Helsinki University of Technology
Communications Laboratory

60 GHz Radio Channel Modeling for WLANs

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I. Introduction

- 60 GHz frequency band has been proposed in IEEE 802.11 WLAN standard (lecture notes page 39).
- Multimedia and computer communications are playing an increasing role in today's society, future wireless communications are calling for higher and higher data rates.
- Due to large available bandwidth, 60 GHz frequency range can provide very high data rates up to a few hundreds of megabites/s, so it is capable for the aggregate multimedia applications of WLANs.

I. Introduction

- Radio propagation channel refers the medium between transmitter (TX) and receiver (RX) antennas.

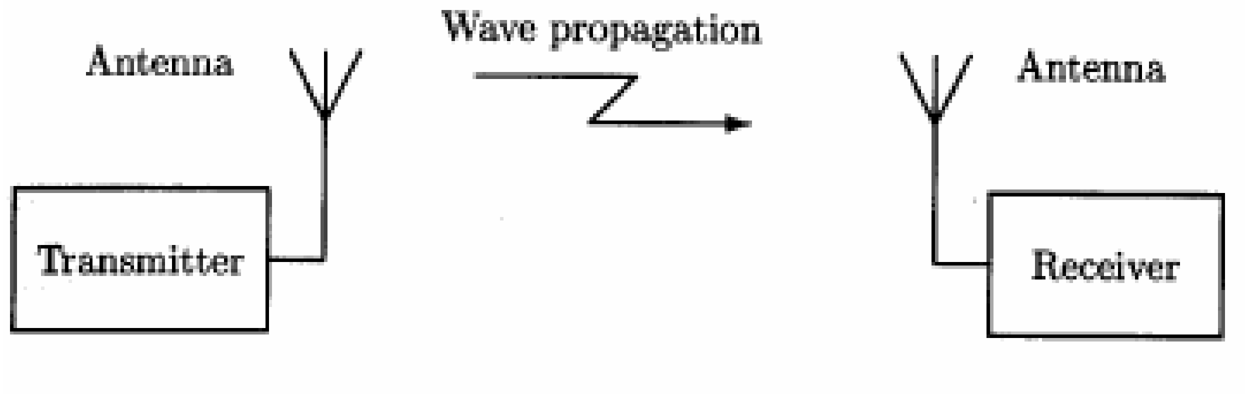


Fig. 1 Block diagram of a radio communication system

- Radio channel modeling play important role in providing information on the obtainable radio system capacity.

I. Introduction

- 60 GHz radio channel is mainly a multipath which results signal spreading in time (delay spread); due to relative motion in channel, each multipath wave experiences an apparent shift in frequency (Doppler spread).
- Signal fading (signal power drops off) due to three effects: Path loss, shadowing and multipath fading.
- Channel dispersion in time and frequency domains and signal fading are the main channel effects which are described below.
- The simulation results at 60 GHz were based on the measurement performed in the first floor of Department of Electrical and Communications Engineering of HUT.

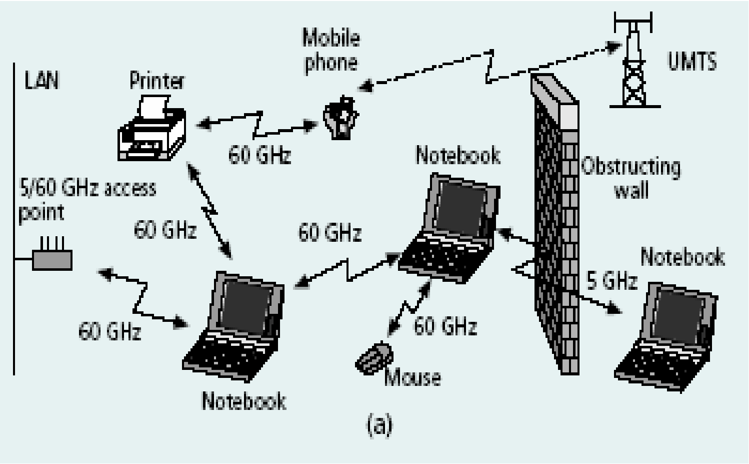
II. General features of 60 GHz channels

- At 60 GHz, the specific atmospheric oxygen attenuation is about of 15 dB/km, this band is of great interests for short range (< 100 m) of dense indoor communications.
- Due to the large amount spectrum is available, OFDM would be the most suitable transmission scheme.
- The wave propagations is quite similar to the light of wave, it suffers very severe shadowing phenomenon.
- The wavelengh is as small as 5 mm, so there is potential of small size of antennas and other part of radio systems.

