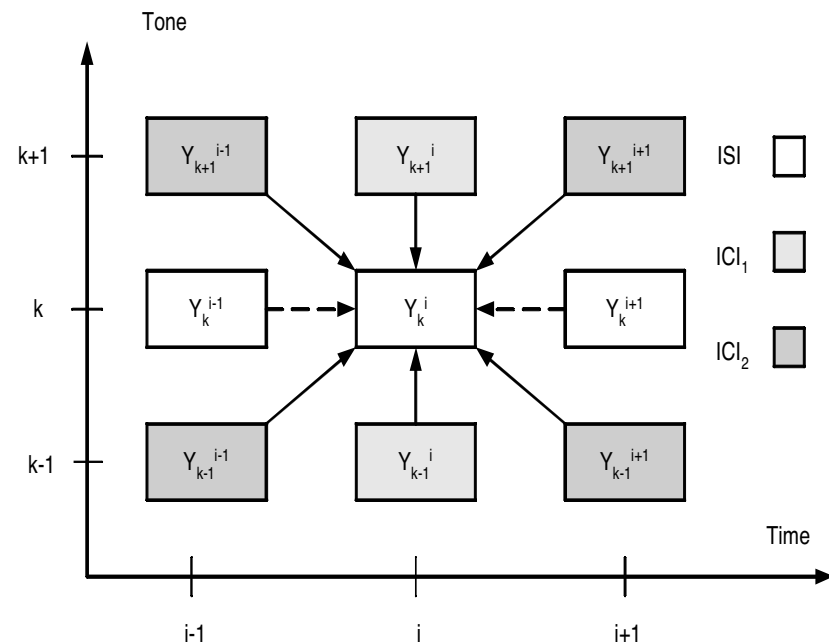
Note: SUI6 channel is highly dispersive.

Effect of Insufficient Guard Interval in OFDM

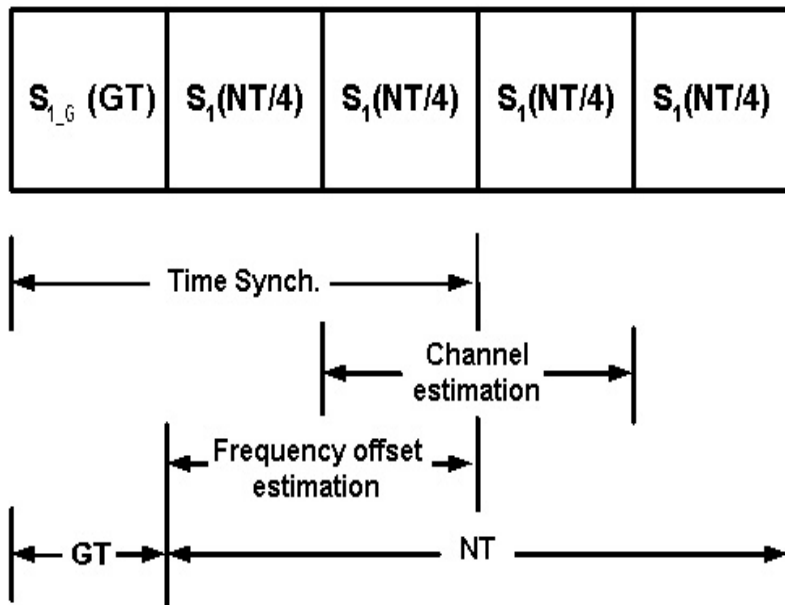
- Insufficient guard interval causes ISI, Inter Carrier Interference (ICI_1) and Intra Carrier Interference (ICI_2)

