$$\lambda = \frac{c}{f} = \frac{0.3 \not{E8}\ \frac{m}{\not{s}}}{f\,[1\not{E9}\ \frac{1}{\not{s}}]} = \frac{30\,cm}{f\,[GHz]}$$

f_{GHz}	λ_{cm}
1	30
10	3
20	1.5

Shannon:

$$\text{Capacity} = W \cdot \log_2(1 + SNR)$$

W: bandwidth

$SNR = \frac{\text{signal}}{\text{noise}}$

typical values

128 kbit/s — GSM = 200 kHz

1-2 Mbit/s (7.5 Mbit/s) — UMTS ≈ 5 MHz (3.8 MHz) — 25x GSM

2-11 Mbit/s (12.5 Mbit/s) — 802.11b 25 MHz ~5x UMTS all phys systems

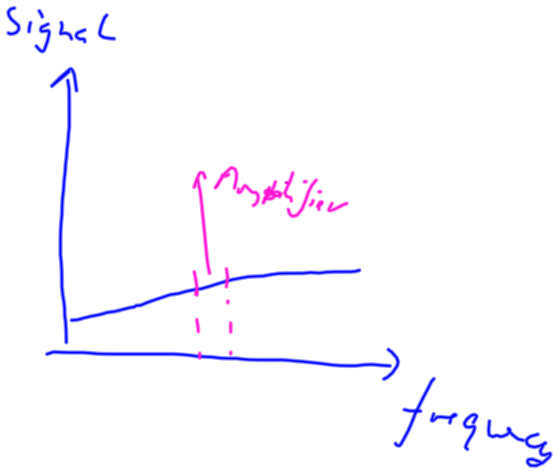
FM = 88.8 ... 107 MHz
GSM = 900 / 1800 / 1900 MHz
UMTS = 2100 MHz

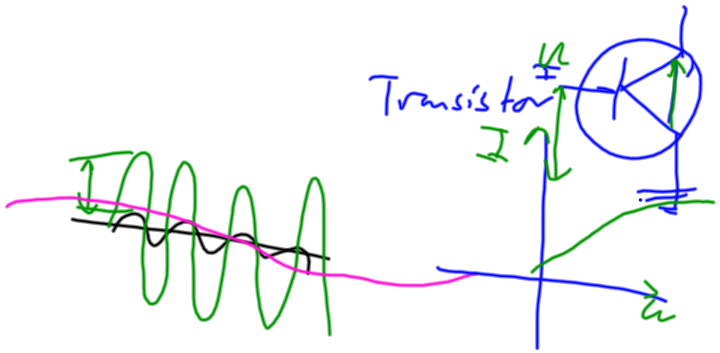
$$W_s \sim \frac{1}{10} f_c$$

W_s ← realistic system bandwidth

f_c ← carrier frequency

	f_c	W_s
	900 MHz	90 MHz
	850 .... 950 MHz	
802.11b	2.4 GHz	240 MHz
802.11a	5.1 GHz	510 MHz



