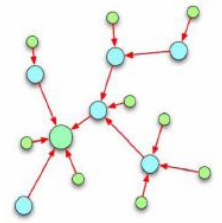


Wireless Sensor and Actuator Networks: *Technologies, Analysis and Design*

The Radio Environment at 2.4 GHz

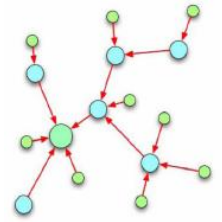
Roberto Verdone

roberto.verdone@unibo.it
<http://www.robertoverdone.org>



Outline

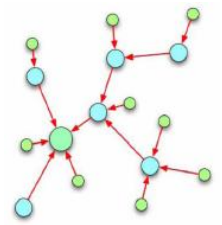
- 1. 2.4 GHz ISM Band**
- 2. UWB**



Section 1

2.4 GHz ISM Band

Path Loss
Channel Fluctuations
Maximum Transmission Range



Experimental Platform

Freescale devices

- 4 DIG536
- 3 DIG528
- “FreeScale 802.15.4 Analyzer” or “Packet Sniffer USB”

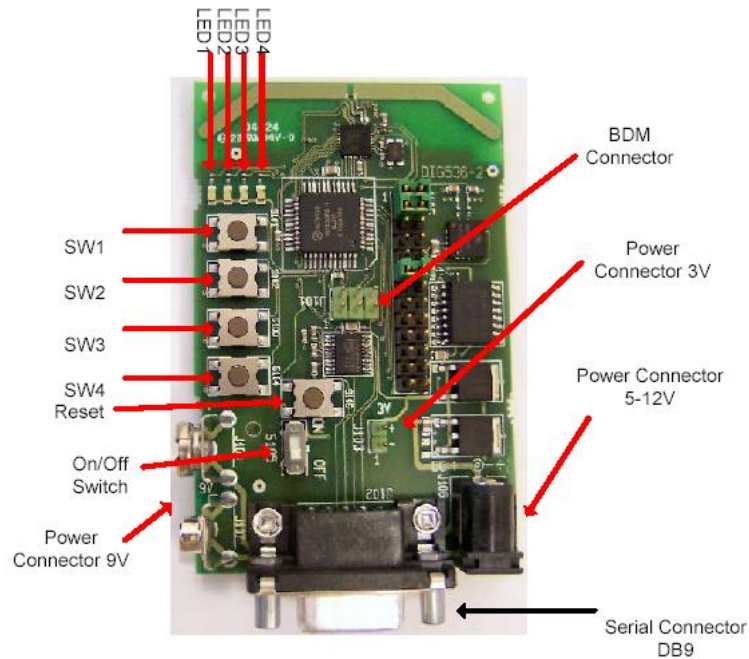


Figure 1. - DIG536 Evaluation Board

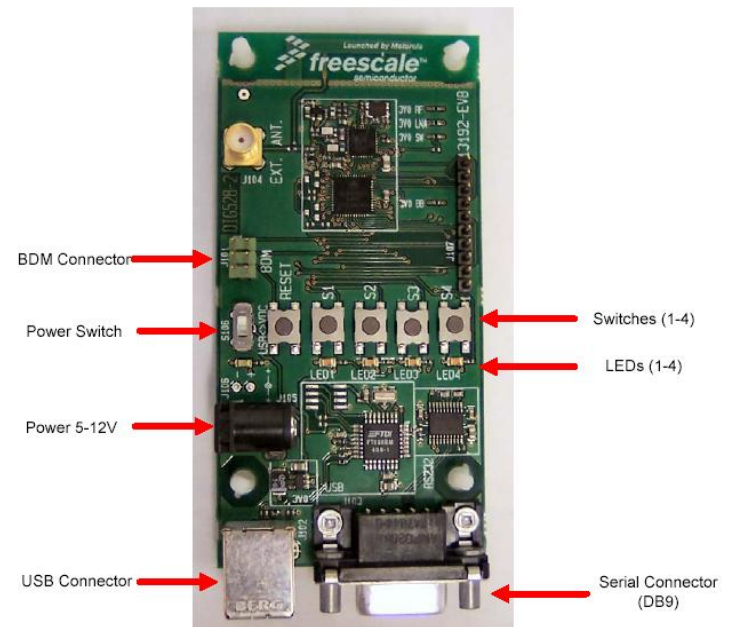
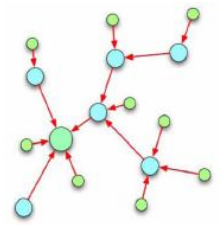
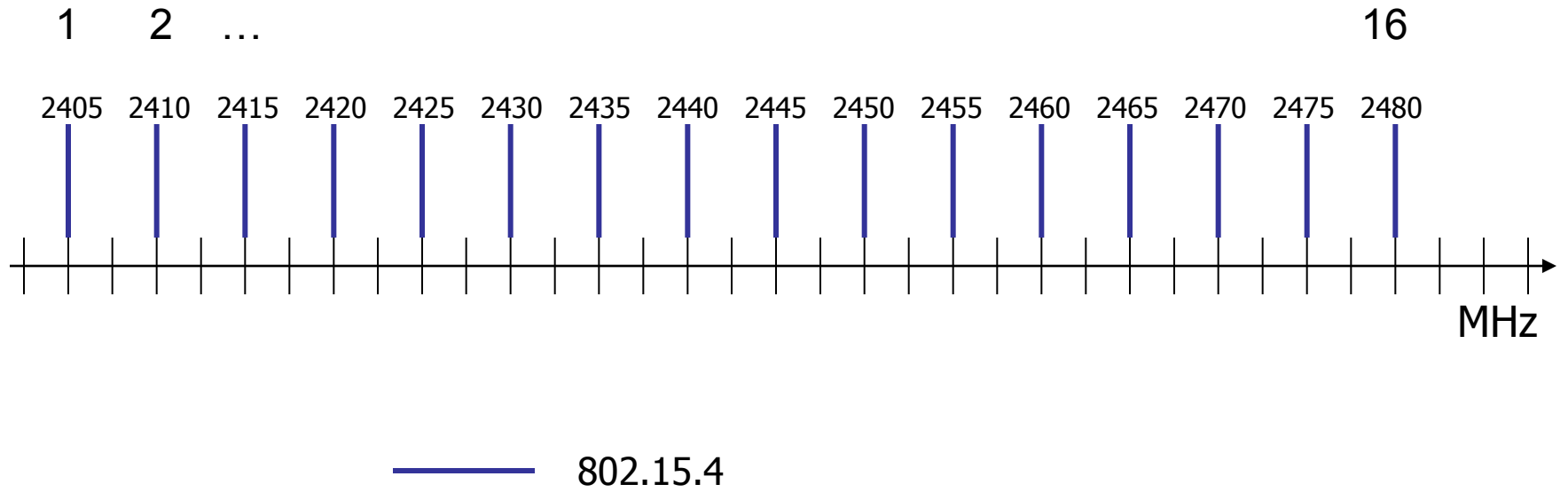
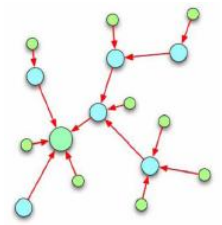


Figure 2. - DIG528 Evaluation Board

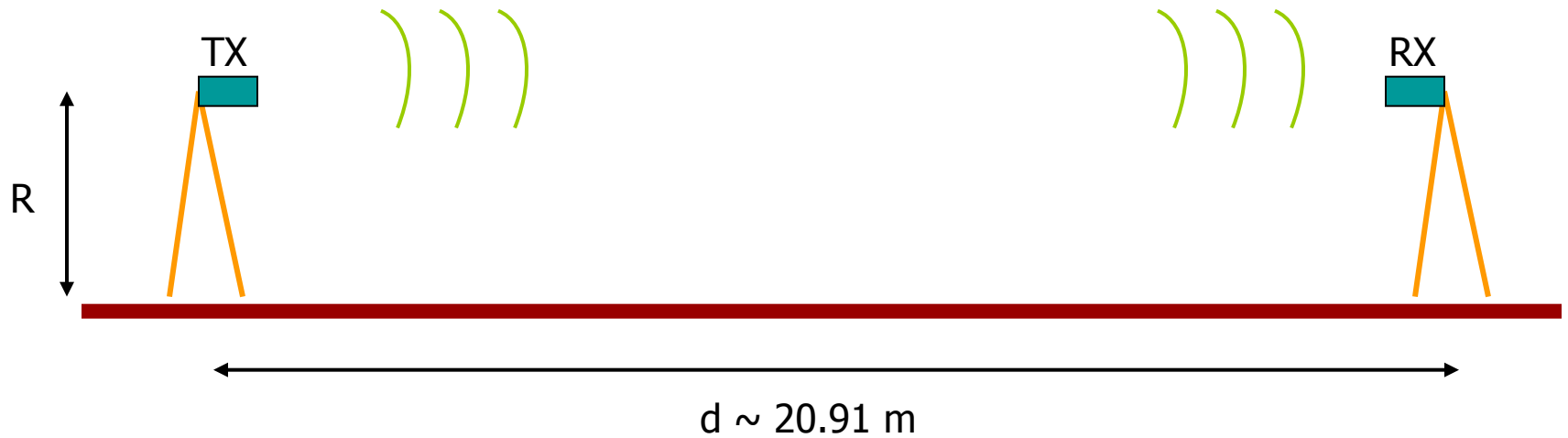


Frequency Bands Explored





First Ellipsoid free



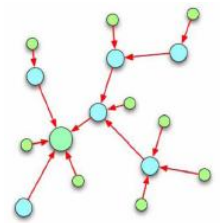
$R=80$ cm. First Fresnel ellipsoid is free.

