Wirelss signal propagation: indoor environment

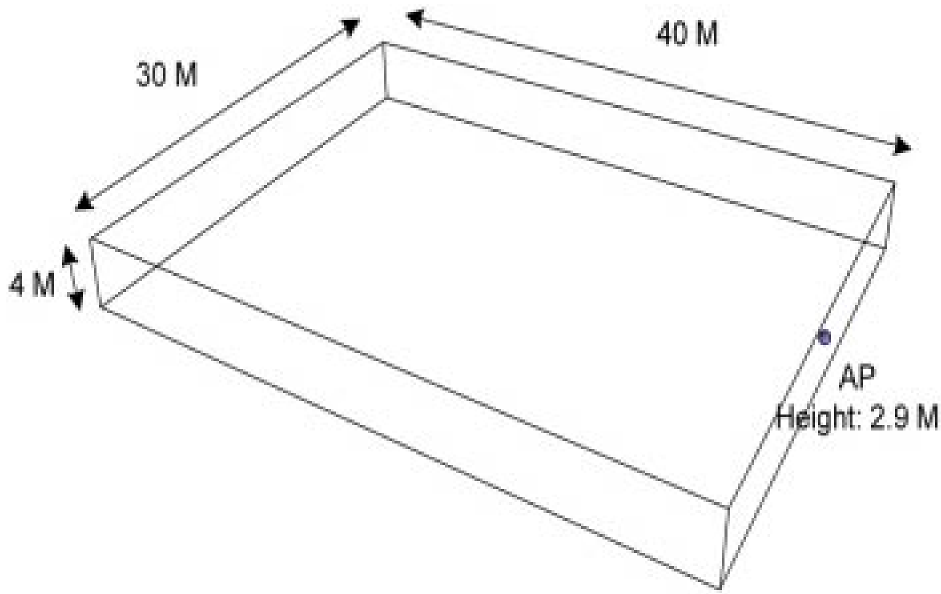
→ outdoors: signal strength rapidly decreases with distance

→ indoors: more complex

→ distance need not be dominant factor

→ spatial diversity

Consider empty room with no obstructions:



→ large lecture room

→ e.g., 802.11 WLAN hot spot

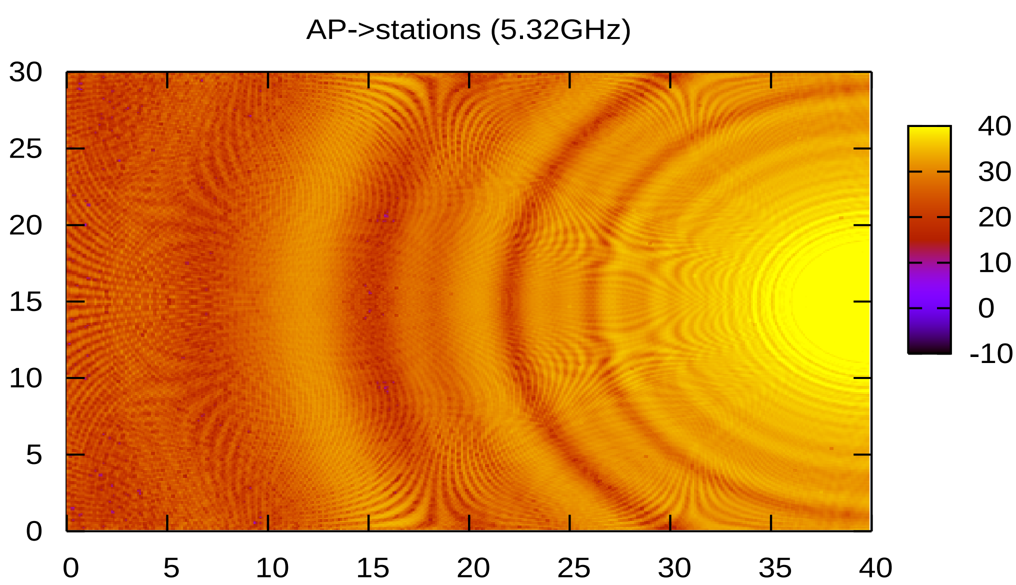
→ AP sends out signal at 2.4 (802.11b/g) or 5 GHz (802.11a/n) frequency

→ how does indoor signal reception look like?

