The Wireless Communication Channel

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Objectives

- Understand fundamentals associated with free-space propagation.
- Define key sources of propagation effects both at the large- and small-scales
- Understand the key differences between a channel for a mobile communications application and one for a wireless sensor network

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Objectives (cont.)

- Define basic diversity schemes to mitigate small-scale effects
- Synthesize these concepts to develop a link budget for a wireless sensor application which includes appropriate margins for large- and small-scale propagation effects

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Outline

- Free-space propagation
- Large-scale effects and models
- Small-scale effects and models
- Mobile communication channels vs. wireless sensor network channels
- Diversity schemes
- Link budgets
- Example Application: WSSW

Free-space propagation

- Scenario

Relevant Equations

- Friis Equation
- EIRP

Alternative Representations

- PFD
- Friis Equation in dBm

Free-space propagation: 3 of 4

Issues

- How useful is the free-space scenario for most wireless systems?

Free-space propagation: 4 of 4

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Large-scale effects

- Reflection
- Diffraction
- Scattering

Large-scale effects: 1 of 7

Modeling Impact of Reflection

- Plane-Earth model

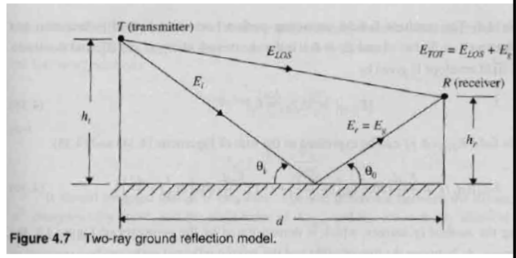


Figure 4.7 Two-ray ground reflection model.

Fig. Rappaport

Large-scale effects: 2 of 7

Modeling Impact of Diffraction

- Knife-edge model

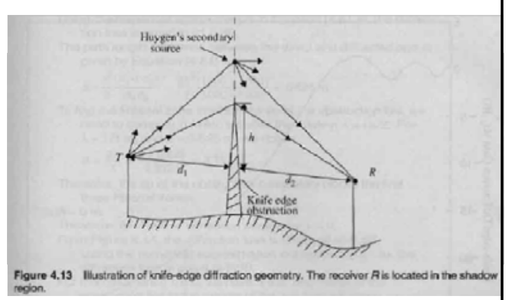


Figure 4.13 Illustration of knife-edge diffraction geometry. The receiver R is located in the shadow region.

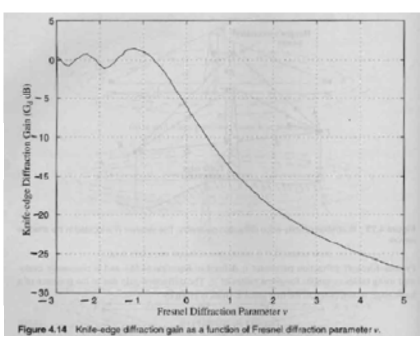


Figure 4.14 Knife-edge diffraction gain as a function of Fresnel diffraction parameter v.

Fig. Rappaport

Large-scale effects: 3 of 7

Modeling Impact of Scattering

- Radar cross-section model

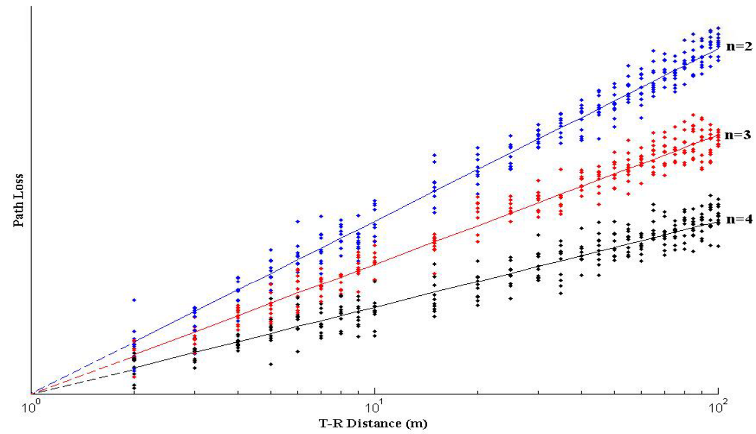
Large-scale effects: 4 of 7

Modeling Overall Impact

- Log-normal model
- Log-normal shadowing model

Large-scale effects: 5 of 7

Log-log plot



Large-scale effects: 6 of 7

Issues

- How useful are large-scale models when WSN links are 10-100m at best?