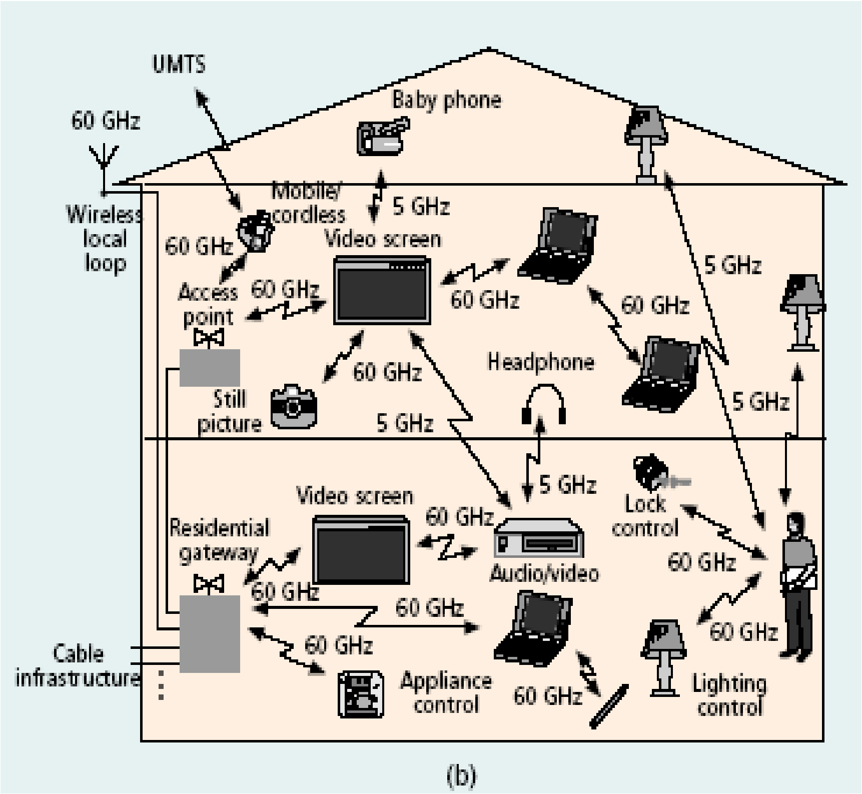
II. General features of 60 GHz channels

- An obvious option is to combine with lower band 5 GHz system for achieving interoperability.

