An Efficient Abstraction Method for Implementing WiFi Channel and WiFi OFDM-MIMO PHY Models in Network-Simulator-3 (ns-3)

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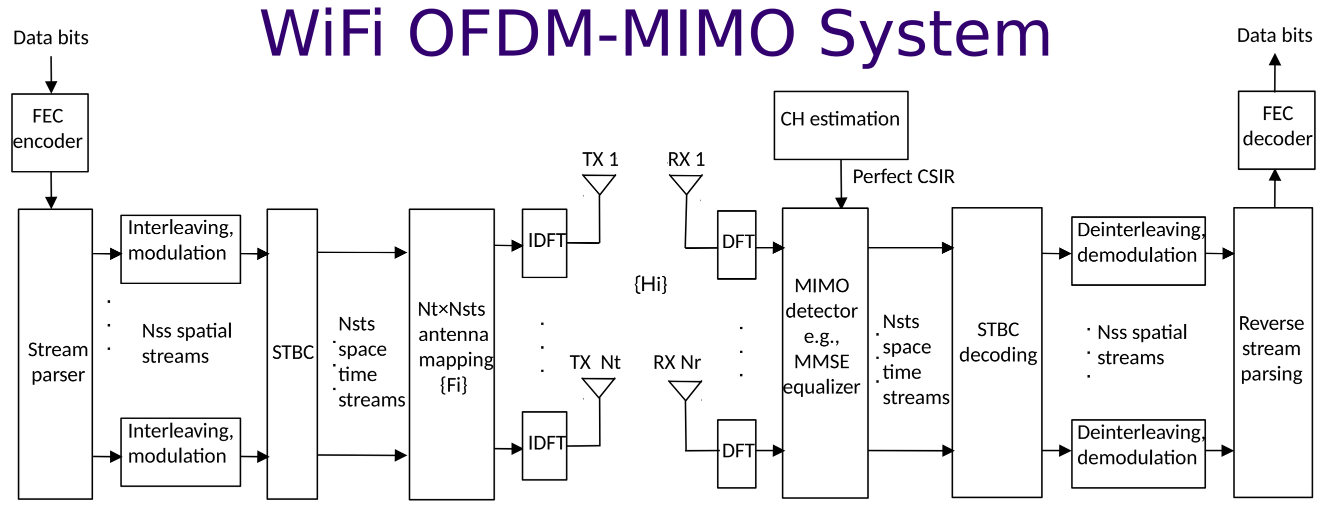
Abstract

Packet-level network simulators such as ns-3 require physical (PHY) layer error models that faithfully model the packet errors that result from fading wireless channels. Abstraction is required to generate packet error rate (PER) VS. signal-to-noise-ratio (SNR) curve with low complexity. A technique known as link-to-system mapping can distill PER and effective link SNR results from PHY layer simulator into network simulators, but still requires a channel generator and a PHY layer model to generate packets of different SNR. Typical full implementation is computationally intensive and suffers from scalability problems on modern Wi-Fi links employing higher dimensionality Orthogonal Frequency-Division Multiplexing (OFDM) subcarriers and Multiple Input Multiple Output (MIMO) antennas. Our novelty is to use offline link simulations to directly characterize a probability distribution for effective SNR as used by link-to-system mapping, thereby bypassing the computationally intensive steps of generating fading channel instances and conducting PHY layer processing. This probability distribution can be further characterized by a specialized random variable requiring only a few parameters. This approach reduces the ns-3 runtime problem of computing effective SNR and PER.