Ways to mitigate highly dispersive channels

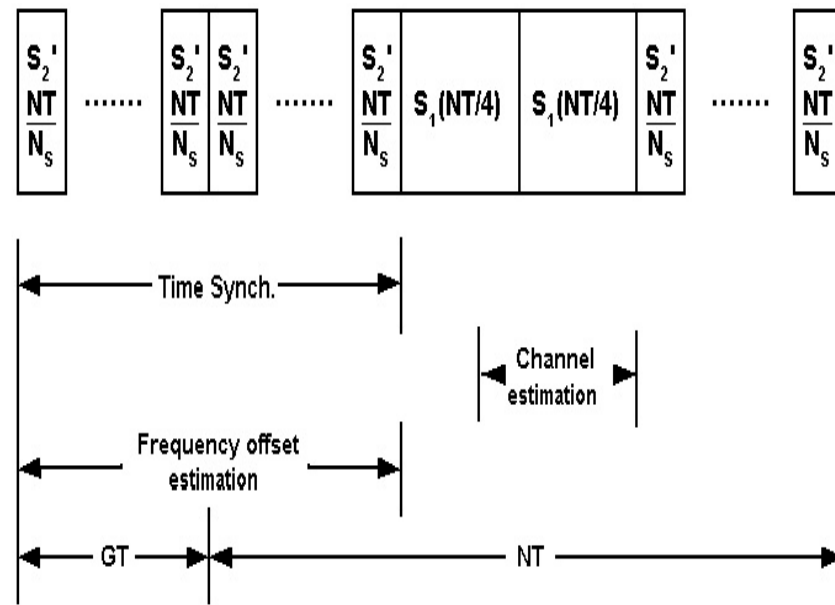
- **Blocksize of the OFDM can be increased (256→512) such that it permits the use of a larger guard interval (64→128).**
- **Impulse response shortening techniques can be used to combat insufficient guard interval (SUI6).**



One OFDM Symbol Long Preambles that Allow for Greater Frequency Estimation Range



SCHEME 1. Frequency offset estimation range = $4/(NT)$ or 4 subcarrier spacings. Better frequency offset estimates. **WILL WORK FOR SUI6 IF N=512.**



SCHEME 2. Frequency offset estimation range = $N_s/(NT)$ or N_s subcarrier spacings. Larger frequency estimation error. **WILL WORK FOR SUI6 IF N=512.**

Sequence Construction

- **SCHEME 1**

- S_1 represents a sequence in the frequency domain.

- For $NT/4 = 64$,

$$S_1 = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 1 \ 1 \ 1 \ 1 \ -1 \ -1 \ -1 \ -1 \ -1 \ 1 \ 1 \ -1 \ -1 \ 1 \ -1 \ -1 \ 1 \ 1 \ -1 \\ -1 \ -1 \ 1 \ 1 \ -1 \ 1 \ 0 \ -1 \ 1 \ -1 \ 1 \ -1 \ 1 \ 1 \ 1 \ -1 \ 1 \ -1 \ -1 \ 1 \ -1 \ 1 \ 1 \ -1 \ -1 \\ -1 \ 1 \ -1 \ 1 \ -1 \ -1 \ 1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0] \text{ — PAPR} = 3.15 \text{ dB.}$$

- An $NT/4$ point IFFT is taken to form s_1 and the resultant sequence is used to construct the preamble.

- The preamble is constructed as

$$[s_1 \ s_1 \ s_1 \ s_1]$$

in the time domain and a suitable guard interval is inserted as a cyclic prefix.

Sequence Construction (Contnd.)

- **SCHEME 2**

- S_1 is as in Scheme 1, S_2 is an N/N_s point sequence in the frequency domain.

- For $N_s = 8$,

$$S_2 = [0 \ 0 \ 0 \ 0 \ -1 \ 1 \ -1 \ -1 \ 1 \ -1 \ -1 \ 1 \ 1 \ 1 \ 1 \ -1 \ 0 \ -1 \ 1 \ 1 \ 1 \ -1 \ 1 \ 1 \ 1 \ -1 \\ 1 \ 1 \ 1 \ 0 \ 0 \ 0] \text{ — PAPR}=2.355\text{dB.}$$

- For $N_s = 16$,

$$S_2 = [0 \ 0 \ -1 \ -1 \ 1 \ 1 \ 1 \ 1 \ 0 \ 1 \ -1 \ 1 \ -1 \ -1 \ 1 \ 0] \text{ — PAPR}=1.76 \\ \text{dB.}$$

- N/N_s point IFFT is taken to obtain s_2

- The preamble is constructed as

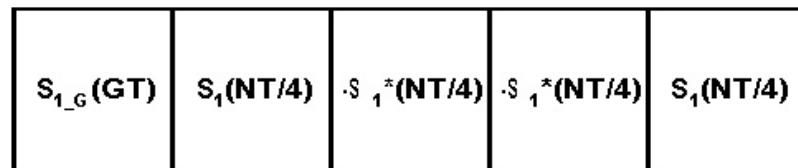
$$[s_2 \quad \cdot \quad s_2 \quad s_1 \quad s_1 \quad s_2 \quad \dots \quad s_2 \quad]$$

and a suitable guard interval is inserted as a cyclic prefix.

