Wireless Physical Layer Concepts: Part III

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These slides are available on-line at:
http://www.cse.wustl.edu/~jain/cse574-08/

1. Empirical Channel Models
2. Multi-Antenna Systems: Beam forming and MIMO
3. Space-Time Block Codes
4. Time Division Duplexing
5. OFDM, OFDMA, SOFDMA

Empirical Channel Models

Based on measured data in the field

1. Hata Model
2. COST 231 Extension to Hata Model
3. COST 231-Walfish-Ikegami Model
4. Erceg Model
5. Stanford University Interim (SUI) Models
6. ITU Path Loss Models

Hata Model

$$P_{L,urban}(d)dB = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d)$$

- Based on 1968 measurement in Tokyo by Okumura
- Closed form expression by Hata in 1980
- f_c = carrier frequency,
  h_t = height of the transmitting (base station) antenna,
  h_r = height of the receiving (mobile) antenna
  a() = correction factor for the mobile antenna height based on the size of the coverage area
- Designed for 150-1500 MHz

COST 231 Extension to Hata Model

$$P_{L,urban}(d)dB = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d) + C_M$$

- European Cooperative for Scientific and Technical (COST)
- Extended Hata model to 2 GHz:
- C_M = 0 dB for medium sized cities and suburbs
  = 3 dB for metropolitan areas
- Other Parameters:
  - Carrier Frequency: 1.5 GHz to 2 GHz
  - Base Antenna Height: 30 m to 300 m
  - Mobile Antenna Height: 1m to 10 m
  - Distance: 1 km to 20 km

COST 231-Walfish-Ikegami Model

- Combining with models proposed by Walfisch and Ikegami
- Considers additional characteristics of the urban environment:
  - Heights of buildings
  - Width of roads
  - Building separation
  - Road orientation with respect to the direct radio path
- Distinguishes LoS and NLoS. For LoS, the total path loss is:

$$P_L dB = 42.6 + 26\log(d) + 20\log(f_c)$$

- Other Parameters:
  - Carrier frequency: 800–2,000 MHz
  - Height of BS antenna: 4–50m
  - Height of MS antenna: 1–3m
  - Distance: 0.02–5km

Erceg Model

- Experimental data collected by AT&T Wireless Services across the United States in 95 existing macro cells at 1.9GHz
- The median path loss at distance is given by:

$$P_L\ dB = 20\log_{10}(4\pi d_0/\lambda) + 10\gamma\log_{10}(d/d_0) + s \quad for\ d > d_0$$

- D_0=100 m, γ is the path-loss exponent with:

$$\gamma = a - bh_b + d/h_b$$

- h_b is the height of the base station in meters

Model Parameter	**Terrain A**	**Terrain B**	**Terrain C**
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

Stanford University Interim (SUI) Models

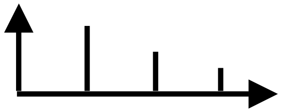
- Set of 6 channel models: 3 terrain types, a variety of Doppler spreads, delay spread and line-of-sight/non-line-of-site

Channel	**Terrain Type**	**Doppler Spread**	**Delay Spread**	**LOS**
SUI-1	C	Low	Low	High
SUI-2	C	Low	Low	High
SUI-3	B	Low	Low	Low
SUI-4	B	High	Moderate	Low
SUI-5	A	Low	High	Low
SUI-6	A	High	High	Low

SUI – 1 Channel Model

	Tap 1	Tap 2	Tap 3	Units
Delay	0	0.4	0.9	µs
Power (omni ant.)	0	-15	-20	dB
90% K-factor (omni)	4	0	0	
75% K-factor (omni)	20	0	0	
Power (30° ant.)	0	-21	-32	dB
90% K-factor (30°)	16	0	0	
75% K-factor (30°)	72	0	0	
Doppler	0.4	0.3	0.5	Hz

Antenna Correlation: $\rho_{ENV} = 0.7$ **Gain Reduction Factor:** GRF = 0 dB **Normalization Factor:** Fomni = -0.1771 dB, F30° = -0.0371 dB	**Terrain Type:** C **Omni antenna:** $\tau_{RMS} = 0.111$ µs, overall K: K = 3.3 (90%); K = 10.4 (75%) **30° antenna:** $\tau_{RMS} = 0.042$ µs, overall K: K = 14.0 (90%); K = 44.2 (75%)