WiFi OFDM-MIMO System

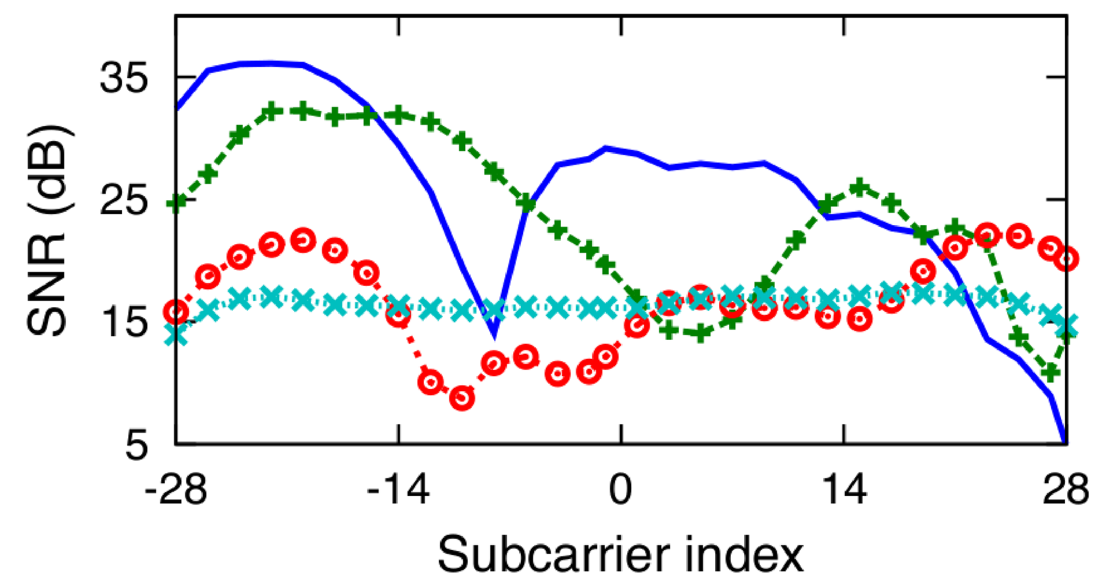


Our Contributions

- Implement a full WiFi TGn channel model in ns-3
- Implement a WiFi OFDM-MIMO PHY model in ns-3
- Adopt EESM based link-to-system mapping method along with the above 2 models in ns-3
- Propose an efficient abstraction method that characterize effective SNR distribution directly for WiFi system
- Implement the new method in ns-3
- Verify both methods in ns-3

WiFi Channel Response

Subcarrier Gains on 4 SISO Links Achieving Almost Equal PER [1]



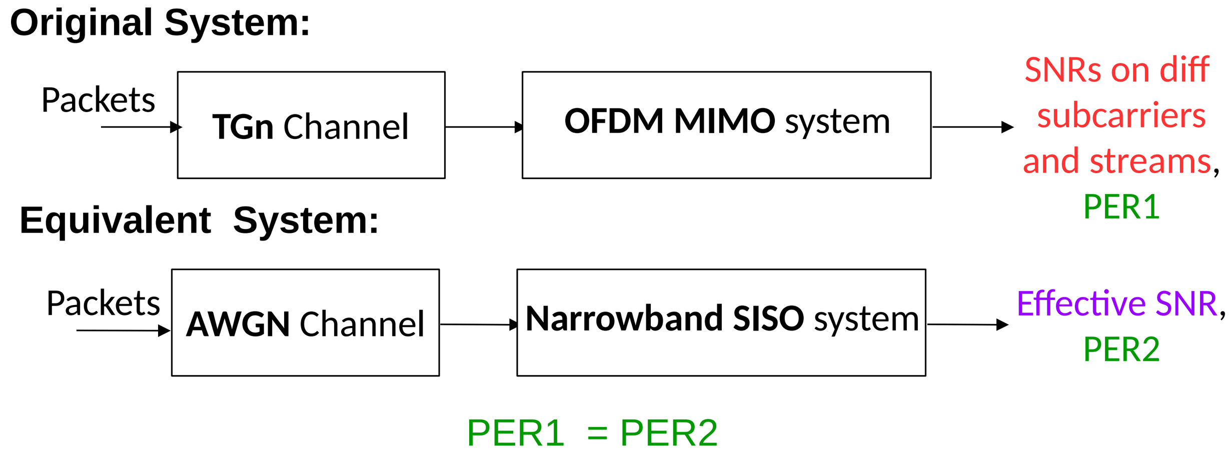
[1] D. Halperin, W. Hu, A. Sheth, and D. Wetherall. "Predictable 802.11 packet delivery from wireless channel measurements". SIGCOMM 2010

PER is largely dependent on the **worst** few SNRs over different OFDM subcarriers.

Link-to-system Mapping

Question: How to obtain PER for any given SNR vector?

