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Wireless Communications Channels
Lecture 11: UWB Channels

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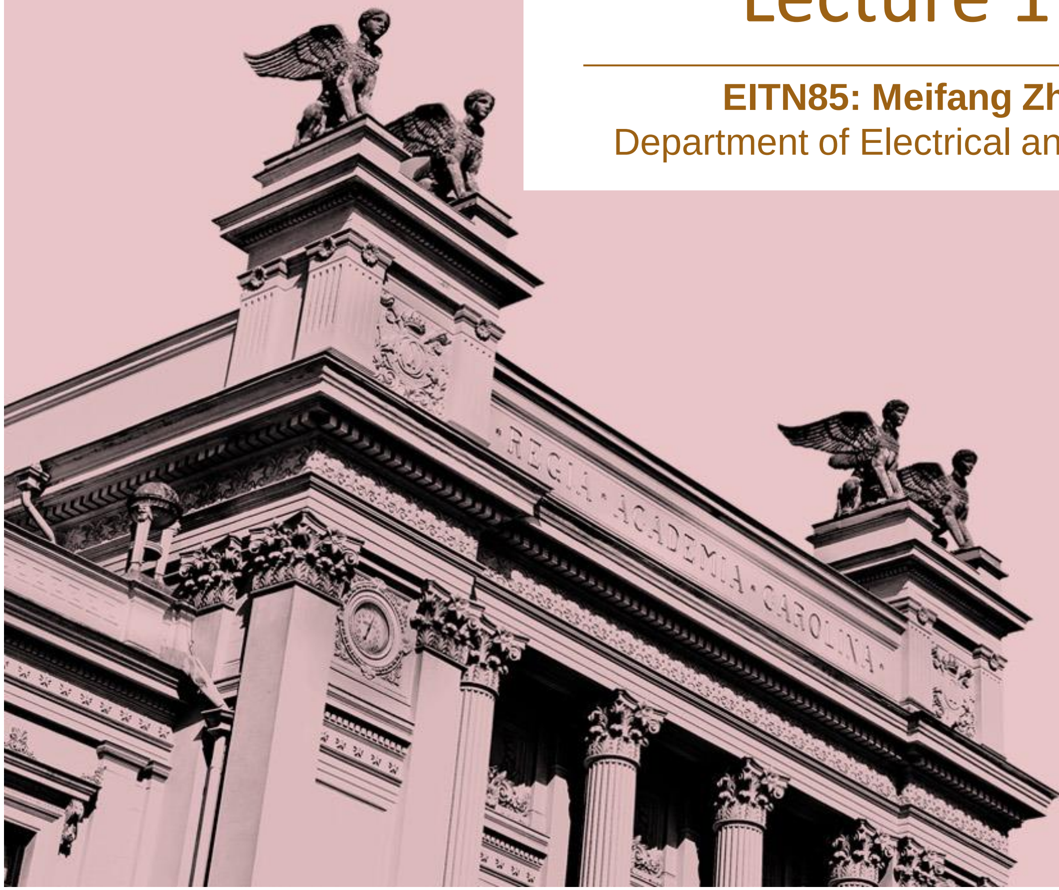

Overview

- What is Ultra-Wideband (UWB)?
- Why do we need UWB channel models?
- UWB channel modeling
- Summary

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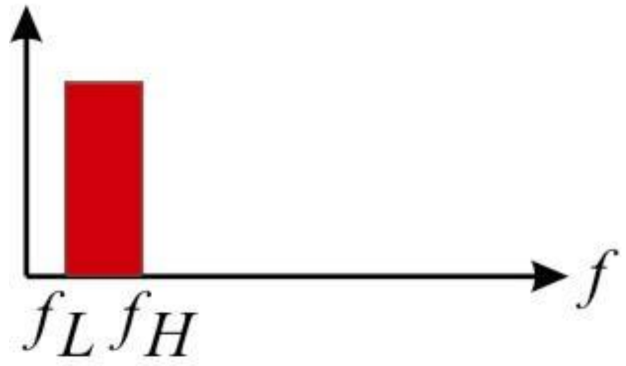
What is Ultra-Wideband (UWB)?

