Channel Models for Indoor Wireless Transmission

P. Sharma, P. Sachetta,
C. Thompson & K. Chandra

Center for Advanced Computation & Telecommunications

University of Massachusetts, Lowell

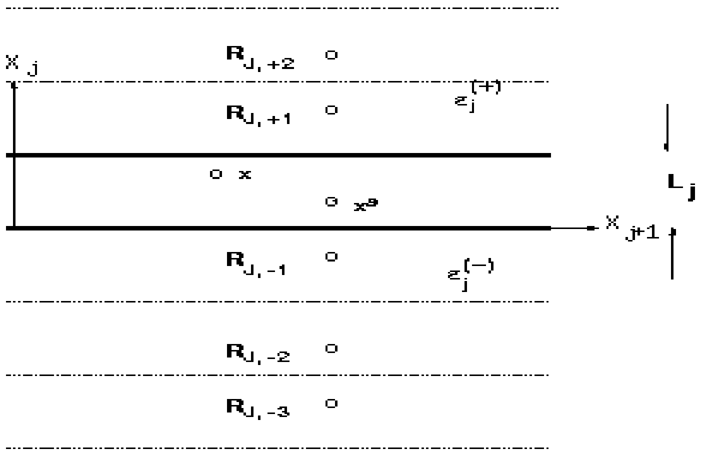
Presentation Outline

- Indoor Wireless Transmission Issues
- Channel Impulse Response (CIR) Estimation
  - Computational Approach: Image Source Method
- Results
  - Frequency Dependence
  - Spatial Variation
- Decision Feedback Equalizer (DFE)
  - Implementation Issues
  - Results
- Conclusions

Indoor Wireless Transmission Issues

- 3rd & 4th Generation Wireless Systems:
  - Data-rates 2-100 Mb/s
  - Frequency Band 24-48 Ghz
  - Millimeter waves: Increased multiple scattering & reflection interference
- Indoor Environment
  - Room geometry: Spatial variations of CIR
  - Wall materials effects: Absorption losses
- Channel Impulse Response
  - Coherent component: Early arrivals
  - Diffuse component: Multiple reflections
- Effective equalization requires shape and amplitude distribution of CIR

CIR using Image Method (1)



- Image Location

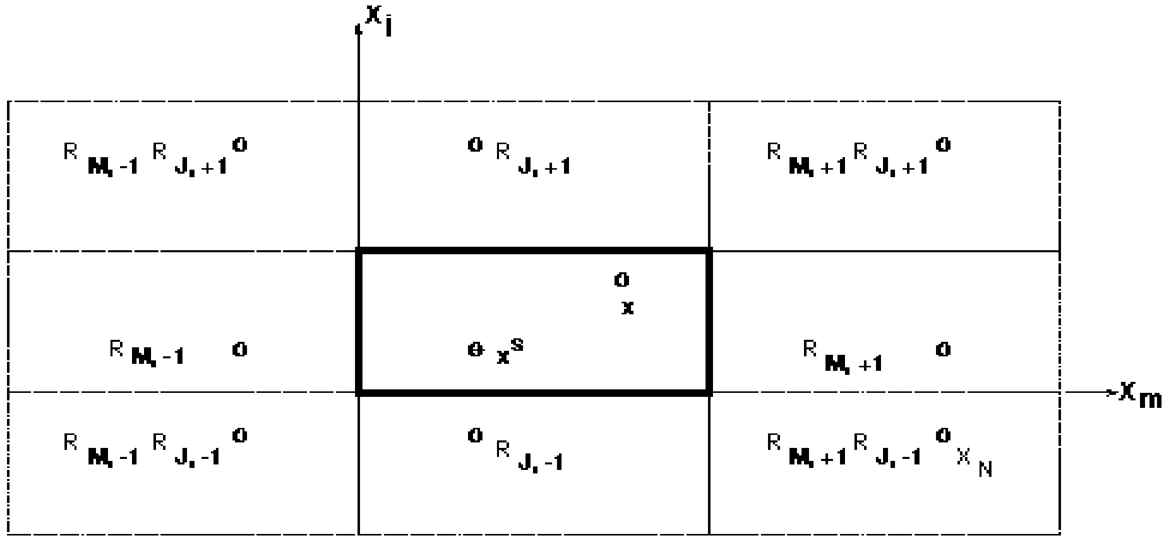
$$\hat{x}_{j,\,N_j} = 2L_j \left[\frac{N_j}{2}\right]_{ceil} + (-1)^{N_j}\; x_j^s$$

