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

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For posting on the 802.16 website, presentation to the preamble ad-hoc and TG3/4.

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

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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)]

$S_1(GT)$	$S_1(GT)$

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

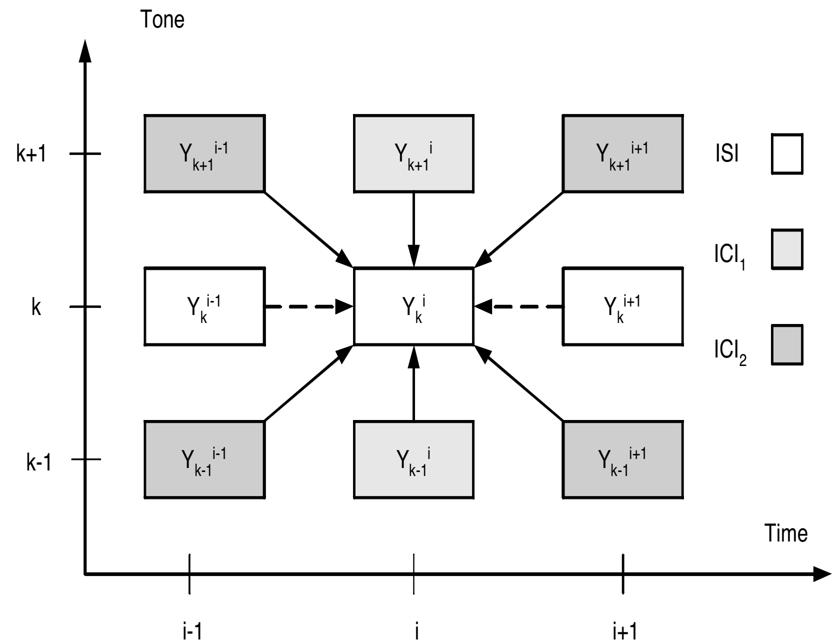
Note: SUI6 channel is highly dispersive.

Effect of Insufficient Guard Interval in OFDM

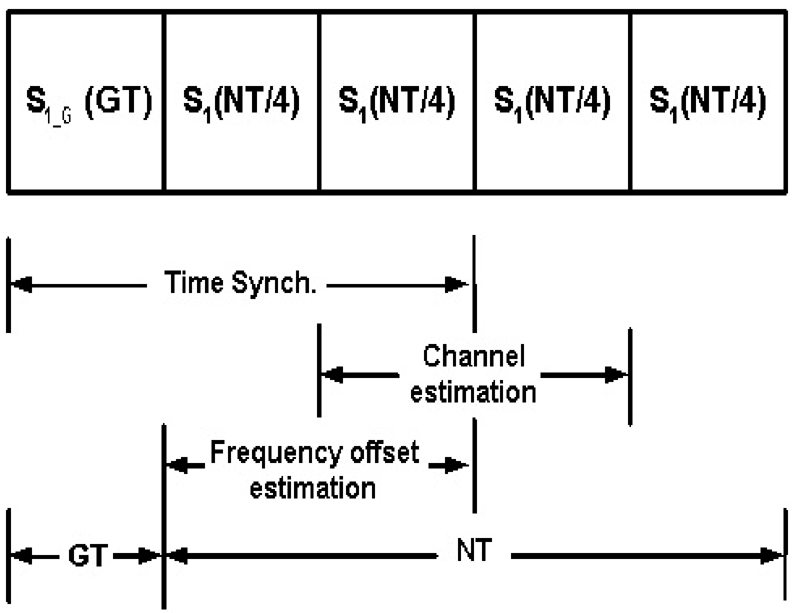
- Insufficient guard interval causes ISI, Inter Carrier Interferece (ICI_1) and Intra Carrier Interference (ICI_2)

