# NeSh: A joint shadowing model for links in a multi-hop network


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## Introduction

We present a ***statistical*** channel model ***more suitable*** for multi-hop ad-hoc networks.
Path-loss on a single link $(i,j)$ has 3 contributions,

- Large-scale path-loss $\bar{L}(d_{i,j})$
- Shadowing loss $X_{i,j}$
- Non-shadowing loss (small scale fading) $Y_{i,j}$

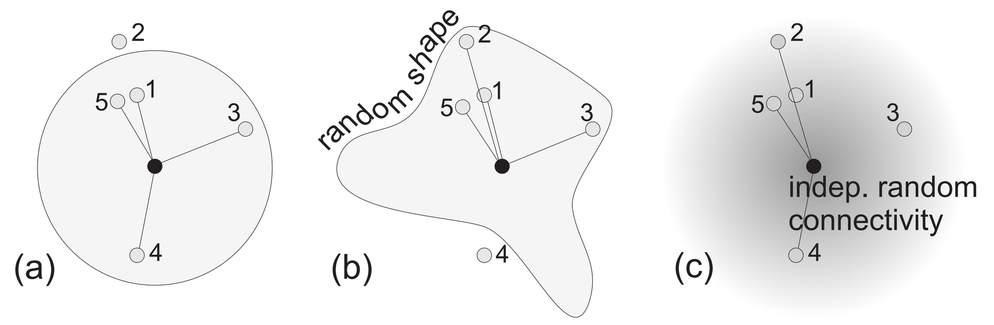
$$L_{i,j}(\text{(dB)}) = \underbrace{L_0 + 10 n_p \log_{10} \frac{||x_i - x_j||}{\Delta_0}}_{\bar{L}(d_{i,j})} + \underbrace{X_{i,j} + Y_{i,j}}_{Z_{i,j}}$$

$Z_{i,j}$ is the total dB fading on link $(i,j)$.

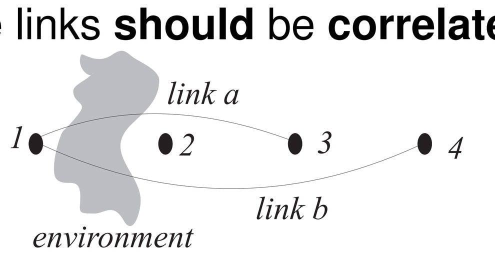
## Motivation

In literature, propagation models are:

- Circular model, $Z_{i,j} = 0$
- i.i.d. log-normal shadowing model, $\{Z_{i,j}\}$ indep. and $\sim \mathcal{N}(0, \sigma_{dB}^2)$




However, proximate links pass through same environment $\Rightarrow$ shadowing on these links **should** be **correlated**.




Fading on links $(1,3)$ and $(1,4)$ should be correlated.

## Experimental Setup

Deploy 4x4 grid of 16 Mica2 motes, 1.22 m apart [Agrawal 07].

## Correlation Data and Results

- **Random Environment:** Randomly generate positions for 10 boxes, 15 different times.
- **Similar link geometries:** Link pairs having end points at the same relative distances are considered equivalent.

Correlation coeffs. calculated for 28 different link geometries:

| Geometry | Correlation $\rho$ Meas-ured | Correlation $\rho$ NeSh Model | Geometry | Correlation $\rho$ Meas-ured | Correlation $\rho$ NeSh Model |
|---|---|---|---|---|---|
| | 0.33‡ | 0.21 | | -0.04 | 0.05 |
| | 0.21‡ | 0.17 | | 0.12‡ | 0.10 |
| | 0.23‡ | 0.24 | | 0.08* | 0.07 |
| | 0.05 | 0.03 | | 0.12‡ | 0.11 |
| | 0.17‡ | 0.19 | | 0.03 | 0.10 |
| | -0.05 | 0.00 | | 0.21‡ | 0.13 |
| | -0.01 | 0.00 | | -0.02 | 0.08 |
| | -0.10† | 0.00 | | 0.23‡ | 0.16 |
| | -0.03 | 0.05 | | 0.00 | 0.05 |
| | 0.18‡ | 0.21 | | 0.06 | 0.16 |
| | 0.04* | 0.08 | | 0.08† | 0.13 |
| | 0.14‡ | 0.08 | | 0.12 | 0.16 |
| | 0.17‡ | 0.08 | | 0.08 | 0.00 |
| | 0.05 | 0.06 | | 0.03 | 0.02 |

‡ $p < 0.005$ † $p < 0.01$ * $p < 0.05$
$p = P[\text{measuring } \rho \,|\, \text{shadowing is } i.i.d.]$

**Observations:**

1. Link correlation coefficients up to 0.33, many $> 0.2$.
2. Correlations (11) have high significance ($p << 0.005$).
3. **NeSh model captures much of measured correlations.**

Compared to relevant model [Gudmundson 91], NeSh model better matches data and is more applicable [Agrawal 07].