$$R = \frac{1}{2} \sqrt{\lambda d}$$



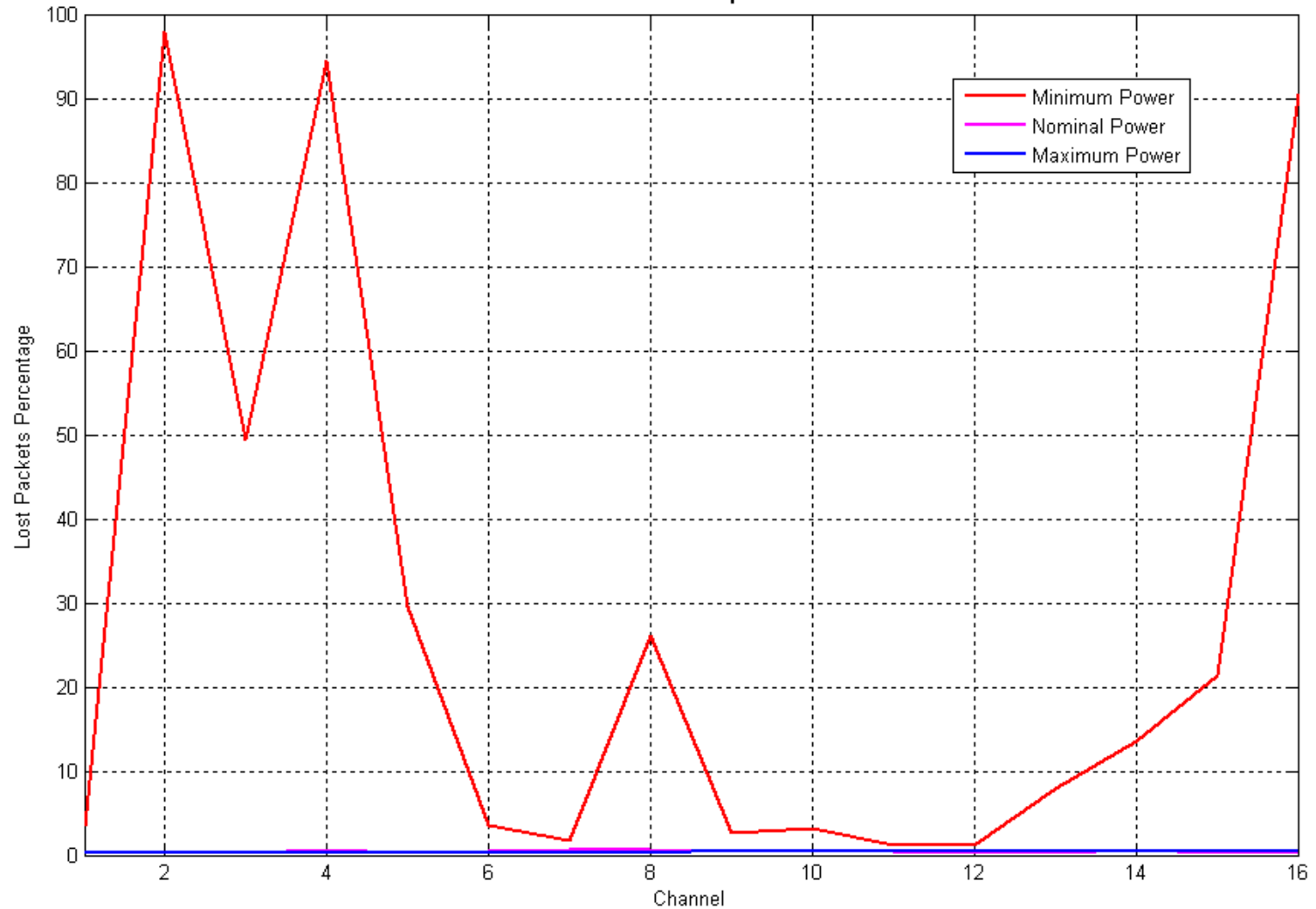
$$d = \frac{4R^2}{\lambda}$$

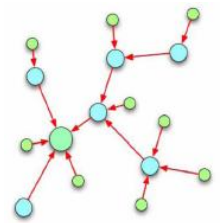
$$\lambda = 0.12245 \text{ m}$$



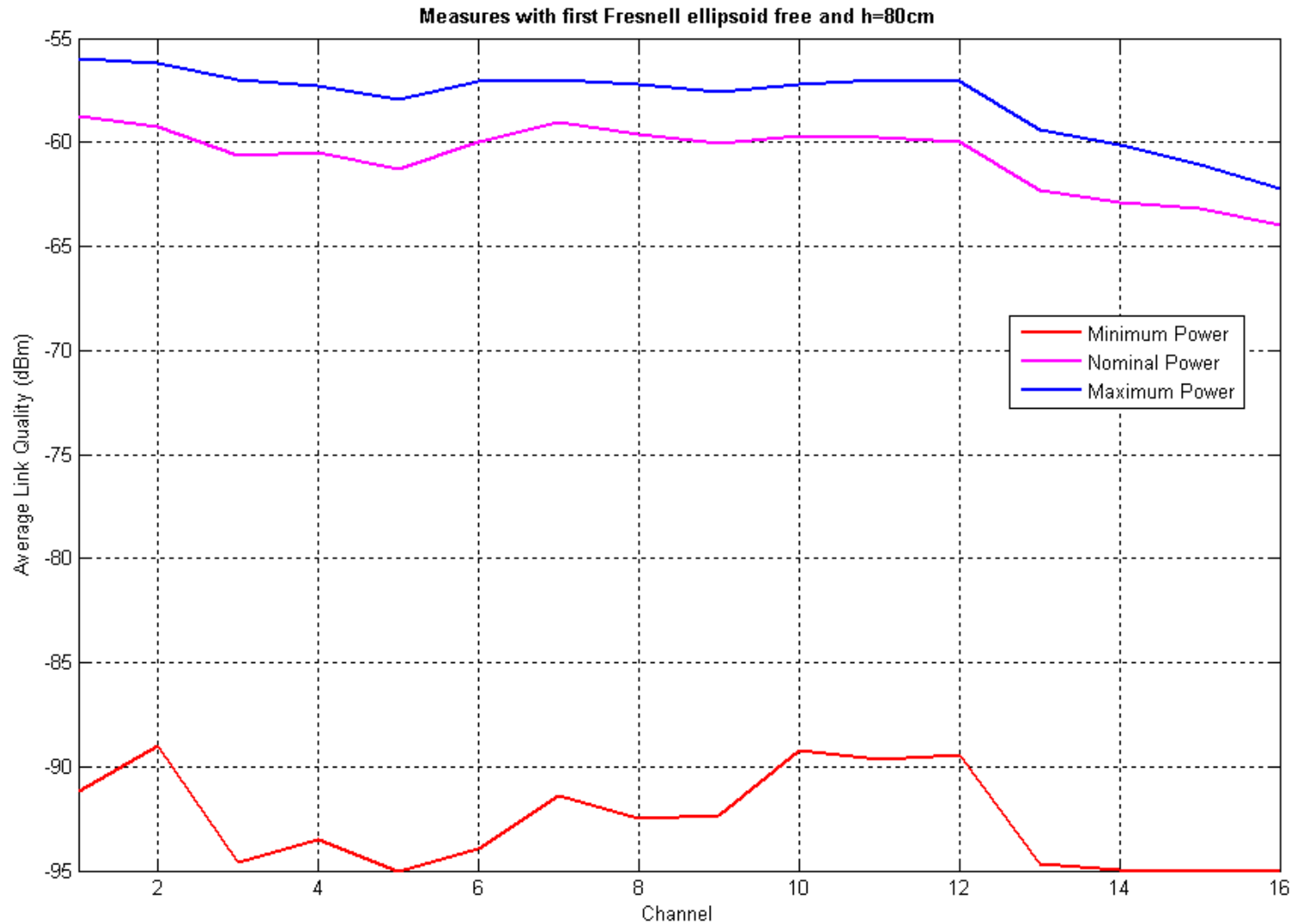
First Ellipsoid free

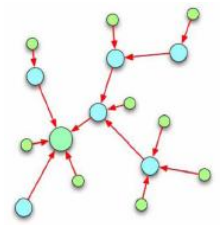
Measures with first Fresnell ellipsoid free and h=80cm



