Lec6

Monday, January 20, 2020 10:17 AM

Main results - 20min

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More specifically, following the multipath model earlier

xmitted signal $E_T e^{j\omega_c t} = S(t)$

k-th path $a_k E_T e^{j(\omega_c t - \phi_k)}$

Both a_k, ϕ_k are stochastic processes.

Total received signal

$$a(t) = E_T \sum_k a_k e^{j(\omega_c t - \phi_k)}$$

As in 2-ray model, the phase randomness dominates

Two components for ϕ_k:

① travel distance

Different paths travel different distance, which leads to dispersion in the time-shift (or delay) τ_k

$$\Rightarrow \theta_k = \omega_c \tau_k = 2\pi f_c \tau_k$$

Define the delay-spread as the difference in delay between the first path & the last path

Typical values for delay-spread:

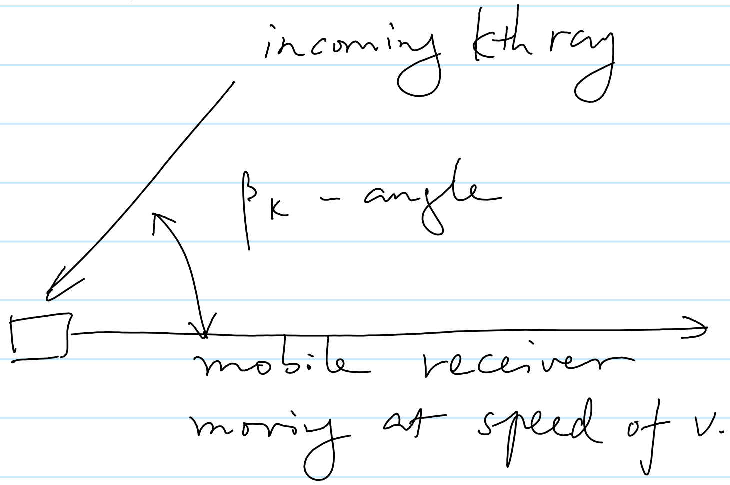
0.2 ~ 0.5 μsec in suburban areas

3 ~ 8 μsec in urban areas

The effect of this time-dispersion will be manifested by frequency-selectivity, since different frequency-component sees different amount of phase shift.

It also leads to inter-symbol interference

② doppler effect



Doppler effect leads to a frequency-shift

$$f_K = \frac{v \cos \beta_K}{\lambda}$$

$$\Rightarrow \quad \omega_k t = 2\pi f_k t = 2\pi \frac{v \cos \beta_K}{\lambda} t.$$

$$\Rightarrow \quad \omega_k t = 2\pi f_k t = 2\pi \frac{v\cos\beta_k}{\lambda} t.$$

Different paths can have diffent f_k due to angle of arrival.

Maximum doppler shift is given by

$$f_m = \frac{v}{\lambda}$$

e.g. $v = 100\,km/hr = 28\,m/s$

$f_c = 1\,GHz \Rightarrow \lambda = 0.3\,m$

$f_m = 90\,Hz$

phase change by 2π every $\frac{1}{90}$ sec

if $v = 0.1\,m/s \rightarrow f_m = 0.33\,Hz$

if $f_c = 30\,GHz \Rightarrow \lambda = 0.01\,m$, $v = 0.1\,m/s$

$\rightarrow f_m = 10\,Hz$

The effect of this doppler shift will be manifested by time-selectivity, since the value of the phase shift changes in time.

In summary:

- Delay spread determines the frequency-

- Delay spread determines the frequency-selectivity of the channel

- Doppler shift determines the rate of fading in time.

Sketch of the main intuition:

As a rough estimate, consider the case when τ_k & f_k are deterministic (non-random)

Effect of τ_k:

Consider two frequency component f_c & $f_c + \Delta f$

The phase difference (of two paths) will vary by $2\pi \Delta f \cdot \tau_k$ at these two frequencies.

If $2\pi \Delta f \tau_k = \pi$, significant variations of the fading levels will be observed by the two frequency components

$\Leftrightarrow \Delta f = \frac{1}{2\tau_k}$ coherenent bandwidth

It determines the frequency-selectivity of the channel.

× If signal BW $B > \Delta f$, will experience freq-selective channel.

Effect of f_K

Consider two time instants $t, \; t + \Delta t$

The phase difference (of two paths) will vary by $2\pi f_K \Delta t$ at these two time instants.

If $2\pi f_K \Delta t = \pi$, significant variations of the fading levels will be observed at these times.

$$\Leftrightarrow \quad \Delta t = \frac{1}{2 f_K} \quad \text{coherent-time}$$

It determines the time-selectivity (or rate of fading)

When f_K, τ_K are random, the correct approach is to study correlation in frequency & time

$$f, \; f + \Delta f$$
$$t, \; t + \Delta t$$

$\rho_a(\Delta t, \Delta f)$ — correlation coefficient as a function of Δt & Δf.