ITU Path Loss Models

- Indoor office, outdoor-to-indoor pedestrian, and vehicular. Low delay spread (A), medium delay spread (B)
- Pedestrian:

Tap	Channel A		Channel B		Doppler spectrum
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)	
1	0	0	0	0	Classic
2	110	–9.7	200	–0.9	Classic
3	190	–19.2	800	–4.9	Classic
4	410	–22.8	1 200	–8.0	Classic
5	–	–	2 300	–7.8	Classic
6	–	–	3 700	–23.9	Classic

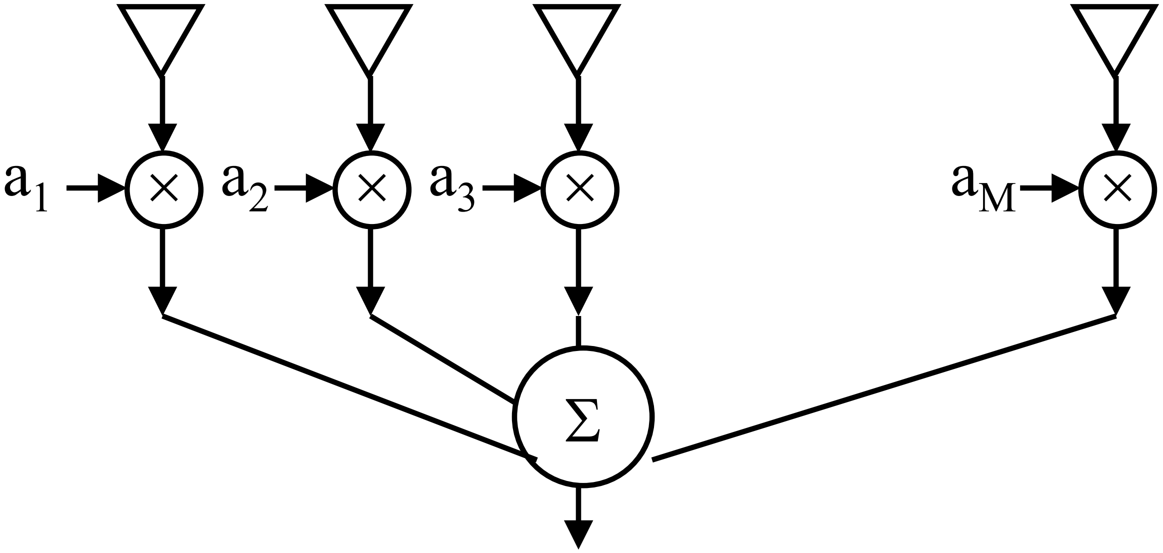
ITU Vehicular Channel Model

Tap	Channel A		Channel B		Doppler spectrum
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)	
1	0	0.0	0	–2.5	Classic
2	310	–1.0	300	0	Classic
3	710	–9.0	8.900	–12.8	Classic
4	1 090	–10.0	12 900	–10.0	Classic
5	1 730	–15.0	17 100	–25.2	Classic
6	2 510	–20.0	20 000	–16.0	Classic