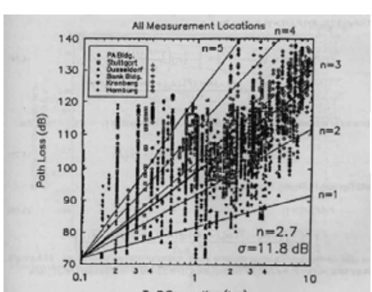


Figure 4.17 Scatter plot of measured data and corresponding MMSE path loss model for many cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB [from [Sei91] © IEEE].

Fig. Rappaport

Free-space propagation: 7 of 7

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- Free-space propagation
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Small-scale effects

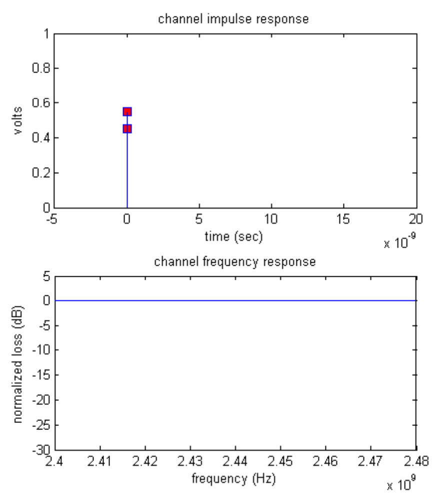
- Multipath
- Time and frequency response
- Models

Multipath

- Scenario
- Equations

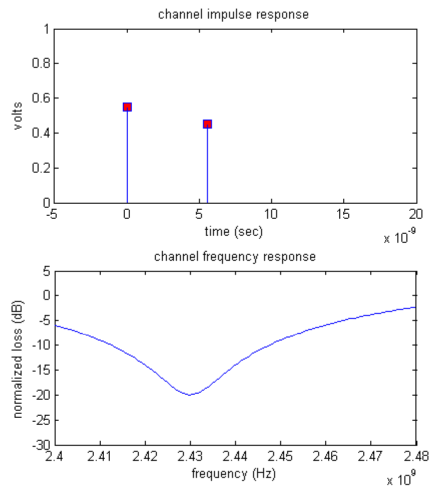
Time and Frequency Response

- Case 1: primary and secondary paths arrive at same time (path Δ = 0)
- Multipath component: -1.7 dB down



Time and Frequency Response

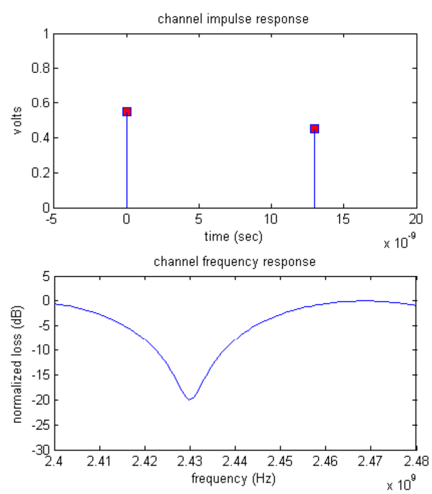
- Case 2: primary and secondary paths arrive at same time (path Δ = 1.5m)



Small-scale effects: 4 of 14

Time and Frequency Response

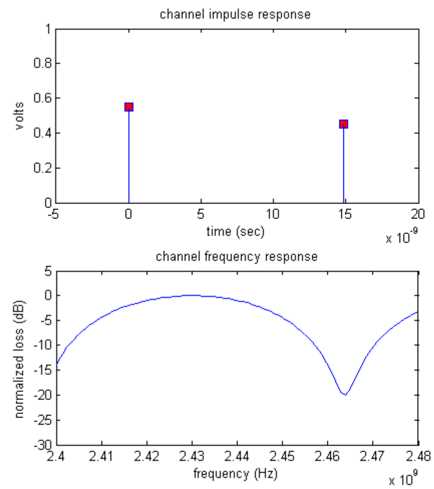
- Case 3: primary and secondary paths arrive at same time (path Δ = 4.0m)



