Fading:

→ signal is time-varying

→ e.g., city environment with many buildings and no direct line of sight between sender and receiver

What happens: received signal is comprised of bounced off copies (i.e., echos) from buildings and other reflective obstructions

→ called multi-path propagation

→ e.g., Rayleigh fading

→ popular model

Clarke's model:

$\rightarrow$ generative model leading to Rayleigh fading

A. If there are many echos and the echos are independent of each other

then the average signal strength of the echos has a Gaussian (i.e., normal) distribution

$\rightarrow$ central limit theorem

B. EM sinusoid has phase in addition to magnitude

$\rightarrow$ two components

$\rightarrow$ assume independence

By assumption A, each component is Gaussian

$\rightarrow$ sum of two independent Gaussians: Rayleigh distribution

$\rightarrow$ statistical property of time-varying envelop

Mobile's signal strength fluctuates

→ fading causes bit flips

→ use FEC

Note: generative method call ray tracing

→ e.g., used in computer graphics

If there is a dominant ray (e.g., line of sight) then leads to Rician fading.

Indoor environment

→ more involved

→ utilize ray tracing

Note: indoor position triangulation using signal strength is difficult

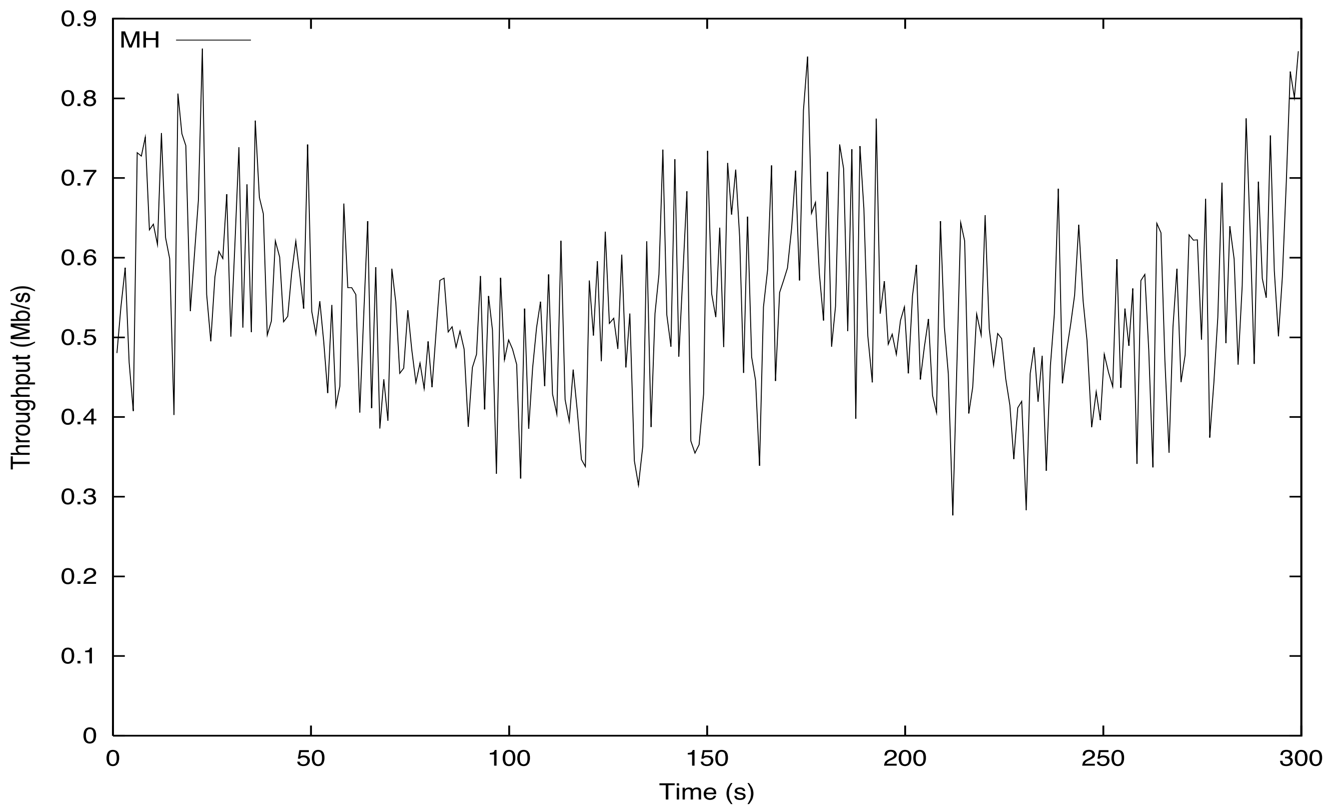
→ practical applications (e.g., companies tracking employees)