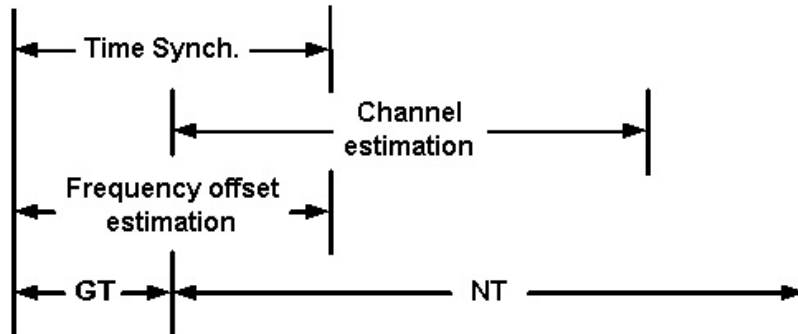
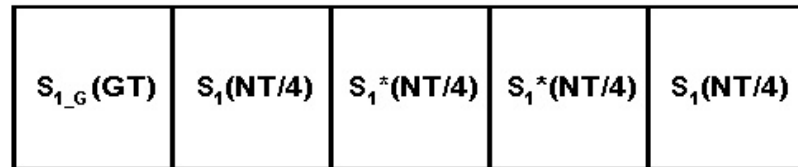
One OFDM Symbol Long Preamble for Alamouti's diversity scheme

SCHEME 3. One OFDM symbol long preamble suitable for a MIMO (2X2) system. Frequency offset estimation range = $4/(NT)$ or 4 subcarrier spacings. **WILL WORK FOR SUI6 IF N=512.**

Antenna 1- Frequency Domain



Antenna 2- Frequency Domain



Sequence Construction (Contnd.)

- **SCHEME 3**

- S_1 is as in Scheme 1,
- S_1^* is the complex conjugate of the sequence S_1 ,
- $-S_1^*$ is the complex conjugate of the sequence S_1 multiplied by -1,
- NT/4 point IFFTs are taken of S_1 , S_1^* and $-S_1^*$ to obtain sequences s_1 , s_{1conj} and s_{1conjn} respectively.
- The preamble is constructed as

Antenna 1 - $[s_1 \ s_{1conjn} \ s_{1conjn} \ s_1]$

Antenna 2 - $[s_1 \ s_{1conj} \ s_{1conj} \ s_1]$

and a suitable guard interval is inserted as a cyclic prefix.

Sequence Reception for **SCHEMES 1 and 2**

Receiver implementation-

- Step1. Coarse time synch. is followed by frequency offset estimation and correction. (Carried out using autocorrelation of the received samples [2])
- Step 2. Fine time synch. is performed to extract the samples corresponding to the sequence s_1 in the time domain (Carried out using cross correlation between the received and the transmitted sequence s_1).
- Step3. Channel is estimated and a zero forcing equalizer is used to perform 1-tap equalization for the received OFDM tones.

Channel Estimation for SCHEMES 1 and 2

Step1. The $N/4$ point received sequence corresponding to the transmitted sequence s_1 is converted to the frequency domain.

$$R_{s_1} = \frac{1}{\sqrt{N/4}} \text{FFT} \{r_{s_1}, N/4\}$$

Step2. Channel estimates are obtained for non-zero tones using

$$H_{s_1,k} = \frac{R_{s_1,k}}{S_{1,k}} \quad k = -N/8, \dots, -1 \text{ and } 1, \dots, N/8 - 1$$

Step3. Frequency domain interpolation performed to obtain channel coefficients for $(N - N_{\text{zero}})$ tones.

Channel Estimation for SCHEME 3

Step1. The received demodulated OFDM sample matrix \mathbf{R} can be expressed in terms of the transmitted sample matrix \mathbf{S} , the channel coefficient matrix \mathbf{H} and the noise matrix \mathbf{W} as [1]:

$$\mathbf{R}_{k \times 2} = \mathbf{S}_{k,2 \times 2} \cdot \mathbf{H}_{k,2 \times 2} + \mathbf{W}_{k,2 \times 2}$$
$$k = 0, 1, \dots, N - 1$$

Step2. Two NT/4 point sections corresponding to the transmitted sequences S_1 and $-S_1^*$ are removed from the received samples and converted to the frequency domain.

