Wireless Channel Models and Simulators from Real-World Data

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# Introduction

- **Simulation Software:** Simulation of Mobile Radio Channel Impulse Response Models (SMRCIM) and Simulation of Indoor Radio Channel Impulse Response Models (SIRCIM)

- RF channel models utilized by SIRCIM and SMRCIM

- Implementation of geometric models for simulating Angle-of-Arrival (AOA) of multipath components
  - Variations of the Geometrically Based Single-Bounce Elliptical Model (GBSBEM)
The Basic Mobile Multipath Environment

- $A_{l,k}$ = Amplitude
- $t_{l,k}$ = time delay
- $f_{l,k}$ = Carrier phase shift
- $\phi_{l,k}$ = angle-of-arrival (AOA)

of $l$th signal component of $k$th mobile

Channel Impulse Response

Complex baseband discrete representation of the channel impulse response:

\[ h_b(t, \tau_k, \phi_k) = \sum_k \alpha(\phi_k) e^{j\theta_k} p(t - \tau_k) \]

Where:

\[ \alpha^2(\phi_k) = \text{power of } k\text{th multipath component} \]

\[ \tau_k = \text{relative time delay of } k\text{th multipath component} \]

\[ \theta_k = \text{phase of } k\text{th multipath component} \]

\[ p(t) = \text{narrow pulse approximating delta function} \]

\[ \phi_k = \text{angle-of-arrival of } k\text{th multipath component} \]
Why do we want the Impulse Response?

\[ x(t) \rightarrow h_b(t, \tau_k, \phi_k) \rightarrow \sum \rightarrow r(t) \]

- Modem development
- Spatial algorithm development
- Temporal Equalization
- Position location and tracking
- Smart antennas
- 3G, 4G
RF Channel Modeling

Background

- **Mid 1970s -- G.L. Turin** at University of California, Berkeley models San Francisco urban/suburban mobile radio channel
  - Transmitted 100ns pulses and received them on three-trace oscilloscopes

- **Suzuki and Hashemi** -- fit measured data to statistical models with intention of developing simulation software Simulation of Urban Propagation (SURP)

- **Devasirvatham and Cox** measures in-building environments at 850 MHz with wideband channel sounding equipment

- **Saleh and Valenzuela** propose a statistical model for the indoor channel based on measured wideband multipath profiles
Continuation of RF Channel Modeling Background

- **Mid 1980s -- T. S. Rappaport** at Purdue University collects data from factories for future of wireless applications

- **1989 -- S. Seidel**, using Rappaport’s research and other published data, creates the initial concept of SIRCIM

- **Early 1990s -- W. Huang & M. Feurestein** acquire data from outdoor environments and begin early development of SMRCIM

- **1990s -- International researchers** publish data used to improve SIRCIM and SMRCIM (e.g. Hashemi, Devasirvatham, Pahlavan)

- **Mid 1990s -- MPRG students** measure noise in various indoor environments and add noise models to SIRCIM

- **1998-99 -- J.E. Nuckols** implements Liberti’s GBSBEM models in SIRCIM and SMRCIM for simulation of AOA
Model Environments

SIRCIM -- Indoor environments
- OPEN PLAN -- Factories, department stores, warehouses
- SOFT PARTITIONED -- Cubicles, voting booths, restaurants, grocery stores
- HARD PARTITIONED -- Apartments, school buildings, homes, hospitals

SMRCIM -- Outdoor environments
- MICROCELLULAR -- Campuses, microcells
- URBAN -- Heavily built up city areas
- SUBURBAN -- Outskirts of a city, open farmland next to small neighborhoods

Physical Channel Model

- Large-scale path loss model for each multipath component
  - $d^n$ model with wide range of values for $n$, $s$
  - Verified by numerous research programs, papers, observed results
- Channel simulated as receiver moves over local area “track”
  - User selectable track length of 4.5, 10, 20, 40, or 80?
  - Mobile direction, $a$, ranges from 0° and 360°
  - 64 time delay bins used to represent $h_b(t)$ at any instant of position in local area
  - Complete doppler, AOA, and second-order effects are modeled

\[ \alpha = \text{vehicle/mobile direction} \]
\[ T_x = \text{Transmitter location} \]
\[ R_x = \text{Receiver location} \]
\[ \tau_i = \text{Multipath delay} \]
**Simulated Multipath Delay Profile**