→ network interface reports RSSI (received signal strength indication)

→ RSSI may not be reliable indicator

RSSI profile combined with mobility

→ walking speed (HAAS corridor)



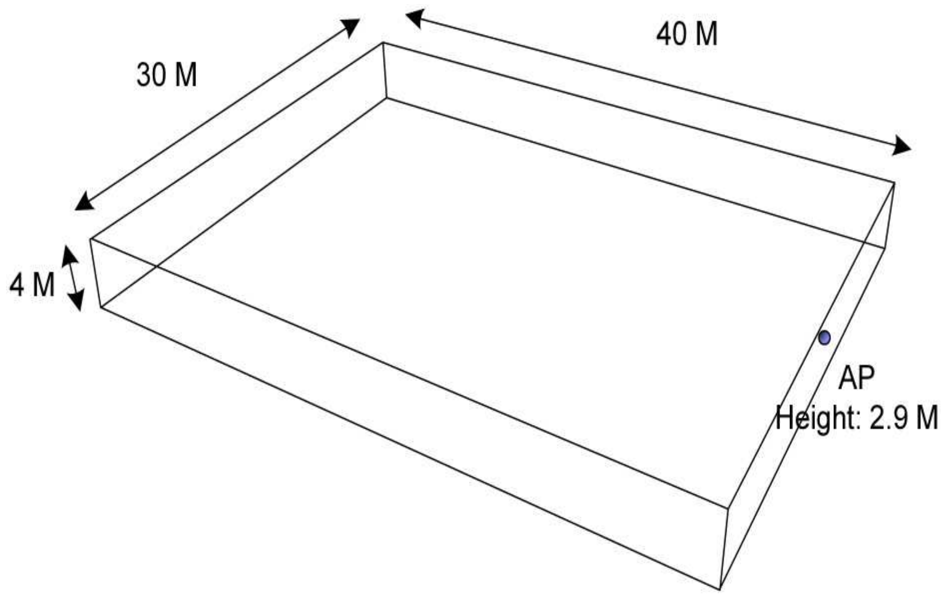
→ walking back-and-forth from AP

→ gradual distance dependence

→ significant short-term fluctuation

→ Doppler shift effect minimal

Indoor signal propagation:



→ large empty room

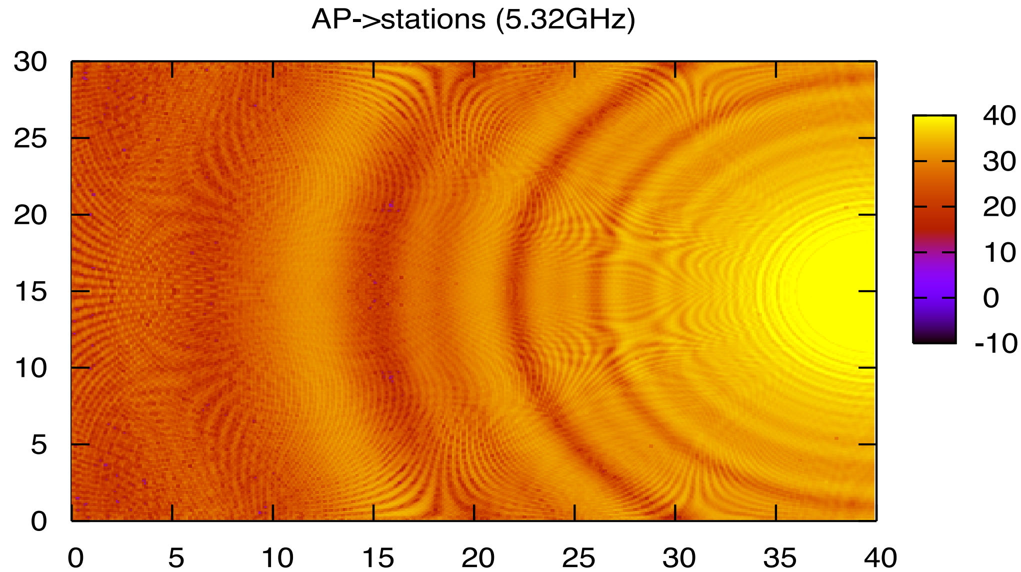
→ no obstructions

→ 802.11 WLAN hot spot: AP attached to wall

Signal strength reception at height 0.7 m:

→ approximate table height

→ carrier frequency: 5.32 GHz



→ signal strength varies by distance

→ but also varies by location

→ further away does not imply weaker signal

Multi-path fading:

→ EM waves interfere constructively and destructively

→ depends on phase

→ use ray tracing

Locations of destructive interference:

→ bad signal reception even though closer to AP

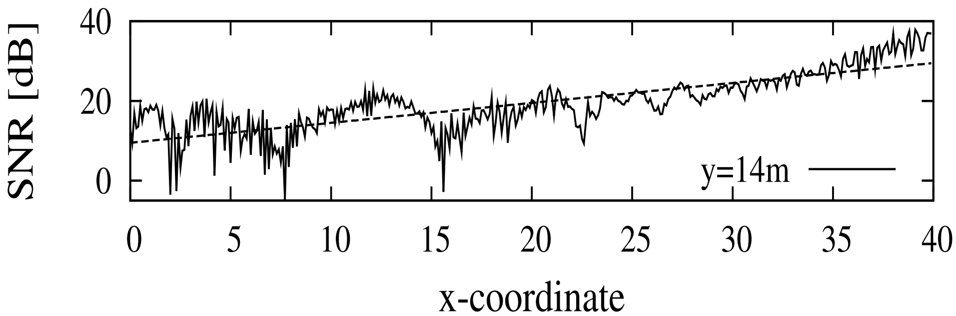
Locations of constructive interference:

→ good signal reception even though farther away from AP

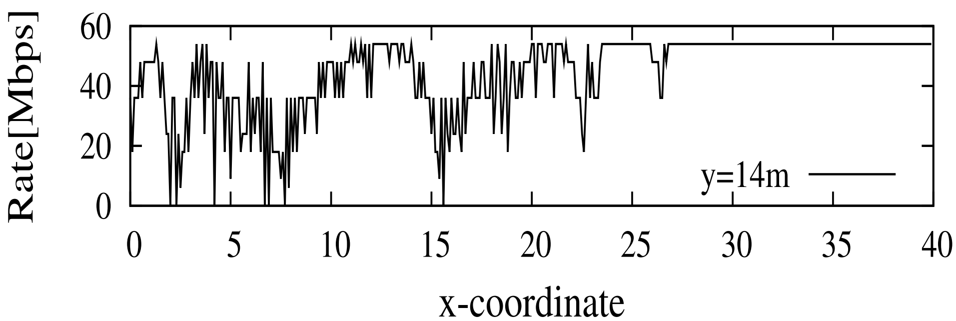
Magnitude of impact.

Throughput:

→ SNR and throughput along straight line from AP



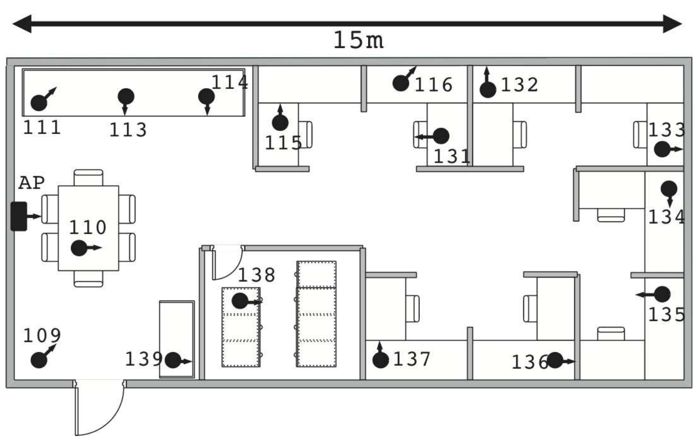
→ significant SNR variation



→ good locations, bad locations

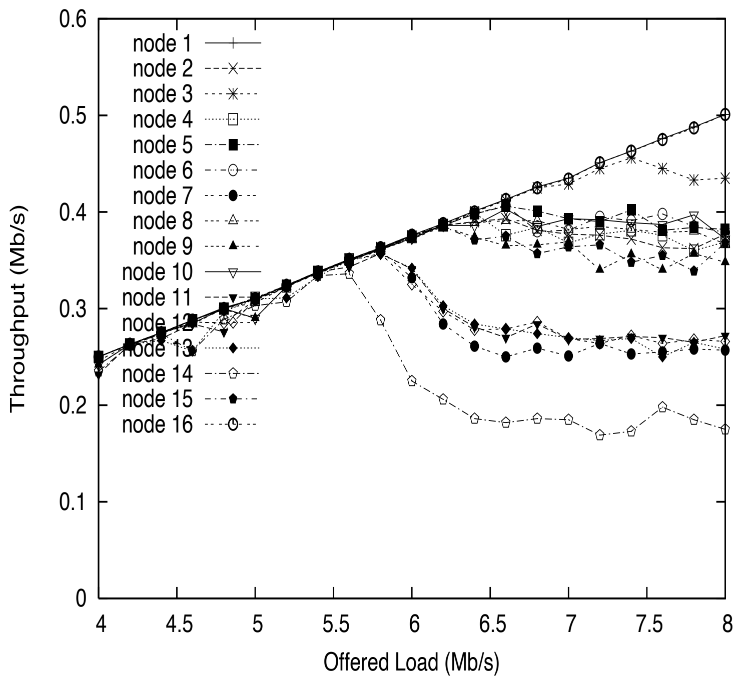
→ leads to unfairness, even starvation

Indoor office 802.11 WLAN hot spot:



Throughput share of 16 HP/Compaq pocket PCs:

→ uplink CSMA competition



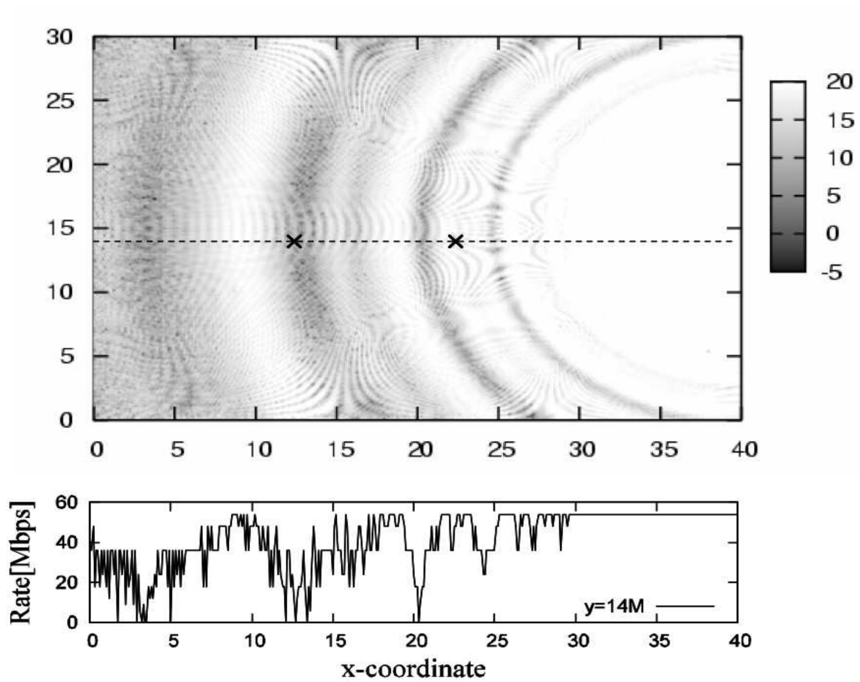
→ offered load: stress placed on the system

→ significant unfairness

→ what can be done?

Changing carrier frequency:

→ 5.805 GHz (channel 12)



→ qualitatively similar to channel 8

→ quantitatively different: frequency selective fading

→ use OFDM to send bits on different subcarriers

→ combined with FEC