See Schwartz ch 2.5, in particular (2.46)

① Delay spread τ_{av}

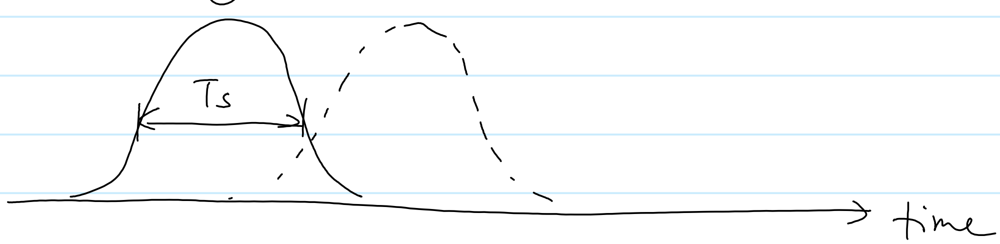
— standard deviation of τ_k

Coherent bw: $\Delta f = \frac{1}{2\pi \tau_{av}}$

If $B > \frac{1}{2\pi \tau_{av}}$, freq-selective fading

$\Leftrightarrow$ $T_s < 2\pi \tau_{av} \approx 6 \tau_{av}$

Inter-symbol interference occurs when the symbol duration is less than 6 times of the delay spread.



If $B < \frac{1}{2\pi \tau_{av}}$ flat fading

If $B \gg \frac{1}{2\pi \tau_{av}}$ $\Leftrightarrow$ $T_s \ll 2\pi \tau_{av}$

— wide-band signal

— different path can be individually resolved (in CDMA)

— like "echos"

(2) Doppler shift

— f_m : max doppler shift

$$f_m = \frac{v}{\lambda}$$

Coherence time :

$$\delta t = \frac{9}{8\omega_m} = \frac{9}{16\pi f_m} \approx 0.18/f_m$$

If $T_B > \Delta T = \frac{1}{5.6 f_m}$, distortion within duration of a block occurs

— time-selective fading

Summary

	flat	freq-selective
slow		
time-selective (fast)		

Depending on the value of the coherent bw & coherent time,

the channel can fall into
one of these four categories

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Summary

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Delay Spread: T_{av} 0.2 – 0.5 μs, 3 – 8 μs

Coherent bandwidth: $\Delta f = \frac{1}{2\pi T_{av}}$

frequency

time	flat	freq-selective
slow		$B > \Delta f \Leftrightarrow T_s < 2\pi T_{av}$ Inter-symbol interference
(time-selective) fast	$T > \Delta t$	

Doppler shift (velocity)

$$f_m = \frac{v}{\lambda}$$

Coherent time

$$\Delta t = \frac{9}{16\pi f_m} = \frac{0.18}{f_m}$$

Example - 10min

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Frequency-selective versus flat:

① Data rate 10kbps,

Assuming binary modulation

$$B = 10\text{kHz}$$

$$T_s = \frac{1}{B} = 0.1\text{msec}$$

Condition for frequency-selective fading

$$\text{delay spread} > \frac{T}{2\pi} = 0.016\text{ msec}$$

unlikely even in urban environment (delay spread 3-8 μsec)

$\Rightarrow$ flat-fading

② Data rate 200kbps, $B = 200\text{kHz}$

$$T_s = \frac{1}{B} = 5\mu\text{sec}$$

need

$$\text{delay spread} > \frac{T}{2\pi} = 0.8\mu\text{sec}$$

$\Rightarrow$ frequency-selective fading

(3) Data rate 54Mbps, $B = 54$ MHz

$$T_s = \frac{1}{B} = 18.5 \text{ nsec}$$

need

$$\text{delay spread} > \frac{T}{2\pi} = 2.9 \text{ nsec}$$

$\Rightarrow$ frequency-selective fading, each path can be resolved individually (with CDMA) – like echoing

- In general, larger B and shorter T_s are more likely to experience frequency selective fading.
- Where does OFDM stand?

Rate of fading:

$v = 100$ km/hr $= 28$ m/s

$f_c = 1$ GHz $\Rightarrow \lambda = 0.3$ m

$$f_m = \frac{v}{\lambda} = 90 \text{ Hz}$$

Coherence time

$$0.18 / f_m = 2 \text{ ms}$$

(T)

if $v = 0.1$ ms $\quad f_m = 0.33$ Hz

if $v = 0.1 \, m/s$ $\quad f_m = 0.33 \, Hz$

$$\Delta\tau = 0.18 / f_m = 0.55 \, s$$

if $v = 0.1 \, m/s$ $\quad \lambda = 0.01 \, m$

$$f_m = \frac{v}{\lambda} = 10$$

$$\Delta\tau = 0.18 / f_m = 0.018 \, s$$

- In general, larger velocity and higher frequency band are more likely to experience fast fading.