Small-scale effects: 5 of 14

Time and Frequency Response

- Case 4: primary and secondary paths arrive at same time (path Δ = 4.5m)



Small-scale effects: 6 of 14

Real World Data

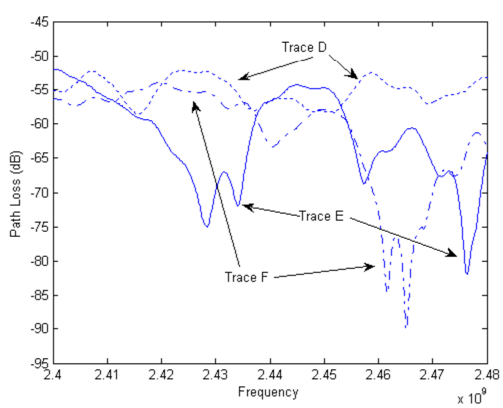


Fig. Frolik – IEEE TWC Apr. 07

Small-scale effects: 7 of 14

Randomness in the Channel

- Sources

- Impact

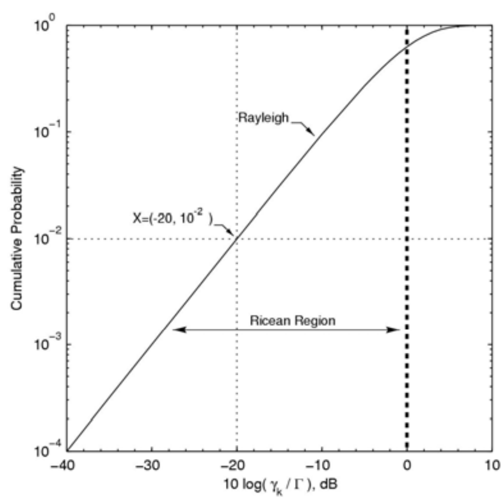
Statistical Channel Models

- TWDP

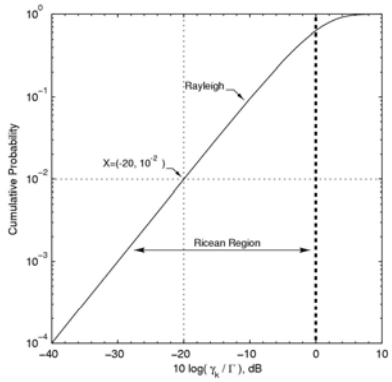
Baseline: Rayleigh Distribution

- Scenario
- Equations

Cumulative Distribution Function

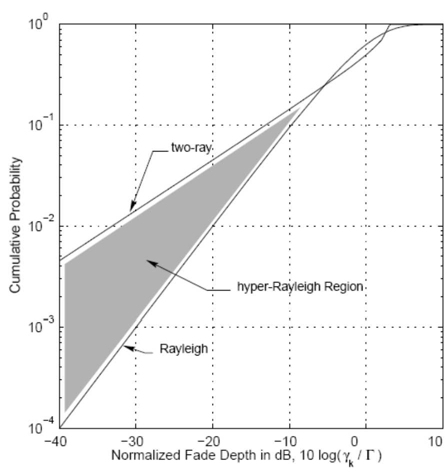


Ricean: Less Severe than Rayleigh



Small-scale effects: 12 of 14

More Severe than Rayleigh?