Signal strength reception at table height 0.7 m:

→ carrier frequency: 5.32 GHz

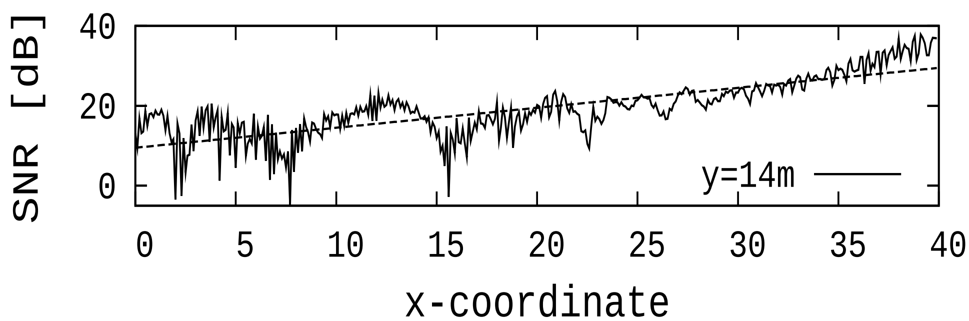
→ channel 8 in U.S. (12 channels in 5 GHz 802.11a/n)



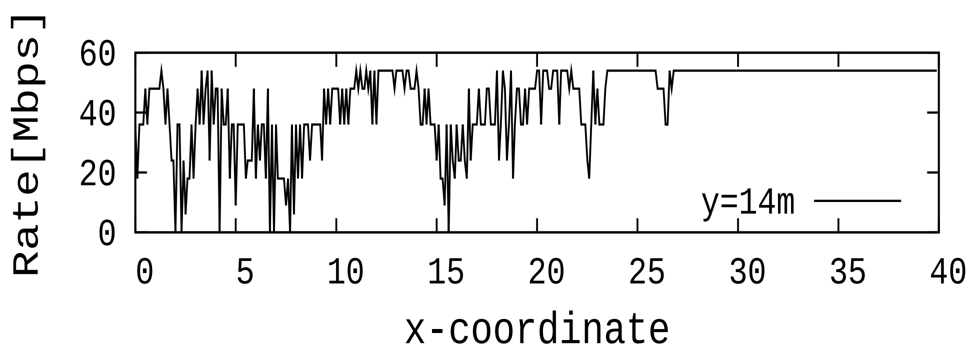
→ called spatial diversity

Impact on throughput:

→ SNR and throughput along straight line



→ SNR: significant variation

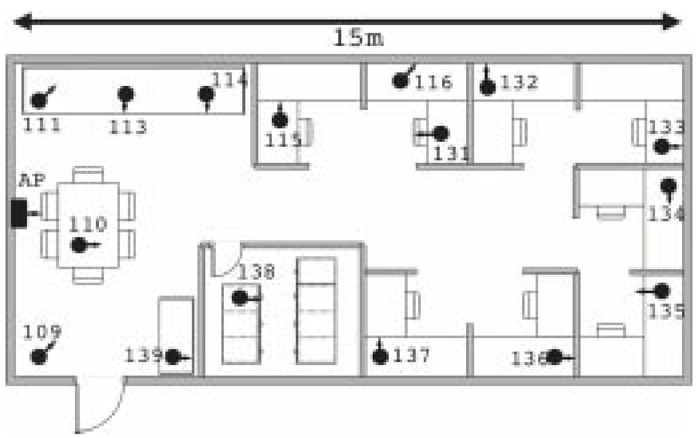


→ distance from AP is relevant but not critical

→ good locations, bad locations

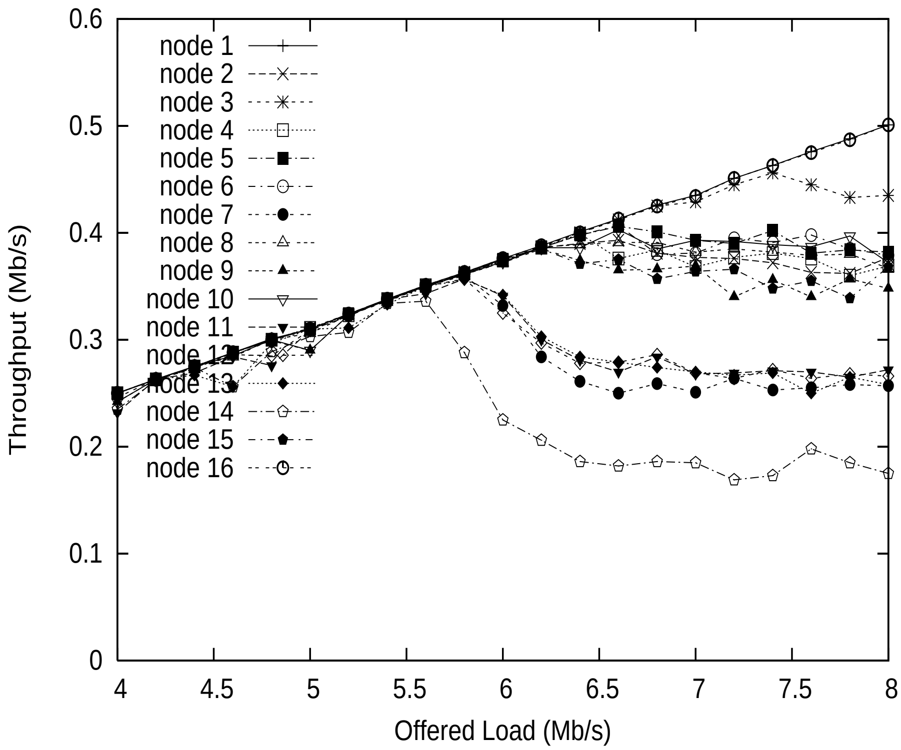
→ can lead to unfairness and even starvation

Indoor office 802.11 WLAN hot spot (HAAS G50):



Throughput share of 16 HP/Compaq pocket PCs:

→ uplink CSMA competition



→ significant unfairness: why?

→ persistent unfairness

→ location (not distance from AP) is determining factor

What causes uneven—some say chaotic—signal strength distribution in indoor environment?

Unique feature of wireless networks: wave interference

$\rightarrow$ echos (multi-path reflections) interact

$\rightarrow$ constructive vs. destructive interference

Ex.: constructive

$\rightarrow$ two sine waves of frequency f meet constructively

$$\sin f + \sin f = 2 \sin f$$

Ex.: destructive

$\rightarrow$ two sine waves of frequency f meet destructively

$$\sin f + \sin(f + \pi) = 0$$

Note: second sine wave is phase-shifted by 180 degrees

$\rightarrow$ multi-path reflection causes phase shifting

$\rightarrow$ longer distance to travel

Thus: indoors—good and bad reception spots due to wave interference

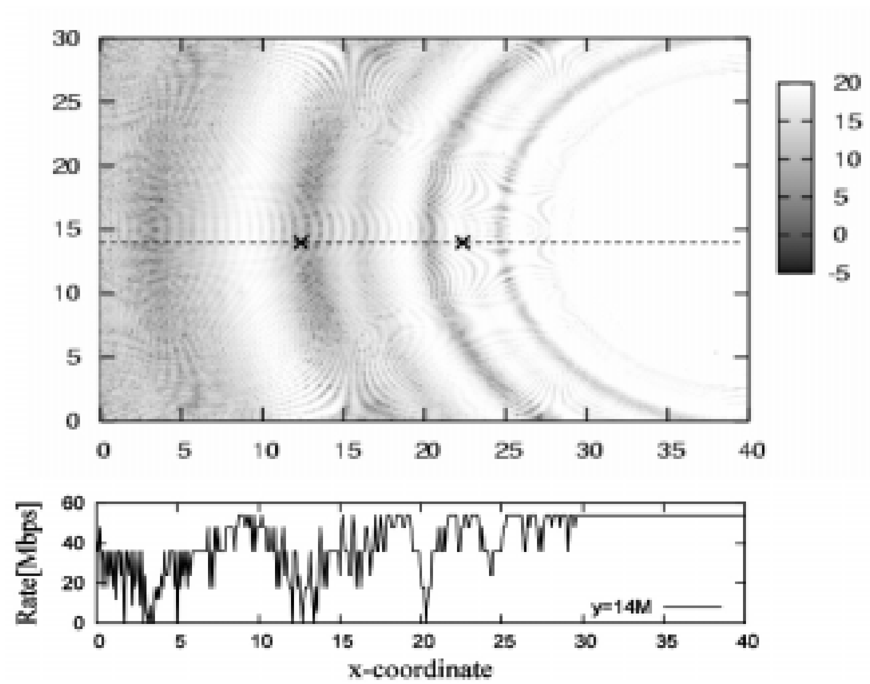
→ moving around (i.e., changing location) helps