Step3. Channel estimates are obtained for non-zero tones using

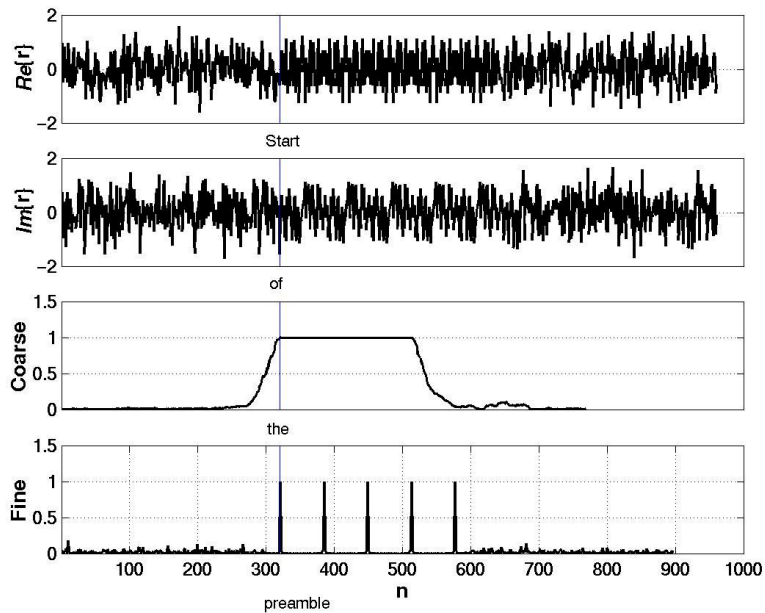
$$H_{s_1, k} = S_{s_1, k}^{-1} R_{s_1, k} \quad k = -N/8, \dots, -1 \text{ and } 1, \dots, N/8 - 1$$

Step4. Frequency domain interpolation performed to obtain the 4 channel coefficients for $(N - N_{\text{zero}})$ tones.

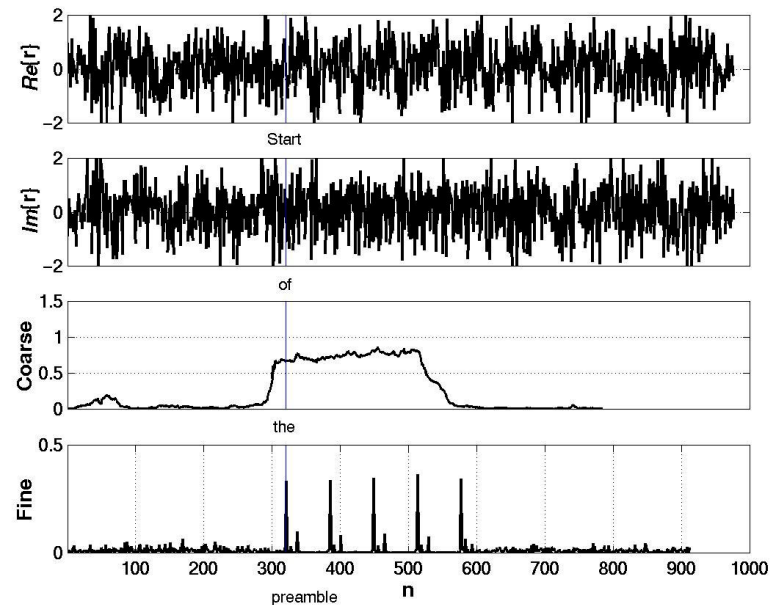
Simulation Performance

- Channel models — SUI-4 and SUI-6 with omni antennas, BW=3.5 MHz, Sampling frequency $f_s=4.0832$ MHz,
- Block fading is assumed,
- Monte-Carlo simulation with 5,000 channel samples,
- 256 point FFT with d.c. and middle 55 tones set to zero ($N_{\text{zero}}=56$).
- Cyclic prefix length = 64 samples,
- Modulation = 16 QAM,
- Coarse time synch. is performed first, followed by frequency offset correction, fine time synch. and channel estimation.