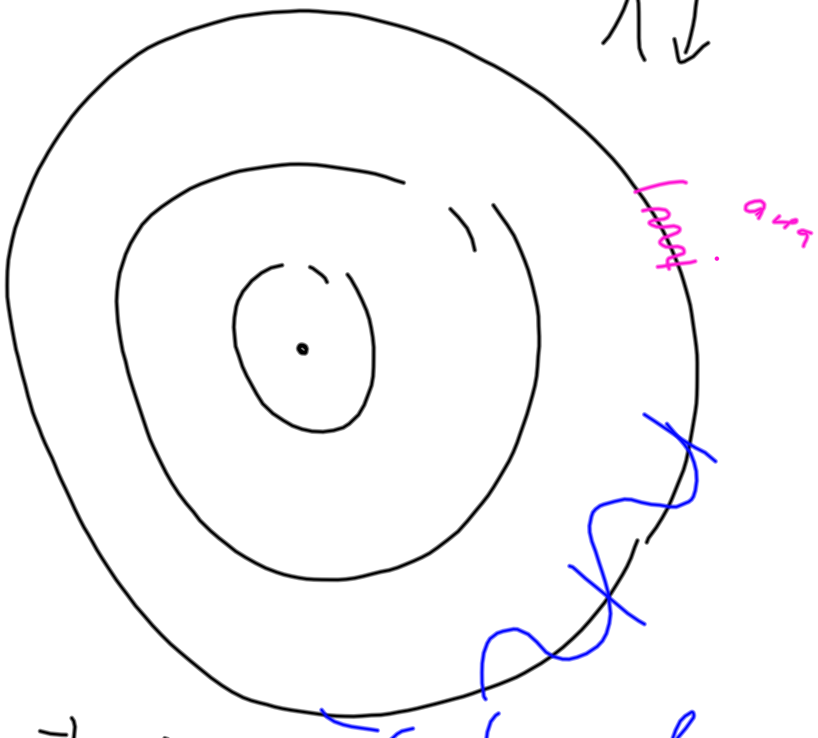


$f \uparrow$ $W \uparrow$ Capacity $\uparrow$

$\lambda \downarrow$ range $\downarrow$

attenuation $\uparrow$

obstacles $\uparrow$