Ways to mitigate highly dispersive channels

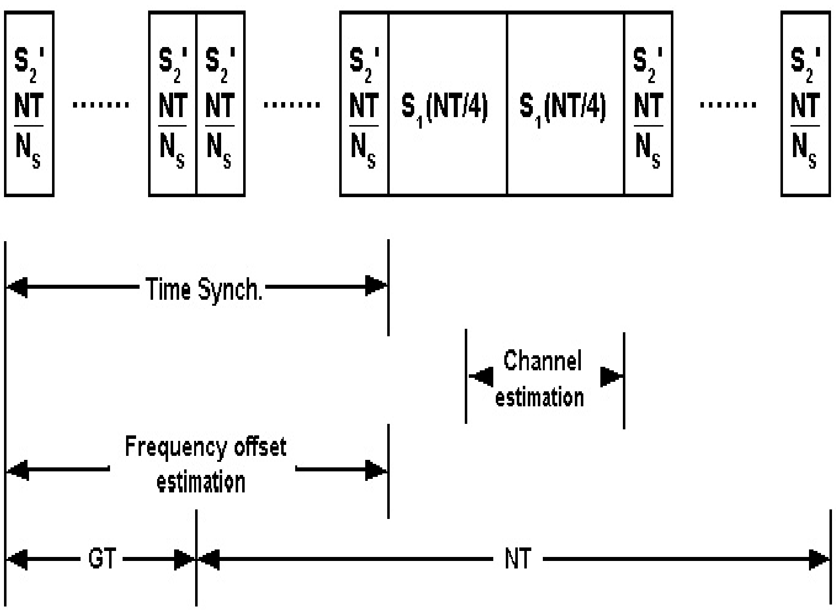
- Blocksize of the OFDM can be increased (256–>512) such that it permits the use of a larger guard interval (64–>128).
- Impulse response shortening techniques can be used to combat insufficient guard interval (SUI6).



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 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] — PAPR=3.15 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/Ns point sequence in the frequency domain.
  - For Ns = 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] — PAPR=2.355dB.
  - For Ns = 16,

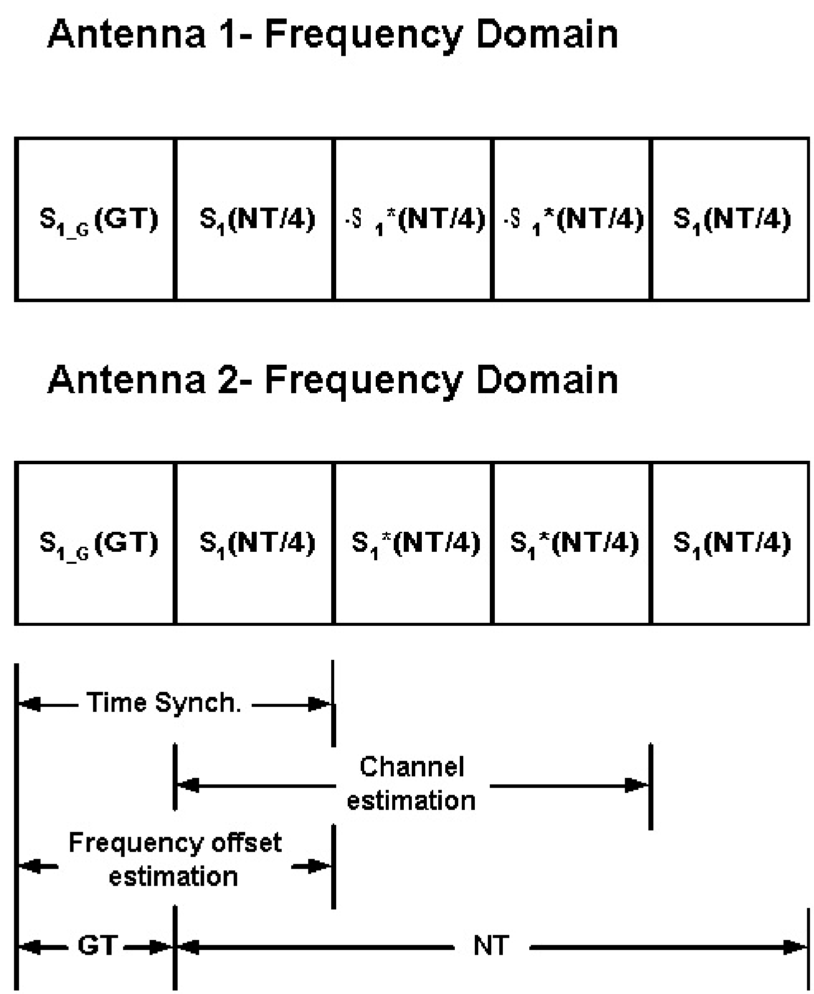
    S_2 =[0 0 -1 -1 1 1 1 1 0 1 -1 1 -1 -1 1 0] — PAPR=1.76 dB.
  - N/Ns point IFFT is taken to obtain s_2
  - The preamble is constructed as

$$[s_2 \; . \; s_2 \; s_1 \; s_1 \; s_2 \; .. \; s_2]$$

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.**



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 S1, 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 NT/4 point received sequence corresponding to the transmitted sequence s_1 is converted to the frequency domain.