Multi-Antenna Systems

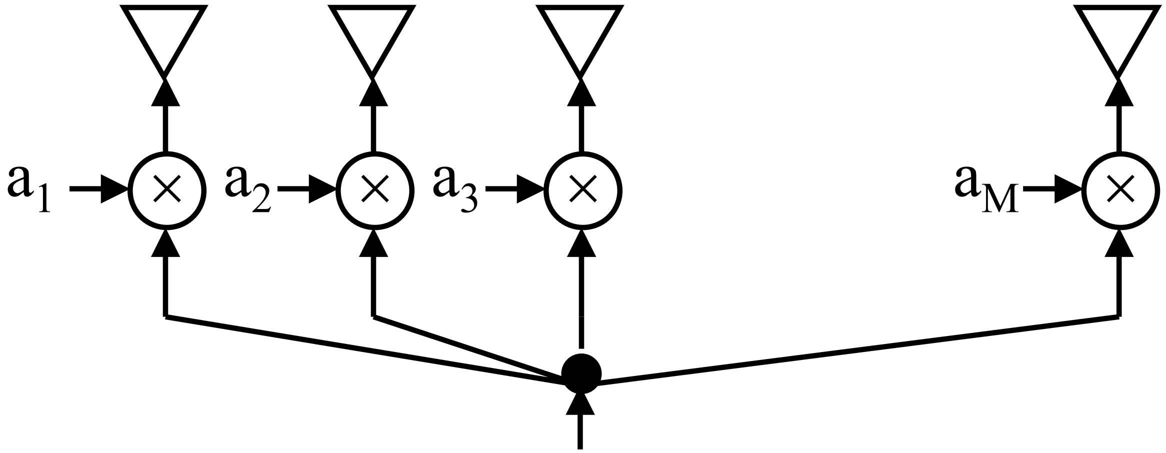
- Receiver Diversity
- Transmitter Diversity
- Beam forming
- MIMO

Receiver Diversity

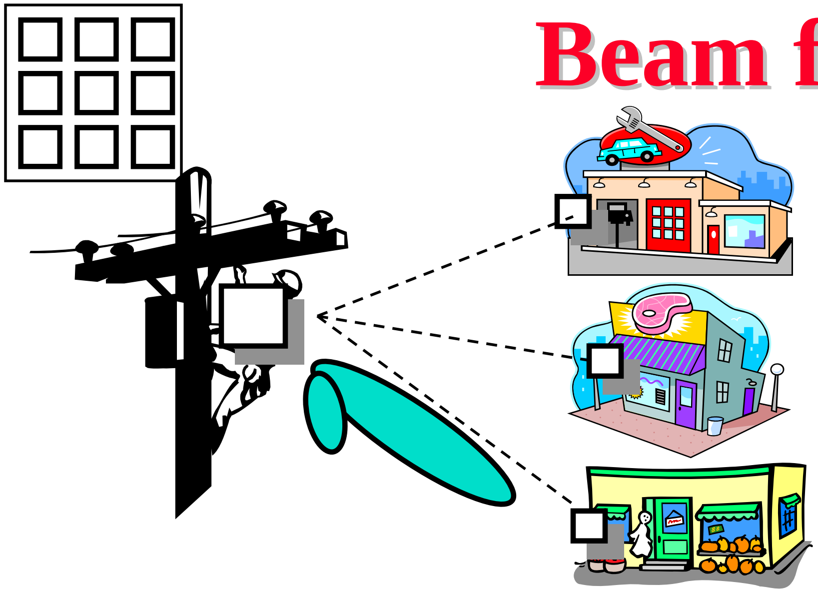


- User multiple receive antenna
- Selection combining: Select antenna with highest SNR
- Threshold combining: Select the first antenna with SNR above a threshold
- Maximal Ratio Combining: Phase is adjusted so that all signals have the same phase. Then weighted sum is used to maximize SNR

Transmitter Diversity



- Use multiple antennas to transmit the signal
  Ample space, power, and processing capacity at the transmitter (but not at the receiver).
- If the channel is known, phase each component and weight it before transmission so that they arrive in phase at the receiver and maximize SNR
- If the channel is not known, use space time block codes