- Transmitted power is spread over an extremely large bandwidth
- Definition: Signals having
  $f_H - f_L > 500 \text{ MHz}$



Large Bandwidth Implications

- High resistance to fading
  - Fine delay resolution; impulse response resolved into many delay-bins
  - Fading within each delay-bin is smaller
  - Sum of all bins have even less fading
- Good ranging capability
- Good wall and floor penetration (for some frequency ranges)
  - Low-frequency components can go through material

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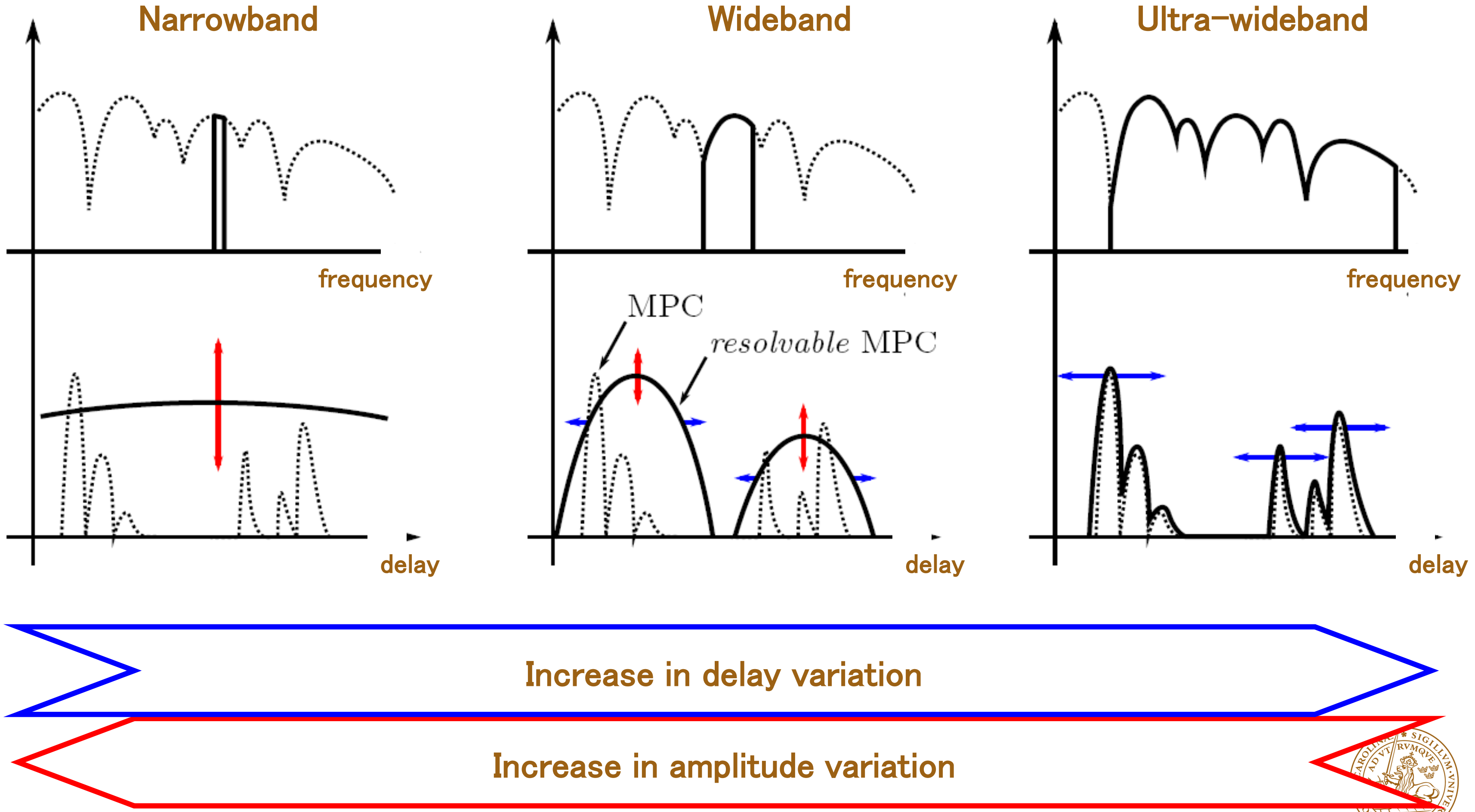
Implications of Higher Bandwidths