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

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

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

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

Channel Estimation for SCHEME 3

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

$$\mathbf{R}_{k,2\times 2} = \mathbf{S}_{k,2\times 2} \cdot \mathrm{H}_{k,2\times 2} + \mathbf{W}_{k,2\times 2}$$

$$k = 0,1,\ldots,N-1$$

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

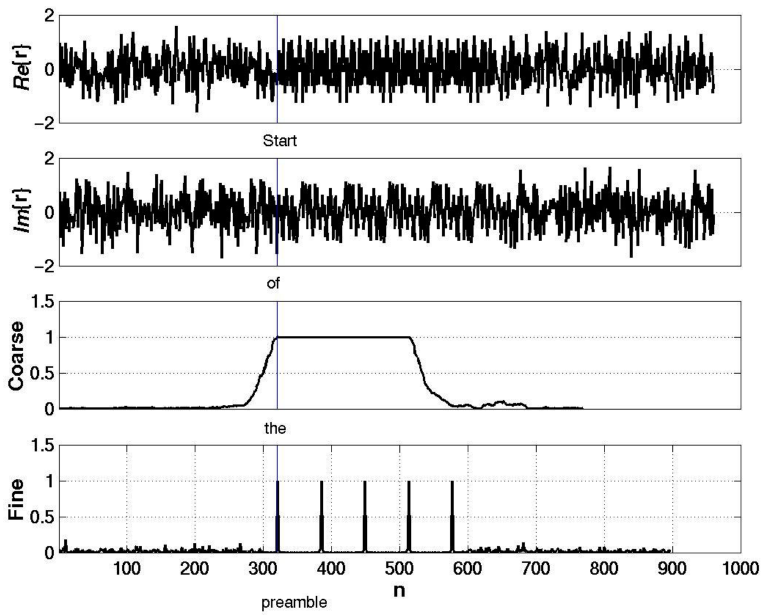
$$H_{s_1,k} = S_{s_1,k}^{-1} R_{s_1,k} \quad k = -N/8,\ldots,-1 \text{ and } 1,\ldots,N/8-1$$

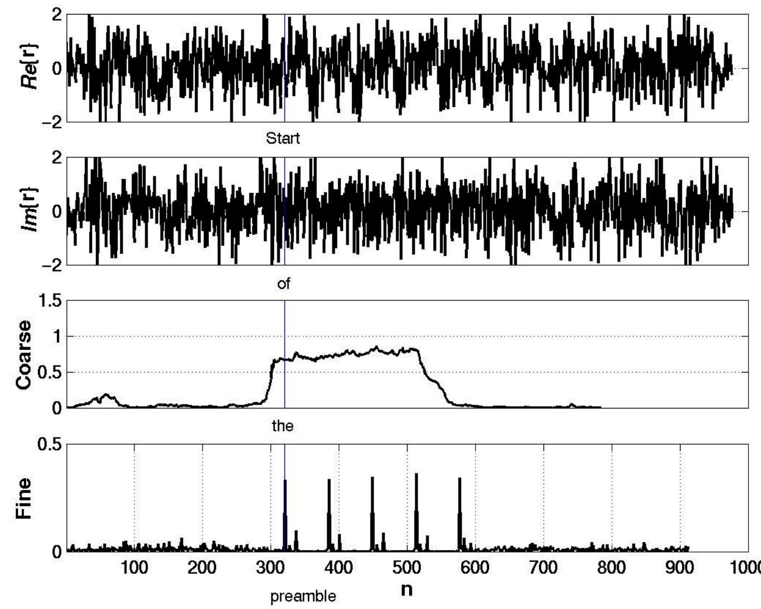
Step4. Frequency domain interpolation performed to obtain the 4 channel coefficients for ($N-N_{zero}$) tones.

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_{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