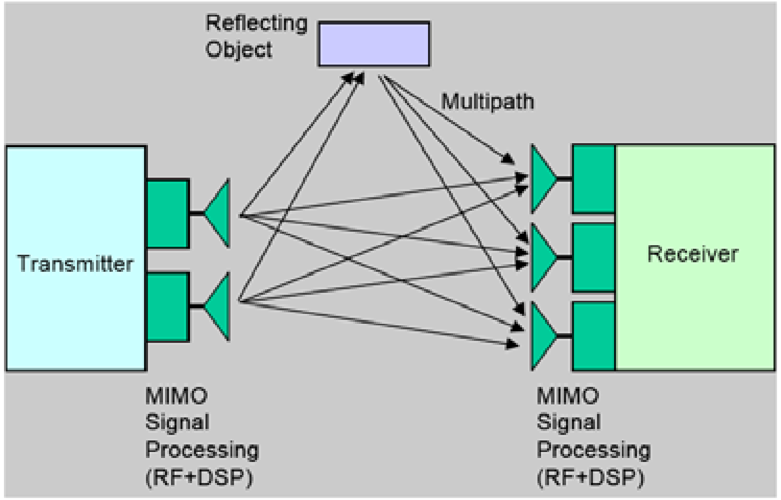


Beam forming

- Phased Antenna Arrays:
  Receive the same signal using multiple antennas
- By phase-shifting various received signals and then summing ⇒ Focus on a narrow directional beam
- Digital Signal Processing (DSP) is used for signal processing ⇒ Self-aligning

MIMO

- Multiple Input Multiple Output
- RF chain for each antenna
  ⇒ Simultaneous reception or transmission of multiple streams



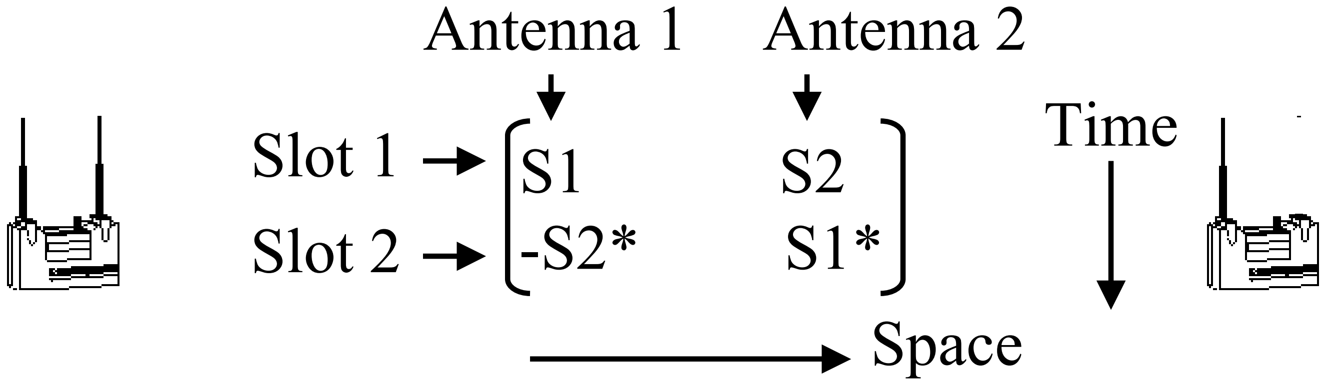
2x3

802.16e at 2.5 GHz, 10 MHz TDD, D:U=2:1

T:R	1x1	1x2	2x2	2x4	4x2	4x4
b/Hz	1.2	1.8	2.8	4.4	3.7	5.1

Space Time Block Codes (STBC)

- Invented 1998 by Vahid Tarokh.
- Transmit multiple redundant copies from multiple antennas
- Precisely coordinate distribution of symbols in space and time.
- Receiver combines multiple copies of the received signals optimally to overcome multipath.
- Example: Two antennas:

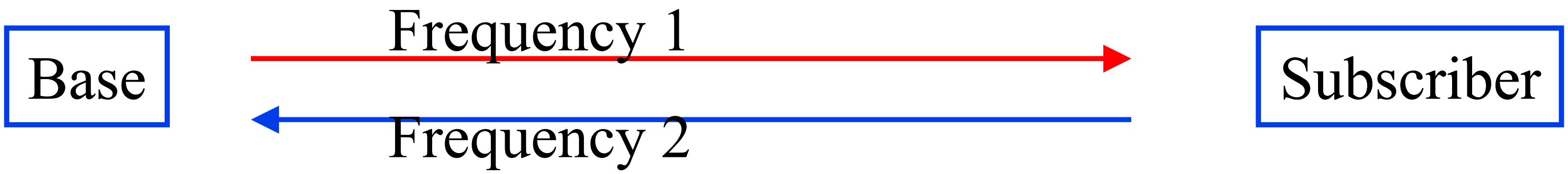


$$\begin{array}{ccc} & \text{Antenna 1} \downarrow & \text{Antenna 2} \downarrow \\ \text{Slot 1} \rightarrow & \left[\begin{array}{c} S1 \\ -S2^* \end{array} \right. & \left. \begin{array}{c} S2 \\ S1^* \end{array} \right] \\ \text{Slot 2} \rightarrow & & \end{array}$$