Step1: Construct an equivalent system

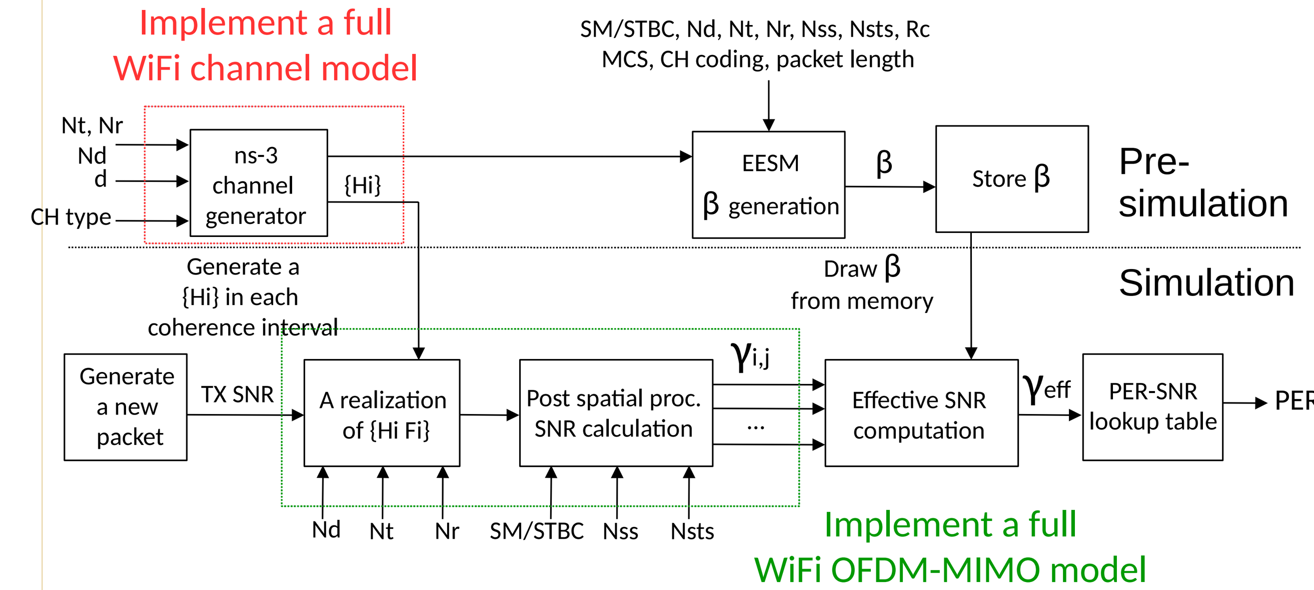


Step2: In equivalent system, map effective SNR into PER1 using AWGN PER-SNR lookup table

Remaining key question: How to obtain effective SNR?

Our Full Implementation

Link-to-system Mapping Based Full Implementation of WiFi System



Run-time Comparison

Antennas	BW	MATLAB PHY Sim	ns-3 Link-to-system Mapping
1×1	20MHz	28 min	13.34 s
1×1	40MHz	25 min	24.97 s
2×2	20MHz	37 min	25.45 s
2×2	40MHz	39 min	48.82 s
3×3	20MHz	51 min	41.37 s
3×3	40MHz	60 min	77.63 s

ns-3 Link-to-system mapping run-times << MATLAB, but **scale with** system parameters (# of TX/RX antennas, BW)

A more efficient technique is still needed in ns-3

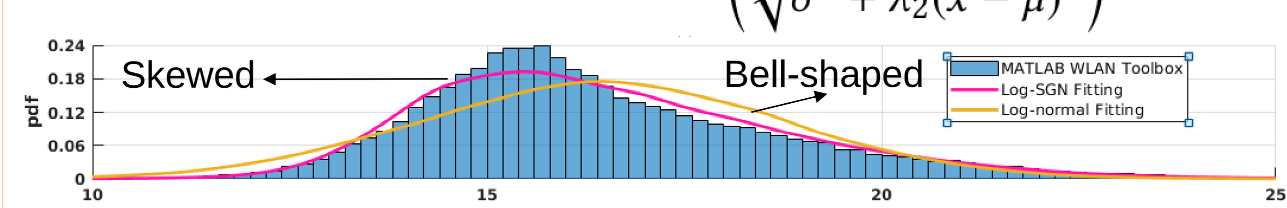
Effective SNR pdf

[2] shows empirically that ln(γeff) can be approximated by normal random variable.