- Multipath delay profile generated in SIRCIM along a 20° track
- OPEN PLAN indoor environment with TR separation of 11.2 m
Geometrically Based Single-Bounce Elliptical Model

1995 - (GBSBEM) developed by MPRG student, Joe Liberti

Assumption of low antenna heights -- scattering near base station as likely as near mobile

\[ a_m = \frac{c \tau_m}{2} \quad b_m = \frac{1}{2} \sqrt{c^2 \tau_m^2 - D^2} \]

Variations of GBSBEM

**Aisle Elliptical Model** -- constricted scattering environments
- **Outdoor**
  - city blocks with rows of buildings
- **Indoor**
  - hallways

**Random Elliptical Model** -- unconstrained scattering environments
- **Outdoor**
  - suburban and urban areas
- **Indoor**
  - factories, warehouses
**Aisle Elliptical Model**

![Diagram](image)

**NOTE: Not drawn to scale**

- Ellipse represents set of all scatterers causing multipath delay of $t_i$
- Aisle represents hallways or rows of buildings
- Model results in end fire clustering at $0^\circ$ and $180^\circ$

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**Random Elliptical Model**

- Ellipse represents set of all scatterers causing multipath delay of $t_i$
- Multipath likely to arrive from any direction -- useful in open areas
- ? uniform and random over $2\pi$ -- determines location of scatterer

Analysis of Aisle Elliptical Model - Geometry

Four “CASES” corresponding to geometry for each of four scatterer locations
Associate 64 randomly chosen cases with each delay $t_i$
Simulate AOA based on user entered parameters in conjunction with geometry

Analysis of Random Elliptical Model

- Generate 64 randomly chosen angles $\theta_i$ associated with each delay $t_i$
- Based on the angles $\theta_i$, determine the scatterer location for each delay
- Using the geometry and scatterer locations simulate the AOA

$$AOA = \pm \cos^{-1} \left( \frac{\langle \vec{R}'S, \vec{R}'T \rangle}{||\vec{R}'S|| \cdot ||\vec{R}'T||} \right)$$

Typical Aisle Elliptical Results

- End fire clustering
- TR-separation distance vs. multipath path distance (size of ellipse)
- As delay increases, aisle quickly constrains AOA to small angles
- Hallways will tend to guide the waves

Source: Output generated by commercial license of SIRCIM Plus 4.0. This software is copyrighted and licensed by Wireless Valley Communications, Inc.
Typical Random Elliptical Results

- Not constricted to end fire clustering
- Multipath likely to arrive from any direction
- Open areas -- well suited to this model due to random scatterers

Source: Output generated by commercial license of SIRCIM Plus 4.0. This software is copyrighted and licensed by Wireless Valley Communications, Inc.
Phase Generation for Narrowband Simulations

- Uniform random phases generated for initial receiver locations
- AOA used to recover scatterer locations along ellipse
- Small changes in radio path length from scatterer to receiver location on track account for change in phase

With motion along track, incremental changes in path length reflect small changes in narrowband phase

Who uses these tools?

SIRCIM and SMRCIM are being used world-wide by many companies and research institutions such as:

- Institute for Advanced Engineering, Korea
- Korea Advanced Institute of Science and Technology
- Australian Department of Defense
- Chinese University of Hong Kong
- Oklahoma Christian University
- ITT Aerospace Communications
- Tantivy Communications
- U.S. Department of Defense
- RF Micro Devices
- Nokia
- Purdue University
- Georgia Tech
- University of Kansas
- Texas Instruments
- Motorola
- Broadcom
- Siemens
- GAT Systems
Conclusion

- Development of the *Random Elliptical and Aisle Elliptical Models* from GBSBEM Model
- Implementation of these models in SIRCIM and SMRCIM
- As a Bradley Industrial Fellow have commercialized SIRCIM and SMRCIM into world class products

SIRCIM and SMRCIM are licensed by Wireless Valley Communications in Blacksburg

- Many companies and universities now have easy to use software tools that provide them with life-like channel information in addition to AOA of multipath delay signals

Future Work
- Current work in MPRG to build measurement apparatuses
- Gather site specific AOA measurements and generate statistics to compare with geometrical models