- Image Amplitude

$$R_{j,\,N_j}(q_j, \underline{\varepsilon}_j, \omega) = \int_0^{\infty} f_{j,\,N_j}(p_j, \underline{\varepsilon}_j, \omega)\; e^{-q_j p_j}\, dp_j$$

where $q_j = k_{x_j}\gamma_j$ and $\gamma_j = (\varepsilon_j^{(+)} - 1)^{-1/2}/k$

CIR using Image Method (2)



- Fourier Amplitude

$$F_{l,\underline{N}}(\underline{x},\omega) = \frac{1}{\left|X_{\underline{N}}\right|}\int_0^{\infty} f_{l,\underline{N}}\,\frac{e^{ik\left|X_{\underline{N}}\right|(\phi-1)}}{\phi}\,D\underline{p}$$

where $X_{\underline{N}} = \underline{x} - \underline{\hat{x}}_{\underline{N}}$, $\underline{p\gamma} = (p_1\gamma_1,\ p_2\gamma_2,\ p_3\gamma_3\ )$ and

$$\phi^2 = \frac{\left(X_{\underline{N}} + i\,\underline{p\gamma}\right)\cdot\left(X_{\underline{N}} + i\,\underline{p\gamma}\right)}{\left|X_{\underline{N}}\right|^2}$$

CIR using Image Method (3)

Laplace Transform of Image Amplitude:

$$f_{l,\underline{N}} = \prod_{j=1}^{3} f_{l,N_j} + \sum_{m=1}^{3} \prod_{j=1}^{3} f_{l,m,N_j}$$

where $N'_j = sgn(N_j)$, $\beta = (\varepsilon^2 - 1)^{-1/2}$,

$$f_{l,N_j} = E_{l,N'_j}(p_j, \varepsilon_j^{N'_j}) * f_{l,-N_j+N'_j}(p_j, \varepsilon_j^{N'_j})$$

$$f_{l,m,N_j} = G_{l,N'_j}(p_j, \varepsilon_j^{N'_j}) * f_{l,-N_j+N'_j} \frac{\partial}{\partial x_m} \qquad \text{for } l = j \neq m$$

$$E_{l,N'_j}(p,\varepsilon) = \begin{cases} \frac{\varepsilon - 1}{\varepsilon + 1}\left[\delta(p) + \frac{\varepsilon\beta}{2} e^{-\beta p}\right] - \varepsilon\beta \int_0^\infty e^{-\beta|p-s|} \frac{J_2(p)}{s}\, ds & \text{for } l = j \\ -2\frac{J_2(p)}{p} & \text{for } l \neq j \end{cases}$$

$$G_{l,N'_j}(p,\varepsilon) = \frac{\varepsilon - 1}{\varepsilon + 1} \frac{\varepsilon\beta}{2} e^{-\beta p} - \varepsilon\beta \int_0^\infty e^{-\beta|p-s|} sgn(p-s) \frac{J_2(p)}{s}\, ds$$

CIR using Image Method (4)

- Time response of the $\underline{N}$ image

$$\pi_{l,\underline{N}}\left(t-\frac{X_{\underline{N}}}{c}\right)=\frac{1}{2\pi}\int_{-\infty}^{\infty}F_{l,\underline{N}}(\underline{x},\omega)e^{-i\omega\left(t-\frac{X_{\underline{N}}}{c}\right)}d\omega$$