Two Possible UWB Techniques

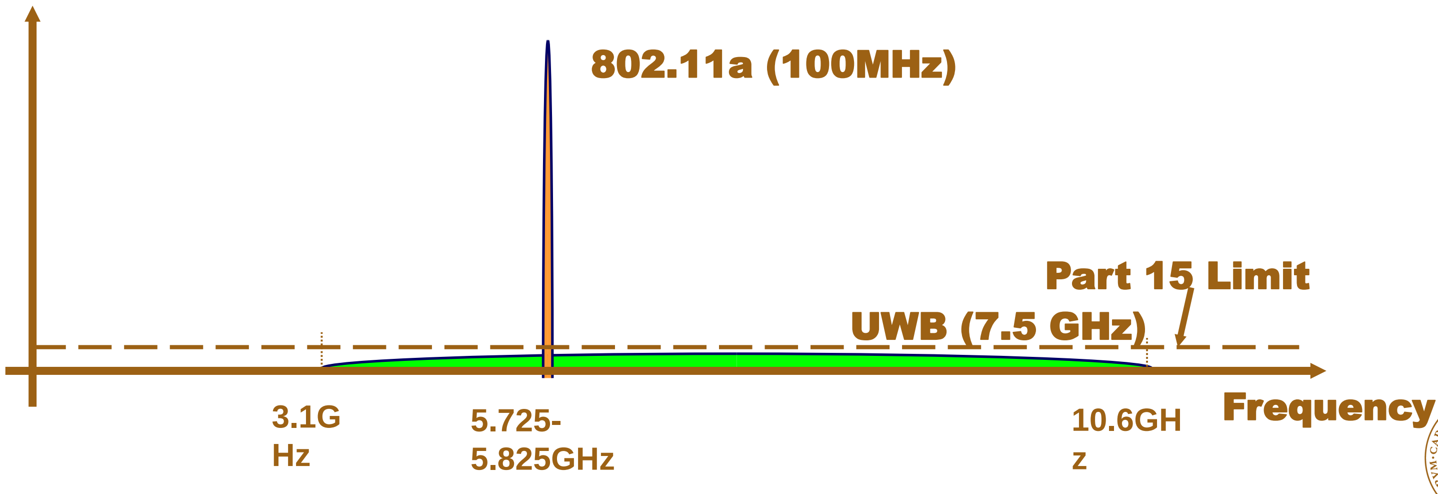
- **Pulse based UWB (impulse radio)**
  - Transmission through ultra short time domain pulses in the baseband
  - Evolution of the radar concept
  - Time hopping codes (Pulse Position Modulation)
- **Multiband OFDM**
  - OFDM-principle with frequency hopping in predefined subbands
  - Generation of UWB signals within carrier based systems
  - Especially for high data rate systems

Basic Principle

UWB makes use of same spectrum as existing services:

1. Information spread over wide spectrum; low power spectral density
2. Very low power

⇨ Small interference – looks like noise to other systems



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Applications

- Personal area networks
  - Small range
  - Home networks (residential and office environments)
  - Consumer electronics
- Positioning, sensor networks
- Other
  - Military applications (frequency range < 1GHz)
  - Through-wall radars

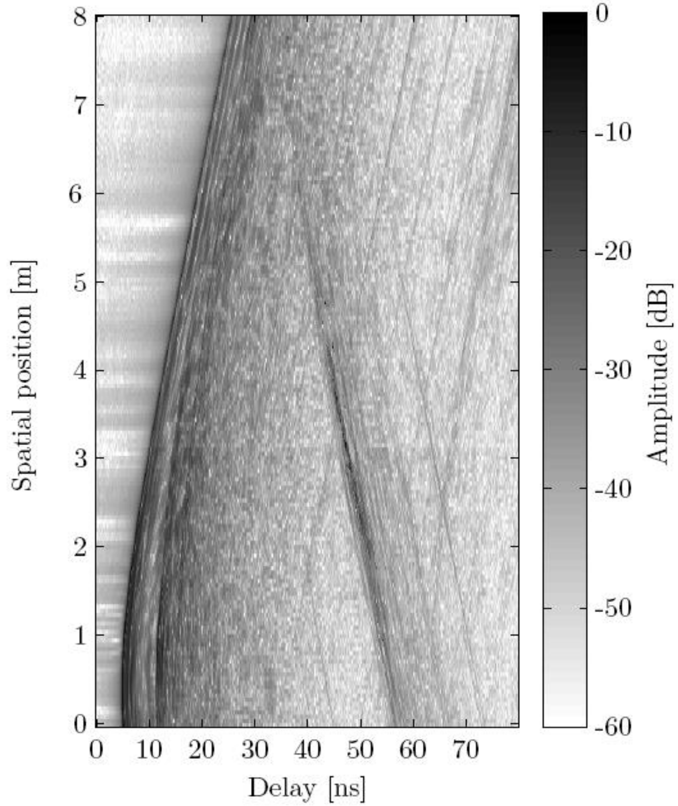
Narrowband vs. UWB Channel Models

- Assumptions about standard wireless channels:
  - "Narrowband" in the RF sense (bandwidth much smaller than carrier frequency
  - WSSUS assumption
  - Complex Gaussian fading (Rayleigh or Rice) in each delay tap
- Specialties of UWB channel:
  - Bandwidth comparable to carrier frequency
  - Different frequency components can "see" different reflection/ diffra
  - Few components per delay bin -> central limit theorem (Gaussian fading) not valid anymore