5/60 GHz dual-band system scenario



Office environment

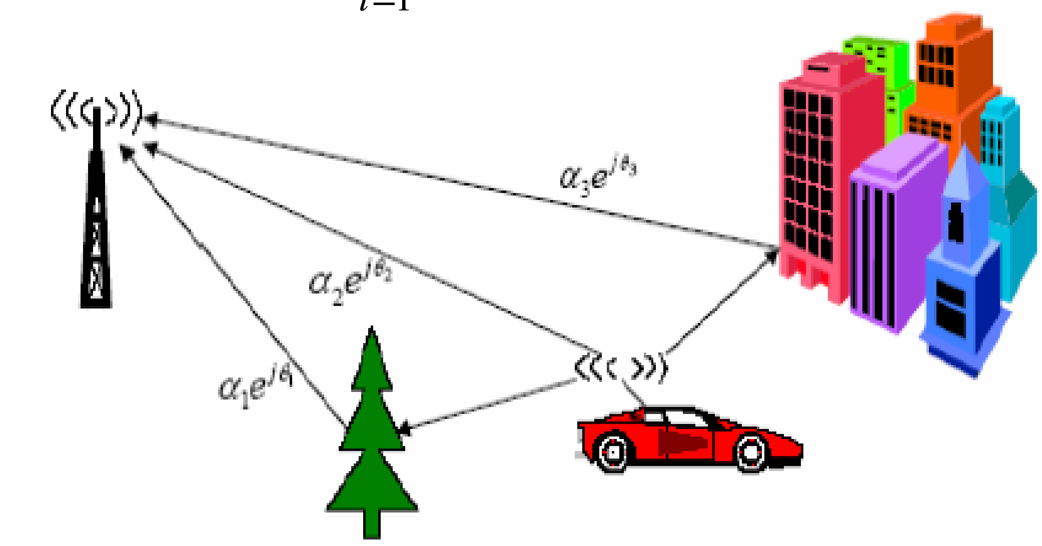


Home environment

III. Multipath channel characterization

- The impulse response (IR) of multipath channel can be expressed as

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



- Multipath components arrive RX via *N* directions, each with delayed version of complex strength $a_i e^{j\theta_i}$.

III. Multipath channel characterization

- In line-of-sight (LOS) environment: LOS plus several reflected or scattered rays which associated with scattering environment of large dimensions, smooth/metallic surface, or favorable incident-reflecting angle constellation.
- For analyzing small-scale multipath fading of channel, assumption of Wide Sense Stationary Uncorrelated Scattering (WSSUS) is often made, i.e., for short time intervals the channel IRs is considered time-invariant.
- However, over what range is valid is naturally an open question, there are indications that a few tens of wavelengths is a good estimate.
- Under WSSUS assumption, many channel parameters/models can be derived/developed.

III. Channel parameters

- Delay spread

  Span of path delays. Multipath channels are commonly quantified by mean excess delay and root mean square (rms) delay spread, define as

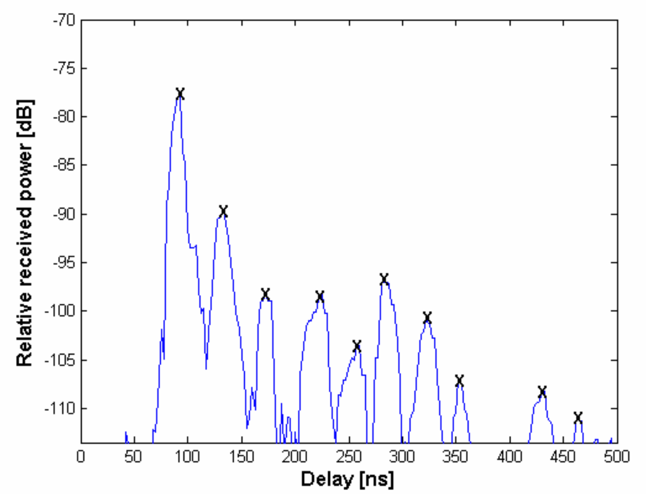
$$\bar{\tau} = \sum_k P(\tau_k)\tau_k \Big/ \sum_k P(\tau_k)$$

$$\sigma_\tau = \sqrt{\overline{\tau^2} - \left(\bar{\tau}\right)^2}$$

where $\sum_k P(\tau_k) = \sum_k h^2(\tau_k)$ and $\overline{\tau^2} = \sum_k P(\tau_k)\tau_k^2 \Big/ \sum_k P(\tau_k)$

III. Channel parameters

- Power delay profile (PDP)



A measured PDP at 60 GHz

- The main peaks denote the appearance of multipath components.
- At 60 GHz typical rms delay spread values are: 15~45 ns for small rooms, 45~ 70 ns for large indoor environments, the largest value was 100 ns.