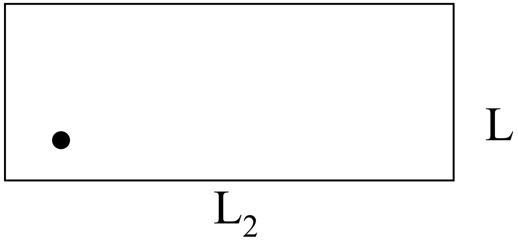
- Total time response

$$\pi_l(\underline{x},\underline{x}^s,t)=\sum_{\underline{N}}\pi_{l,\underline{N}}\left(t-\frac{X_{\underline{N}}}{c}\right)$$

Wide Band Channel Impulse Response

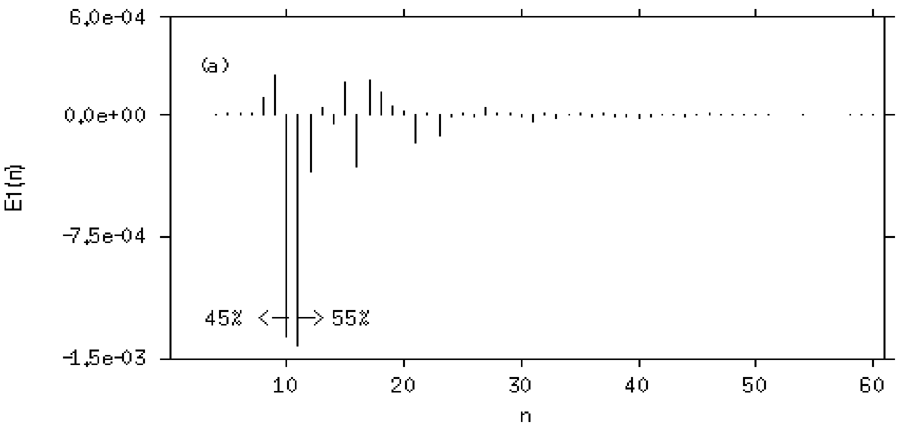
Room Dimensions

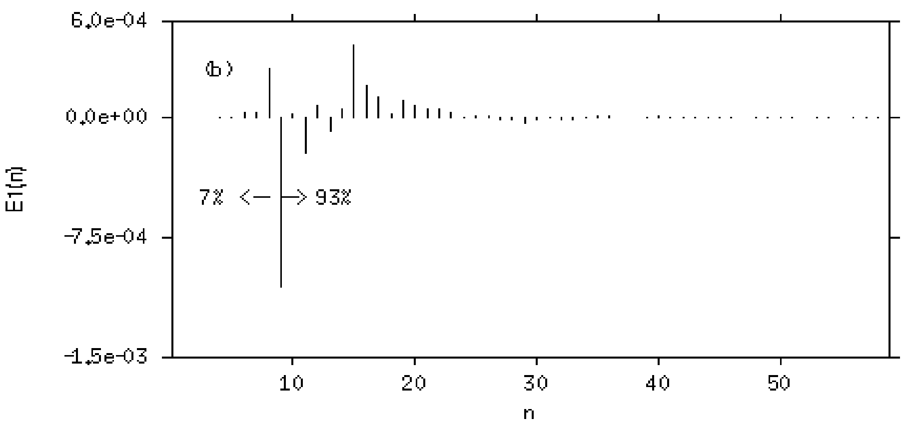
(5.4, 3.3, 2.4)



Narrow Band Channel Impulse Response

- Subband filtering using Quadrature Mirror Filter (QMF)
  32 subbands, bandwidth 161 MHz
- 5th subband, carrier frequency = 0.85 GHz