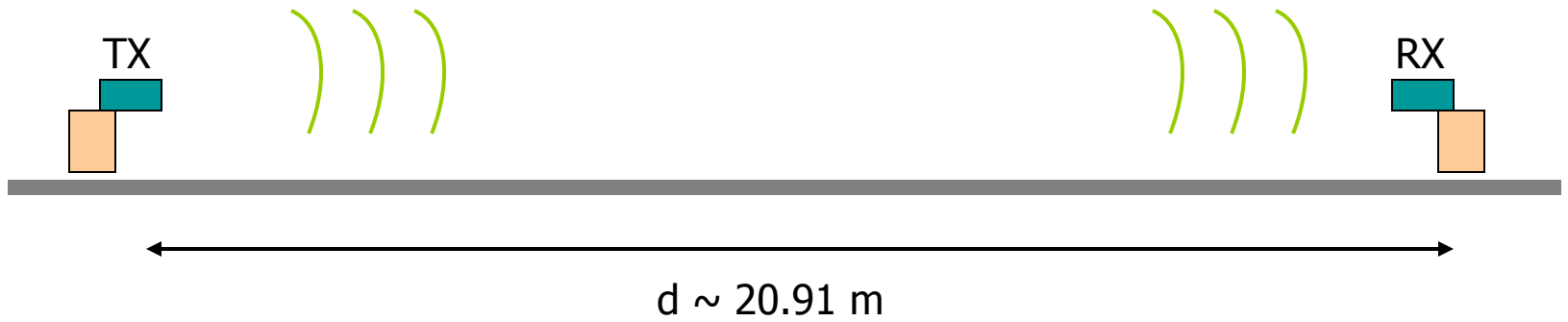


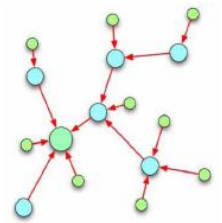
First Ellipsoid free



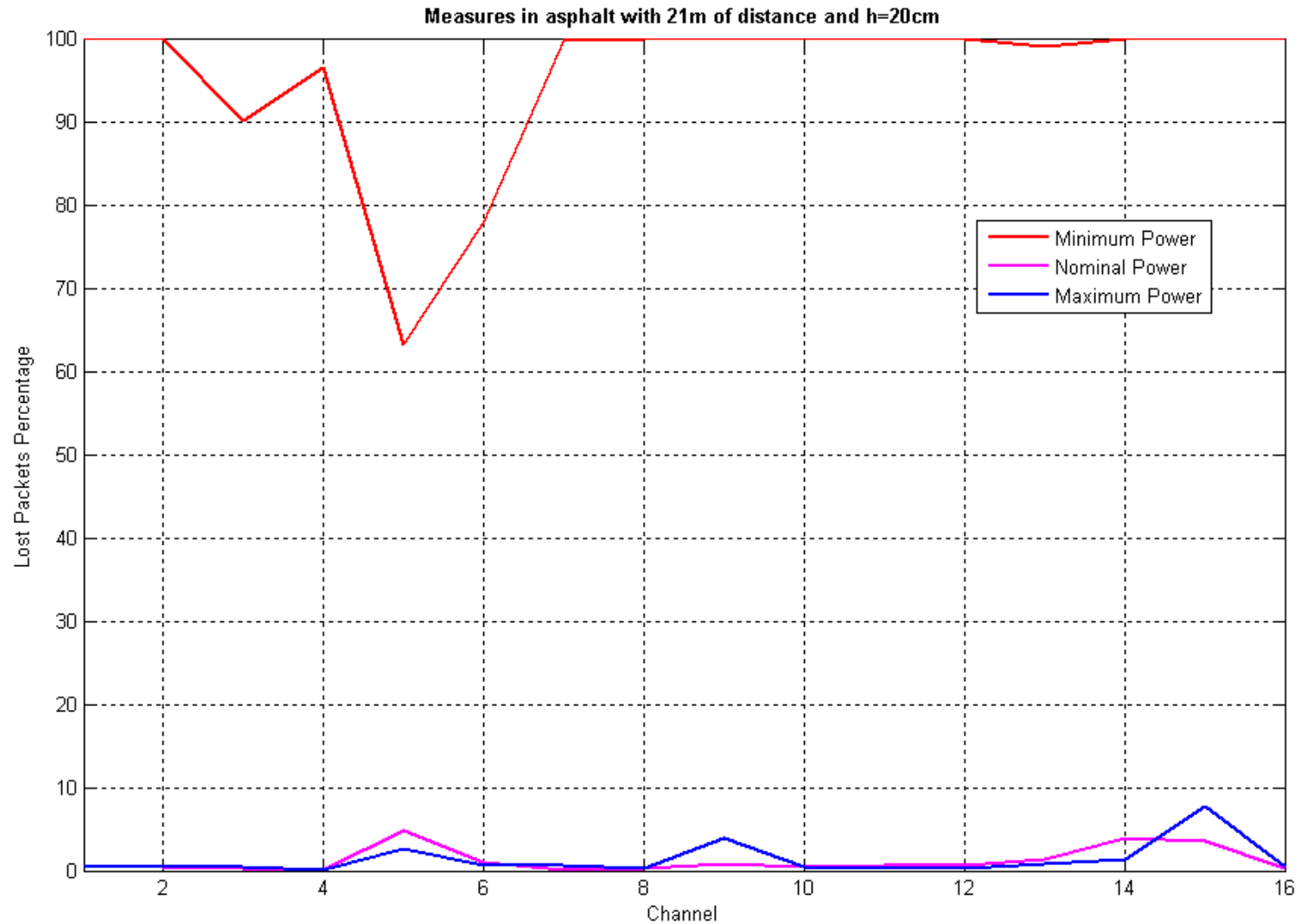


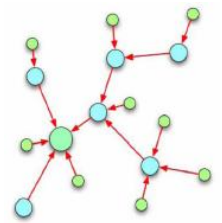
Asphalt



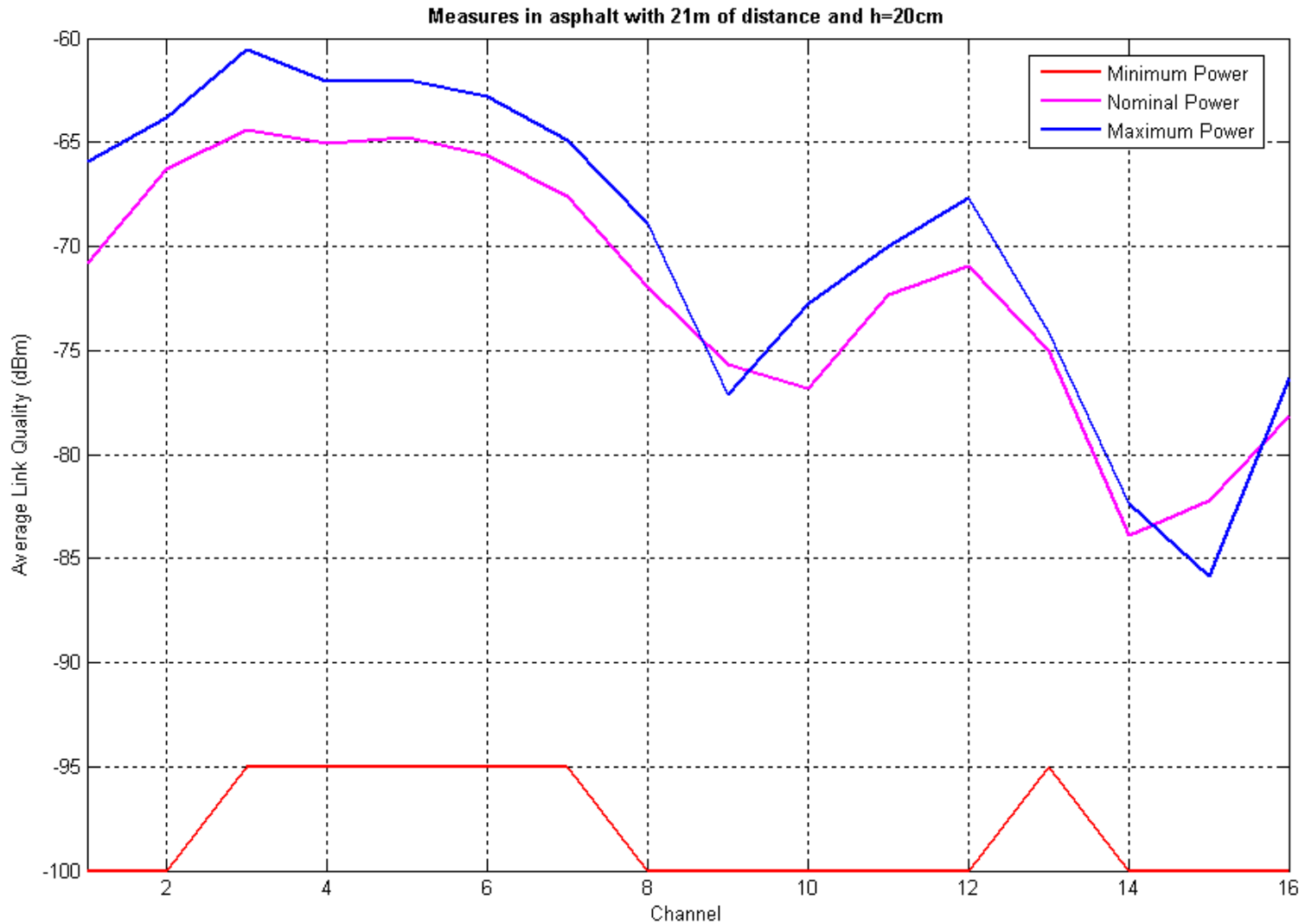


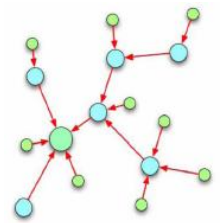
Asphalt



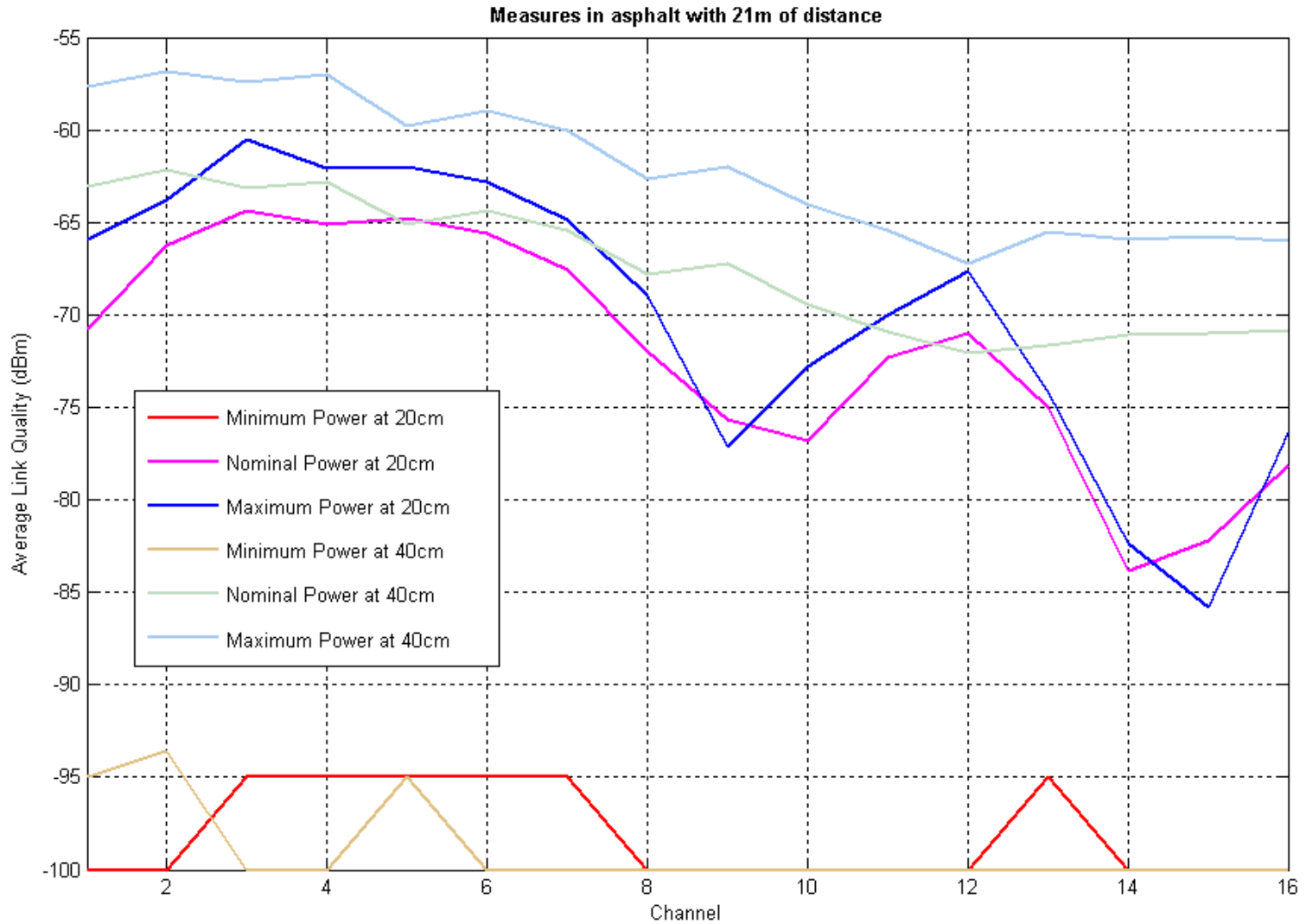


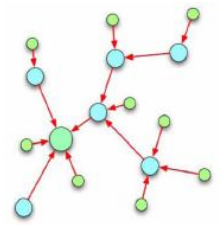
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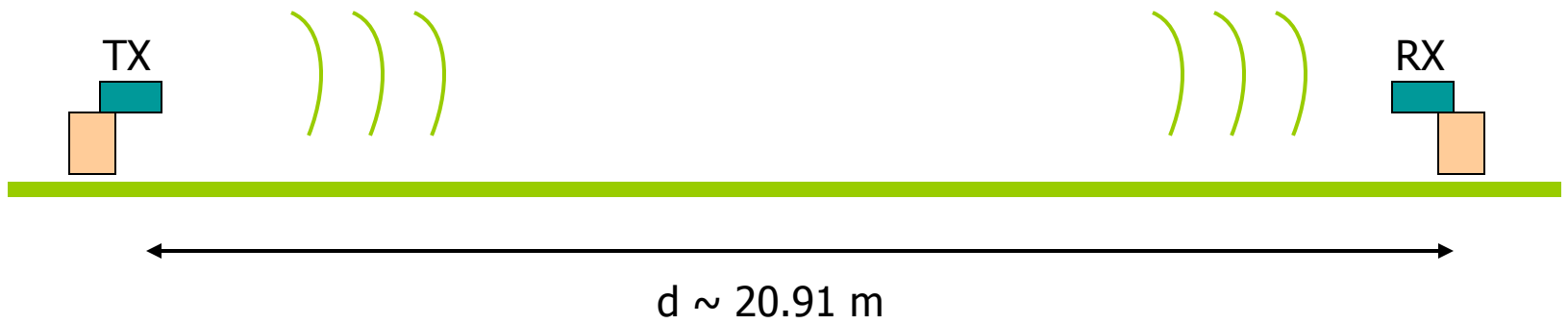


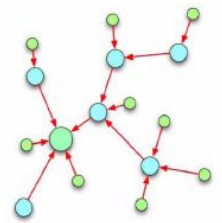
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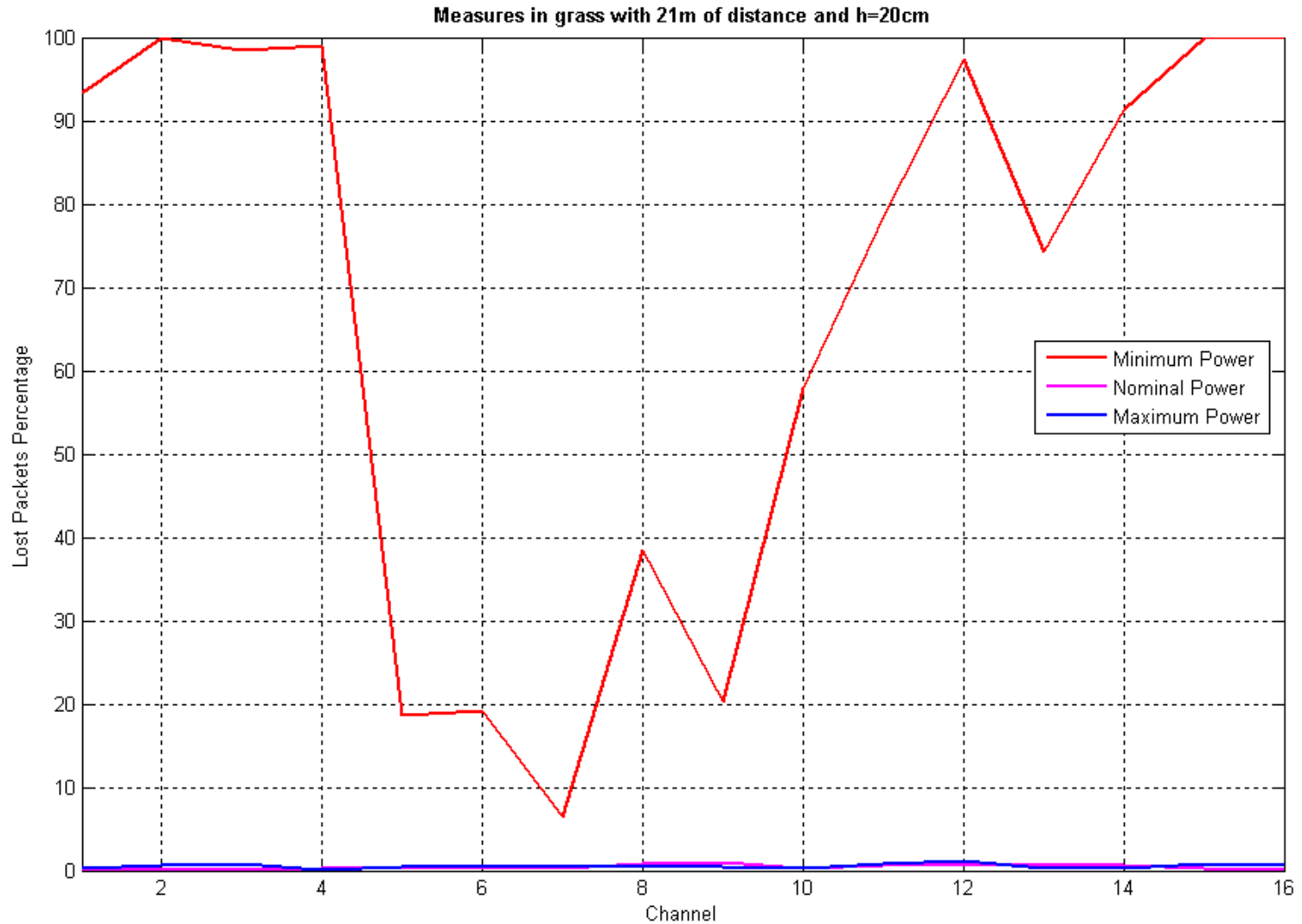


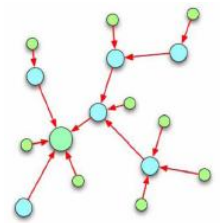
Grass



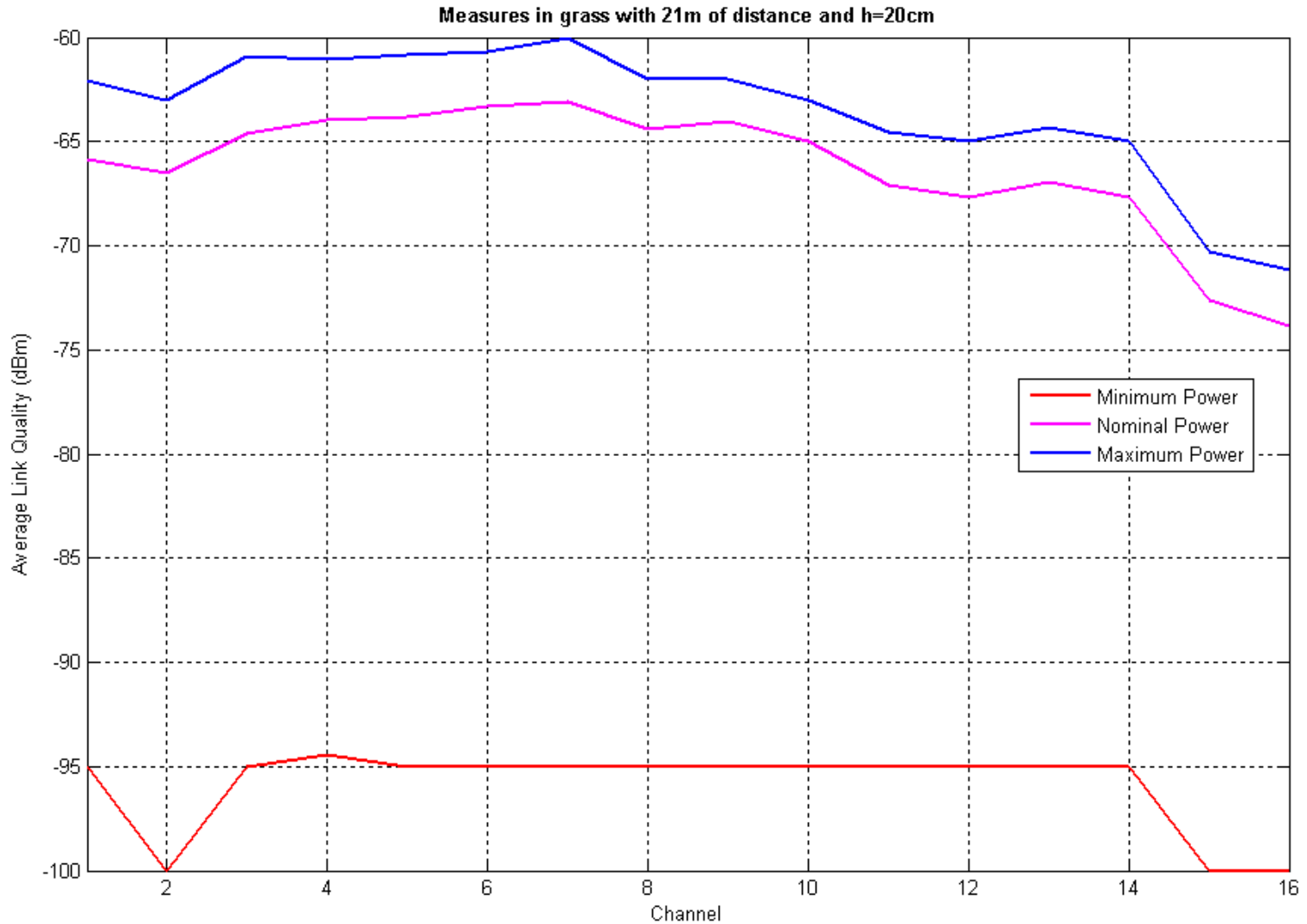


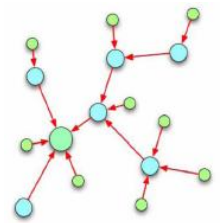
Grass



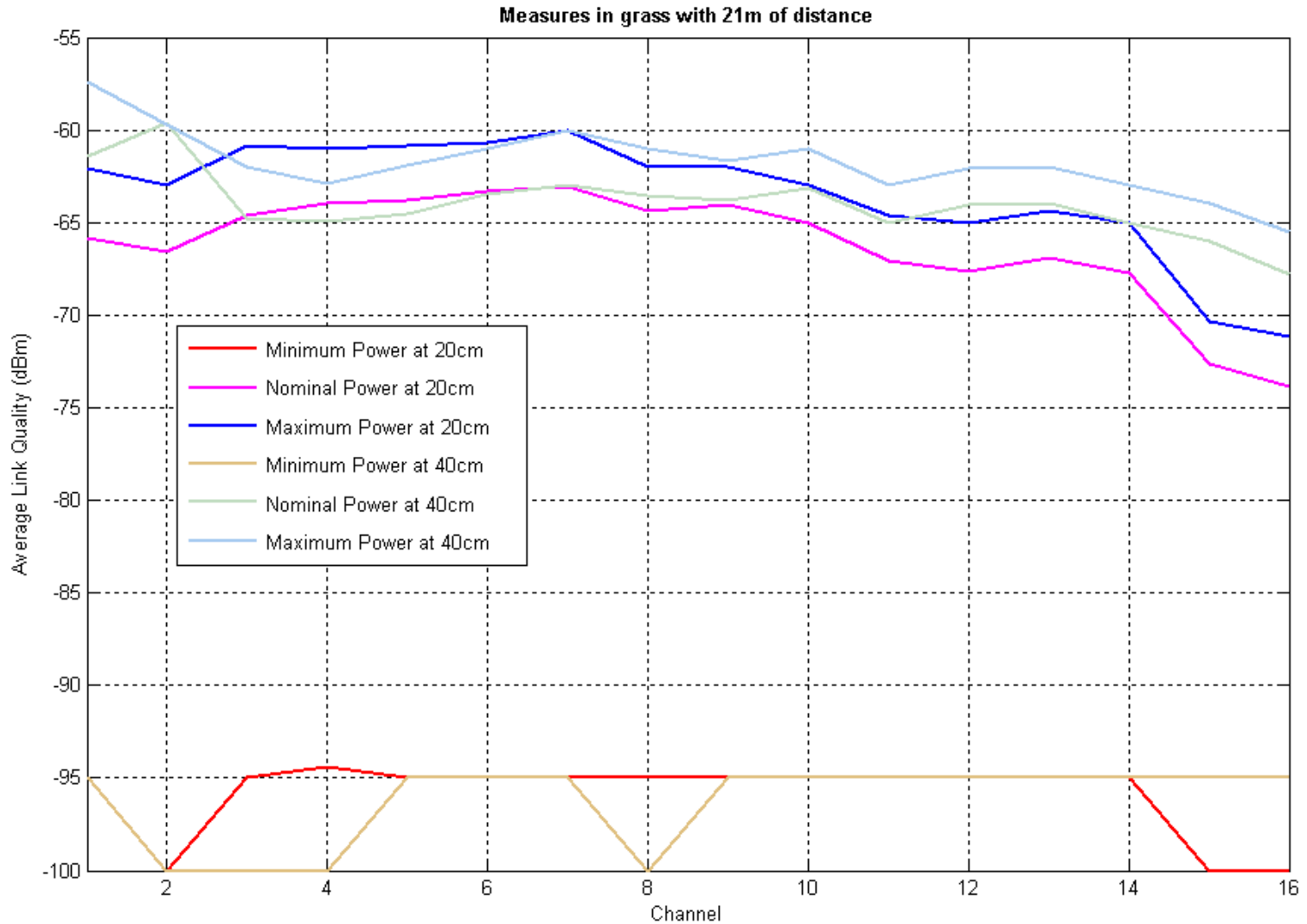


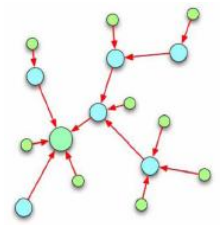
Grass



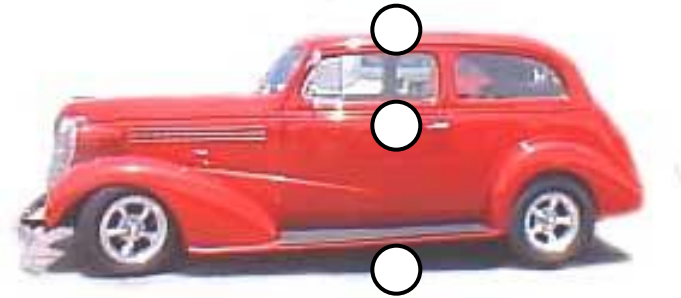
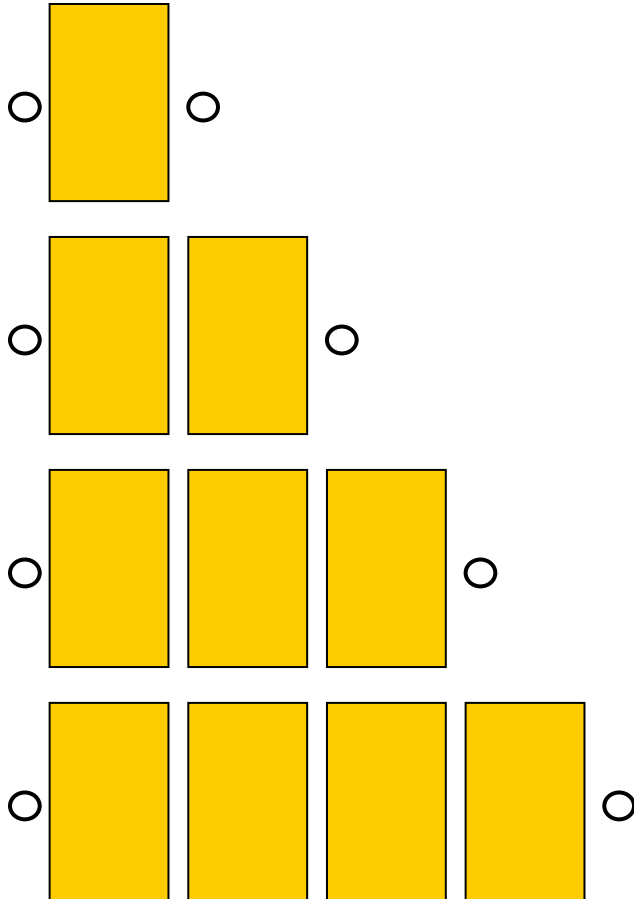