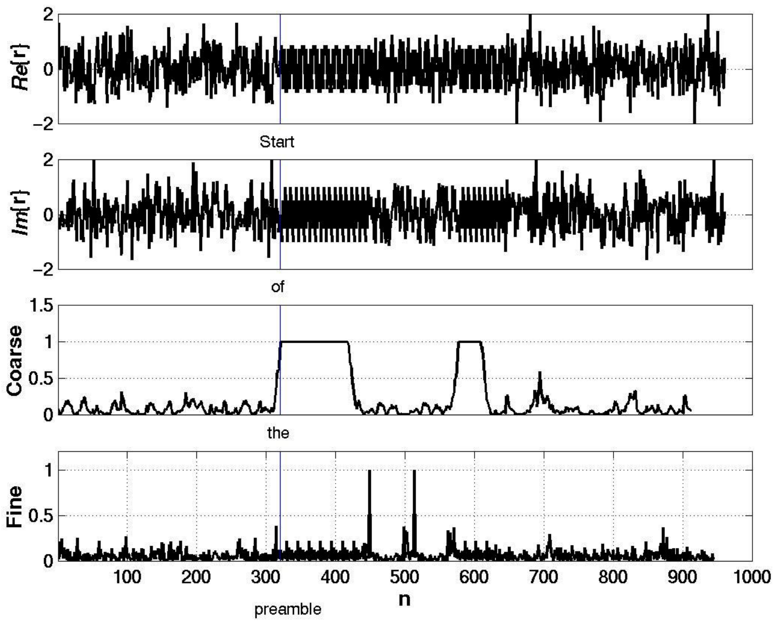
Es/No — High SNR

Channel - awgn

Es/No = 6 dB,

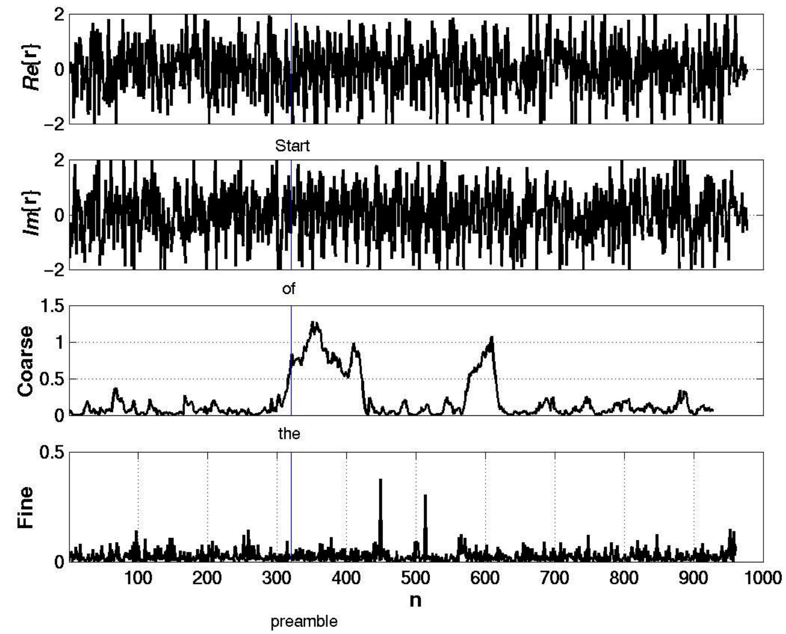
Channel - SUI4 (3.5 MHz)