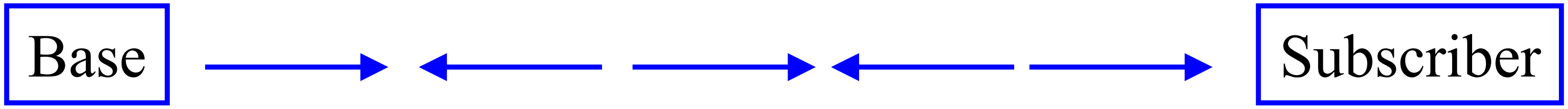
S1* is complex conjugate of S1 ⇒ columns are orthogonal

Time Division Duplexing (TDD)

- Duplex = Bi-Directional Communication
- Frequency division duplexing (FDD) (Full-Duplex)

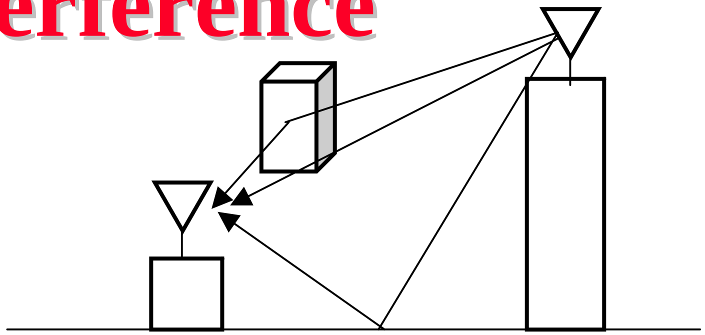


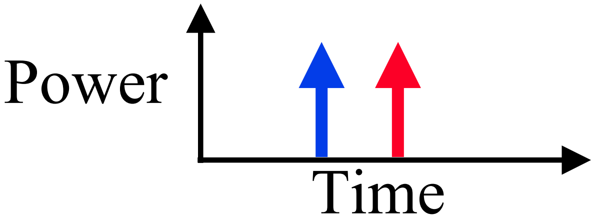
- Time division duplex (TDD): Half-duplex

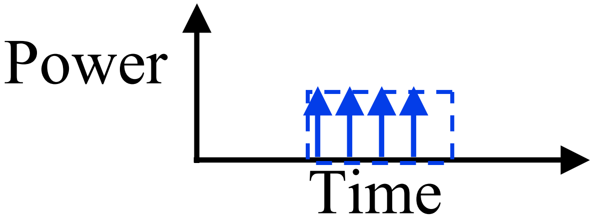


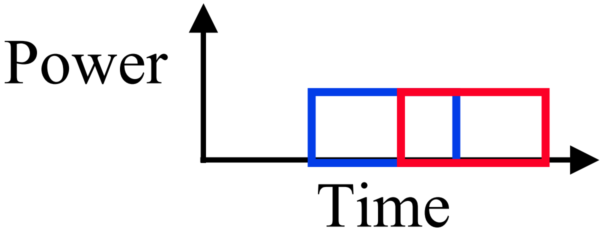
- Most WiMAX deployments will use TDD.
  - Allows more flexible sharing of DL/UL data rate
  - Does not require paired spectrum
  - Easy channel estimation ⇒ Simpler transceiver design
  - Con: All neighboring BS should time synchronize