We find ln(γeff) is skewed, & approx ~ skew generalized normal (SGN) random variable

$$X \triangleq \ln(\gamma_{eff}) \sim \mathrm{SGN}(\hat{\mu}, \hat{\sigma}, \hat{\lambda}_1, \hat{\lambda}_2)$$

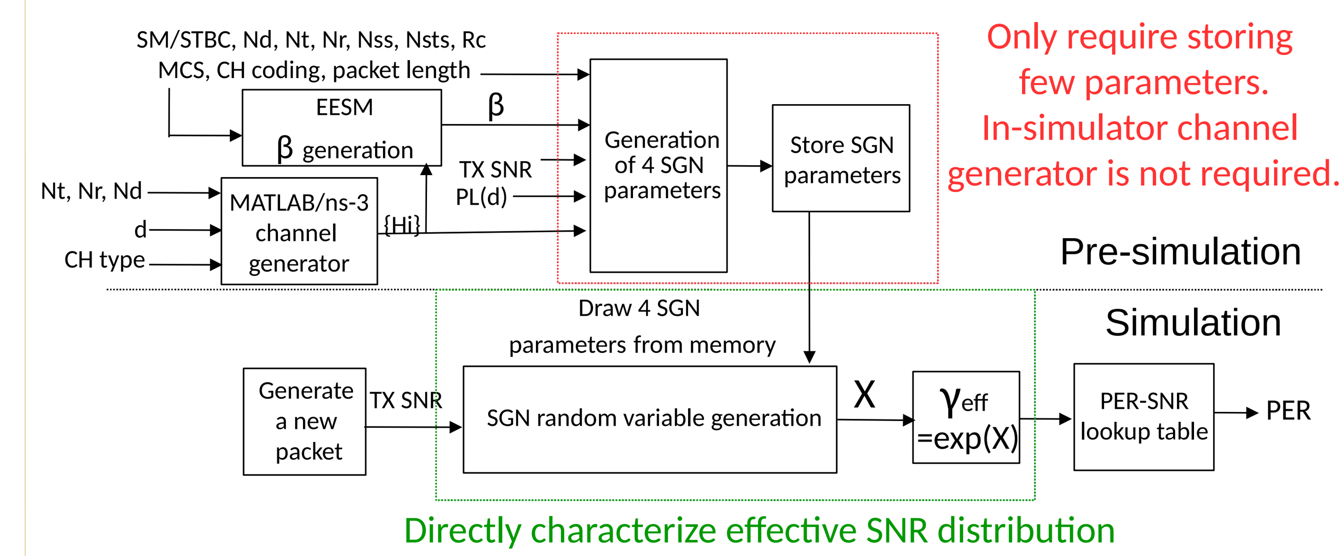
$$f_X(x;\hat{\mu},\hat{\sigma},\hat{\lambda}_1,\hat{\lambda}_2) = \frac{2}{\hat{\sigma}}\phi\left(\frac{x-\hat{\mu}}{\hat{\sigma}}\right)\Phi\left(\frac{\hat{\lambda}_1(x-\hat{\mu})}{\sqrt{\hat{\sigma}^2+\hat{\lambda}_2(x-\hat{\mu})^2}}\right),\ x \in \mathbb{R},$$



[2] S. N. Donthi and N. B. Mehta., "An Accurate Model for EESM and its Application to Analysis of CQI Feedback Schemes and Scheduling in LTE", IEEE TCOM, 2011