## Network Shadowing (NeSh) Model

Shadowing losses are attributed to **underlying spatial loss field** $p(\mathbf{x})$:

- **Isotropic** and **wide-sense stationary** and,
- **Zero mean** Gaussian random field with exponentially decaying spatial correlation:

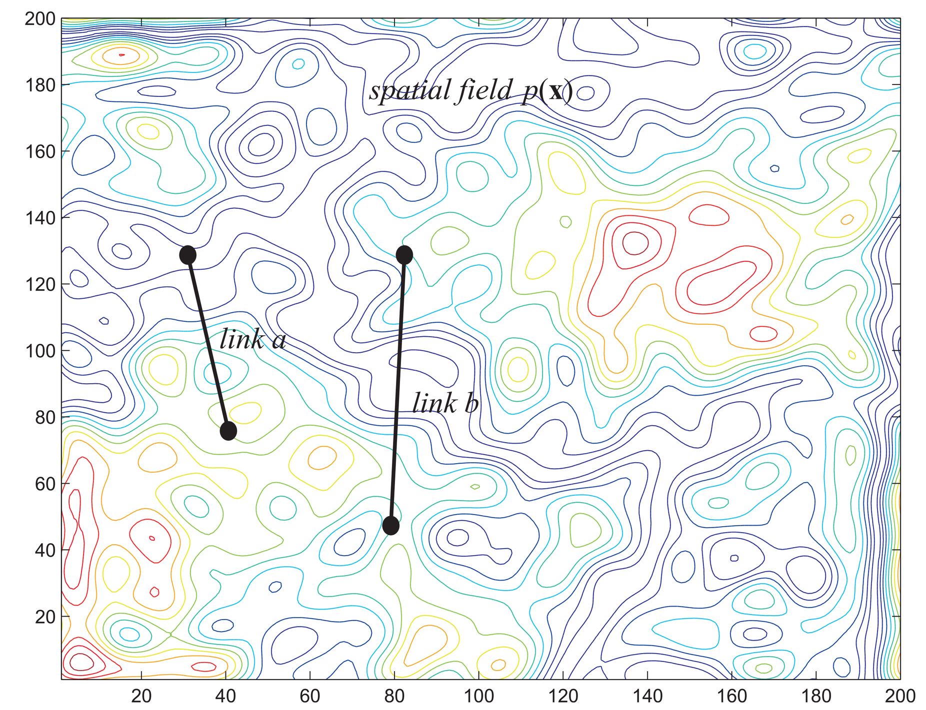
$$\mathrm{E} p(\mathbf{x}_i) p(\mathbf{x}_j) = R_p(||\mathbf{x}_i - \mathbf{x}_j||) = \frac{\sigma_X^2}{\delta} e^{-\frac{||\mathbf{x}_i - \mathbf{x}_j||}{\delta}}$$

- $\delta$ is the space constant
- $\sigma_X^2$ is the variance of shadowing loss $(X_{i,j})$.
- $||\mathbf{x}_i - \mathbf{x}_j||$ is the Euclidian distance between points $\mathbf{x}_i$ and $\mathbf{x}_j$.

## Link Shadowing in NeSh model

We define shadowing on link $(i,j)$, $X_{i,j}$ (in dB) as:

$$X_{i,j} \triangleq \frac{1}{d_{i,j}^{1/2}} \int_{\mathbf{x}_i}^{\mathbf{x}_j} p(\mathbf{x}) d\mathbf{x}$$




## Link Properties of NeSh Model

We prove in this paper that

- Var$[X_{i,j}]$ is approximately constant with path length ($= \sigma_X^2$).
- $X_{i,j}$ is Gaussian in dB.
- The correlation coefficient between the shadowing two links $(i,j)$ and $(k,l)$ is,

$$\rho_{X_{i,j}, X_{l,m}} \approx \frac{1}{\delta d_{i,j}^{1/2} d_{l,m}^{1/2}} \int_{\mathbf{x}_i}^{\mathbf{x}_j} \int_{\mathbf{x}_l}^{\mathbf{x}_m} e^{-\frac{||\boldsymbol{\beta} - \boldsymbol{\alpha}||}{\delta}} d\boldsymbol{\alpha}^T d\boldsymbol{\beta}.$$

The relative contribution of shadowing losses $X_{i,j}$ to the total fading $Z_{i,j}$ can be derived as,

$$\rho_{Z_{i,j}, Z_{l,m}} \approx \frac{\sigma_X^2}{\sigma_{dB}^2} \rho_{X_{i,j}, X_{l,m}}$$

where, $\sigma_{dB}^2 = \sigma_X^2 + \text{Var}[Y_{i,j}]$ $\rho$ of total fading is presented in the table as measured $\rho$.