Grass



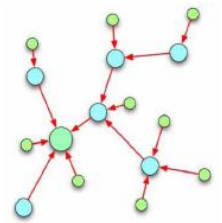


Urban Environment

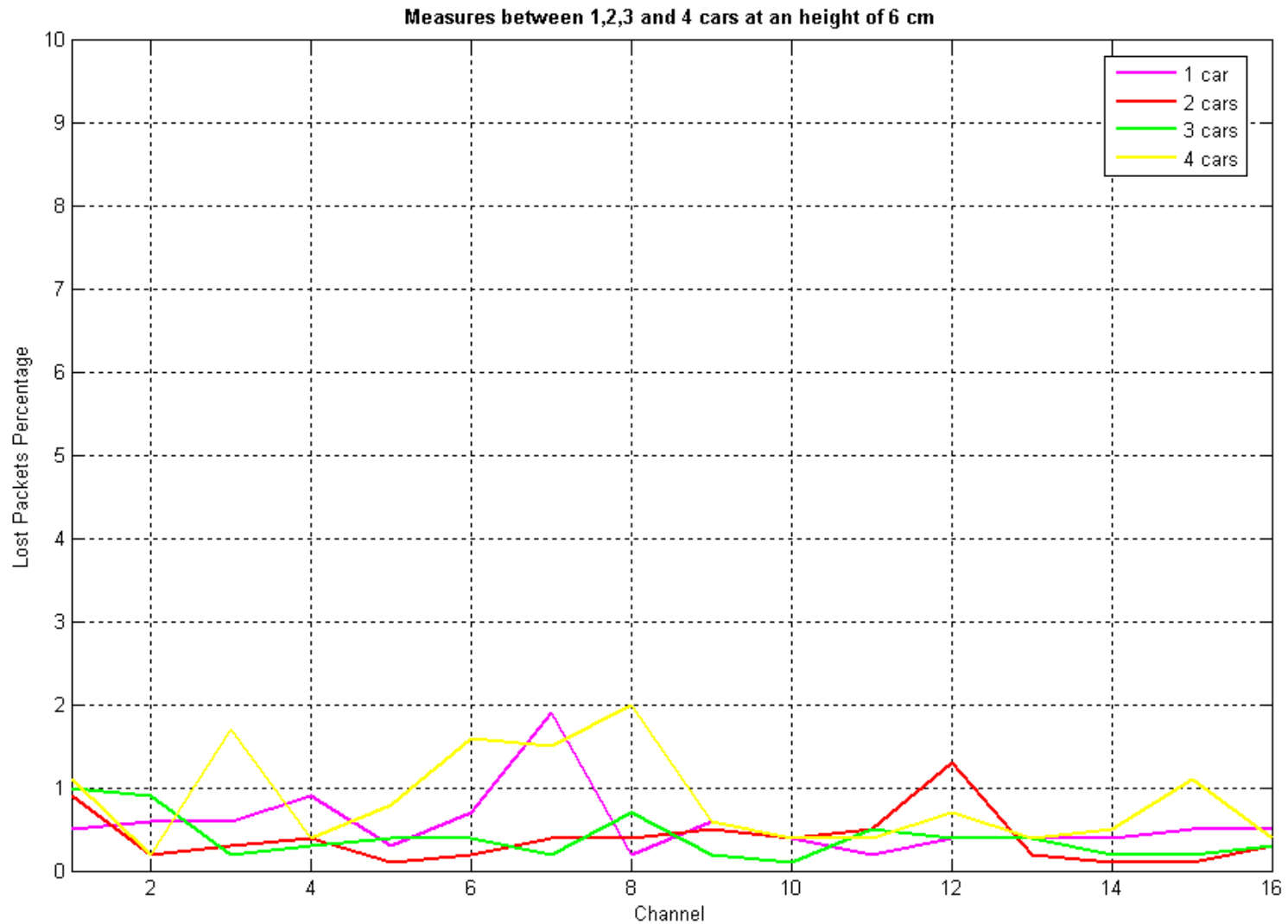


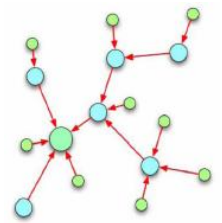
Three heights:

- 6 cm
- 80 cm
- 160 cm

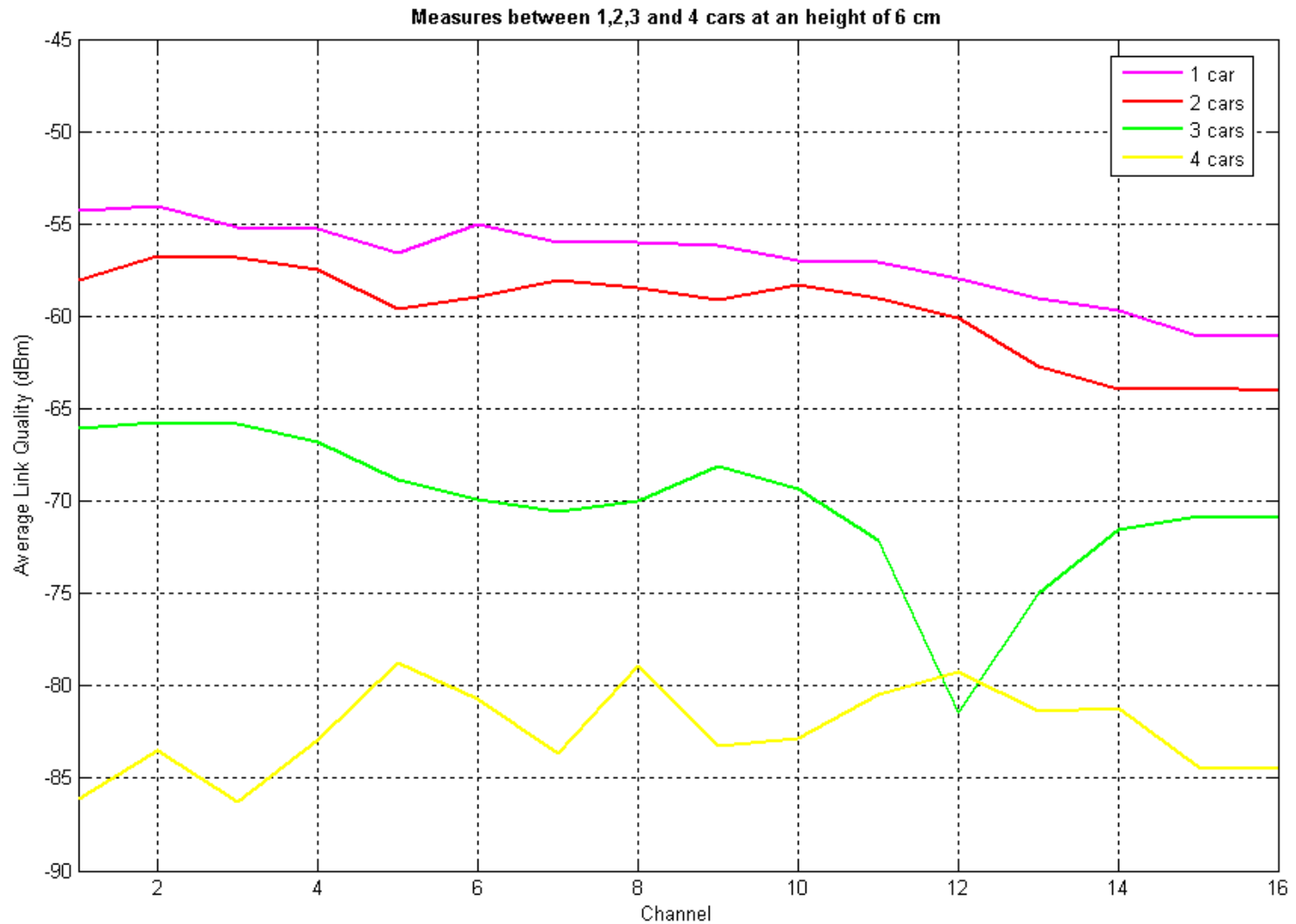


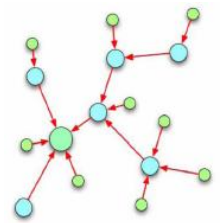
Urban Environment



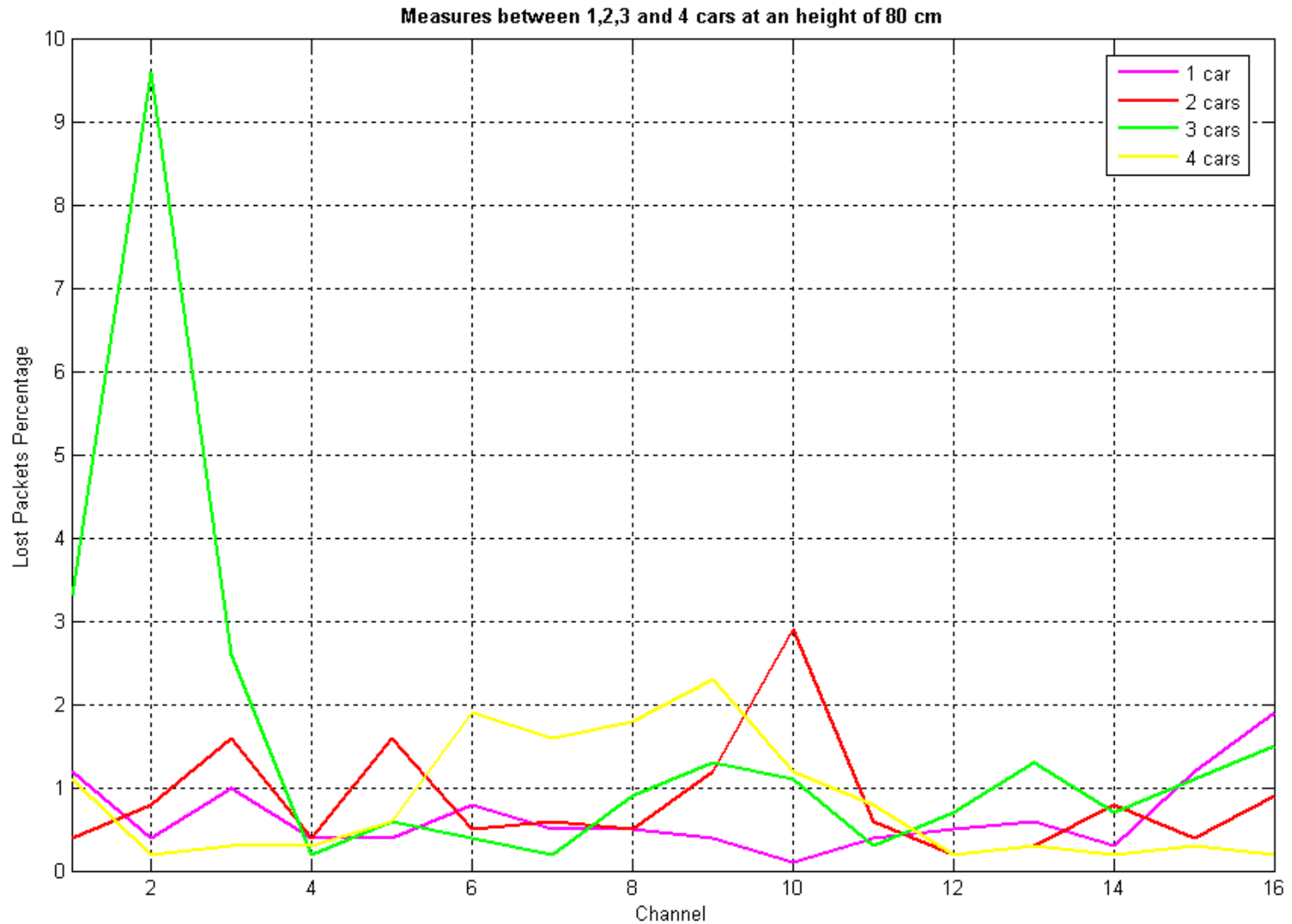


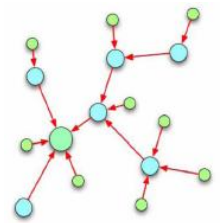
Urban Environment



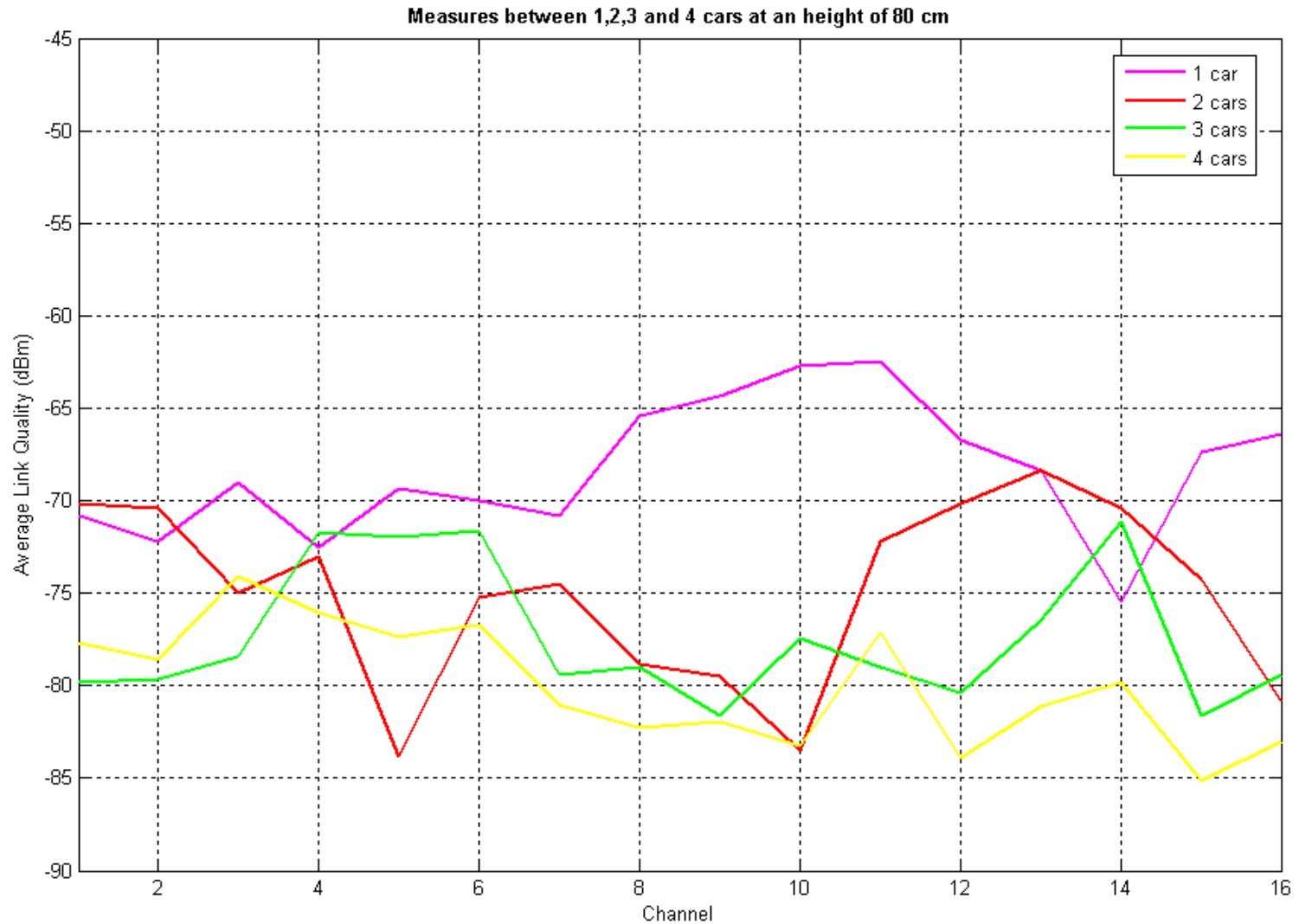


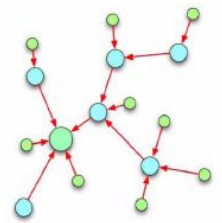
Urban Environment



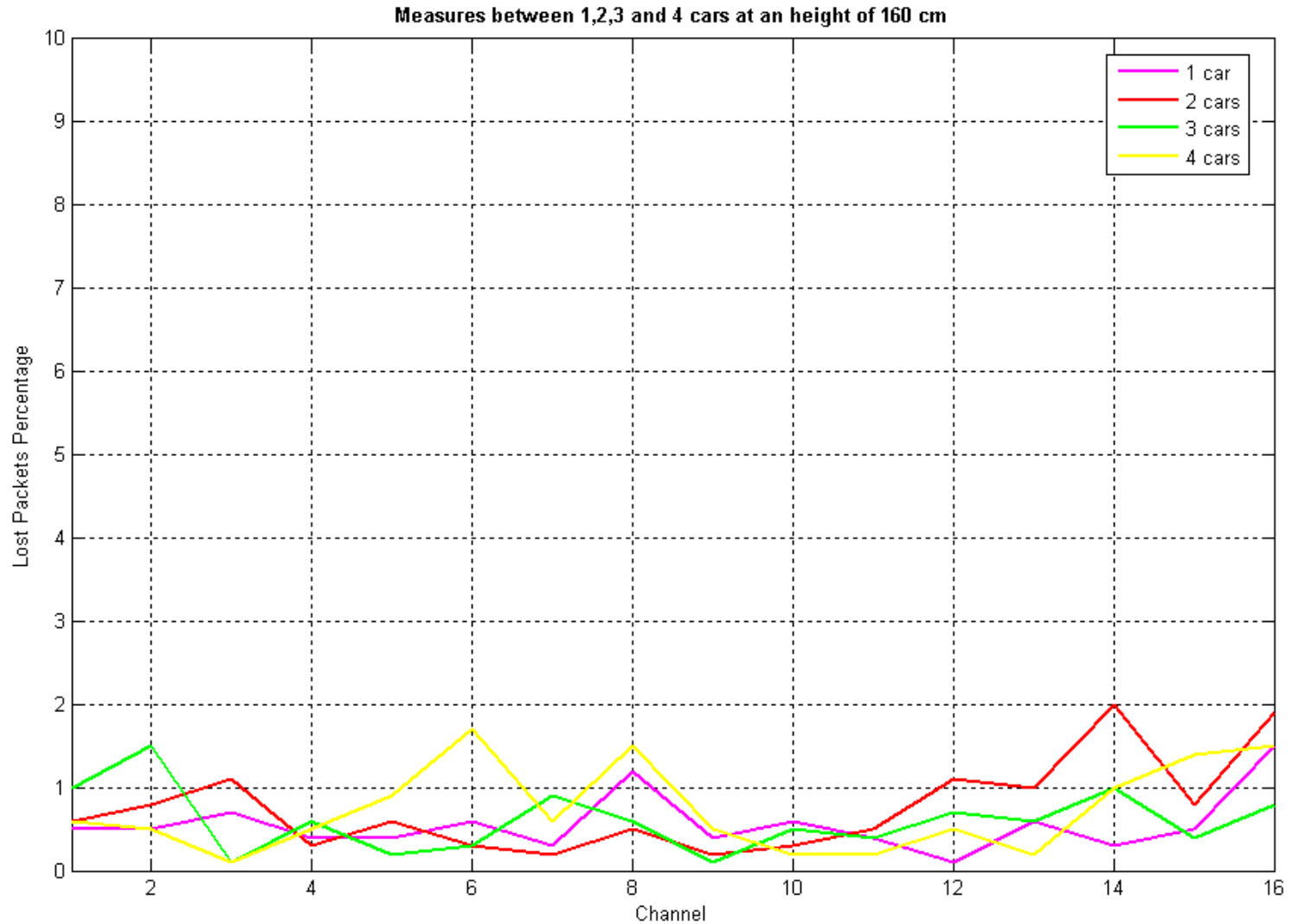


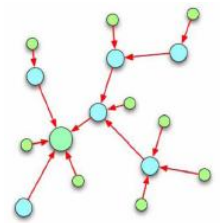
Urban Environment



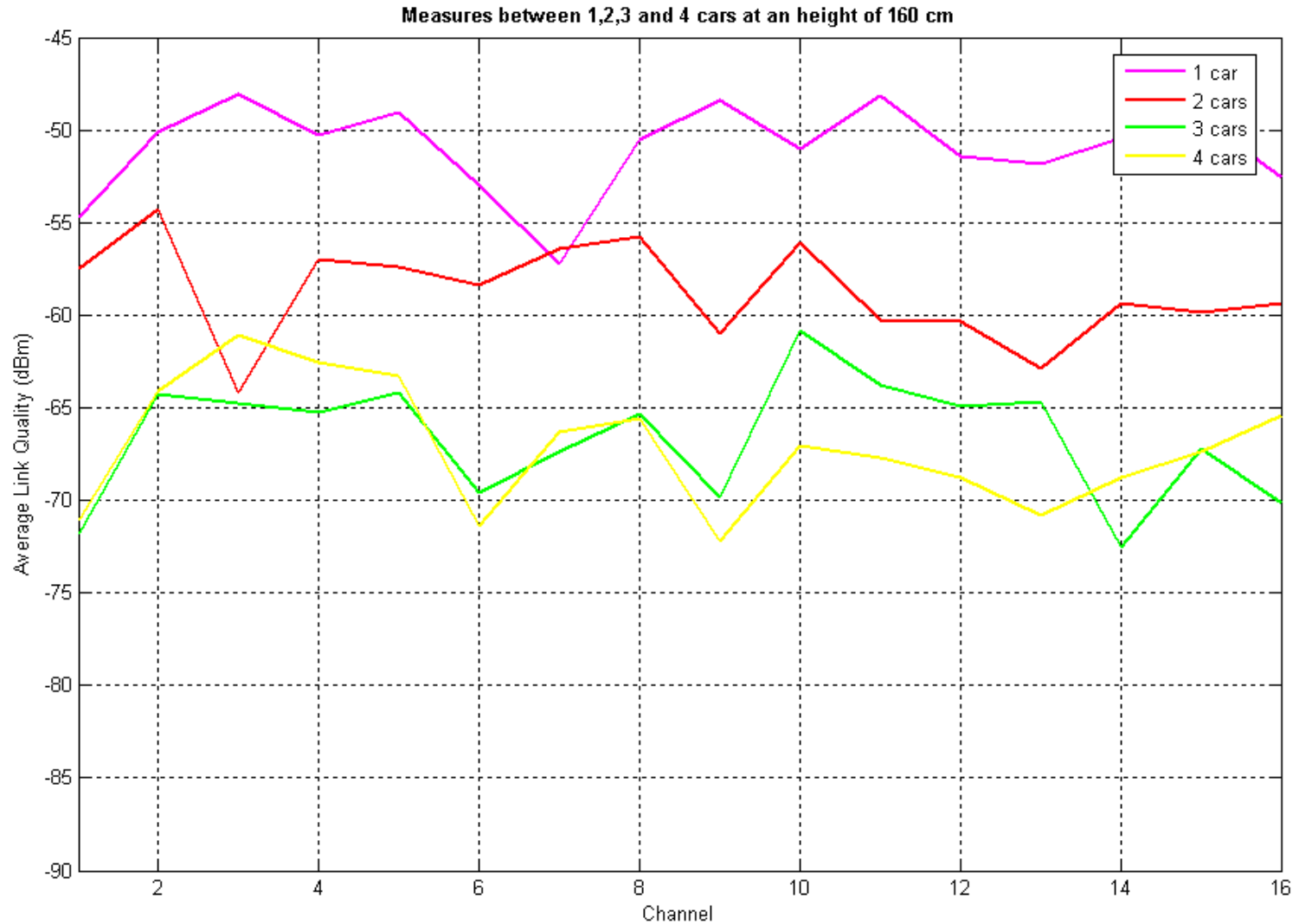


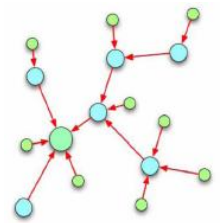
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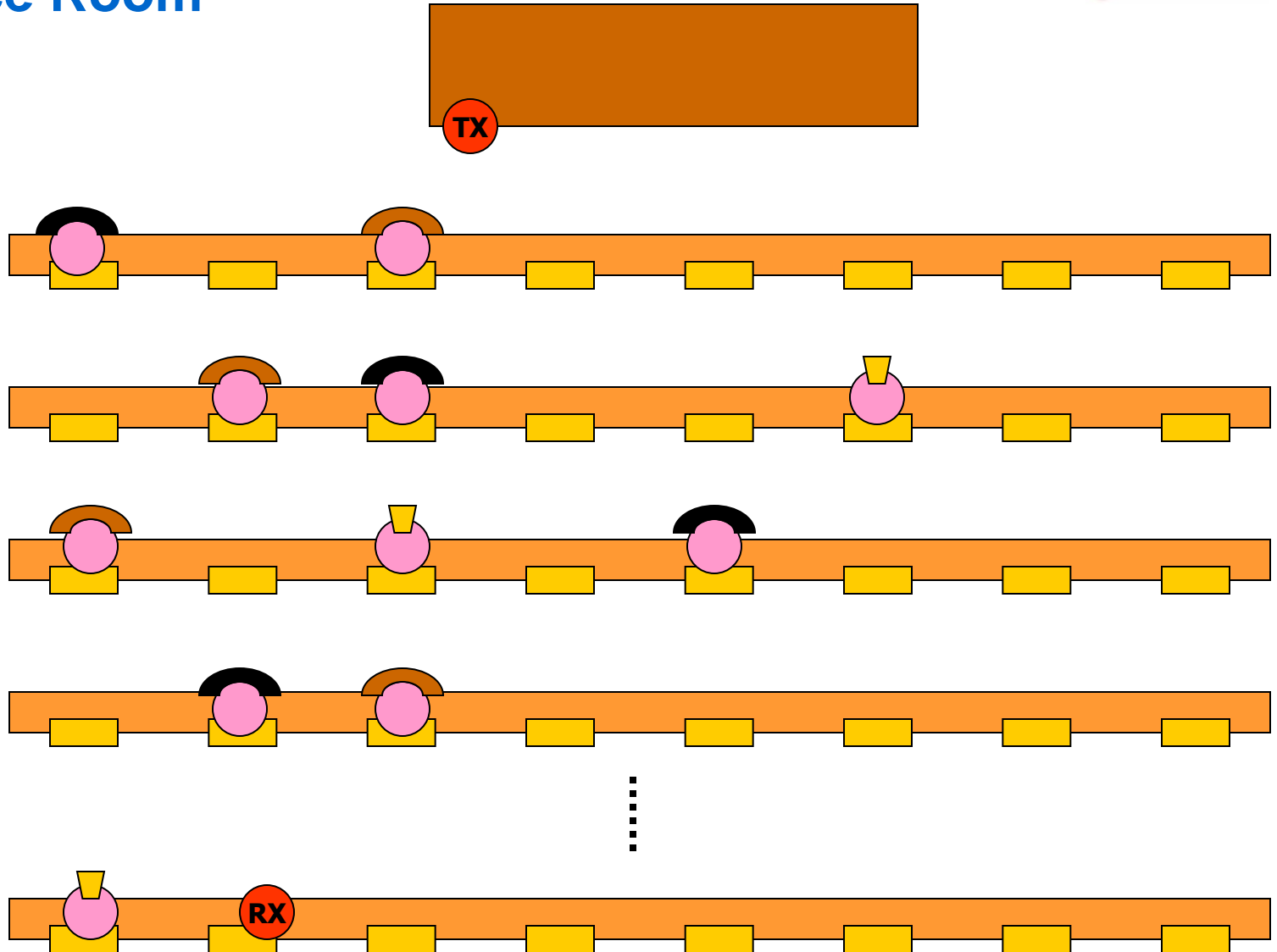