free space attenuation

$$L = \left(\frac{\lambda}{4\pi R}\right)^2$$

surface of a sphere $= 4\pi R^2$

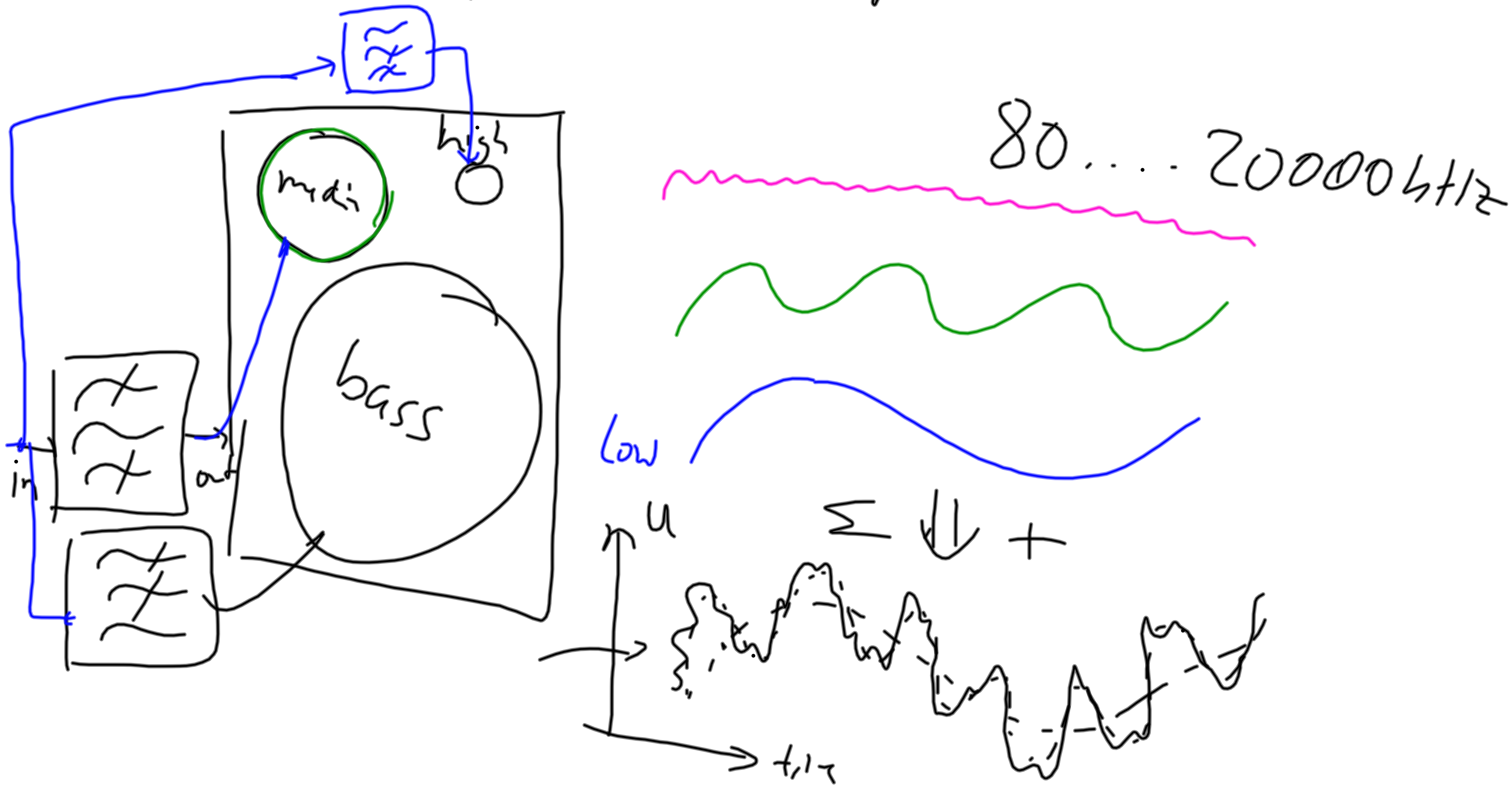
$$L = 20 \log\left(\frac{\lambda}{4\pi R}\right)$$