Small-scale effects: 13 of 14

Importance of Proper Model

Outline

- Free-space propagation
- Large-scale effects and models
- Small-scale effects and models
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- Link budgets
- Example Application: WSSW

Mobile vs. WSN channels

Mobile | WSN

Mobile vs. WSN: 1 of 3

Channel Effects

Mobile | WSN

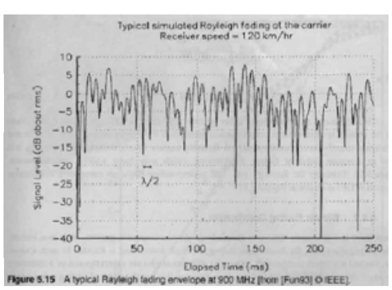
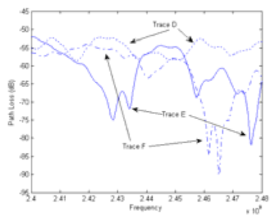


Fig. Rappaport

Mobile vs. WSN: 2 of 3

Real world data revisited



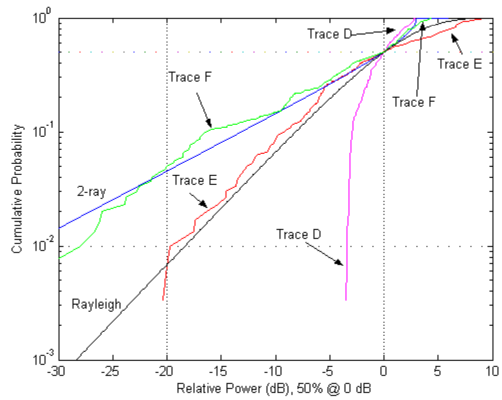


Fig. Frolik – IEEE TWC Apr. 07

Mobile vs. WSN: 3 of 3

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Diversity schemes

- Time
- Space
- Frequency

Diversity schemes: 1 of 3

Approaches

- MRC
- Selection

Diversity schemes: 2 of 3

Benefits

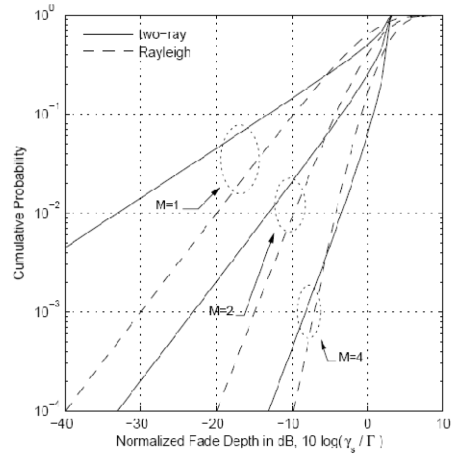

Fig. Bakir – IEEE TWC

Diversity schemes: 3 of 3

Outline

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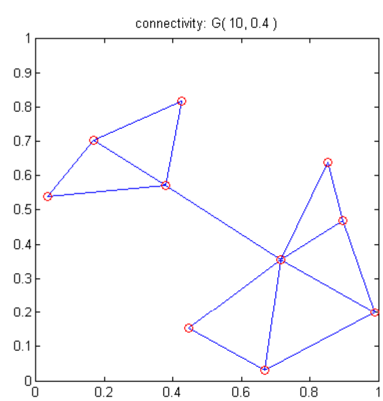
Link budgets

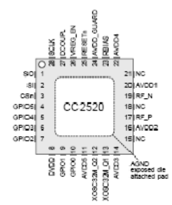
- Link parameters

Antenna Requirement?