III. Coherence bandwidth

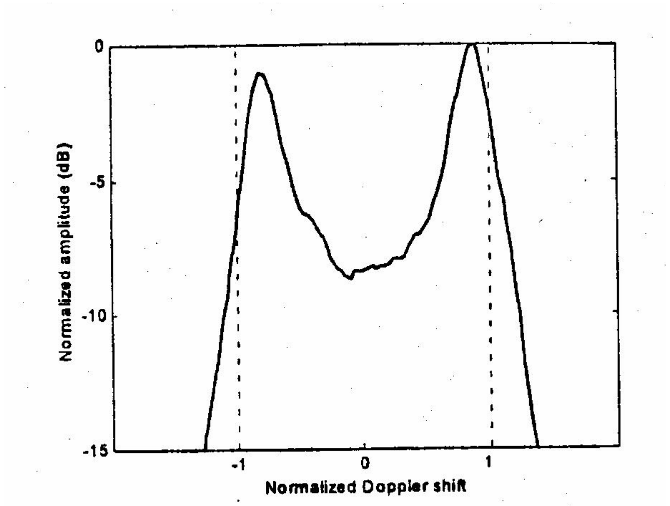
- Delay spread causes frequency selective fading of channel, i.e., different frequency components will subject to different attenuation and phase shift.
- Frequency selective fading can be characterized in terms of coherence bandwidth, which is the frequency range over which signals are correlated.
- PDP and spectral response of a mobile radio channel are related through the Fourier transform.
- Coherence bandwidth/rms delay spread are the equivalent description of the channel in frequency/time domains. Coherence bandwidth is inversely proportional to rms delay spread.

III. Doppler spectrum

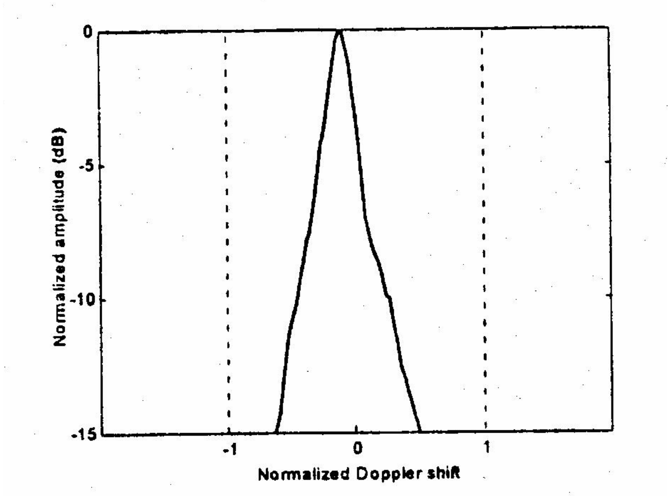
- Radio channel due to scatterers or TX/RX motion results in Doppler spread. The Fourier transform of the autocorrelation of the channel response is defined as Doppler spectrum.
- Doppler spectrum is dependent on the probability density function (pdf) of the angle of arrival (AOA) of the multipath components at the mobile unit with respect to the direction of motion of the mobile.
- If one assumes idealized, uniformly distributed scattering around a terminal, i.e., the AOAs is independent identically distributed (iid) over range of $[-\pi, \pi]$, Doppler spectrum shows U-shaped.
- However, in practice Doppler spectrum show variation from U-shaped.

III. Doppler spectrum

- Analysis of measured Doppler spectrum at 60 GHz



(a)