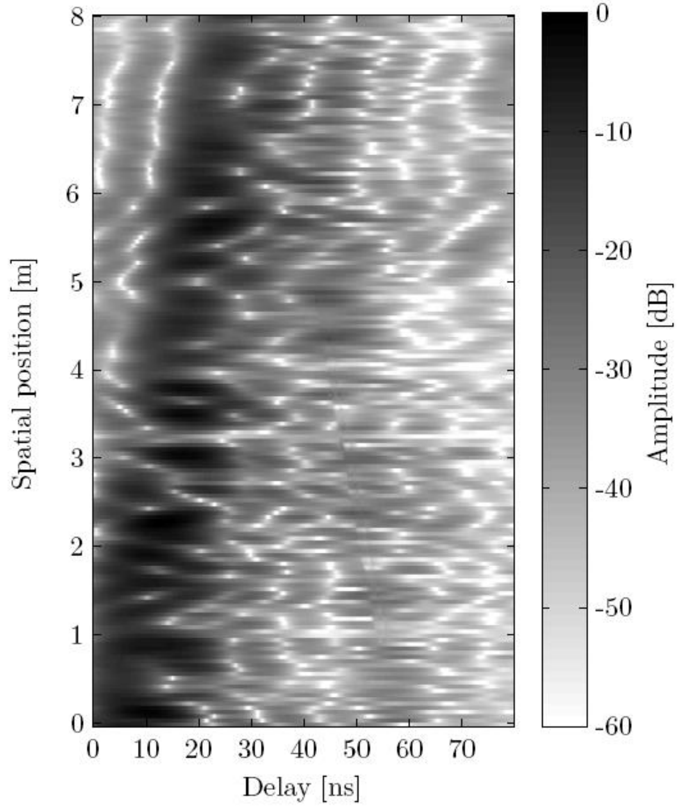
New channel models are needed!!

Bandwidth Effect on Delay Tap Amplitude

Ultra-wideband: 7.5 GHz



Wideband: 0.1 GHz



Ultra-wideband is immune to multipath.

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Propagation Processes

Fundamental propagation processes:

- Free space propagation
- Reflection and transmission
- Diffraction
- Diffuse scattering

All are frequency dependent!

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A Generic UWB Channel Model

- The classical tapped delay line model:

$$h(t,\tau) = \sum_{i=1}^{N} a_i(t)\,\delta(\tau - \tau_i)$$

- For UWB, each MPC show distortion:

$$h(t,\tau) = \sum_{i=1}^{N} a_i(t)\,\chi_i(t,\tau) \otimes \delta(\tau - \tau_i)$$

where $\chi_i(t,\tau)$ is the distortion function.

- Adjacent taps are influenced by a single physical scatterer ⇨ WSSUS assumption violated.

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Deterministic Modeling for UWB

- Interaction processes now all depend on frequency and/or direction
- Suggested solutions:
  - perform ray tracing at different frequencies, combine results
  - compute delay dispersion for each interaction process (possibly different for different directions), concatenate
- Combine deterministic rays with diffuse clutter (statistically described)

Statistical Channel Models

- Modeling of:
  - Pathloss (total power)
  - Large-scale effects
    - Shadowing
    - Delay dispersion (decay time constant)
    - Rice factor
    - Mean angle of arrival
  - Small-scale effects
    - Small-scale fading parameters

Modeling Path Gain

- Narrowband path gain:

$$G_{\text{path}}(d) = \frac{E\{P_{RX}(d, f_c)\}}{P_{TX}} = E\left\{|H(d, f_c)|^2\right\}$$

- For UWB channel, define frequency-dependent path gain:

$$G_{\text{path}}(d, f) = E\left\{\int_{f-\Delta f/2}^{f+\Delta f/2} \left|H\left(\tilde{f}, d\right)\right|^2 d\tilde{f}\right\}$$

- Simplified modeling:

$$G_{\text{path}}(d, f) = G_{\text{path}}(f)\, G_{\text{path}}(d)$$

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Modeling Path Gain (cont'd)