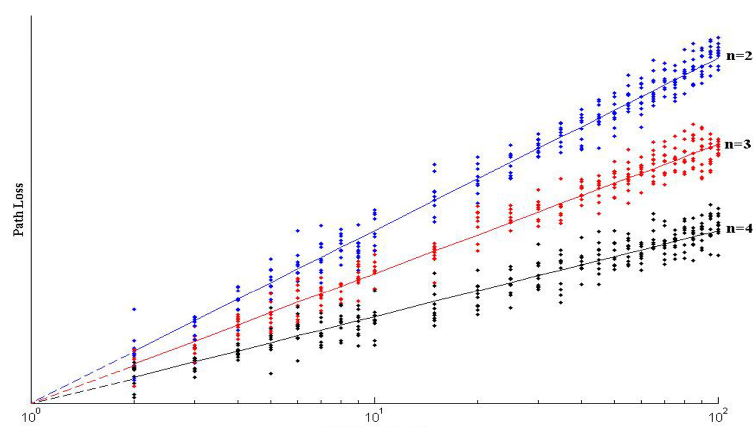
Example Spreadsheet

Parameter	Units	Value	Comments
Transmitting Node			
Frequency	GHz	2.4	ISM band
Transmit Power	dBm	0.0	1 mW - Chipcon CC2520 -20 to +5 dBm
Transmit Antenna Gain	dBi	3.0	Hyperlink 'rubber-duck' antenna
Transmit EIRP	dBm	3.0	
Free-space loss to 1m	dB	-40.0	(lambda/4pi)^2
Power at 1m	dBm	-37.0	
Losses			
Path loss exponent		3.0	determined from empirical data
Range	m	30.0	
Median path loss	dB	-44.3	from log-normal model
Received Signal			
Receive Antenna Gain	dBi	3.0	Hyperlink 'rubber-duck' antenna
Median Received Signal Strength	dBm	-78.3	
Receiver Sensitivity	dBm	-98.0	Chipcon CC2520
Fading Margin	**dB**	**19.7**	**Reliability?**



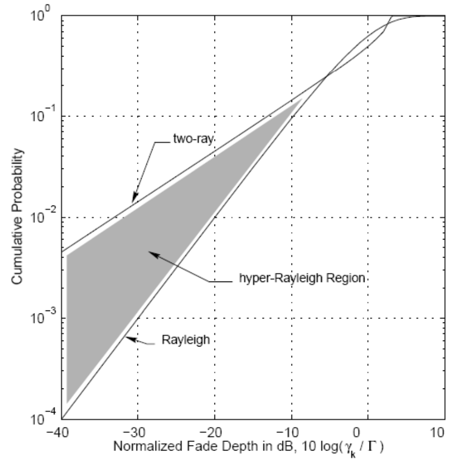
Link budgets: 3 of 5

Path loss exponent



Link budgets: 4 of 5

Margin Calculation



Link budgets: 5 of 5

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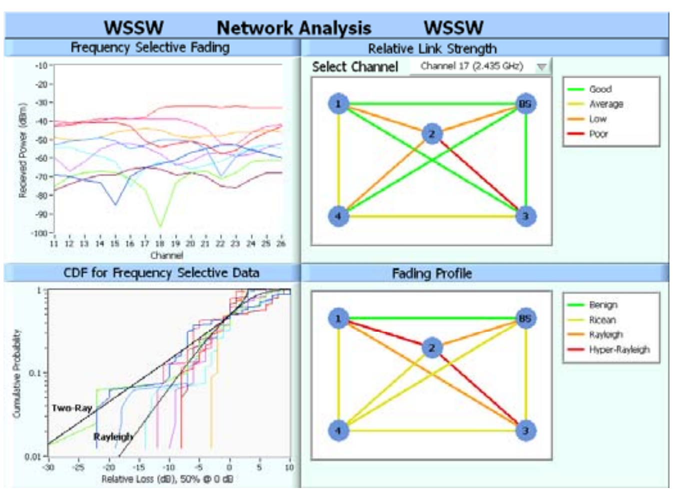
Example: WSSW

- Motivation
- Approach

WSSW: 1 of 2

WSSW Results



WSSW: 2 of 2

Conclusions - 1

- As intuitively suspected, signal strength on average decreases with T-R distance
- Large-scale effects determine the rate of signal strength degradation with distance
- Small-scale effects may severely impact signal strength in highly reflective environments
- Diversity schemes can mitigate the small-scale effects

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Conclusions - 2

- WSN have unique constrains which may not be best modeled using mobile communication methods
- Link budgets are critical in order ascertain requisite transmit powers, expected connectivity length, etc.
- Sensor nodes themselves can be utilized to ascertain channel characteristics

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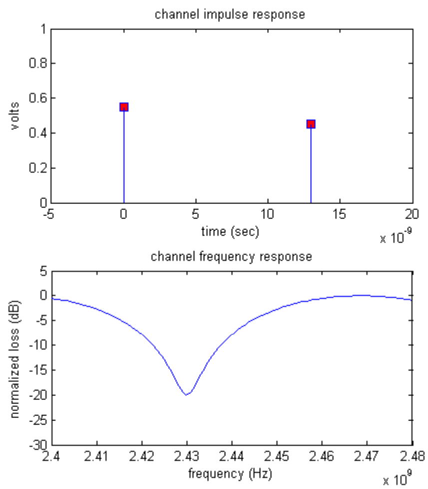
Want to know more?