Coarse/Fine Time Synchronization performance for **SCHEME 1**

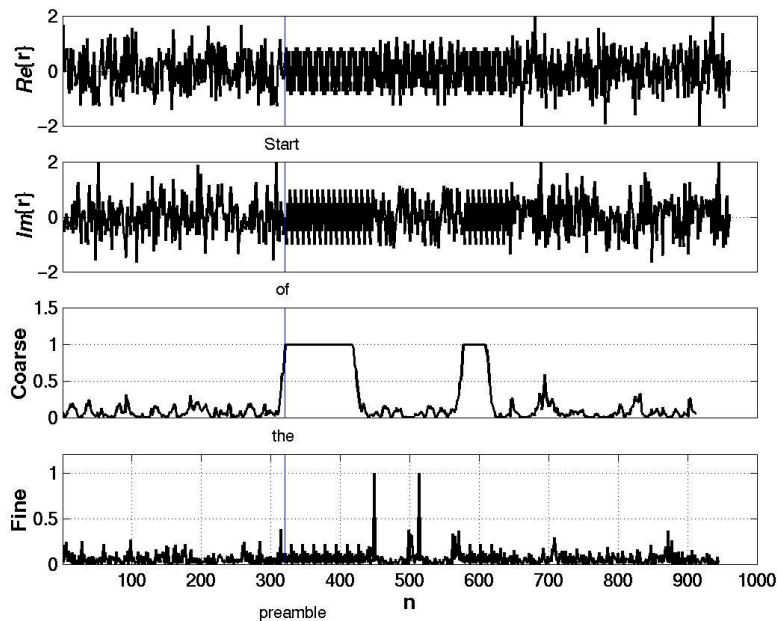


Es/No — High SNR
Channel - awgn

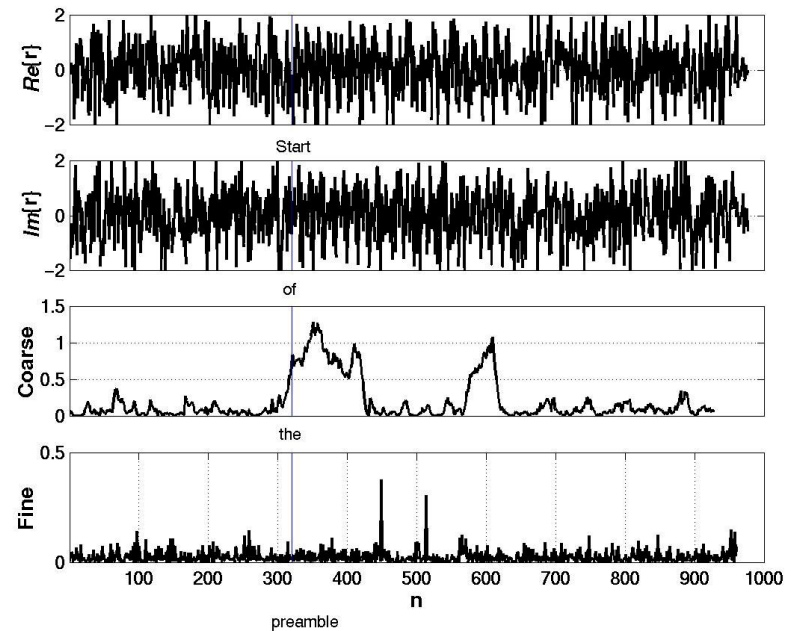


Es/No = 6 dB,
Channel - SUI4 (3.5 MHz)