Inter-Symbol Interference





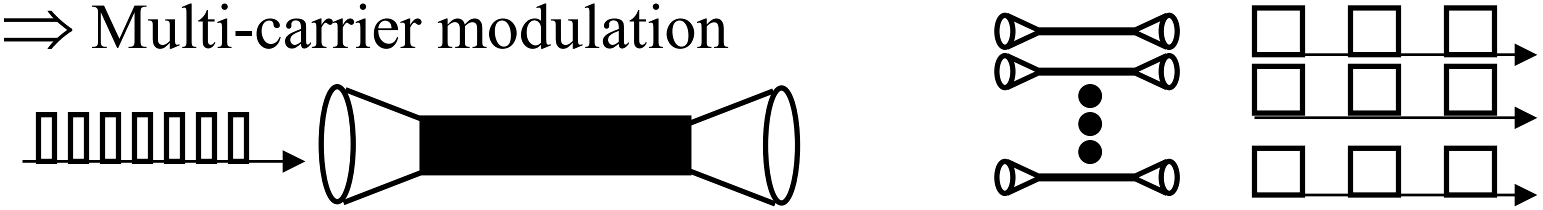




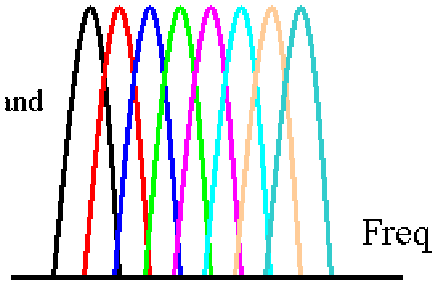
- Symbols become wider
  ⇒ Limits the number of bits/s

OFDM

- ❑ Orthogonal Frequency Division Multiplexing
- ❑ Ten 100 kHz channels are better than one 1 MHz Channel
  ⇒ Multi-carrier modulation



- ❑ Frequency band is divided into 256 or more sub-bands.
  Orthogonal ⇒ Peak of one at null of others
- ❑ Each carrier is modulated with a BPSK, QPSK, 16-QAM, 64-QAM etc depending on the noise (Frequency selective fading)
- ❑ Used in 802.11a/g, 802.16,
  Digital Video Broadcast handheld (DVB-H)
- ❑ Easy to implement using FFT/IFFT

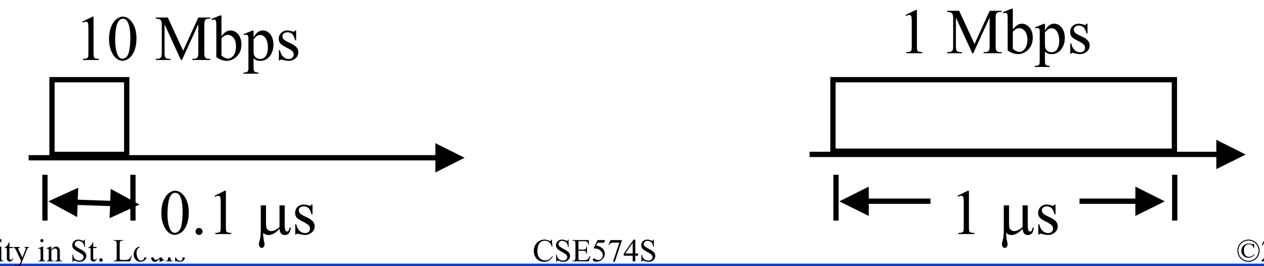


Advantages of OFDM

- Easy to implement using FFT/IFFT
- Computational complexity = O(B log BT) compared to previous O(B^2T) for Equalization. Here B is the bandwidth and T is the delay spread.
- Graceful degradation if excess delay
- Robustness against frequency selective burst errors
- Allows adaptive modulation and coding of subcarriers
- Robust against narrowband interference (affecting only some subcarriers)
- Allows pilot subcarriers for channel estimation