→ does increasing power help?

One more thing that can help: change channels

$\rightarrow$ good/bad location depends on carrier frequency

Carrier frequency 5.805 GHz (channel 12)



$\rightarrow$ qualitatively similar to channel 8

$\rightarrow$ but quantitatively different

Thus: good spot under channel 8 may become bad spot under channel 12, and vice versa

→ different from channel switching to reduce overcrowding

Ex.: old cordless phones with manual channel switch button

→ switch to channel that no one else is using

→ avoiding multi-user interference

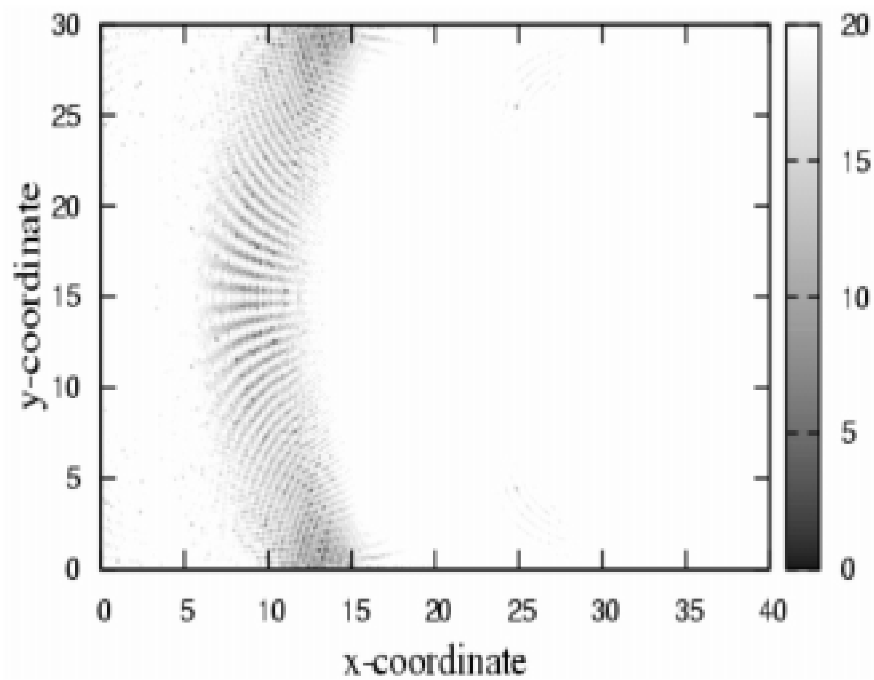
→ different from bad throughput due to spatial diversity

Severity of spatial diversity in 5 GHz vs. 2.4 GHz WLANs

$\rightarrow$ which is worse?