$\vec{k} \cdot \vec{r}$

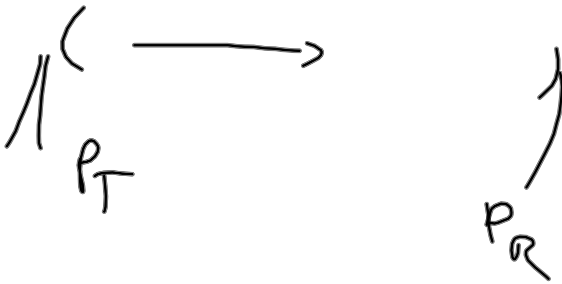
$\frac{2\pi}{\lambda} \cdot \vec{r}$

Example

Loud speaker



Free space propagation equation

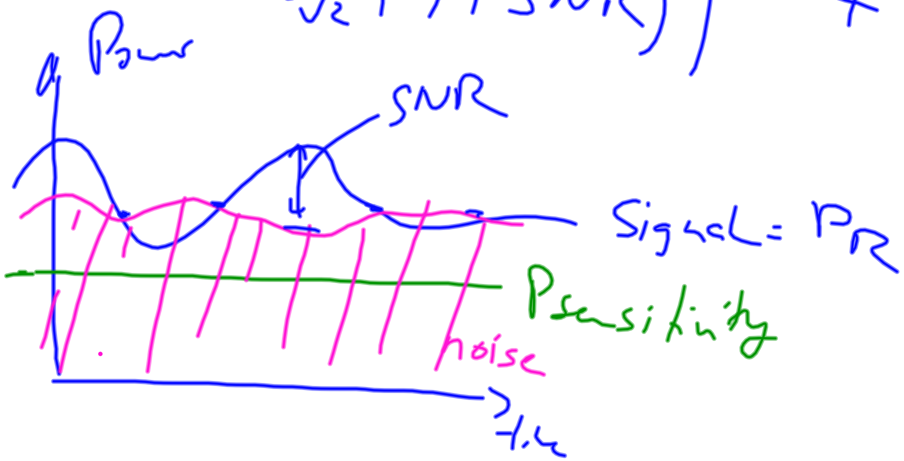


$$P_R = P_T \cdot G_T \cdot G_R \cdot \left(\frac{\lambda}{4\pi R}\right)^2$$

↑ free space attenuation

$$P_R > P_{sensitivity} + P_{noise}$$

$$\left(C = W \log_2(1 + SNR) \right)$$

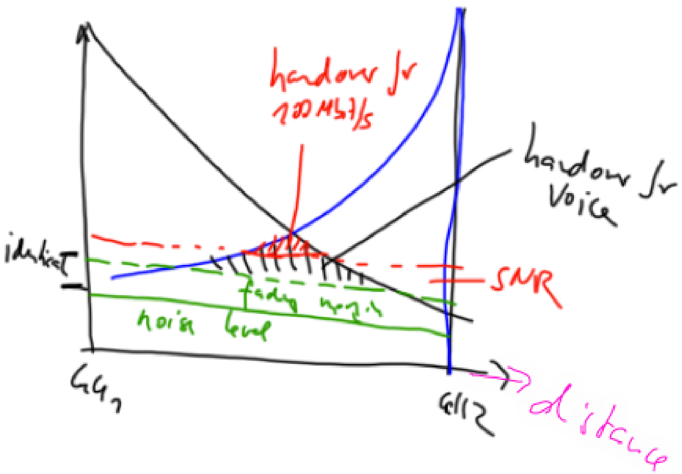


Scenario 1

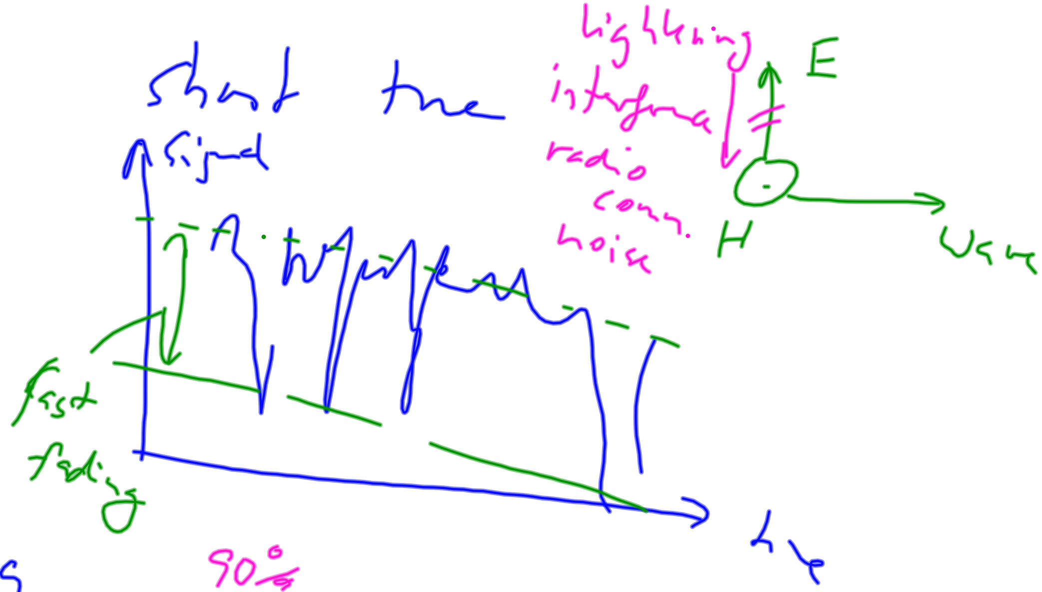
Thoughts:
- precision of results
  ∅ input param
- distance ?
  PReceive

- 3 minutes and 50 seconds to complete handover (GSM - UMTS)

