Introducing Probabilistic Radio Propagation Models in OMNeT++ Mobility Framework and Cross Validation Check with NS-2

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Why probabilistic models?

- **Radio propagation models**
  - Determine signal strength at receiving node
  - Simple deterministic models
    - Signal strength is a simple function of distance

- **Consequences of deterministic models** [Kotz2004]
  - A radio’s transmission area is circular
  - All radios have equal range
  - If I can hear you, you can hear me
  - If I can hear you at all, I can hear you perfectly

- **Deterministic models are unrealistic**
  - But standard model for many simulators
Deterministic Free Space propagation model

$$Pr_{det}(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

All relevant rx events in unit disk graph

Basis for MF Channel Control implementation

- Connects nodes in max. propagation distance
Probabilistic Models

- **General structure**
  - Use deterministic path loss
    - Average reception power
  - Add probabilistic small scale fading
    - Characterized by some distribution
  - \( \Pr_{\text{Distr}}(d; \text{args}) \sim \text{Distr}(\Pr_{\text{det}}(d); \text{args}) \)

- **Newly included models**
  - Log Normal Shadowing
  - Rayleigh
  - Rice
  - Nakagami
    - \( \Pr_{\text{Nak}}(d; m) \sim \text{Gamma}(m, \frac{\Pr_{\text{det}}(d)}{m}) \)

\[ \text{[Nakagami1960]} \quad \text{[Rappaport1996]} \]
Integration into Mobility Framework

- Only 'connected' nodes receive events
  - Channel Control cares about connections
  - Needs access to the RF module
- Calculate Pr(d) on each message arrival
  - RF Models needed in host module
  - SNREval keeps track of SNIR

![Diagram showing integration into Mobility Framework]

- Channel Control
- RF Models
- Host
- Application
- NIC
- MAC
- Decider
- SNR Evaluator
  - RF Models

(send direct)
Probabilistic Propagation Models for OMNeT++ Mobility Framework

Consequences

- **Rx Probability = \{0, 1\}**
- **Relevant events in max propagation distance**
- **cost_{tx} \sim \#nodes in ‘circle’**

- **Rx Probability \neq 0**
- **All events may be relevant**
- **All nodes have to be informed**
- **cost_{tx} \sim \#nodes in scenario**

**Deterministic**

**Probabilistic**

![Diagram showing deterministic and probabilistic scenarios with nodes and connectivity.](image-url)
Max propagation distance (MPD) is tradeoff parameter
- Accuracy vs. speed of simulation
- Large MPD \(\rightarrow\) slow but accurate simulation
- Small MPD \(\rightarrow\) fast but inaccurate simulation

Probability of relevant event wrt distance

Duration of simulation wrt MPD
How to determine MPD (sketch)

- Track one single event
- Node’s goal
  - receive all relevant events
- Relevant event
  - $P_{rx}(d) > P_{min}$
- For which distance $d$ holds:
  - $\text{Prob(relevant evt)} < \text{accuracy}$
  - $\text{Prob}(P_{rx}(d) > P_{min}) < \text{accuracy}$

- $P_{rx}(d) \sim \text{probability distribution}$
- Cumulative density function

$$CDF_{P_{rx}(d)}(P_{min}) = \text{Prob}(P_{rx}(d) \leq P_{min})$$
$$1 - CDF_{P_{rx}(d)}(P_{min}) = \text{Prob}(P_{rx}(d) > P_{min})$$

- $1 - CDF_{Prx(d)}(P_{min}) < \text{accuracy}$
- Invert CDF to get the MPD
- Restrict connectivity to distances $< \text{MPD}$
Simulation setup

- **Limitations**
  - Proposed general solution to find MPD
  - Solution applied to Nakagami, m=1

- **General setup**
  - Topologies: chain, grid, random
  - Models: Free Space, Nakagami
  - Playground
    - 2000m x 2000m, torus enabled
    - Up to 1600 nodes and 100 senders
  - Fixed MPD for evaluation
    - Free Space 623m
    - Nakagami 1000m

- **Cross validation**
  - Comparison with NS-2

- **Performance evaluation**
  - Simulation speed
  - Memory usage
Cross Validation Check

![Graph showing cross validation check for different propagation models. The x-axis represents distance in meters, and the y-axis represents the probability of reception in percentage. The graph compares OMNeT++ Free Space, NS-2 Free Space, OMNeT++ Nakagami 1, NS-2 Nakagami 1, OMNeT++ Nakagami 3, NS-2 Nakagami 3, OMNeT++ Nakagami 5, and NS-2 Nakagami 5 models.]
- OMNeT++ MF faster than NS-2
- Nakagami causes more receive events
OMNeT++ MF needs less memory
Nakagami causes memory increase
Summary and Outlook

- Introduced Probabilistic Wave Propagation Models to OMNeT++ Mobility Framework
  - Log Normal Shadowing, Rayleigh, Rice, Nakagami
  - Cross validation check with NS-2
  - Performance evaluation

- Tradeoff: Accuracy vs. Speed
  - General solution for max propagation distance (MPD)
  - Concrete solution for Nakagami, m=1

- Future Work
  - Max propagation distance for Nakagami, m>1
  - Analytical results for other models
  - Improved modeling for multiple interfering events

- Availability
  - Extension online: www.tm.uka.de/sne4omf
    (Sensor Network Extensions for the OMNeT++ Mobility Framework)
Literature