- T. Rappaport, *Wireless Communications: Principles and Practice, 2nd ed.,* Prentice Hall.
- J. Frolik, 'A case for considering hyper-Rayleigh fading,' IEEE Trans. Wireless Comm., Vol. 6, No. 4, April 2007.
- L. Bakir and J. Frolik, 'Diversity gains in two-ray fading channels,' in review IEEE Trans. Wireless Comm.

Discussion of Code

Code: 1 of 5

Time and Frequency Response



Code: 2 of 5

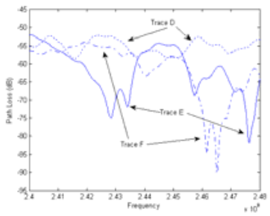
Matlab Code for Channel Response

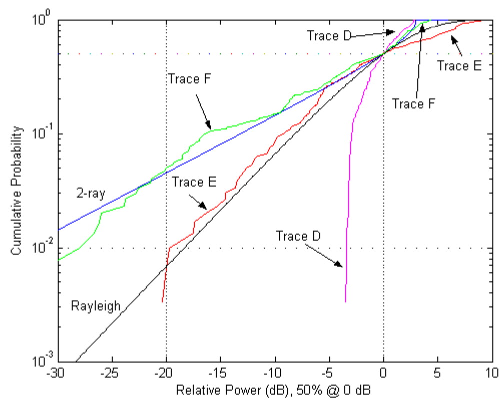
```
c=3e8;     %speed of light

d=linspace(0, 5, 10);   %relative distance in meters
f=linspace(2.4e9, 2.48e9, 100); % frequency: 2.4 GHz
      ISM band

for i=1:10,
 for   k=1:100,

   s1=.55;        % voltage of primary path

   s2=(1-s1)*exp(-j*2*pi*f(k)*d(i)/c); % voltage of
      multipath (1-s1) as a function of frequency and
      path difference

   x(i,k)=20*log10(abs(s1+s2)); %received voltage
      (complex)

   t(i)=d(i)/c; % time delay (sec)

 end
```

```
%create stem plot of channel impulse response
 subplot(2,1,1)
X=[0,t(i)];
Y=[s1,abs(s2)];
h=stem(X,Y);
set(h(1),'MarkerFaceColor','red','Marker','square')
axis([-.5e-8,2e-8, 0, 1])
title('channel impulse response')
xlabel('time (sec)')
ylabel('volts')

%create channel frequency response plot
 subplot(2,1,2)
 plot(f,x(i,:))
 axis([2.4e9, 2.48e9, -30, 5])
 title('channel frequency response')
 xlabel('frequency (Hz)')
 ylabel('normalized loss (dB)')

pause
end
```

Code: 3 of 5

CDF plots





Code: 4 of 5

Matlab Code for CDF

```
% CDF routine
Rsort=sort(Rlog);  %Rlog is the data from the inband
n=max(size(Rsort));
for i=1:n,

cdf(i)=i;

end
cdf=cdf/max(cdf);  % index equals probability

% searching for 1/2 to make 0 dB
for i=1:n,
   if cdf(i)>=0.5,
      shiftzero=Rsort(i) %median value
      break
   end
end
Rsortzs=Rsort-shiftzero;

semilogy(Rsortzs, cdf, 'g')
axis([-30 10 1e-3 1])
axis square
xlabel('Relative Amplitude (dB), 50% @ 0 dB')
ylabel('Cumulative Probability')
```

Code: 5 of 5