Coarse/Fine Time Synchronization performance for **SCHEME 2**

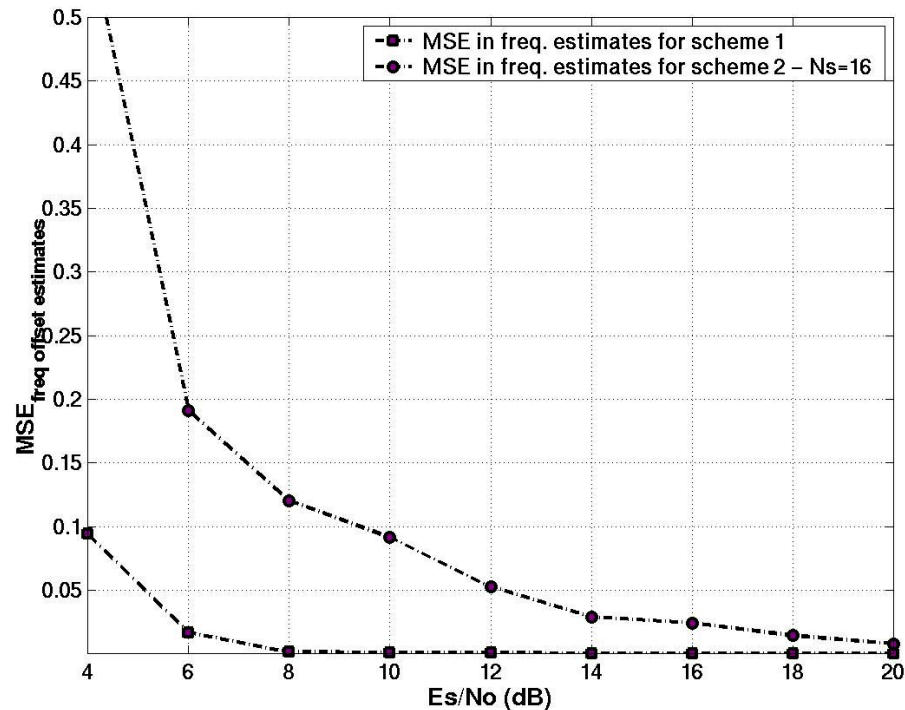


Es/No — High SNR
Channel - awgn



Es/No = 6 dB,
Channel - SUI4 (3.5 MHz)

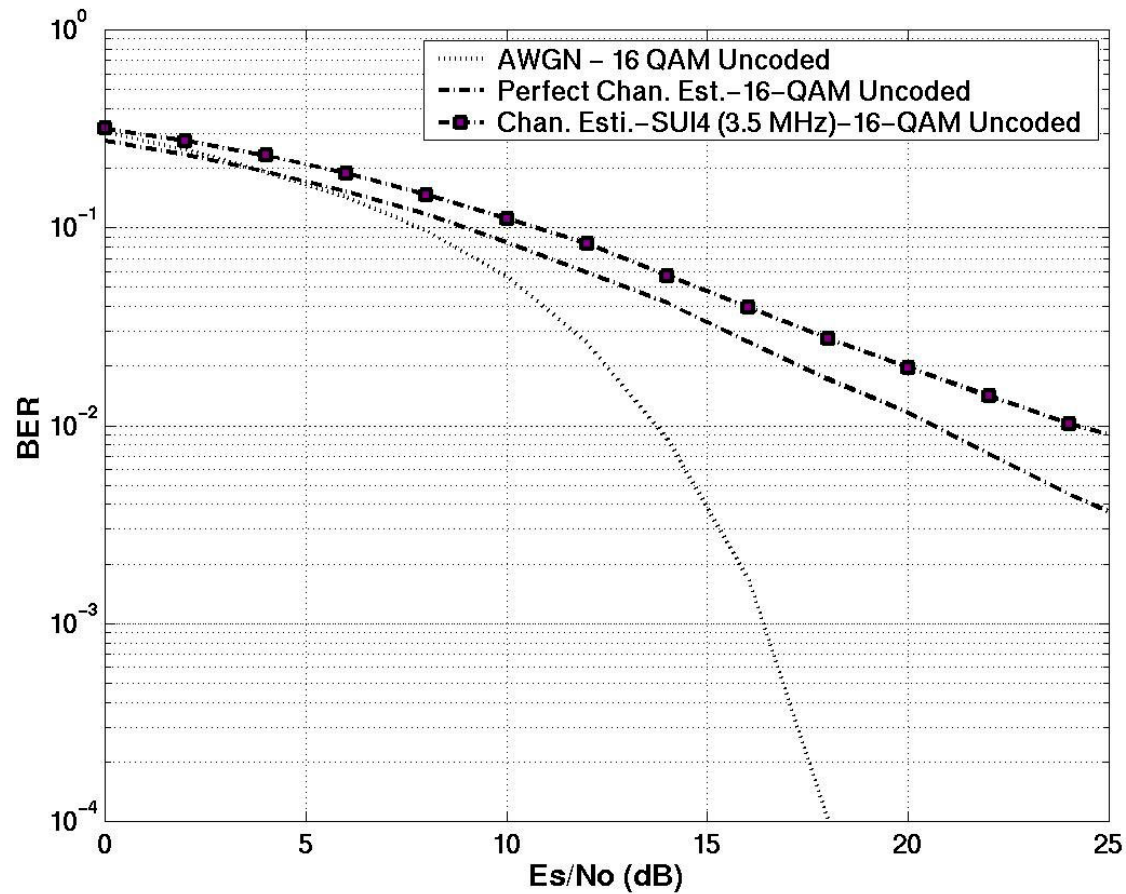
Comparison of MSE in Frequency Offset Estimates between **SCHEMES 1 & 2**