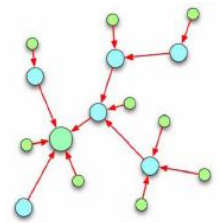
Urban Environment



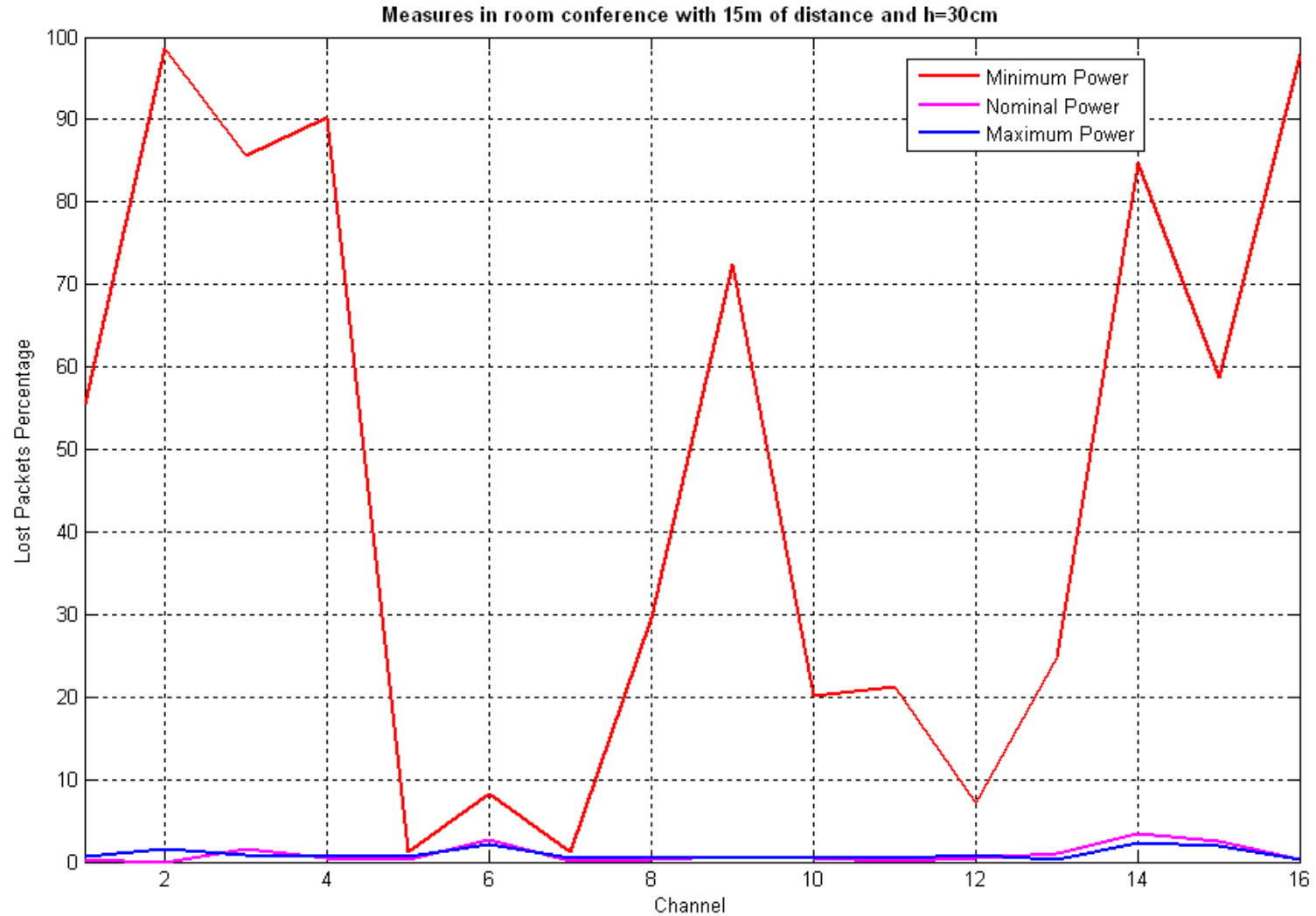


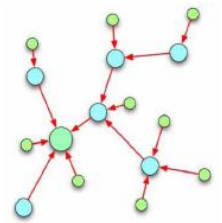
Conference Room



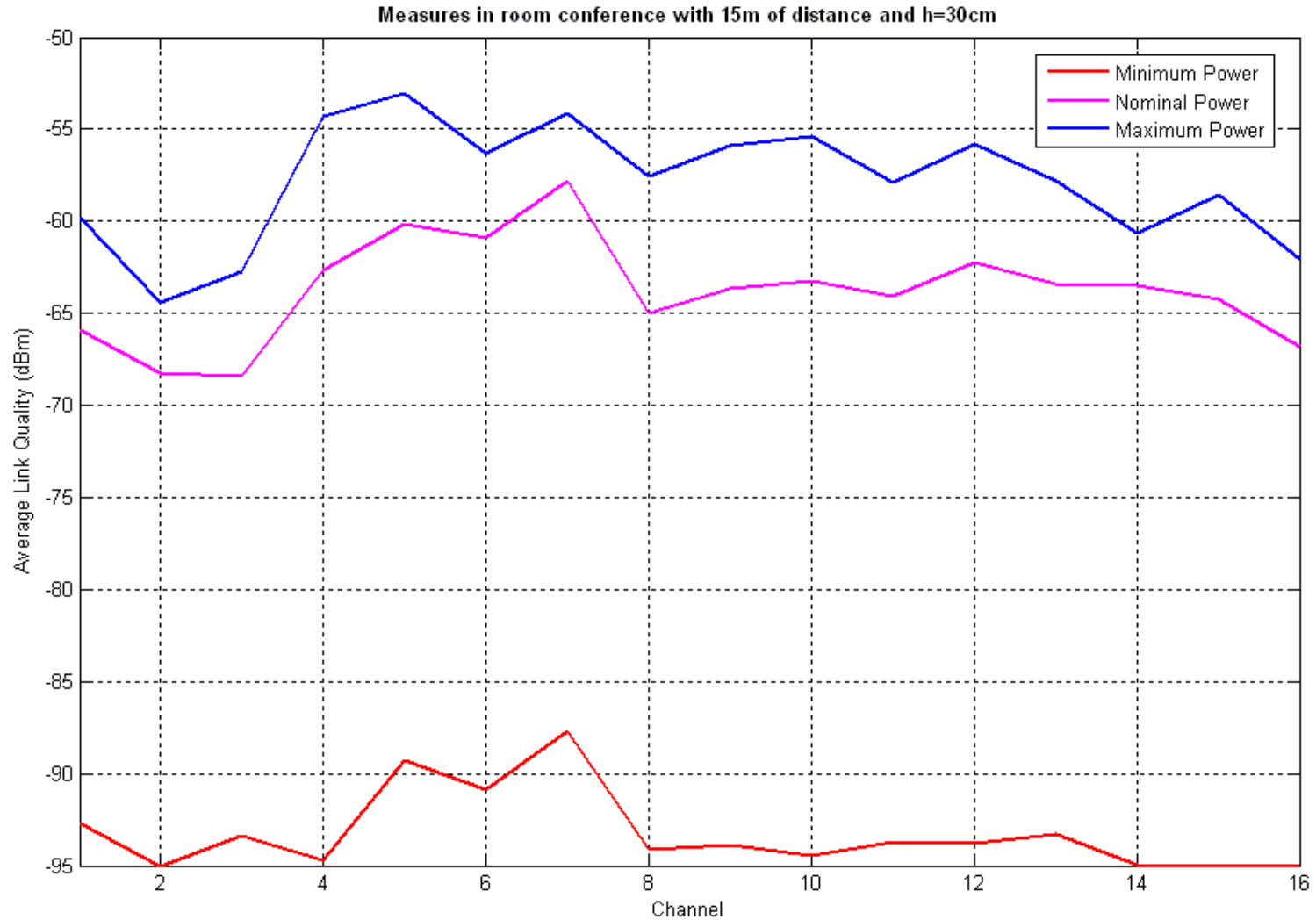


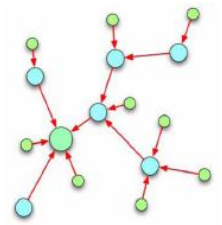
Conference Room



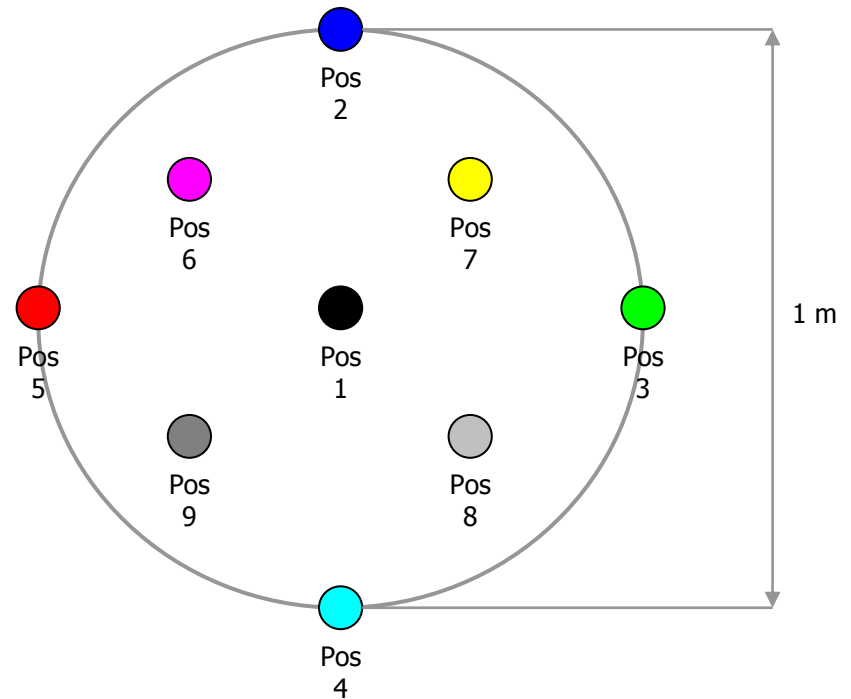
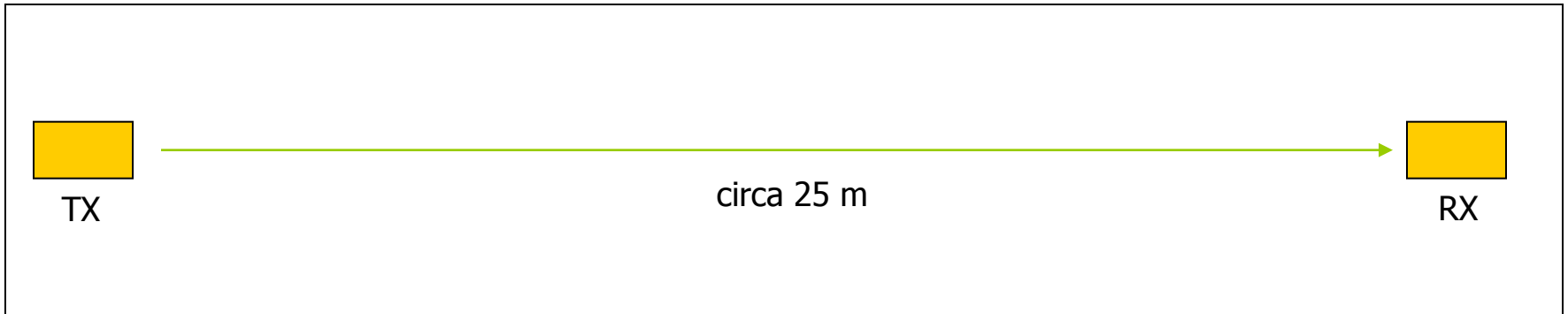