## Channel Model Parameter Estimation

As with existing channel models, the NeSh model also requires estimation of two parameters ($\sigma_X^2$ and $\delta$).

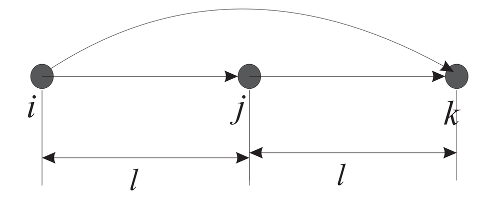
- $\sigma_X^2$ relates the contribution of shadowing to total fading. It is a function of bandwidth, center frequency, and deployment environment.
- $\delta$ is an space constant, proportional to the size and dimension of the shadowing causing obstacle.

In our measurement experiments [Agrawal 07], parameter values are:

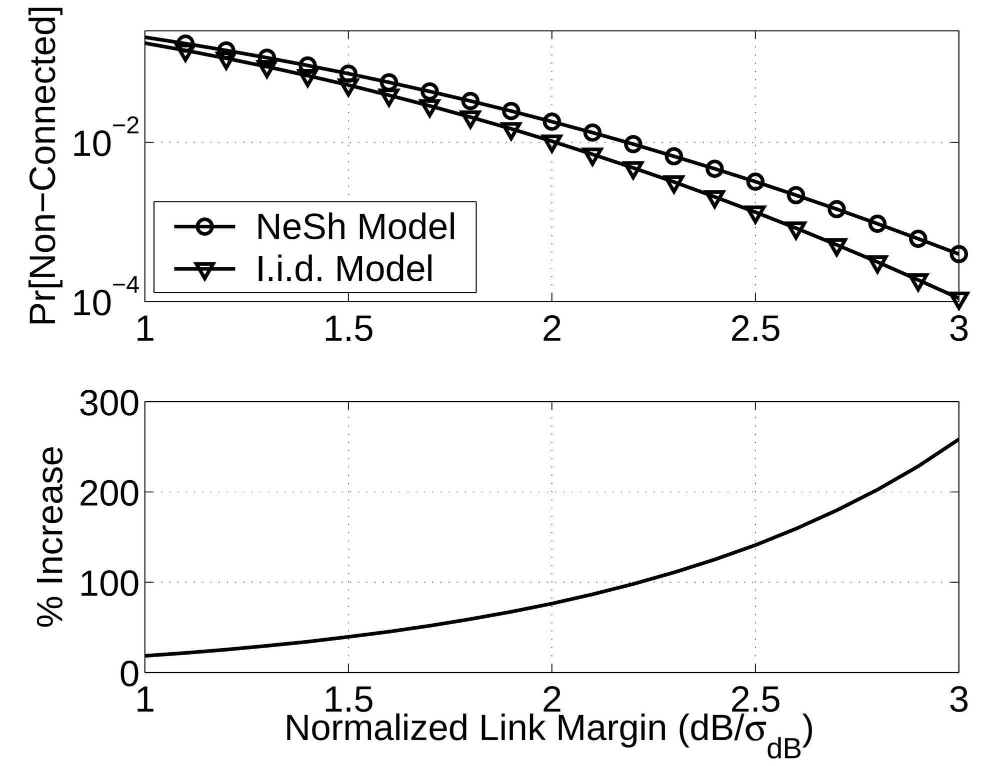
- $\sigma_X^2 = 0.29\sigma_{dB}^2$ and $\delta = 0.21$ m.

## Comparison of NeSh and i.i.d. Shadowing

$A = (i,k)$ connected
$B = (i,j)$ & $(j,k)$ connected
$P[F] = 1 - P[A \cup B]$




Compare analytical probability of non-connected network, $P[F]$, for i.i.d. model and NeSh model for the 3 node multi-hop link:




## Conclusions

- Introduce NeSh model for shadow fading in multi-hop networks.
- Show NeSh model's agreement w/ measured shadow correlations.
- Show that NeSh model accounts for higher probability of route failure than current i.i.d. link shadowing model.

Future work:

- Conduct more experiments in realistic ensembles of indoor and outdoor environments.
- Explore other underlying spatial loss functions.
- Quantify the effects of correlated shadowing on higher layers (eg. networking & MAC protocols).
- Exploit link shadowing correlations for *radio tomographic imaging*.

## Reference


- P. Agrawal, N. Patwari, "Correlated link shadow fading in multi-hop wireless networks," *IEEE Trans. Wireless Commun.* (submitted). [Online]`http://span.ece.utah.edu/pmwiki`
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- N. Patwari, Y. Wang, R.J. ODea, "The importance of the multipoint-to-multipoint indoor radio channel in ad hoc networks," *IEEE Wireless Commun. and Networking Conf. (WCNC)*, March 2002, pp. 608612.