Coarse/Fine Time Synchronization performance for SCHEME 2



Es/No — High SNR

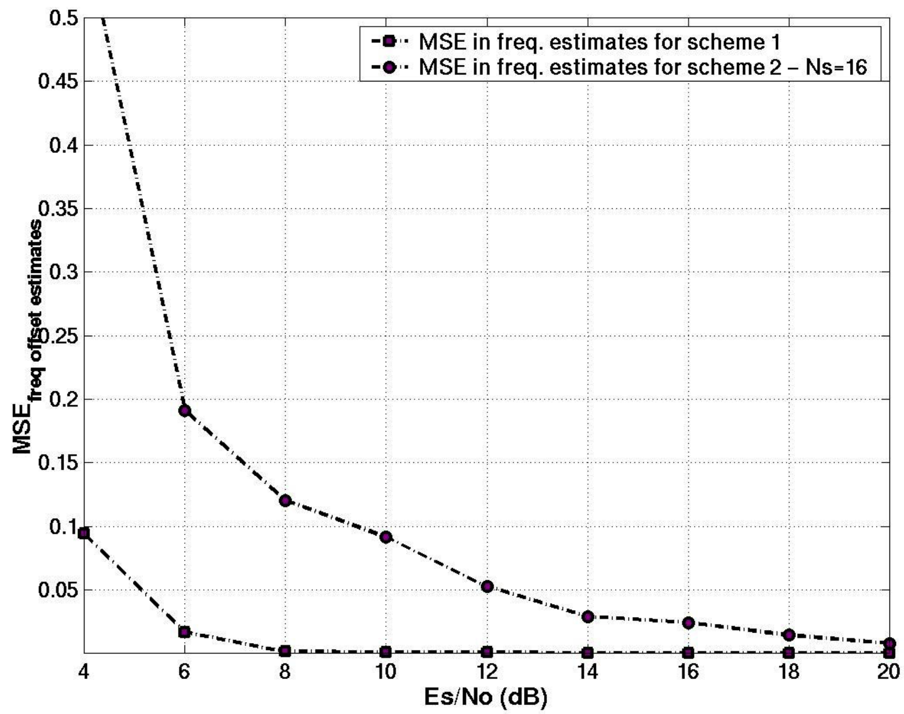
Channel - awgn



Es/No = 6 dB,

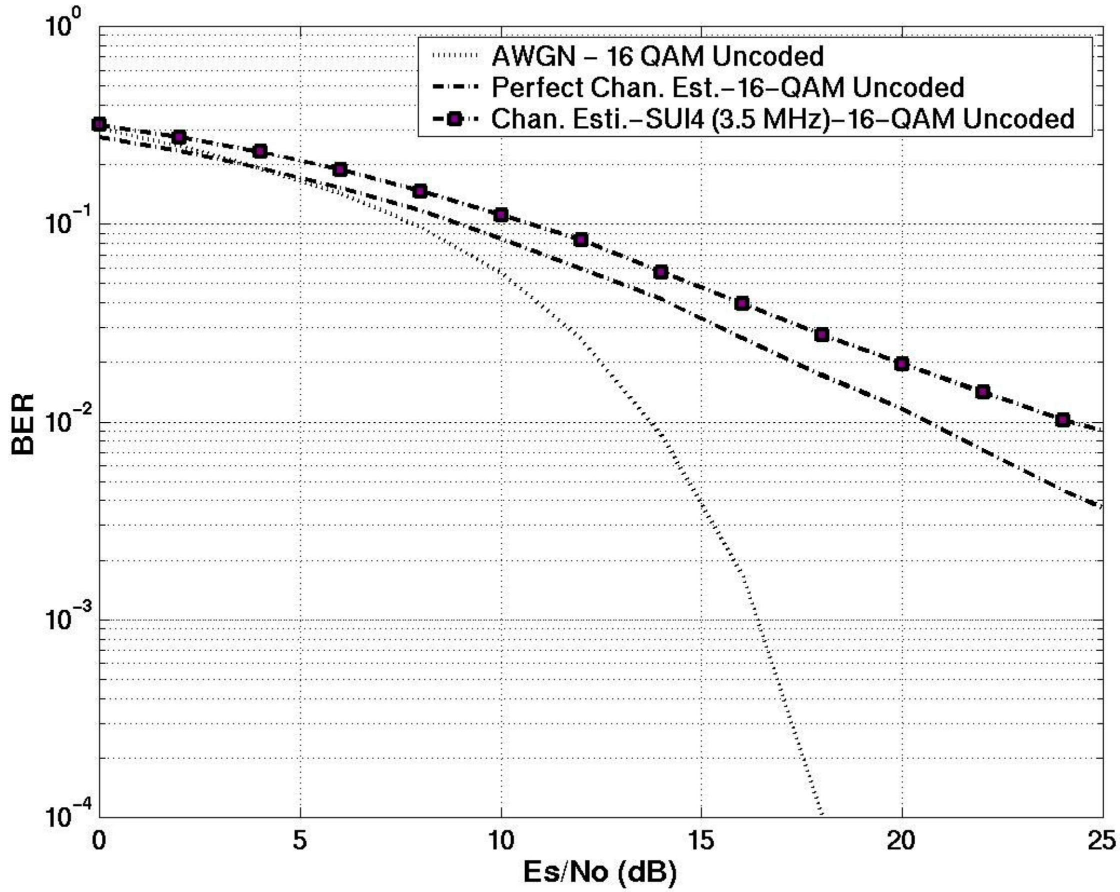
Channel - SUI4 (3.5 MHz)