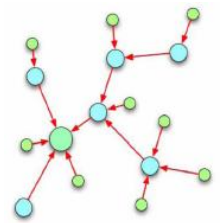
Conference Room



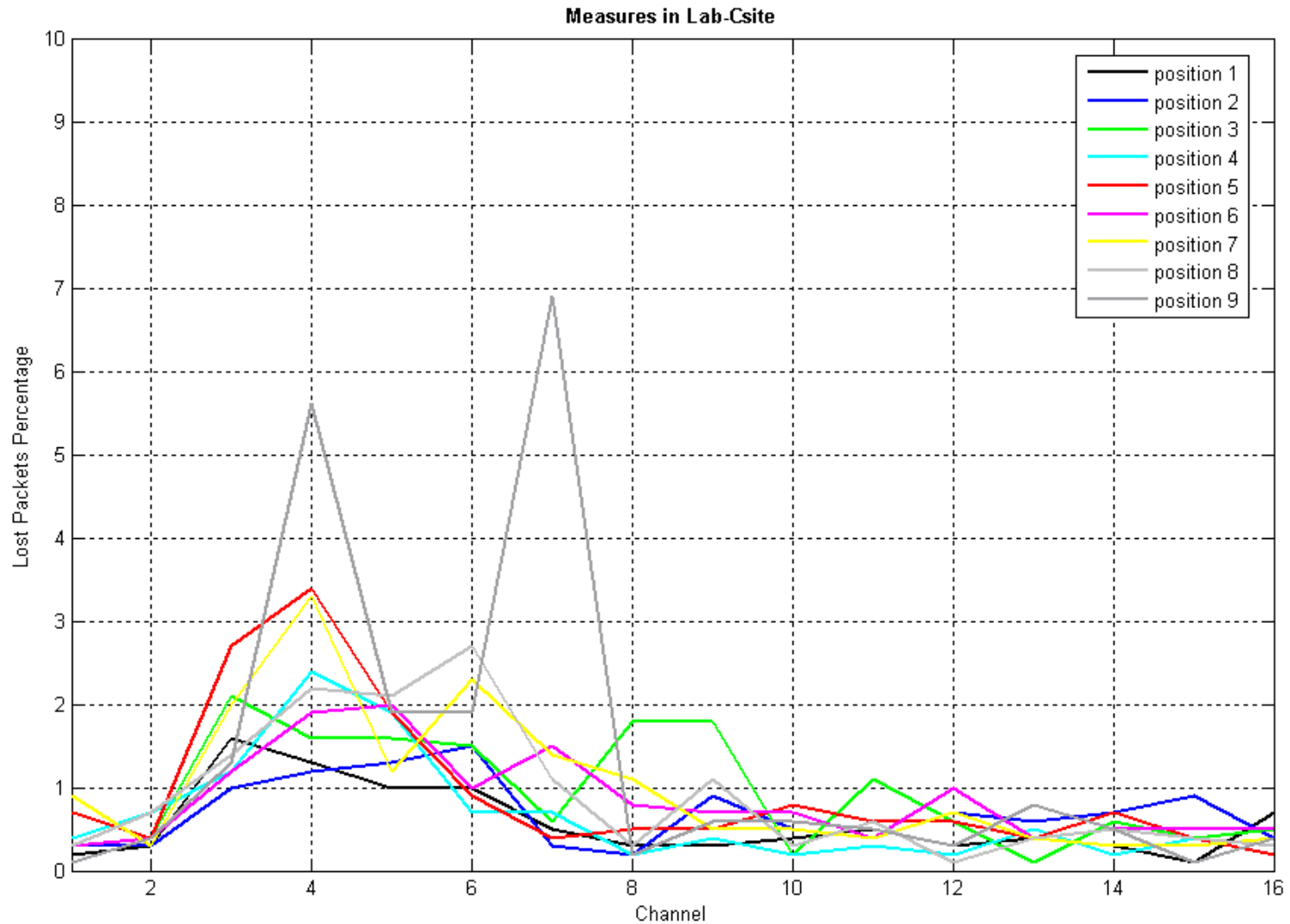


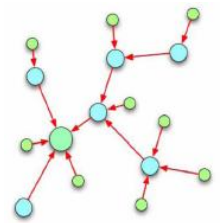
Indoor Environment



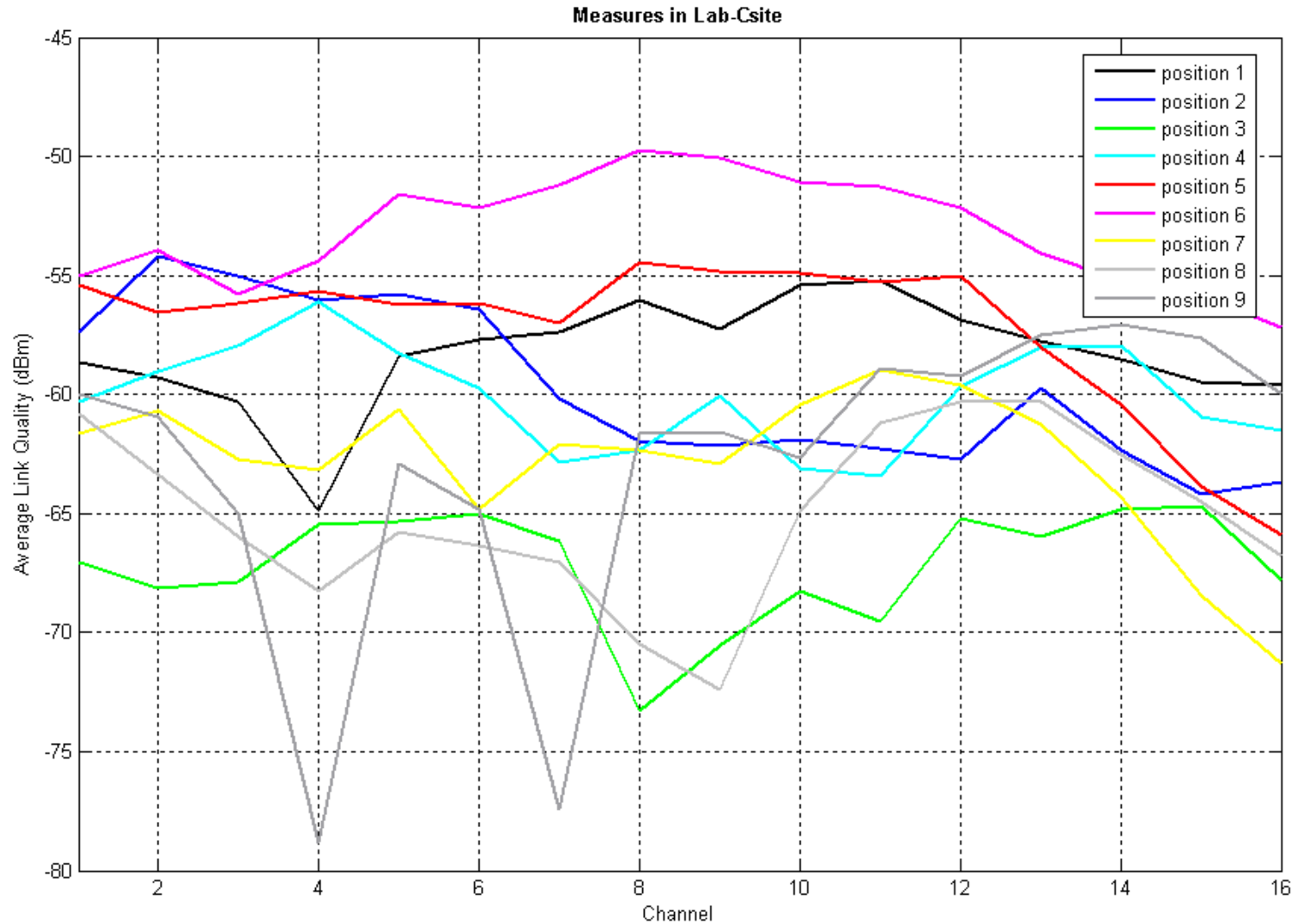


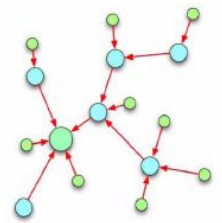
Indoor Environment



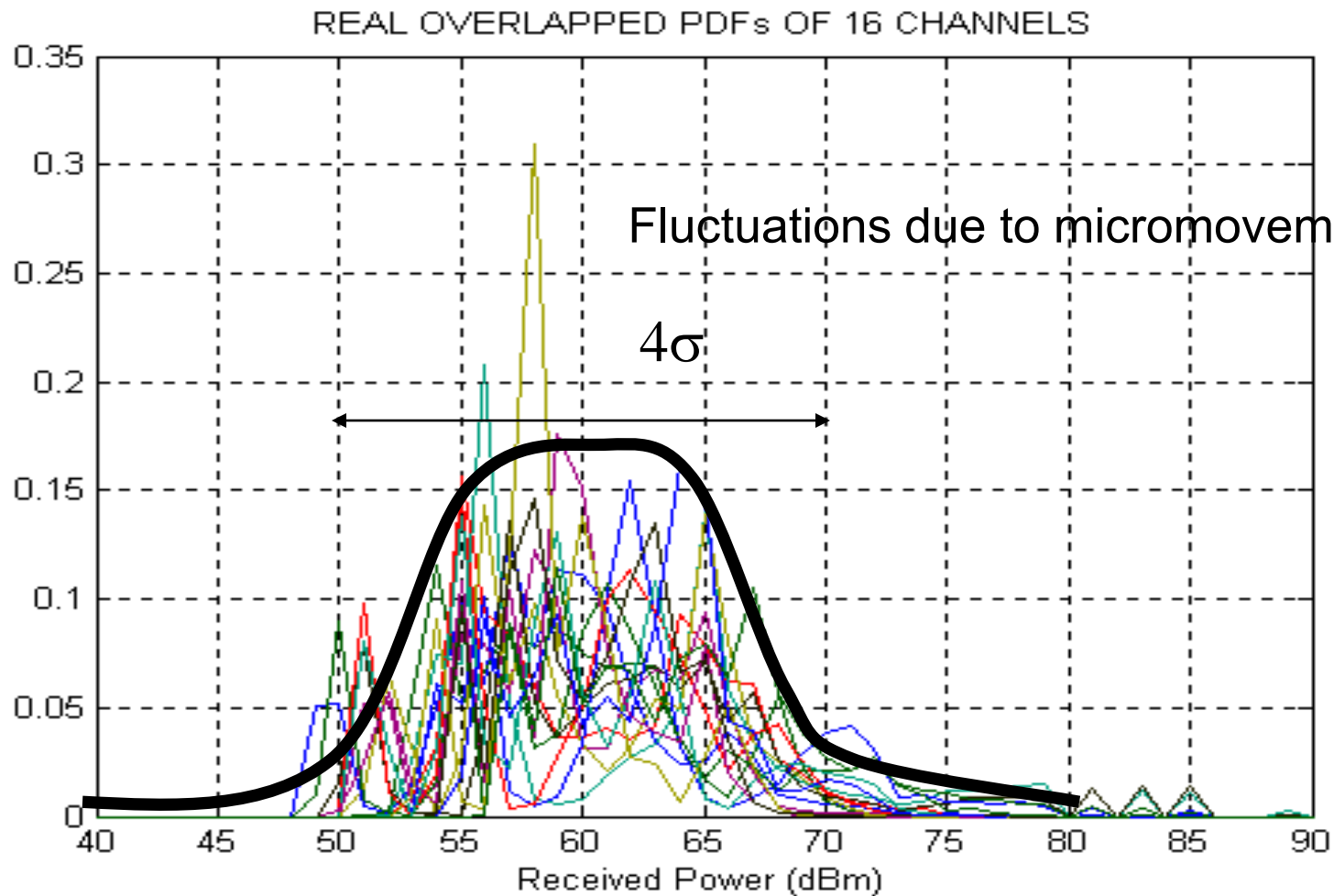


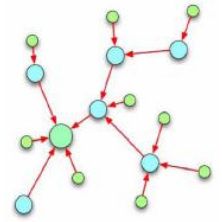
Indoor Environment





Indoor Environment





A Model for Channel Fluctuations

$P_r = P_t - L$ logarithmic units

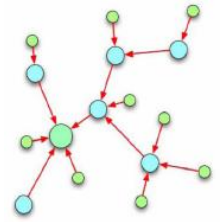
$$L = k_0 + k_1 \ln(d) + s$$

s is Gaussian (zero mean) with variance σ^2

s has time coherence T_{WCOH}

s has angular coherence Φ_{WCOH}

- Fading and shadowing not distinguished
- Variance depends on environment

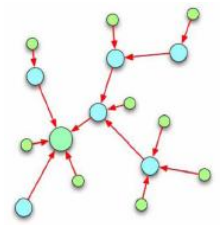


A Model for Channel Fluctuations

**A Gaussian approximation for loss in dB
seems to be a good approximation,
with values of sigma which depend on the environment
(indoor, rural, etc)**

Indoor: $\sigma = 5$

Rural: $\sigma = 2 - 4$



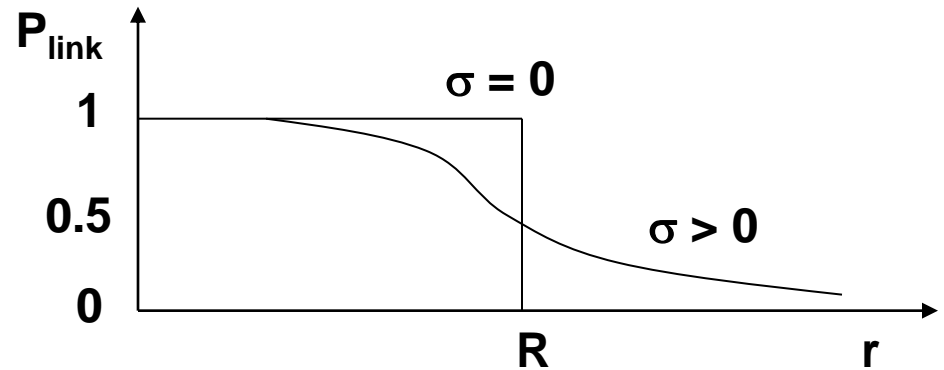
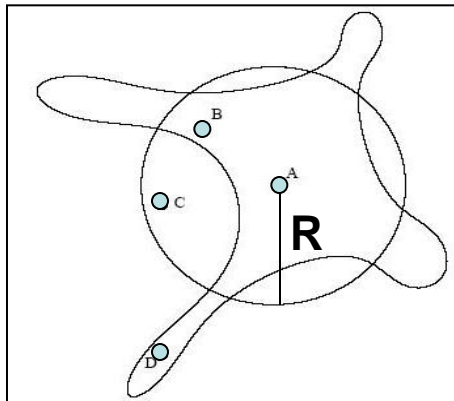
A Model for Channel Fluctuations

Link Level Connectivity:

Probability of a link being connected ($L < L_{th}$) given a distance r

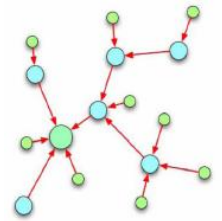
$$P_{link} = \Pr\{L(dB) < L_{th}\} = \Pr\{s < L_{th} - k_0 - k_1 \ln(r)\} =$$

$$= \frac{1}{2} + \frac{1}{2} \operatorname{erf}\left(\frac{L_{th} - k_0 - k_1 \ln(r)}{\sqrt{2}\sigma}\right)$$

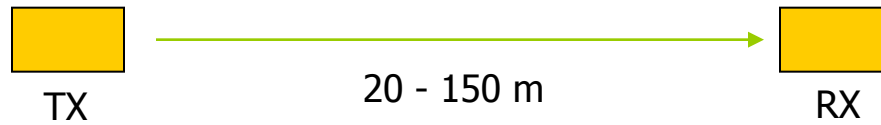


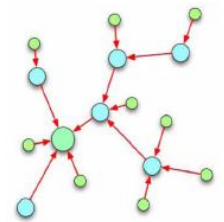
R is the ideal transmission range

No circles. However, >90% of papers deal with circles.

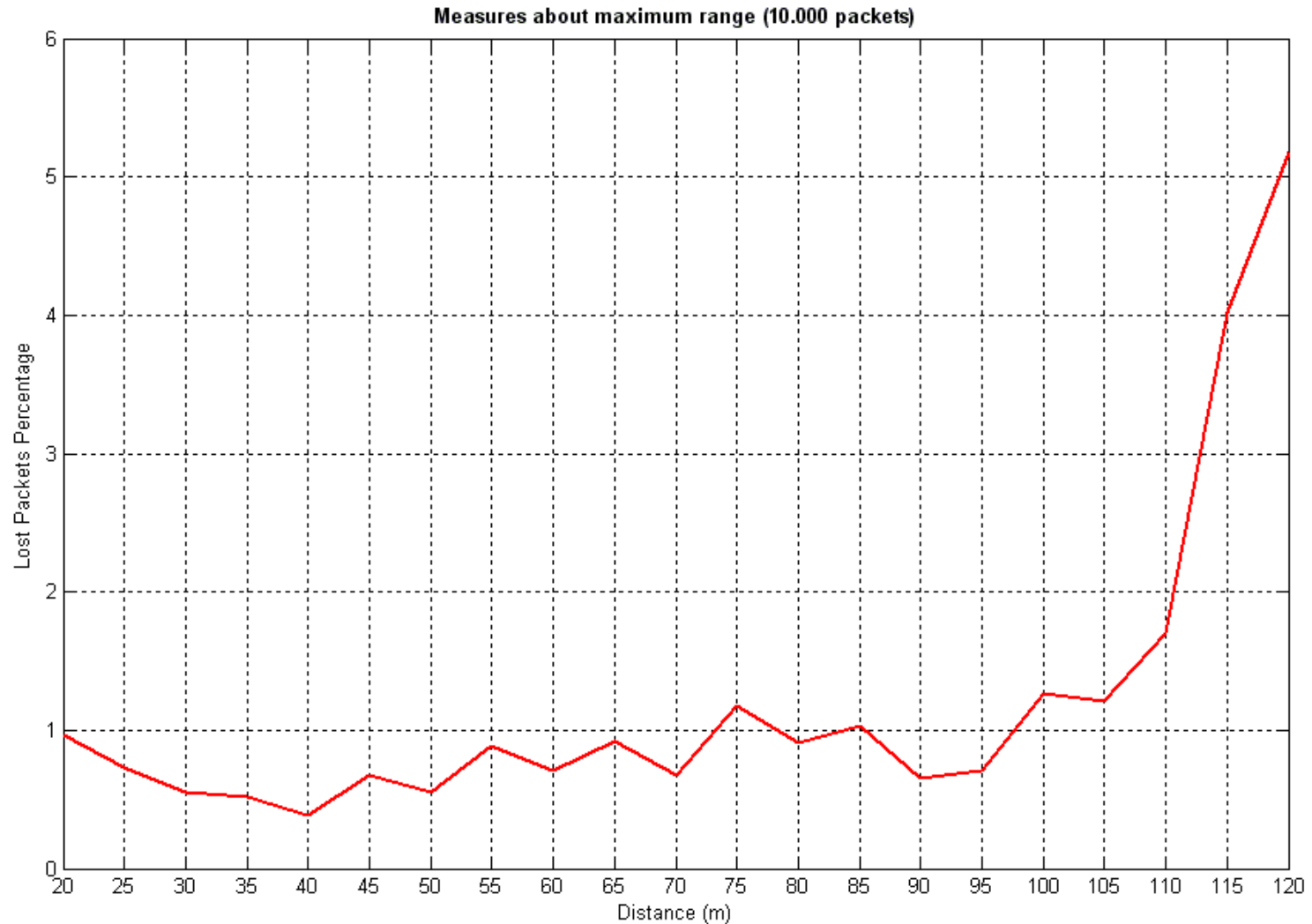


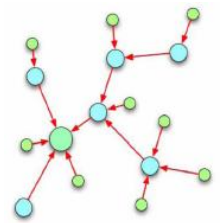
Maximum Transmission Range (Rural Environment)