Scenario 1: UMTS — GSM
UMTS



fast Fading



hm > −40dBm

$P_R >$ slow fading

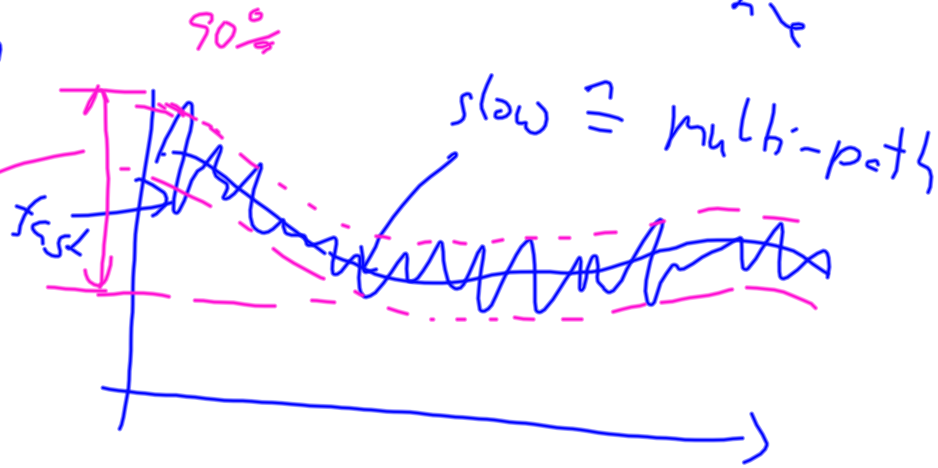
Σ

$+ P_{Fading}$ 30dB

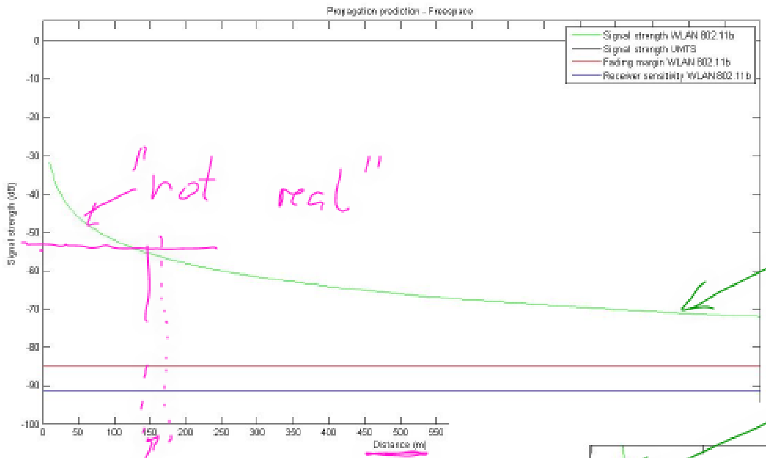
$+ P_{noise}$ 15 dB

total variation

$P_{sensitivity}$ −85dBm



Scenario 2



→ new propag. model

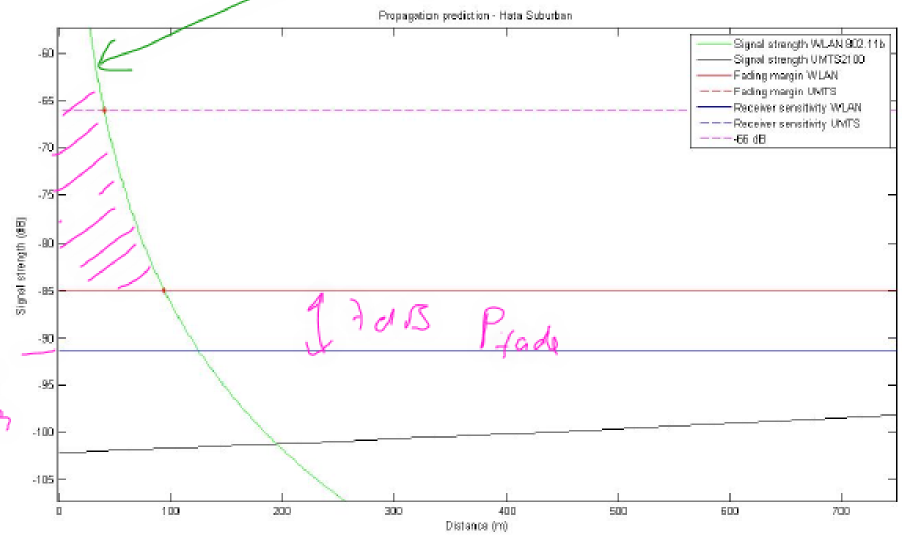
[] Fading!