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

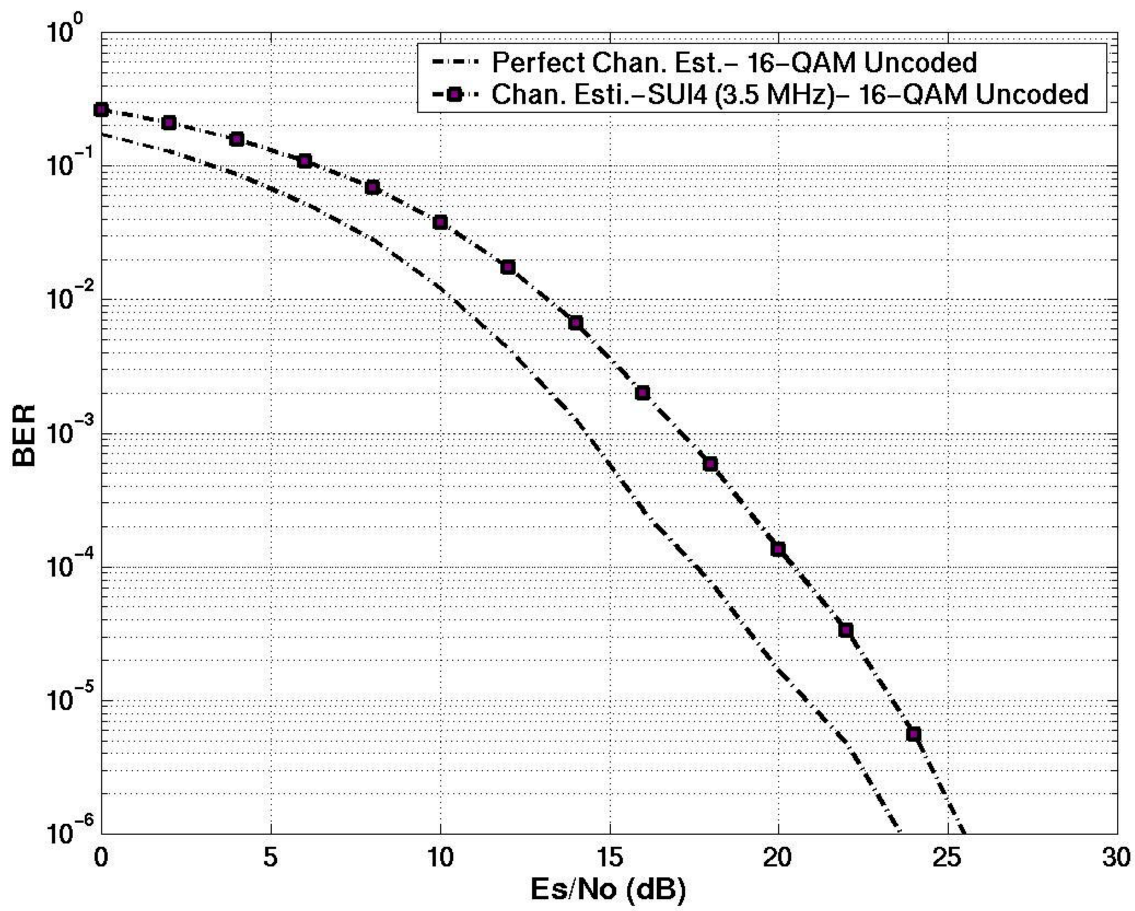


SCHEME 2 has a larger frequency offset estimation range but it also has a larger frequency offset estimation error as compared to **SCHEME 1.**

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

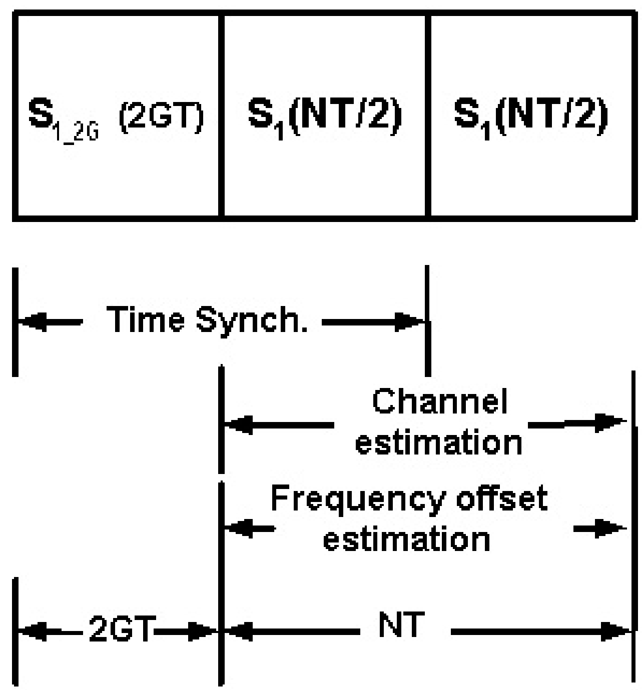
LEK.

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

	SCHEMES 1, 2 and 3	SCHEME by Lek
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 Ns sucarrier 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," 6^{th} 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.