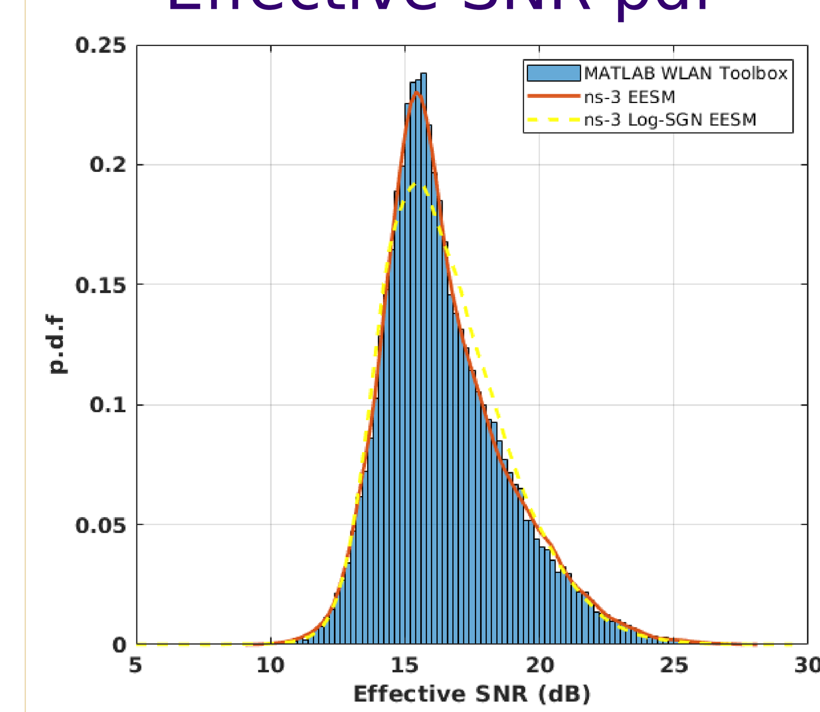
Our Abstraction Method

Implementation of SGN Abstracted Link-to-system Mapping

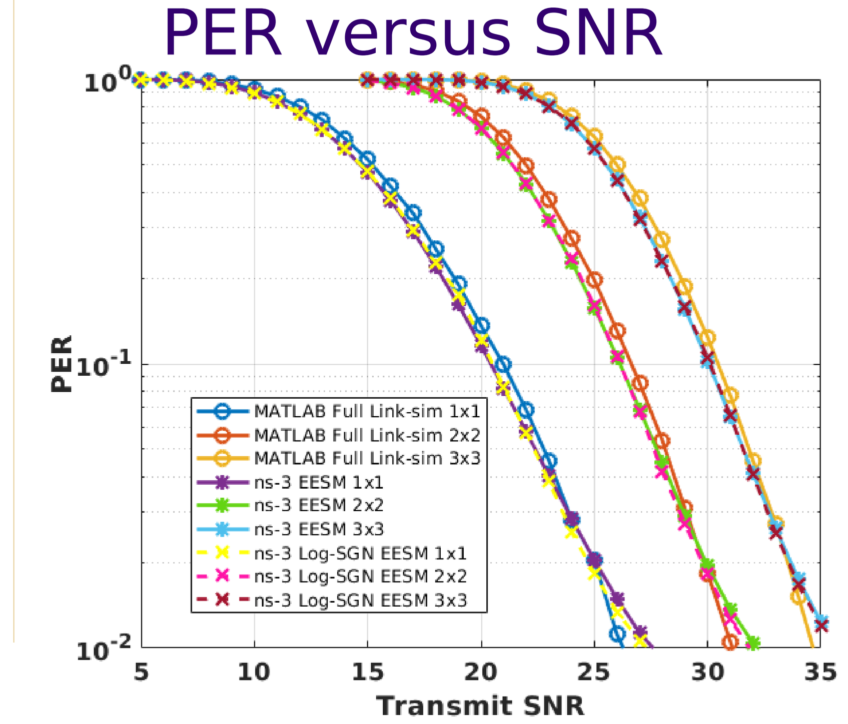


Verification

Effective SNR pdf



PER versus SNR



Complexity Of New Method

> For **each** TGn channel type (A-F), CH BW (20MHz/40MHz), Nr (1 ~ 4) and Nt (1 ~ 4), the proposed log-SGN based method requires storing **819.2 KB** log-SGN tuples under different MCS, received SNRs, channel coding types, etc

> For **any** given CH bandwidth, Nt, Nr, runtime of the log-SGN based model is **always 2.1 s**

> **Storage and runtime complexity do not scale**