SCHEME 2 has a larger frequency offset estimation range but it also has a larger frequency offset estimation error as compared to **SCHEME 1**.

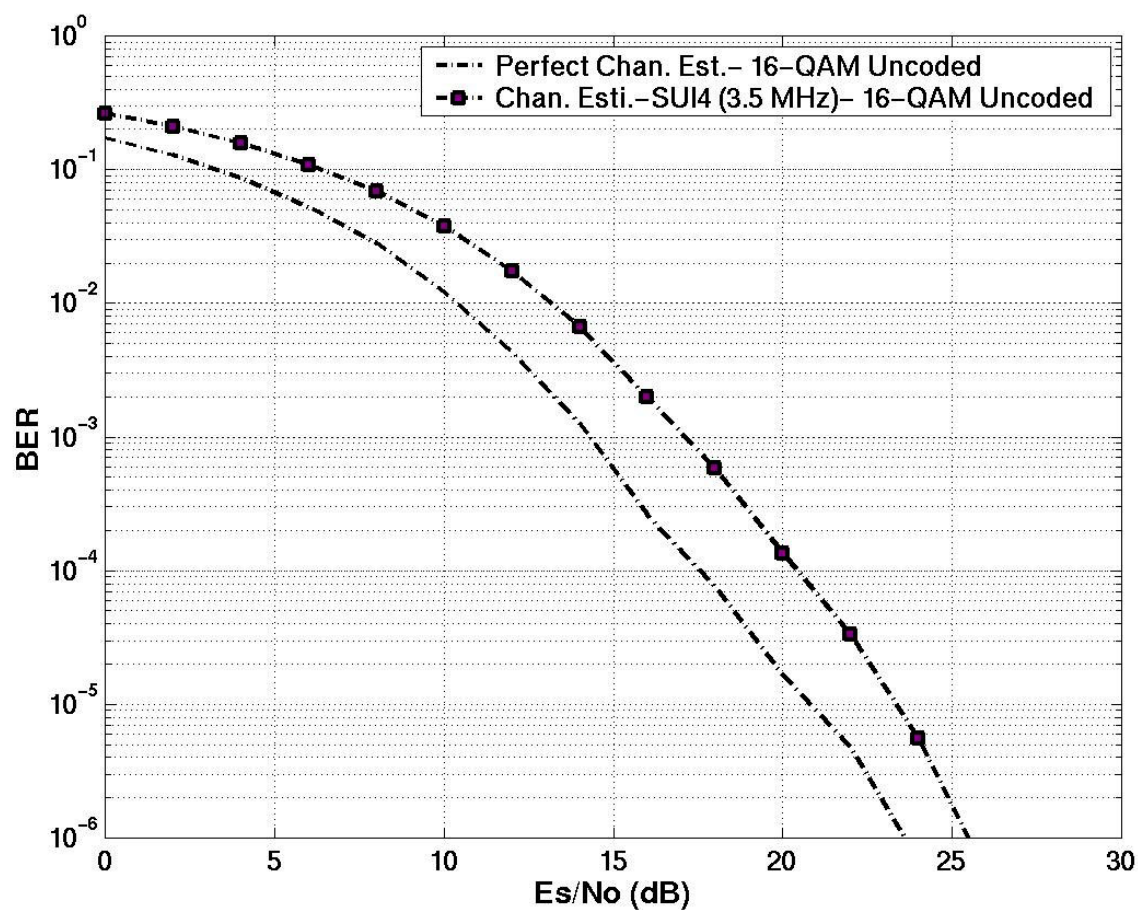
1X1 System: 16-QAM Uncoded BER

Performance using **SCHEMES 1 & 2**



2X2 System: 16-QAM Uncoded BER

Performance using **SCHEME 3**



Preamble Proposed by Lek

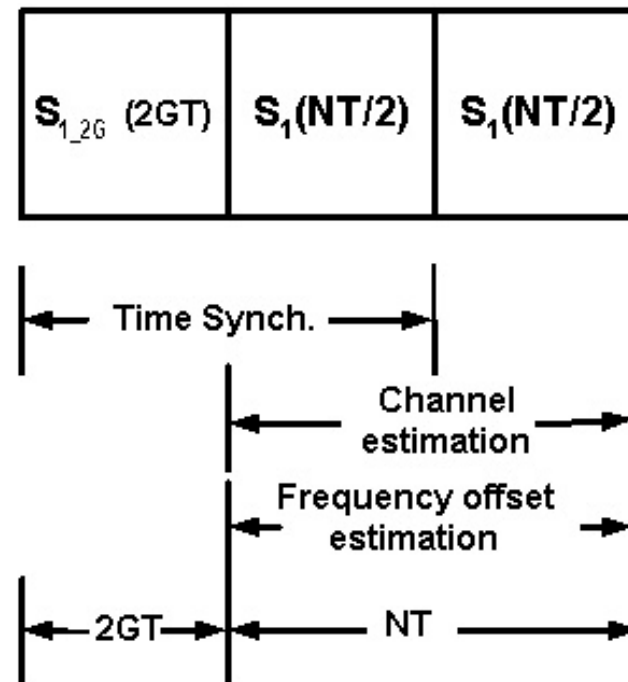
LEK.

Advantages —

- Can be used to estimate SUI6 (3.5 MHz) channel, **however, such a system would require an equalizer for channel impulse response shortening.**

Disadvantages

- Coarse freq. offset estimation is not possible,
- Fine time synch. has higher computational complexity ($N/2$ multiplies and $N/2-1$ additions).



Preamble Comparisons

	<u>SCHEMES 1, 2 and 3</u>	<u>SCHEME by Lek</u>
Length of preamble (CP+preamble=one symbol)	One OFDM symbol	One OFDM symbol if CP=N/4 (SISO) 1.6 OFDM symbols (MIMO)
Frequency offset estimation range	4 subcarrier spacings for SCHEMES 1 & 3 , and N_s subcarrier spacings for SCHEME 2	2 subcarrier spacings
Time Synch.	Less complex (N/4 complex multiplies, N/4-1 adds)	More complex (N/2 complex multiplies, N/2-1 adds)
Performance in SUI 6	Need to increase the blocksize to N=512.	The preamble is suitable but need an equalizer for channel impulse response shortening in the data mode N=256.