- Distance dependent path gain:

$$G_{\text{path}}(d)\big|_{\text{dB}} = G_{\text{path}}(d_0)\big|_{\text{dB}} - 10n\log_{10}\left(\frac{d}{d_0}\right)$$

  - Path loss exponent varies from building to building $\rightarrow$ can be modeled as a random variable

- Frequency dependent path gain:

$$\sqrt{G_{\text{path}}(f)} \propto f^{-\kappa}$$

  - κ varies between 0.8 and 1.4 (including antennas) and -1.4 and 1.5 (excluding antennas)

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Modeling Large-Scale Fading

Defined as the variations of the local mean around the path gain

- Commonly described as exhibiting a log-normal distribution
- Since large-scale fading is associated with diffraction and reflection effects, a frequency dependence would seem likely
- So far, measurements indicate no frequency dependence of shadowing variance

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Multi-Cluster Models

- How is a cluster determined?
- Definition: components of cluster undergo same physical processes
- Extraction from continuous measurements
- Visual extraction from looks of (small-scale-averaged) power delay profile
- Fitting to measurement data
  - Very sensitive to small changes
- Better resolution when spatial information is taken into account

Saleh-Valenzuela Model

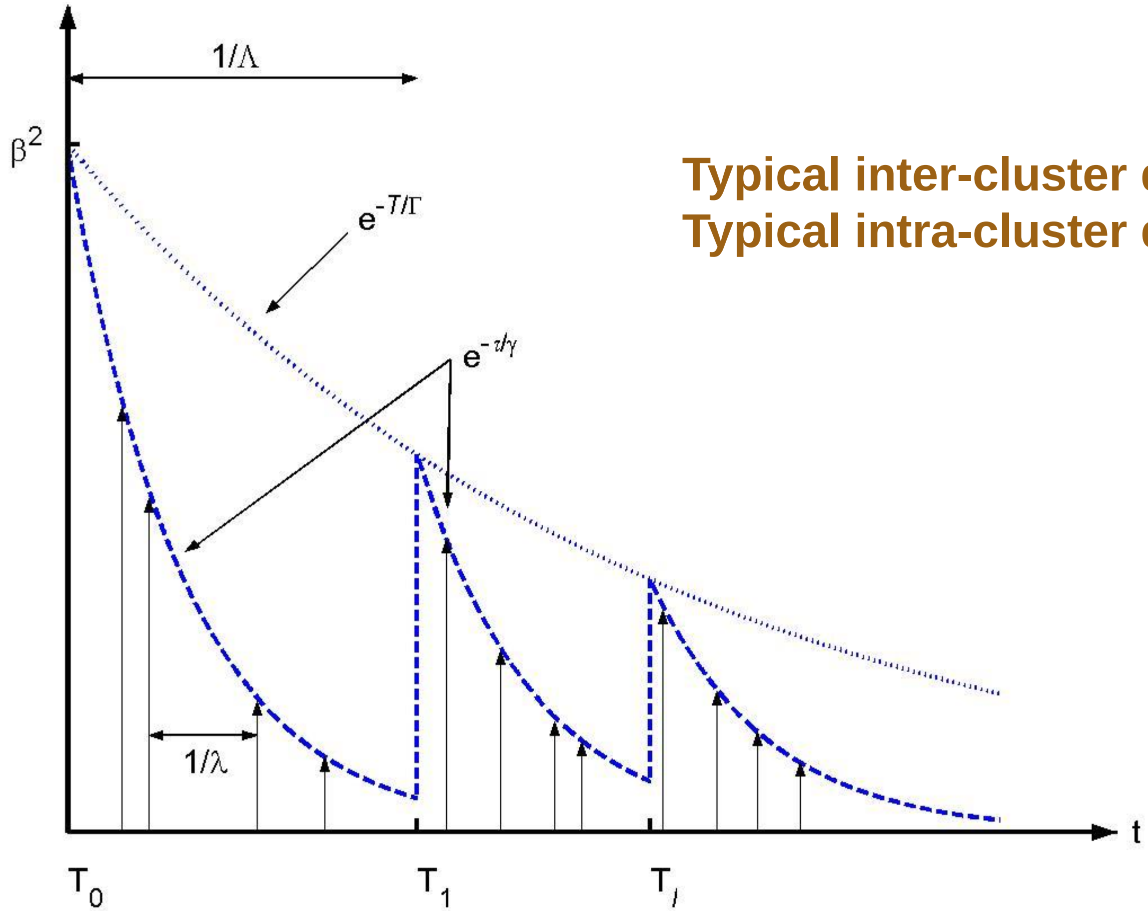
- Originally not for UWB [A.M. Saleh, R.A. Valenzuela, 1987]
- MPCs arrive in clusters
- Impulse responses given by

$$h(t) = \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \beta_{kl} e^{j\theta_{kl}} \delta(t - T_l - \tau_{kl})$$

$$\overline{\beta_{kl}^2} \equiv \overline{\beta^2(T_l, \tau_{kl})} = \overline{\beta^2(0,0)} e^{-T_l/\Gamma} e^{-\tau_{kl}/\gamma}$$