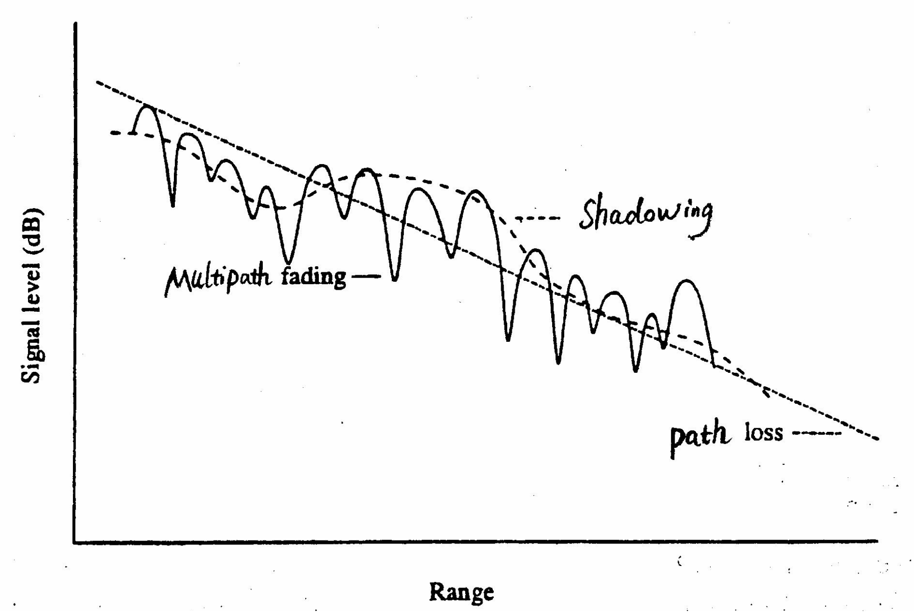


(b)

- ➢ Figure (a) shows large range of AOAs of the arriving signals.
- ➢ Obviously, narrow range of signal AOAs appear in case (b).

III. Channel models

- Radio wave propagation fading effects:
  - Path loss
  - Shadowing
  - Multipath fading



- Path (mean) loss, shadowing (long term) results from a blocking effect by buildings and natural features, multipath (short term) fading results from constructive and destructive combination of multipath.

III. Free space pathloss

- Pathloss is used to predict coverage area. The free-space pathloss as

$$PL(d) = 20\log(4\pi d/\lambda)$$

In dB $$PL[dB] = 32.45 + 20\log f[GHz] + 20\log d[m]$$

- Path loss values represent the signal power loss from TX to RX antennas, do not depend on the antenna gains or the transmitted power levels.
- In free space at 60 GHz, at $d = 1$ m, pathloss is 68 dB.

III. Pathloss models

- Log-normal shadowing model

$$PL(d) = \overline{PL}(d_0) + 10n\log(d/d_0) + X_\sigma$$

  - where X_σ is a zero-mean Gaussian variable with standard deviation σ, d_0 is the reference distance, 1 m is often taken in indoor environments.

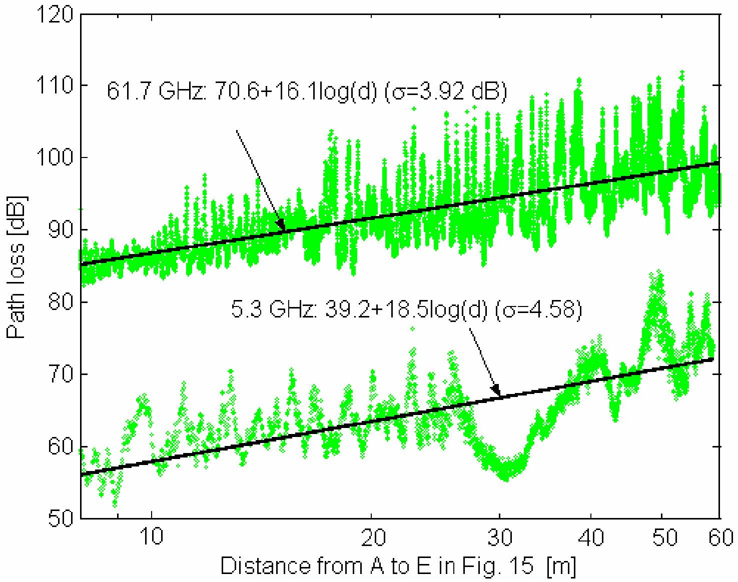
- Slope-intercept model

$$PL(d) = b + 10n\log_{10}(d)$$

  - Avoids choosing the value of d_0, instead extracting the slope (n) and intercept (b) values directly in semi-log coordinates from measured data.

III. Pathloss models

- Comparison of pathloss models at 60 and 5 GHz



- Path loss is higher at 61.7 GHz, e.g, at $d = 10$m, total difference is 29 dB, which is larger than 21 dB difference in free space loss.
- The fluctuation of path loss is proportional to the frequency.