free space loss $\left(\frac{\lambda}{4\pi R}\right)^2$ wrong

Hata model

max range of 802.11b

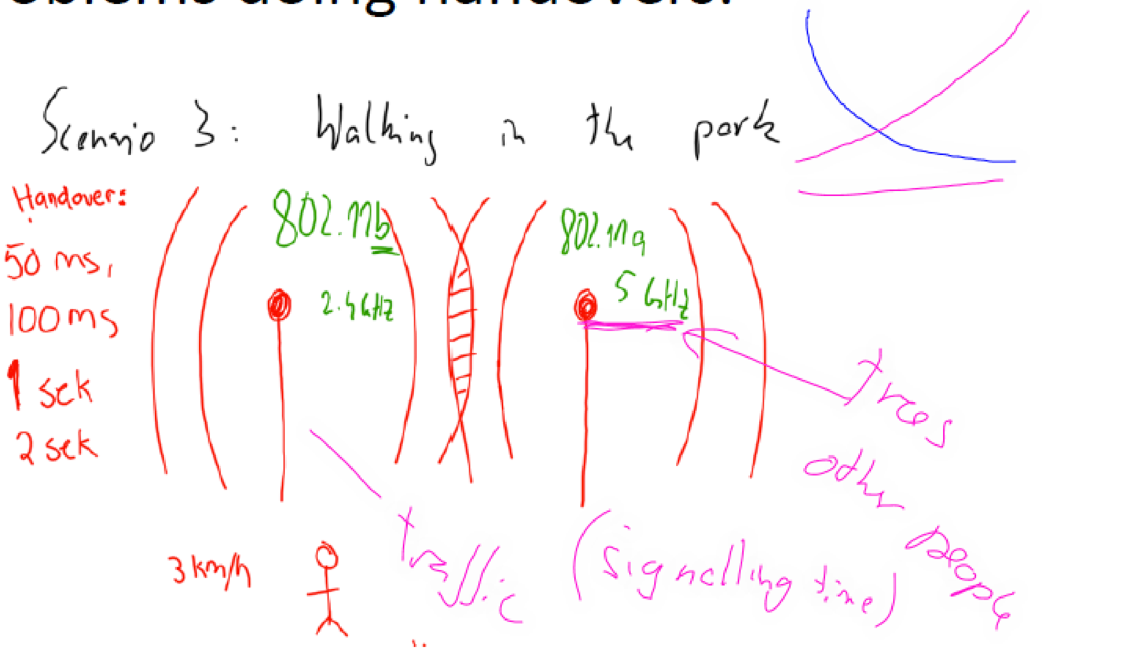
corresp. receive power here: −53dB



Scenario 3

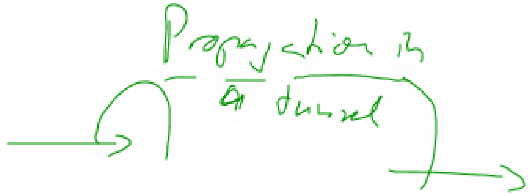
errors
signal distortion

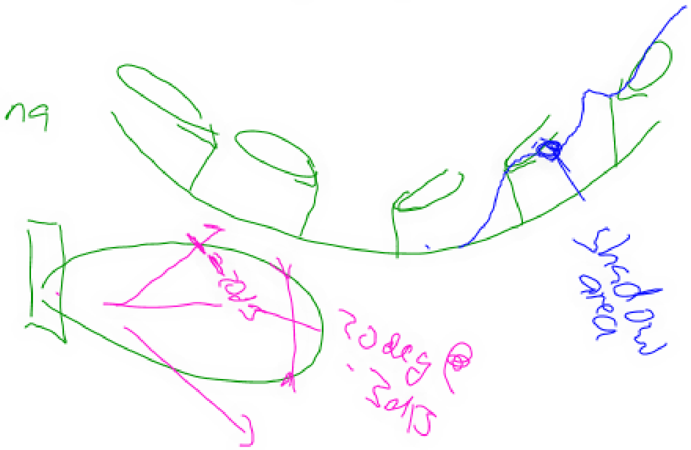
- We never hit the fading margin, and should have no problems doing handovers.