Fade duration - 5min

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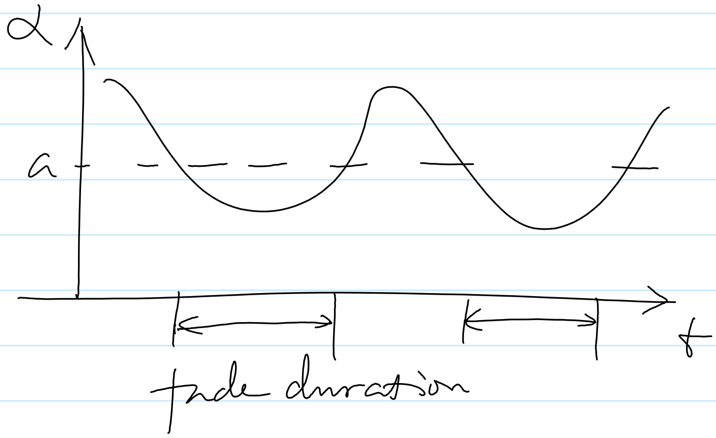
- The amount of time the multipath fading component α is below a particular level a.



"deep fade"

- Closely related to coherent time
- determined by doppler shift.

see Schwartz Ch 2.4

$$\tau_f = \frac{e^{\rho^2} - 1}{\rho f_m \sqrt{2\pi}}$$

where $f_m = \frac{v}{\lambda}$ is max doppler shift

$\rho = \frac{a}{\sqrt{E(\alpha^2)}}$ is determined by the fading level we are interested in.

Example: $v = 100 km/hr = 28 m/sec$

$f_c = 1\ GHz$, $\lambda = 0.3\ m$

$f_m = \frac{v}{\lambda} = 90\ Hz$

If $\rho = 1$, $\tau_f = \frac{0.7}{f_m} = 8\ msec$

$\rho = 0.3$ $\tau_f = 1\ msec$

If $v = 5\ km/hr$, these numbers ↑.

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How to deal with fading? - 10min

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Or, is fading a good thing, or a bad thing?

As we discussed at the introduction, you can either

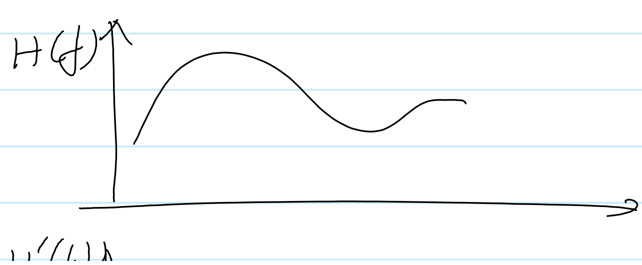
① do nothing

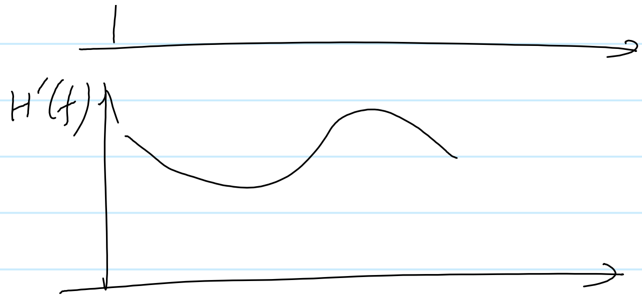
② work against fading

③ exploit fading : diversity

<u>General fading</u> Mitigation techniques → ②

- Power control
  - good for slow fading
- Repetition/coding
- Interleaving
  - good for fast-fading
- Equalization
  - for freq-selective channels

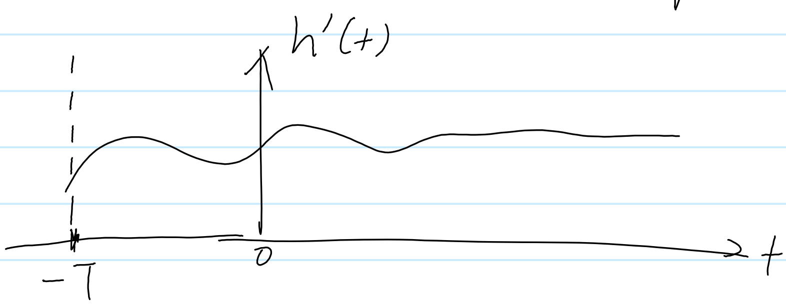




⇓

$H(f)\,H'(f) = C$

$H'(f)$ may correspond to non-causal impulse response



- either unrealizable
- or need large time delay

Special techniques to address a particular type of fading → (3)