III. Shadowing

- Shadowing effect caused by a terminal moving behind a building/hill.

  It is determined by local mean of received signal, i.e., the received power averaged over some ranges approaches a log-normal distribution

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

- where **x** (in decibels) is a random variable, μ and σ are the mean and standard deviation (STD) of **x,** they are also expressed in decibles.
- μ is equal to distance dependent path loss, σ varies with frequency and environment, a tendency of increasing with frequency, σ range is 8-12 dB.

III. Multipath fading

- In a multipath environment, received signal is a summation of multipath components, the probability density function (PDF) of received signal amplitude (*r*) normally follows Rayleigh and Rice distributions

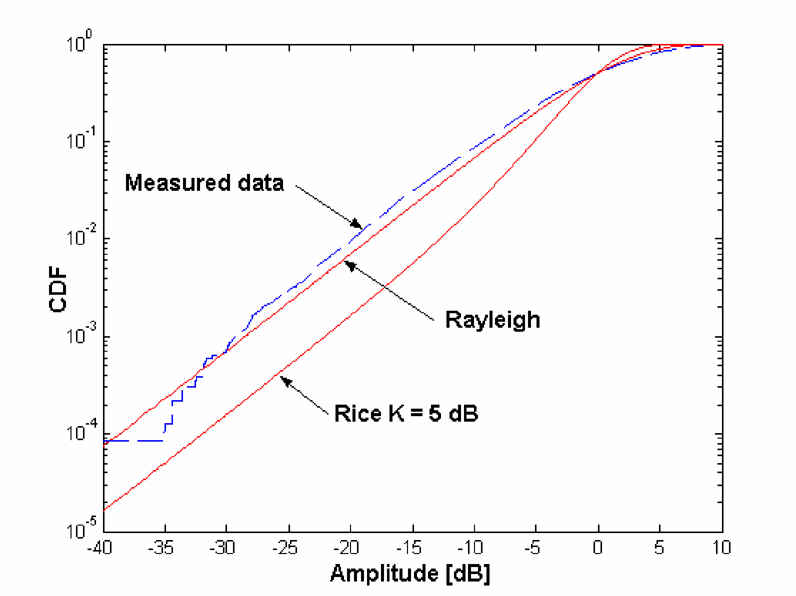
$$p(r) = \frac{r}{\sigma^2} e^{-r^2/2\sigma^2}$$

$$p(r) = \frac{r}{\sigma^2} e^{-\left(r^2 + A^2\right)/2\sigma^2} I_0\left(Ar/\sigma^2\right)$$

- Assume multipath phase is uniform distributed over $[-\pi, \pi]$.
- Rayleigh & Rice distributions often used in NLOS and LOS environments.
- Rice-*K* factor defined: $K = A^2/2\sigma^2$. $I_0(x)$ is zero order Bessel function.

III. Multipath fading

- Cumulative density function (CDF) of signal amplitude [in dB]



➢ It follows Rayleigh distribution. CDFs are plotted with signal levels relative to median value.

IV. Summary

- 60 GHz radio channel modeling can provide useful information for the design of future WLANs.
- Multipath is very severe in 60 GHz radio channels, which causes signal dispersion in both time and frequency domains. The general properties of delay spread and Doppler spread were investigated.
- Three different fading effects: pathloss, shadowing and multipath fading are also studied in the 60 GHz frequency band.

V. References

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[5] J. Kivinen, X. Zhao, and P. Vainikainen, "Wideband indoor radio channel measurements with direction of arrival estimations in the 5 GHz band," *Proc. VTC'99*, vol. 4, pp. 2308-2312, Amsterdam, The Netherlands, Sept. 19-22, 1999.

Homework

- The probability density function of a Rayleigh distributed is given by

$$p(r) = \frac{r}{\sigma^2} e^{-r^2/2\sigma^2}$$

where σ^2 is the variance. Show that the cumulative distribution function (CDF) is as

$$p(r \le R) = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right)$$

Also find the percentage of time that a signal is 10 dB or more below the rms value for a Rayleigh fading signal.