Channel Estimation	2.5 dB BER performance penalty from perfect channel	2.2 dB BER performance penalty from perfect channel.

Conclusions

- Efficient preamble structures were presented for SISO and MIMO OFDM systems that are **one OFDM symbol long**.
- The preamble structures have a **higher frequency offset correction range** and **lower implementation complexity**.
- The structures were designed assuming that the length of the guard is greater than the channel impulse response.
- For highly dispersive channels (SUI6), we need to increase the OFDM blocksize or else use an equalizer for channel impulse response shortening.

References

- [1] A. N. Mody and G. L. Stüber, "Parameter Estimation for OFDM with Transmit Receive Diversity," *VTC2001*, Rhodes, Greece.
- [2] A. N. Mody and G. L. Stüber, "Synchronization for MIMO OFDM Systems," to appear *GLOBECOM 2001*, San Antonio, Texas, November 2001.
- [3] A. N. Mody and G. L. Stüber, "Efficient Training and Synchronization Sequence Structures for MIMO OFDM," 6th International OFDM-Workshop, Hamburg, Germany, September 2001.
- [4] C. Tellambura, M. G. Parker, Y. Jay Guo, S. Shepherd and S. Barton, "Optimal Sequences for Channel Estimation Using Discrete Fourier Transform Techniques," *IEEE Tran. on Comm.*, Vol. 47, No. 2, Feb. 1999.
- [5] J. H. Manton, "Optimal Training Sequences and Pilot Tones for OFDM Systems," *IEEE Comm. Letters*, Vol. 5, No. 4, April 2001.