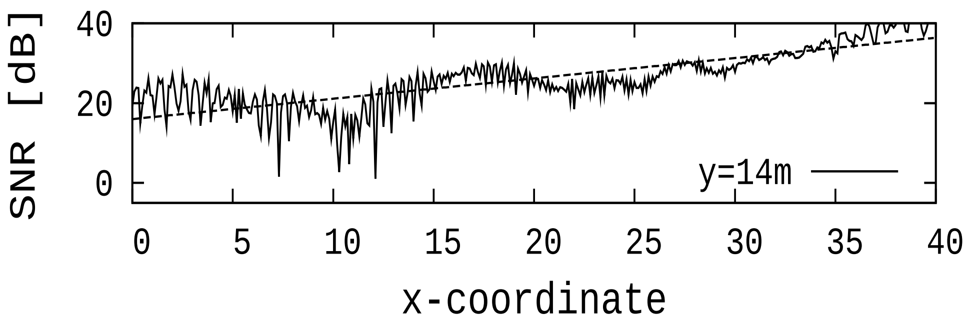
IEEE 802.11g/b operating in 2.4 GHz band:

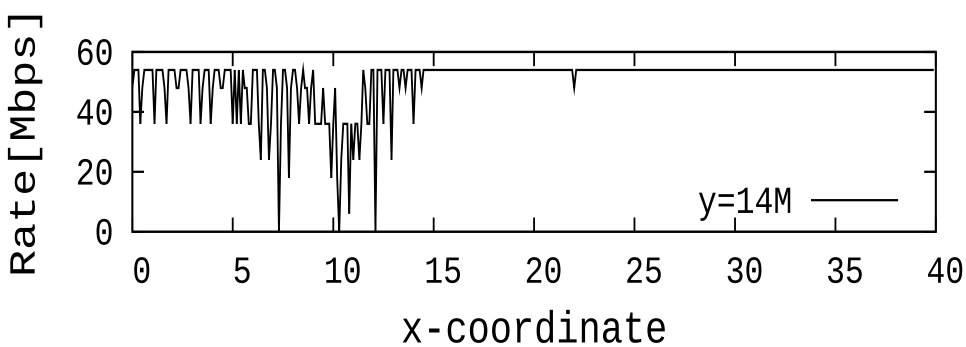
→ 2.412 GHz (channel 1)



→ much less variation compared to 5 GHz carrier frequencies

SNR and throughput along straight line:





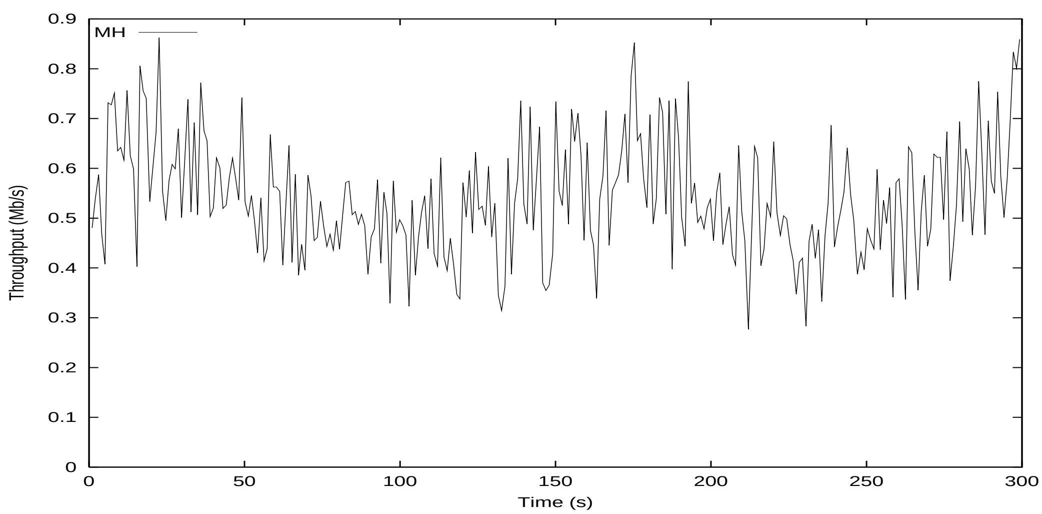
→ throughput unfairness doesn't go away

→ but less pronounced

→ how about 700 MHz super WiFi case?

Combined with mobility

→ mobile throughput at walking speed (HAAS corridor)



→ walking back-and-forth from AP

→ can observe gradual distance dependence

→ but short-term fluctuation dominate

→ not due to Doppler shift but spatial diversity

→ moving in and out of good/bad spots