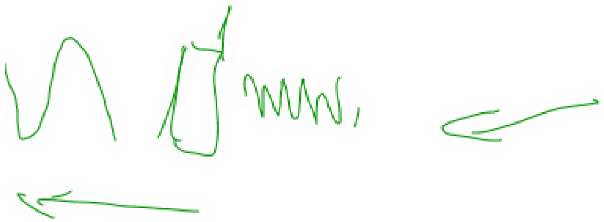


Another scenarios

- Driving through a tunnel ✓
- (Signal source is moving) F....... effect
  not this course
- We are moving up the hill
  higher than antenna







World description

h ≈ infinite (LOS)

$$\left(\frac{\lambda}{4\pi R}\right)^2$$

$$\frac{1}{r^2}$$

realistic model with variances

$$L = L_{FSL} + A_{MU} - H_{MG} - H_{BG} - \sum K_{correction}$$

real: close to buildings, ground, ...

System parameters

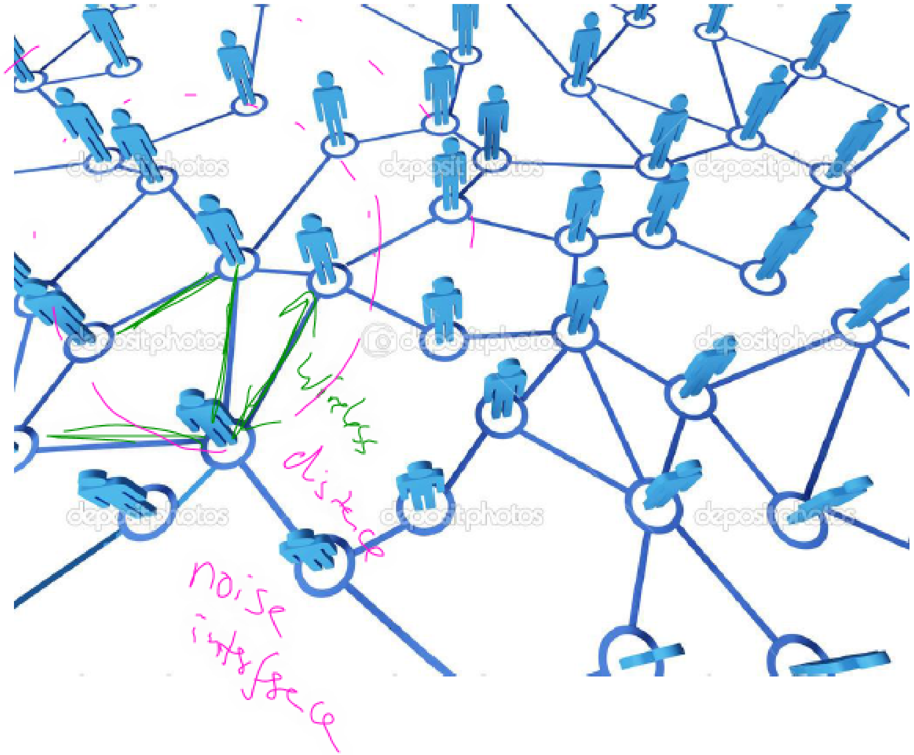
- Other model to compare
- Precise results ?
- Good parameters = success ?
- Wave interference

Examples
- trees
- varying environments
- other users
- other networks...

More detailed simulations?

– a) realistic propag. models < outdoor / indoor

802.11 LTE, WLAN



wiki.unik.no
Thomas

distance // walls // floors

802.11 (1.)

- Propagation models
  - indoor
  - outdoor

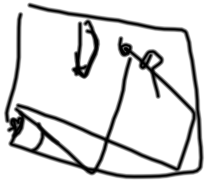
(LTE later)

((Cost 231 ?))

$L = f(\text{distance}) \cdot \text{correction factor} + \ldots$

but statistical, quasi-natural

not: ray tracing



1.) IEEE, scholar, Gard
3-4 papers

Tools on WiFi / (Mobile Networks)

- measure signal strength

Measurements of 802.11

6,9 2.4 GHz

9,9 5.x GHz

outdoor
indoor

- description (photo)
- Table

#	2 m	3	...
P_{level}	-65	-69	