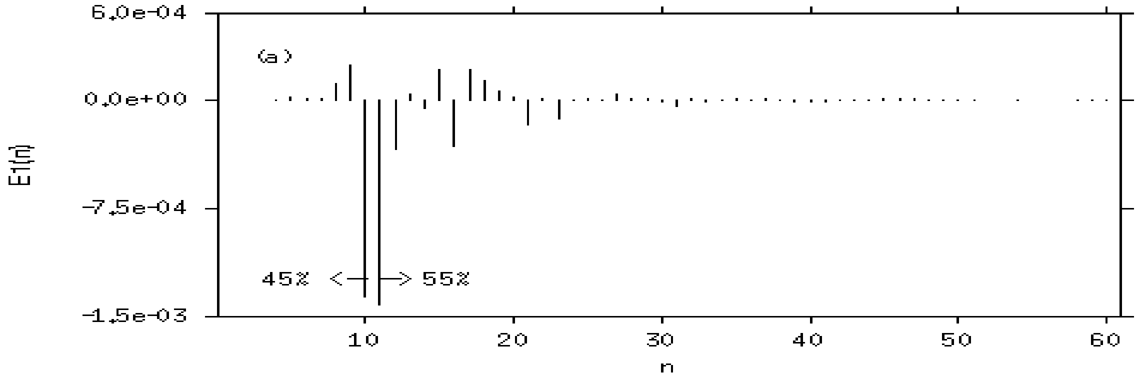




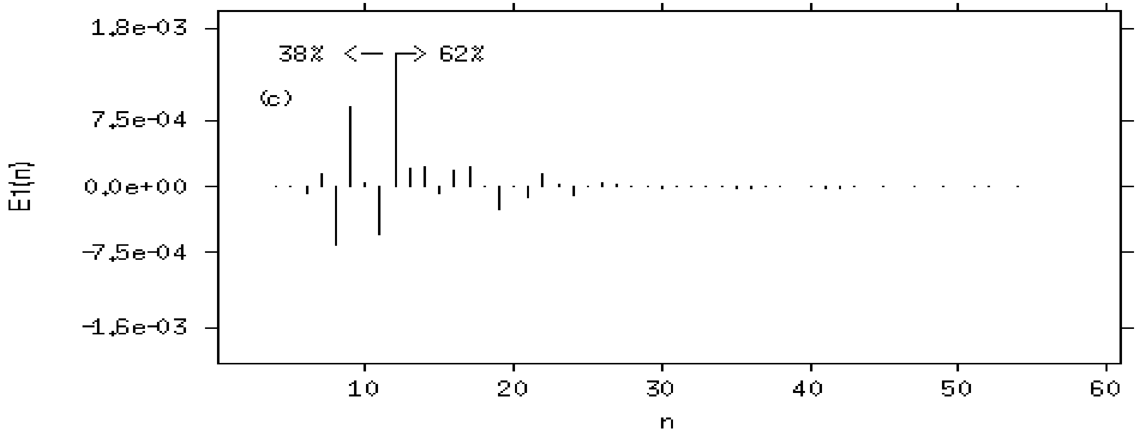
CIR Variation with Frequency

Location A:

- 5th subband, frequency 0.85 GHz



- 10th subband, frequency 2.11 GHz



Decision Feedback Equalizer

Issues:

- Convergence
  - Spectral behavior of input
  - Delay spread
  - Fading rate
- Variation in CIR amplitude and shape:
  - Observation location
  - Carrier Frequency
- Energy distributions in pre & post-cursor sections of CIR

Implementation:

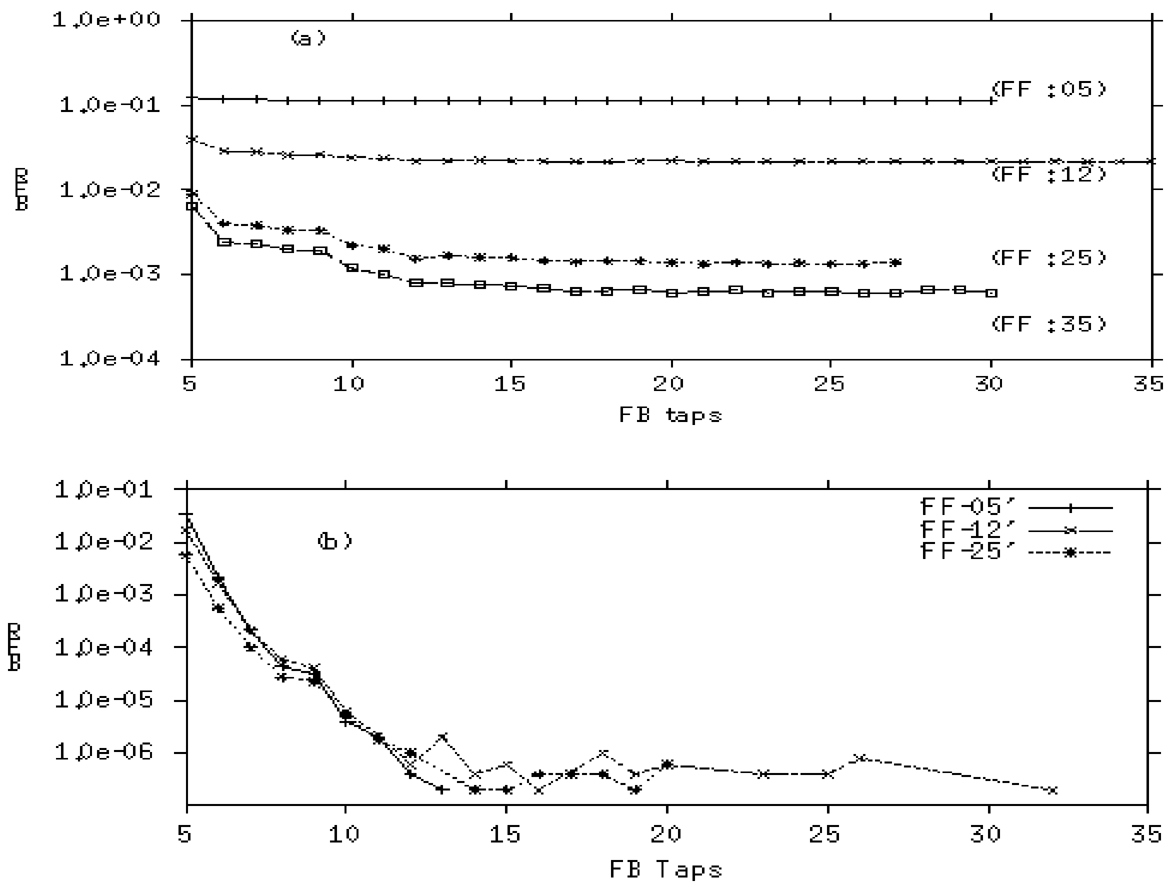
- Output

$$\hat{x}(n) = \sum_{i=-N_f+1}^{0} c_i x(n-i) + \sum_{i=1}^{N_b} c_i \tilde{x}(n-i)$$

- Coefficients estimation using least mean square (LMS) algorithm
- Modulation using Binary Phase Shift Keying (BPSK)

Results: Equalizer Performance

- Parameters: Training sequence = 25 microsec. $\mu = 10^{-4}$, Sampling interval 3.2 ns, Peak SNR = 12 dB



Conclusions

- CIR using Image Source Method
  - Provides spatial distribution of E-field
  - Length of CIR determines computational complexity
  - Coherent Region: Spatially varying
  - Diffuse Region: Stationary in space
- Impact of CIR in Equalizer Design
  - FF taps: Influenced by coherent region, $N_f > 15$
  - FB taps: Influenced by diffuse region, $N_b > 15$
  - Requires careful selection of channel delays
    - Influences FF convergence rate