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Wireless Communications Channels

Lecture 11: UWB Channels

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Overview

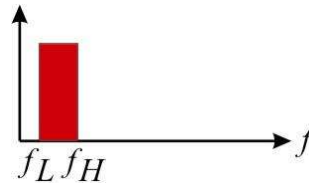
- What is Ultra-Wideband (UWB)?
- Why do we need UWB channel models?
- UWB channel modeling
- Summary

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What is Ultra-Wideband (UWB)?

- Transmitted power is spread over an extremely large bandwidth

- Definition: Signals having $f_H - f_L > 500$ MHz

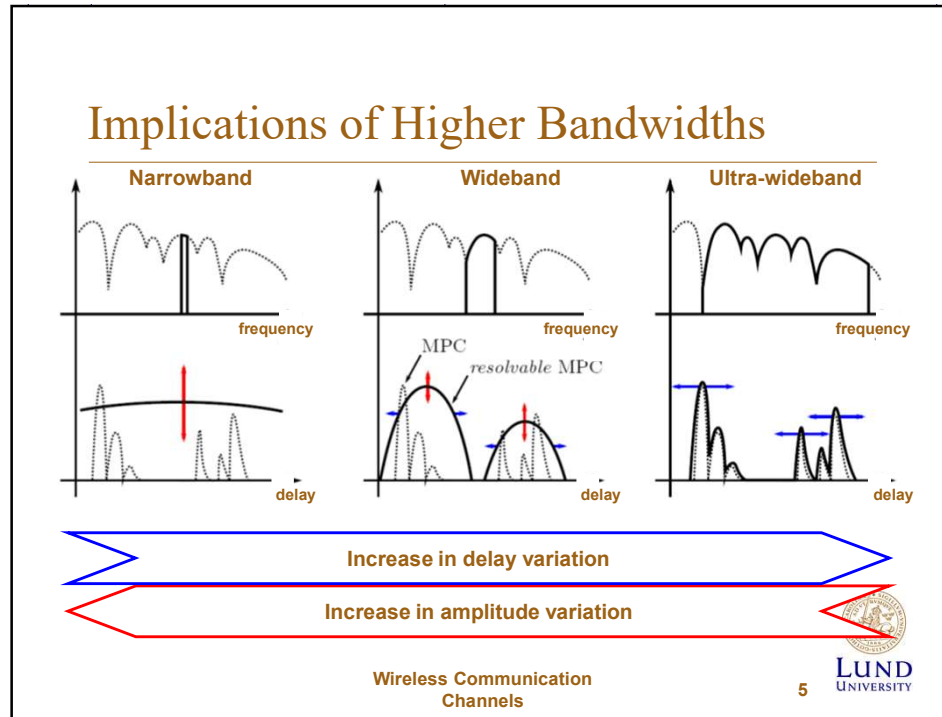


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Large Bandwidth Implications

- 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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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

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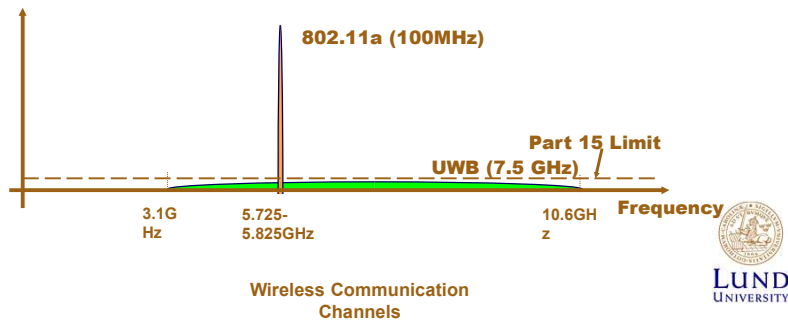
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Basic Principle

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

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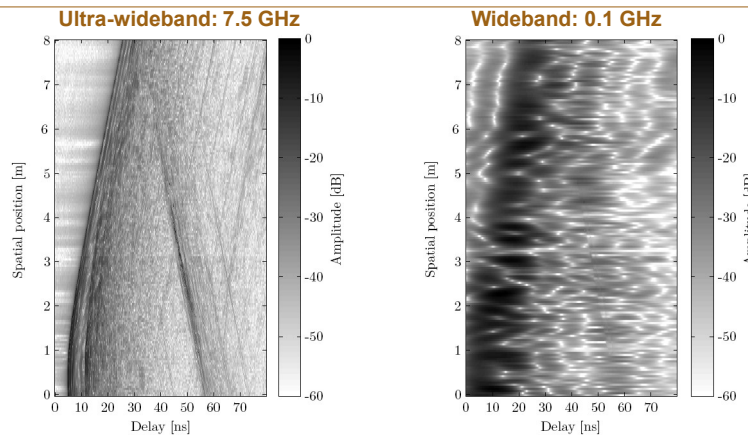
Narrowband vs. UWB Channel Models

- 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/diffraction
 - 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 is immune to multipath.



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 MPC \Leftrightarrow 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:

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

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

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

- Simplified modeling:

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

Modeling Path Gain (cont'd)

- Distance dependent path gain:

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

- Path loss exponent varies from building to building → 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)

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

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

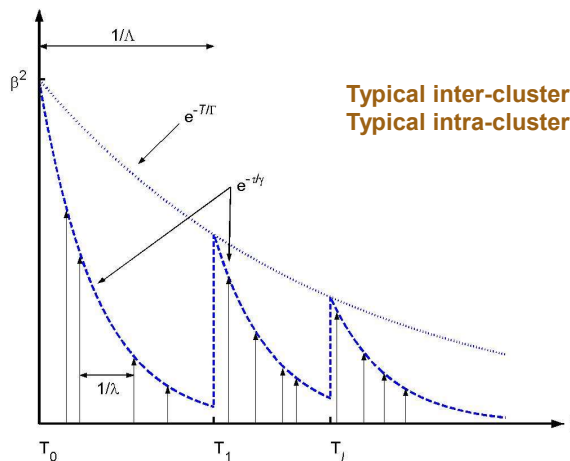
$$h(t) = \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \beta_{kl} e^{j\theta_{kl}} \delta(t - T_l - \tau_{kl})$$

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

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



Saleh-Valenzuela Model (cont'd)

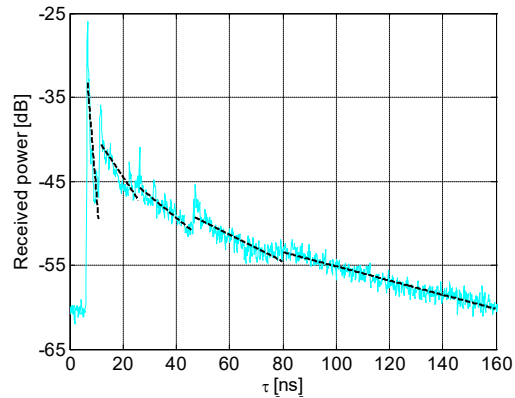


Typical inter-cluster decay: 10-30 ns
 Typical intra-cluster decay: 1-60 ns



Measured Power Delay Profile (LOS)

From 2m LOS measurement in factory hall:



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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

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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

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!