- Path interarrival times given by Poisson-distributed arrival process
- Different occurance rates for clusters (Λ) and rays (λ)

Saleh-Valenzuela Model (cont'd)



Typical inter-cluster decay: 10-30 ns
Typical intra-cluster decay: 1-60 ns

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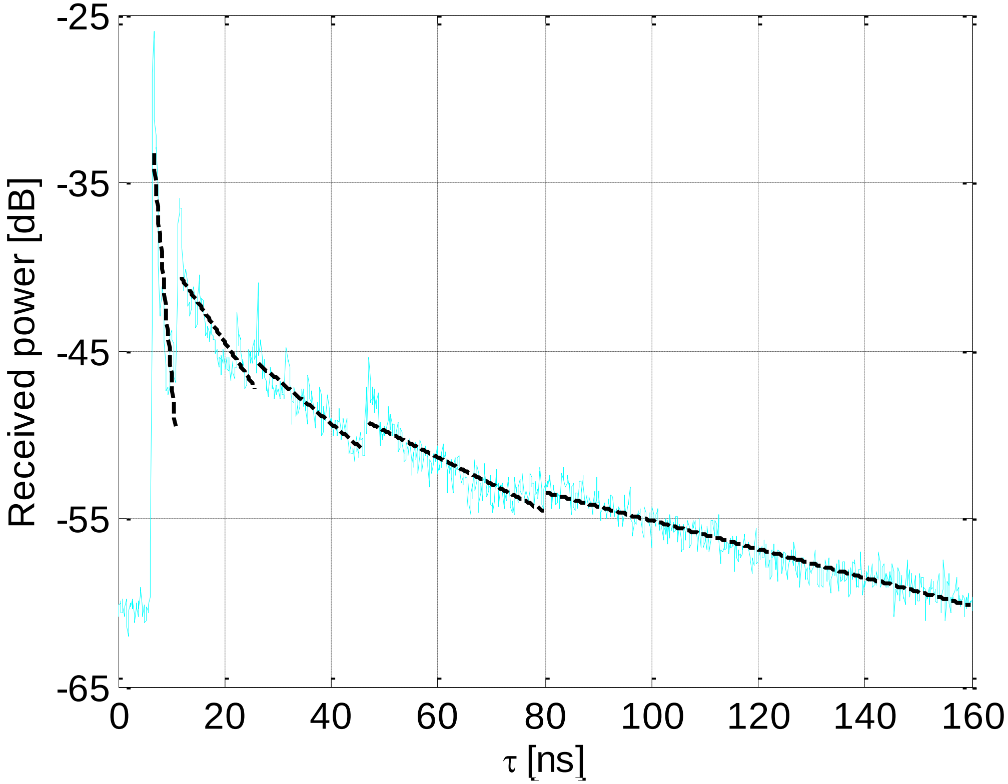
Measured Power Delay Profile (LOS)

From 2m LOS measurement in factory hall:



Generalizations

- Number of clusters as a random variable
- Cluster decay constants and arrival rates change with delay
- Ray arrival rates change with delay
- Cluster power varies due to shadowing
- Path interarrival times
  - Dense channel model - regularly spaced arrival times
  - Sparse channel model - Poisson arrival times

Small-Scale Fading Statistics

- Measurements report power within each bin being Gamma-distributed, amplitude is m-Nakagami distributed:

$$p(x) = \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^m x^{2m-1} \exp\left(-\frac{m}{\Omega}x^2\right)$$

  where m-factors are modeled as random variables

- Fading of delay bins is modeled as uncorrelated

- Phases modeled as uniformly distributed

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Summary

UWB is a promising area for

- home networks (consumer electronics)
- Positioning, sensor networks
- military applications

Fundamental differences of UWB channels to narrowband channels

- Propagation mechanisms processes are frequency dependent
- Different small-scale statistics of fading
- Sparse impulse responses occur

Standard channel models will not work for the UWB channel!

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