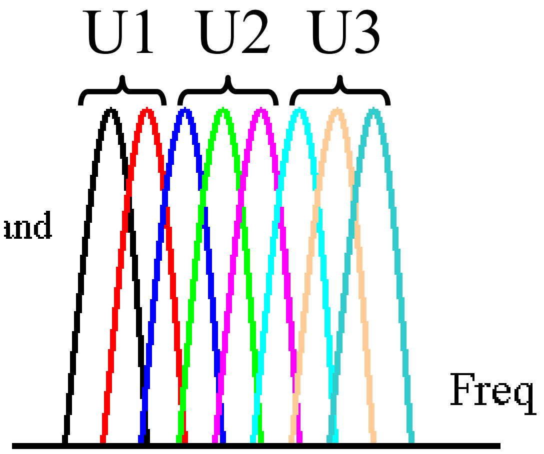
OFDM: Design considerations

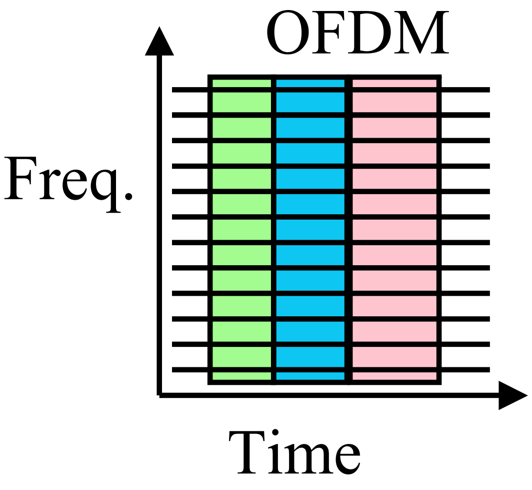
- Large number of carriers ⇒ Smaller data rate per carrier ⇒ Larger symbol duration ⇒ Less inter-symbol interference
- Reduced subcarrier spacing ⇒ Increased inter-carrier interference due to Doppler spread in mobile applications
- Easily implemented as Inverse Discrete Fourier Transform (IDFT) of data symbol block
- Fast Fourier Transform (FFT) is a computationally efficient way of computing DFT

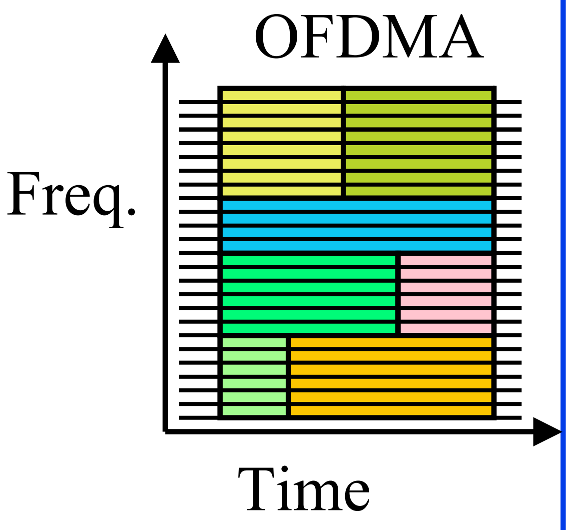


OFDMA

- Orthogonal Frequency Division Multiple Access
- Each user has a subset of subcarriers for a few slots
- OFDM systems use TDMA
- OFDMA allows Time+Freq DMA ⇒ 2D Scheduling



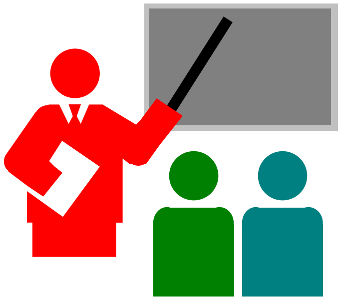




Scalable OFDMA (SOFDMA)

- OFDM symbol duration = f(subcarrier spacing)
- Subcarrier spacing = Frequency bandwidth/Number of subcarriers
- Frequency bandwidth=1.25 MHz, 3.5 MHz, 5 MHz, 10 MHz, 20 MHz, etc.
- Symbol duration affects higher layer operation
  ⇒ Keep symbol duration constant at 102.9 us
  ⇒ Keep subcarrier spacing 10.94 kHz
  ⇒ Number of subcarriers ∝ Frequency bandwidth
  This is known as scalable OFDMA

Summary: Wireless PHY Part III



1. Empirical Channel models give path loss based on measured data
2. Multiple Antennas: Receive diversity, transmit diversity, Smart Antenna, MIMO
3. MIMO use multiple antennas for high throughput
4. Space-time block codes use multiple antennas to transmit related signals
5. OFDM splits a band in to many orthogonal subcarriers. OFDMA = FDMA + TDMA

Homework 5

- In a scalable OFDMA system, the number of carriers for 10 MHz channel is 1024. How many carriers will be used if the channel was 1.25 MHz, 5 MHz, or 8.75 MHz.