- Rake receiver
- OFDM
- Opportunistic Scheduling
- MIMO

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Opportunistic scheduling

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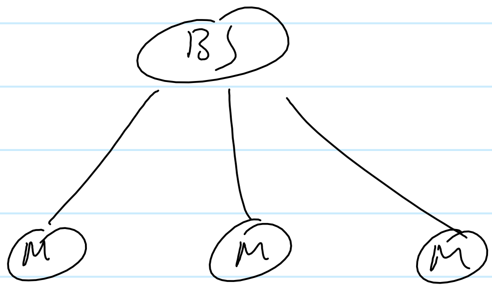
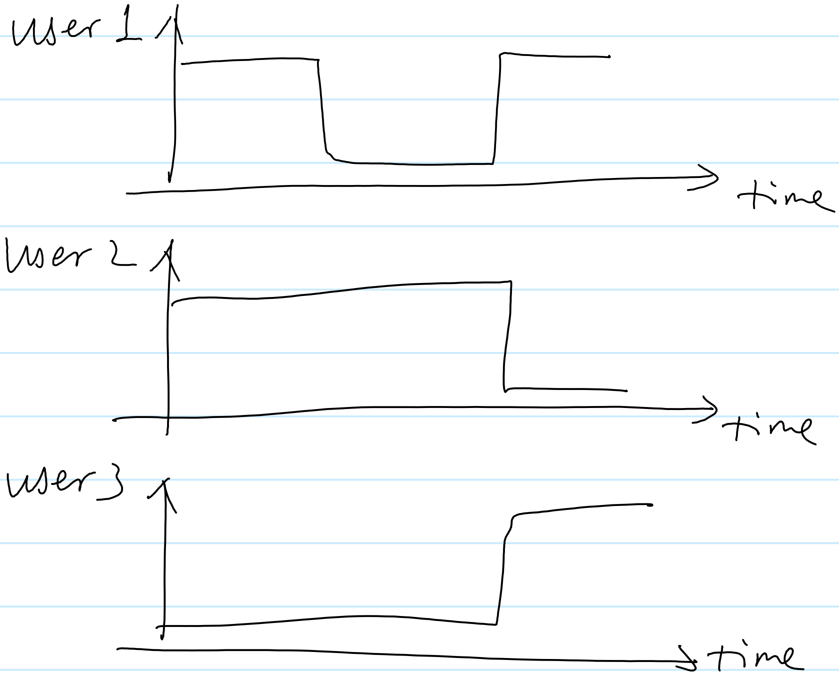
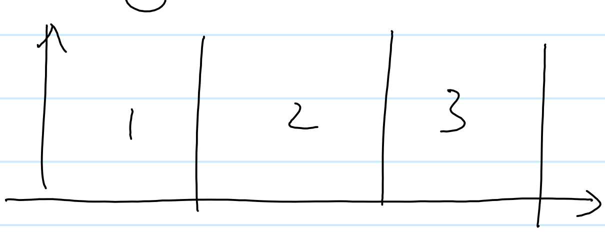
When there are multiple receivers, the BS can schedule the receiver with the best SINR

— opportunistic scheduling





Scheduling decision



Improves overall data throughput

However, this also increases the delay for the poor user.

45 Good if the coherence time is larger than the time to estimate the channel condition, but shorter than the delay that the application can tolerate.

OFDM

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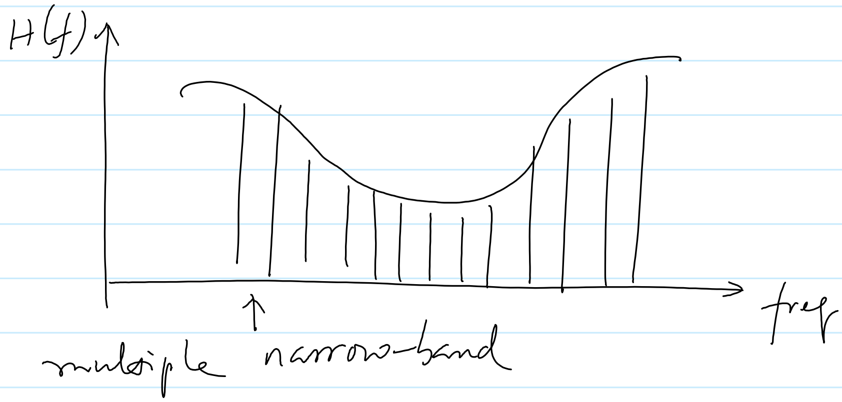
In order to combat frequency selective fading, OFDM transmits data simultaneously over multiple narrow-band carrier frequencies that are closely apart.



Each carrier freq faces a flat channel. (lower symbol rate)

- smaller signal distortion / ISI

(4D)

- OFDMA schedules data on better sub-carriers