Deterministic Models of the Physical Layer through Signal Simulation

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Introduction

- Wireless networks are ubiquitous, e.g. VANETs
- Simulation is a powerful tool for development
- Sophisticated wireless network simulators available
- Physical Layer is simplified using stochastic model: (no alteration, no parameter optimization, unable to model some techniques)
- We present a novel approach for a universal deterministic model of the Physical Layer
Wireless Network Simulation

- Application
- Protocol Simulation
- Physical Layer
- Channel Model
Wireless Network Simulation

- Application: deterministic
- Protocol Simulation
- Physical Layer: stochastic
- Channel Model: deterministic/stochastic
### Stochastic vs. Deterministic Model

<table>
<thead>
<tr>
<th>Stochastic Model</th>
<th>Deterministic Model</th>
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<tbody>
<tr>
<td>▶ Measure relevant values in real world</td>
<td>▶ Output depends only on internal state and inputs</td>
</tr>
<tr>
<td>▶ Create probability distribution</td>
<td>▶ Model replicates real world process</td>
</tr>
<tr>
<td>▶ Use random variable to choose output from probability distribution</td>
<td>▶ Parameters can be optimized</td>
</tr>
<tr>
<td>▶ Needs real world counterpart to conduct data</td>
<td>▶ Can be used to model not yet existing real world counterpart</td>
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Wireless Network Simulation

Application

Protocol Simulation

Physical Layer

Channel Model
Channel Model

- Simulates propagation of signals
- Multi-path propagation
- Ray-optical channel models calculate possible paths: Delay spread
- SNR can be estimated from delay spread but enormous reduction of information
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Physical Layer (PHY)

- Interface between analog signals and data packets
- Stochastic model: Outcome of reception depends on SNR
- Deterministic model: Simulates transmitting and receiving of analog signals
- Interference: other signals, multipath copies, thermal noise
Our approach

- Create discrete signal
- Add interference and effects of channel
- Decode signal and decide if it could be received successful
- Software-defined Radio for signal processing
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Ideal SDR
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Our Approach in Detail

- Veins for protocol simulation (Sommer et al., 2011)
- PHY modul interfaces Software-defined Radio
- Fully-functional SDR transceiver for VANET available (Bloessl et al., 2013)

Signal simulation

- Signalbuffer replicates received signal mix
- Interfaces event-based simulation
- Beginning of packet: Create signal and superimpose in buffer
- End of packet: Try to decode signal from buffer
Superposition of Discrete Signals

- For simulation discrete signals are used
- Discrete signals are superimposed by vector addition
- Signals need to be sampled at the same absolute points in time
- Otherwise: Reconstruct samples at correct point in time using Fractional-delay filter:

\[ h_n^d = w(n - d) \text{sinc}(\pi(n - d)) \]

\( n \) sample index, \( d \) delay, \( w \) windowing function
⇒ Vector addition not possible
Vector addition possible
Contribution

- Deterministic model for the Physical Layer
- Signal Simulation
  - Creates signals
  - Superimposes interfering signals
  - Decodes signals
- Software-defined Radio offers easy development and alteration
- Deterministic PHY is precondition for:
  - Full exploitation of ray-optical channel model
  - Simulation of CDMA
- Can be used to conduct data for stochastic model
Study

- Comparision of isolated Physical Layer Models
- Stochastic channel model
- Simulate different signal-to-noise ratios
- Goal: Verification, plausible results
Stochastic Model compared to Signal Simulation

![Graph comparing stochastic model and signal simulation](image)

- **Signal simulation**
- **Veins**

**Axes:**
- **Y-axis:** Probability of successful reception
- **X-axis:** dB

**Legend:**
- Red circles: Signal simulation
- Blue circles: Veins

**Data Points:**
- dB values from 20 to 44
- Probability of successful reception ranging from 0.0 to 1.0
Thermic Noise compared to Signal Interference

![Graph showing the comparison between Thermic Noise and Signal Interference. The x-axis represents dB, and the y-axis represents the probability of successful reception. The graph illustrates the increasing probability of successful reception as the dB level increases, for both Noise and Interference.]
Computation and Memory Costs

- Computation and memory overhead depends on number and length of sent packets
- For specific simulation:
  - 50 fold increase in computational time
  - 1 kB per memory node for signal buffer
- Large optimization possible
- ⇒ There is overhead, but could be justified
Conclusion

- Novel approach for a universal deterministic model of the physical layer
- Signal simulation is working and promises interesting results when used e.g. to simulate MIMO, multi-path propagation and CDMA
- Ray-optical channel models can be fully exploited
- For stochastic channel model the stochastic model PHY works quite well (CSMA/CA)