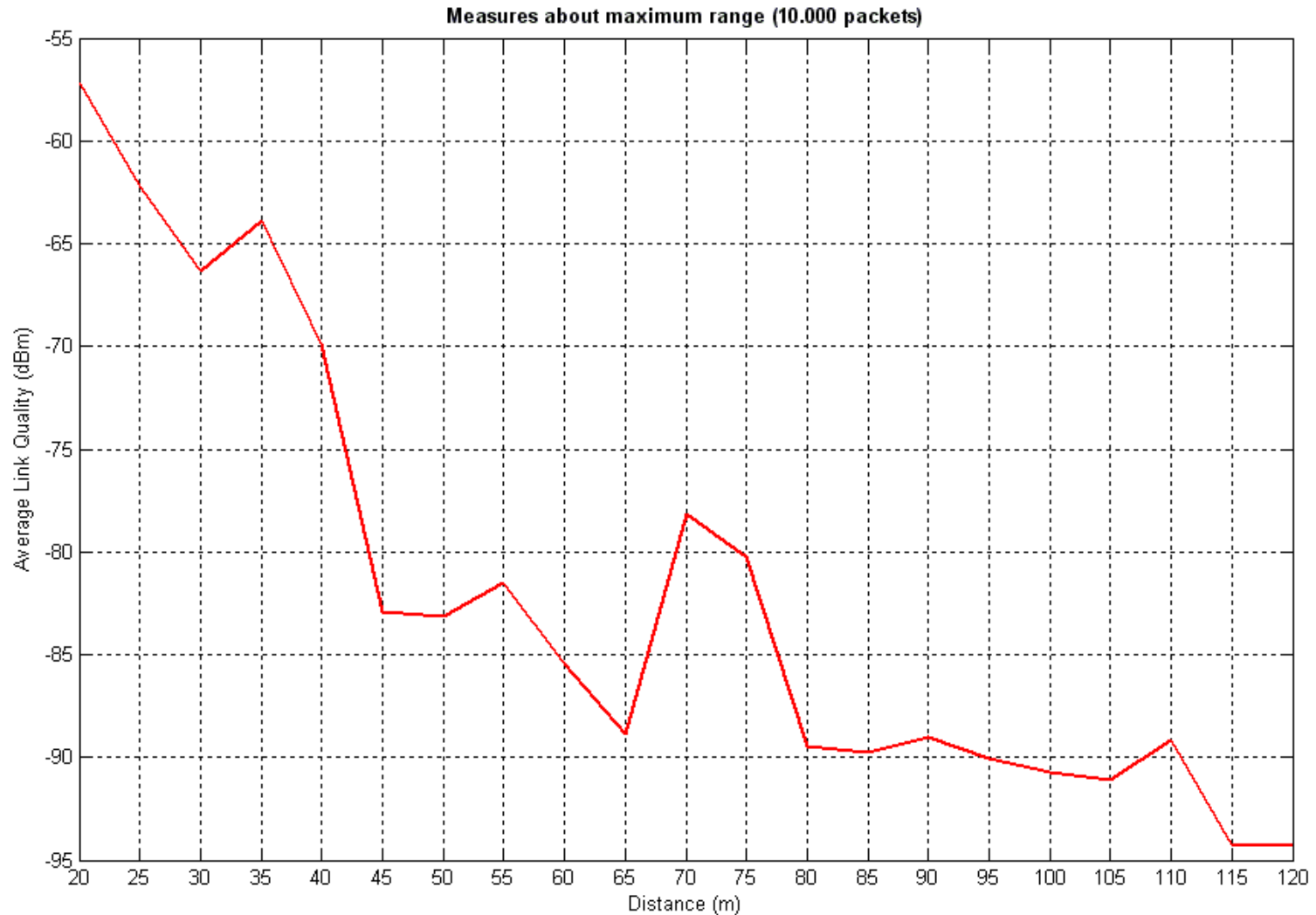


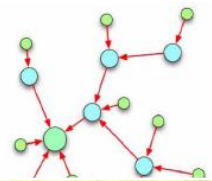
Maximum Transmission Range (Rural Environment)





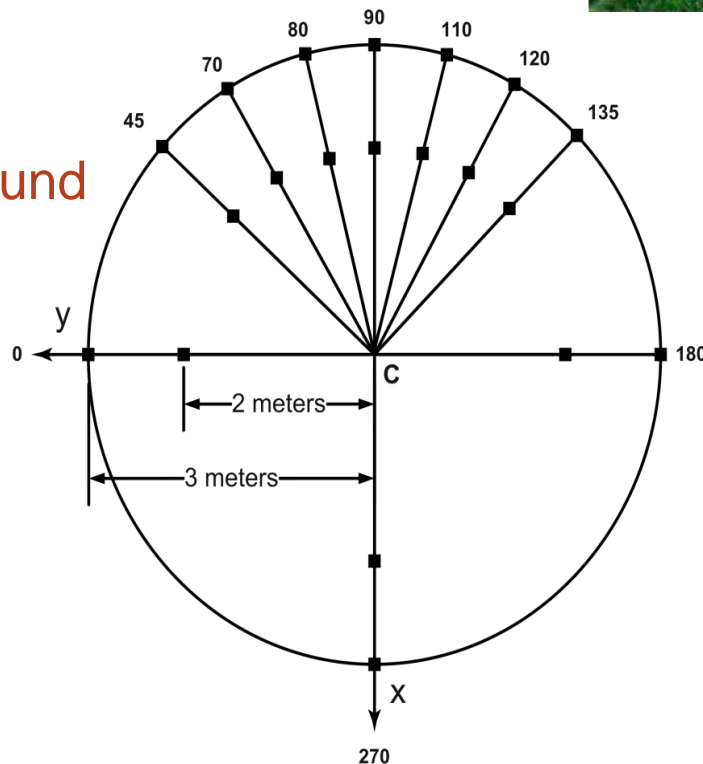
Maximum Transmission Range (Rural Environment)

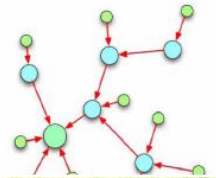




A Model for Channel Fluctuations

- One device fixed, the other rotating
- Sending 20 bytes every 30 msec
- Sampling the received power at 2 and 3 meters distance
- 2 different configurations:
Boards 15 cm above ground
Boards on grass





A Model for Channel Fluctuations

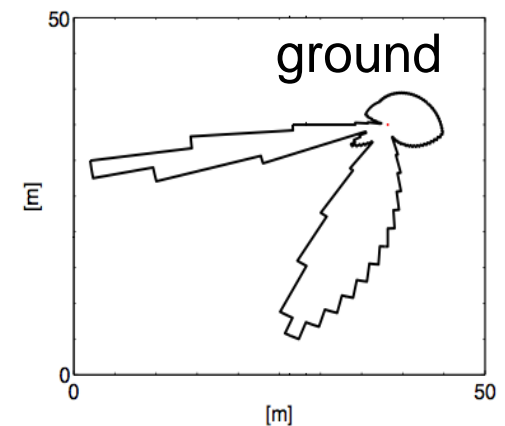
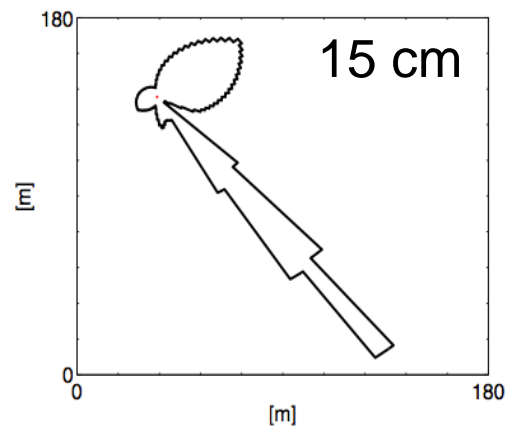
- Solve for k_0 and k_1 for each θ_i

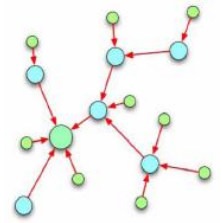
$$\begin{cases} P_r(d_1) = P_T - \hat{k}_0 - \hat{k}_1 \ln d_1 \\ P_r(d_2) = P_T - \hat{k}_0 - \hat{k}_1 \ln d_2 \end{cases}$$

- Find the distance where Loss falls below threshold

$$R(\theta_i) = e^{\frac{L_{th} - \hat{k}_0(\theta_i)}{\hat{k}_1(\theta_i)}}$$

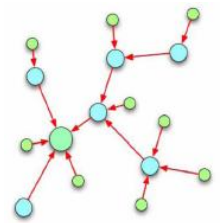
- Interpolate over the 360 degree angle



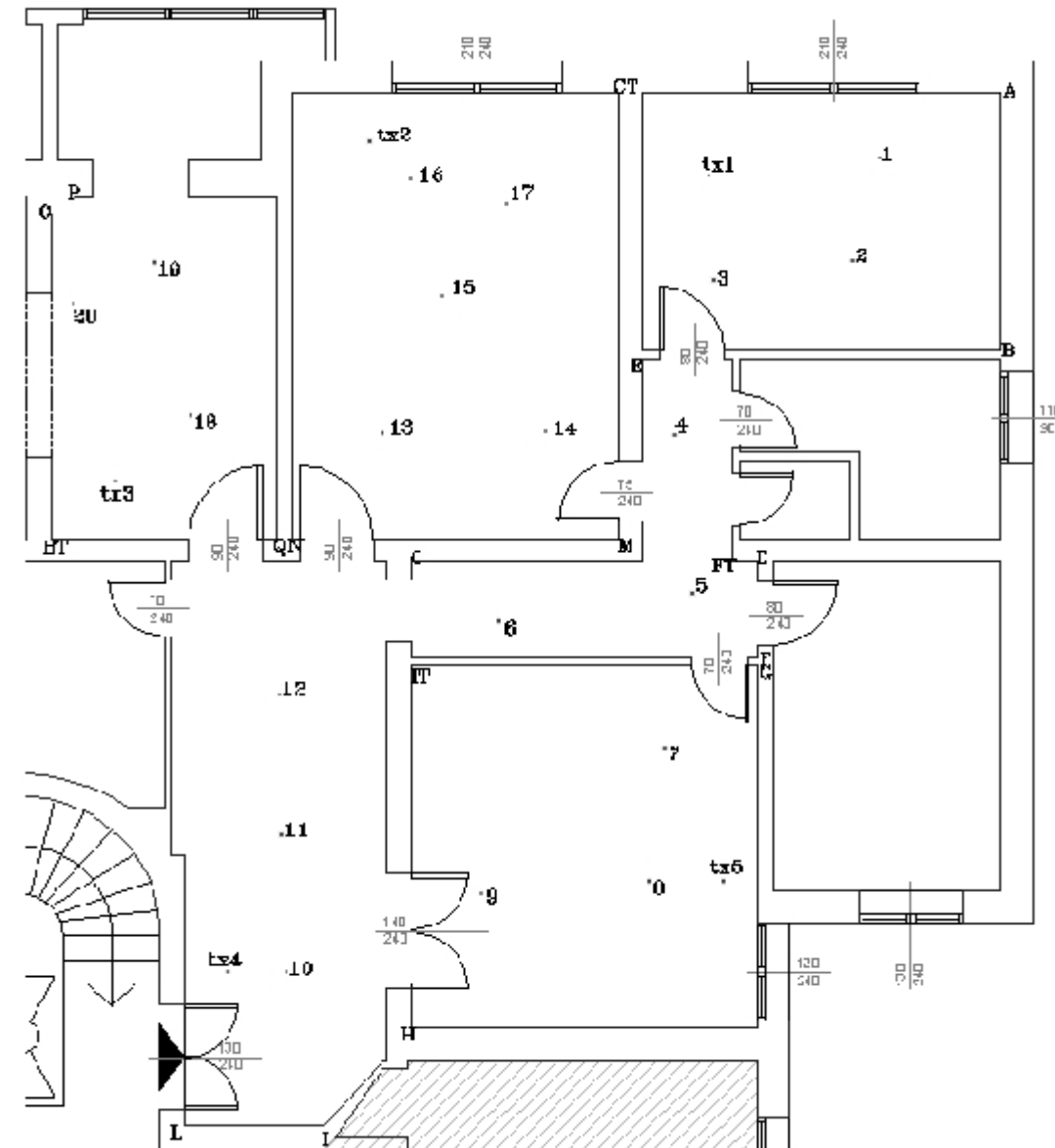


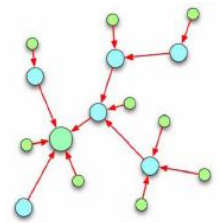
Section 2

UWB

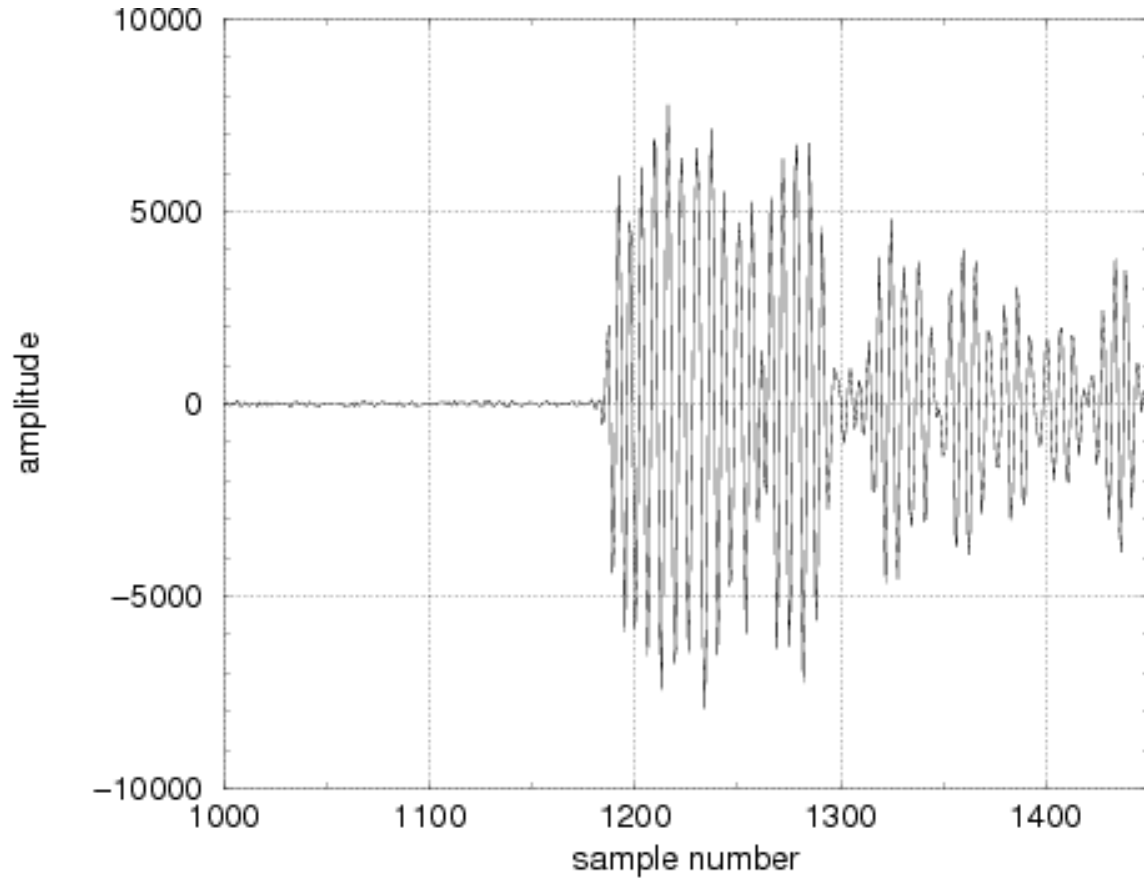


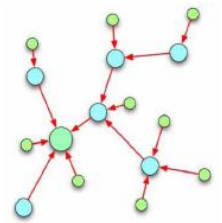
Map





LOS





NLOS

