Project: IEEE 802.11bb Task Group

Submission Title: IEEE 802.11bb Reference Channel Models for Vehicular Communications

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Abstract: This contribution proposes LiFi reference channel models for vehicular communications.

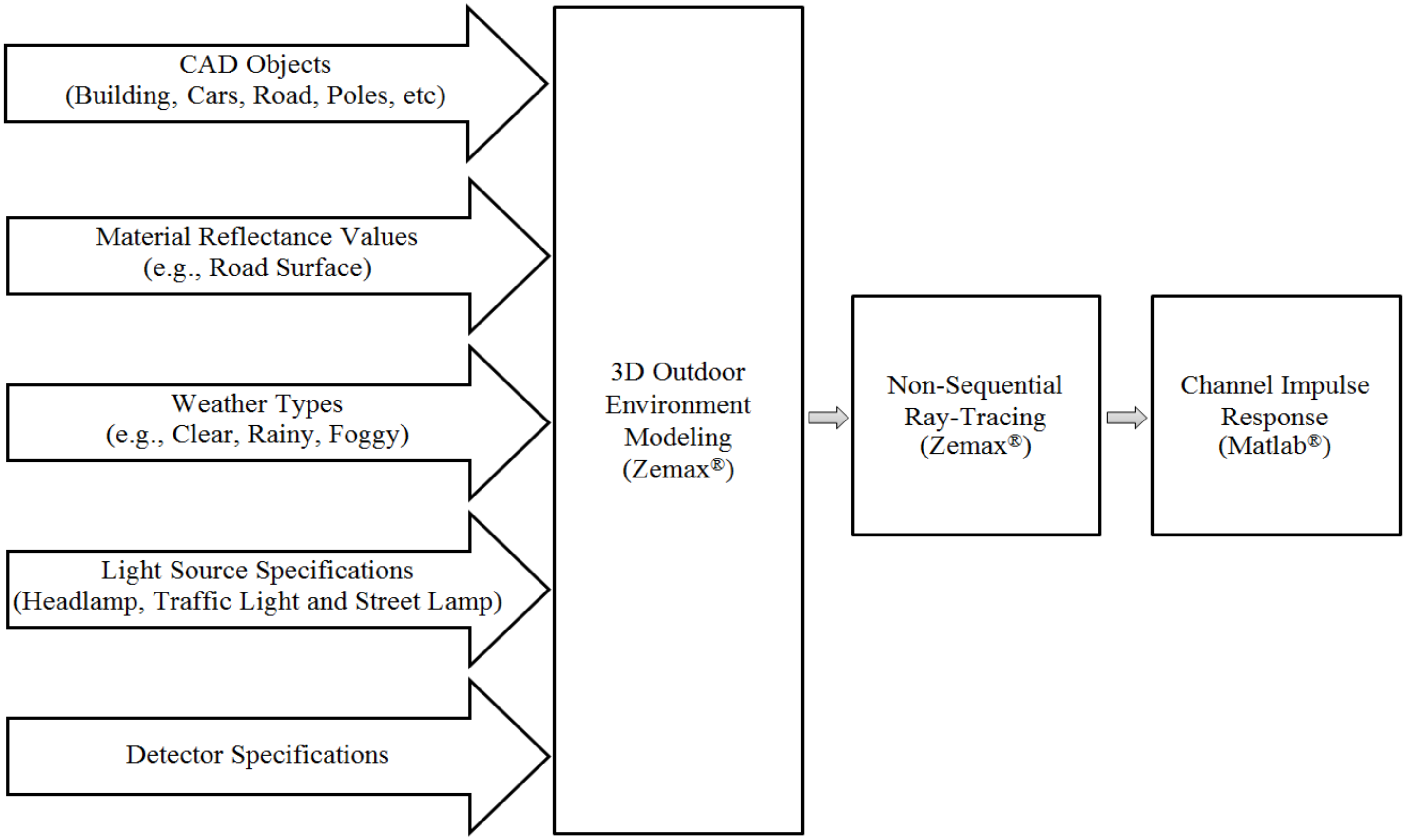
Purpose: To introduce reference channel models for the evaluation of different PHY proposals.

IEEE 802.11bb Reference Channel Models for Vehicular Communications

Outline

- Introduction
  - Overview of Channel Modeling Methodology
  - Modeling of the Outdoor Environment
  - Headlamp Modeling
  - Modeling of Weather Conditions (Clear Weather, Rainy Weather and Foggy Weather)
- Vehicular Scenario under Consideration
  - Channel Impulse Responses (CIRs)
  - Effective Channel Responses
  - Channel Characteristics
- Conclusions

Overview of Channel Modeling Methodology[1]



[1] M. Elamassie, M. Karbalayghareh, F. Miramirkhani, R. C. Kizilirmak, and M. Uysal, "**Effect of fog and rain on the performance of vehicular visible light communications**," *IEEE 87th Vehicular Technology Conference (VTC2018-Spring)*, Porto, Portugal, Jun. 2018.

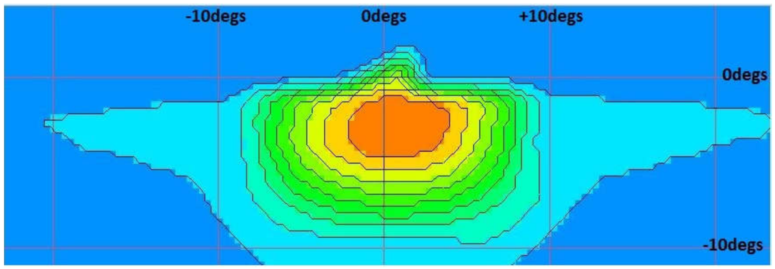
Modeling of the Outdoor Environment

- Creation of 3D outdoor environment in Zemax® involves the selection of
  - Dimension and shape of the outdoor environment
  - CAD objects within the environment (buildings, cars, roads etc)
  - Position and type of transmitters and receivers
  - Type and properties of materials

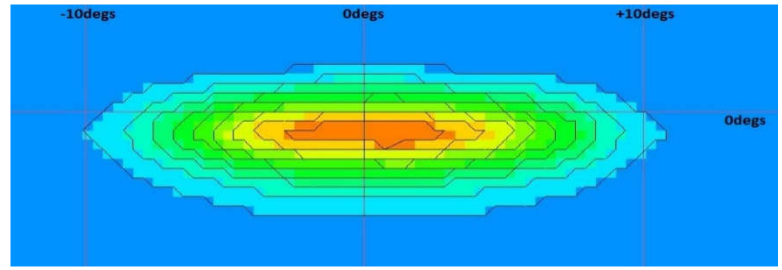
Class	Road Surface Composition	Mode of Reflectance
R1	Asphalt with aggregate including a minimum of 15% artificial brightener aggregate	Mostly diffuse
R2	Asphalt with aggregate including a minimum of 60% gravel sized larger than 10 mm Asphalt with aggregate including a minimum of 10-15% artificial brightener aggregate	Mixed diffuse and specular
R3	Asphalt with dark aggregate-the surface becomes rough after several months of use	Slightly specular
R4	Very smooth asphalt	Mostly specular

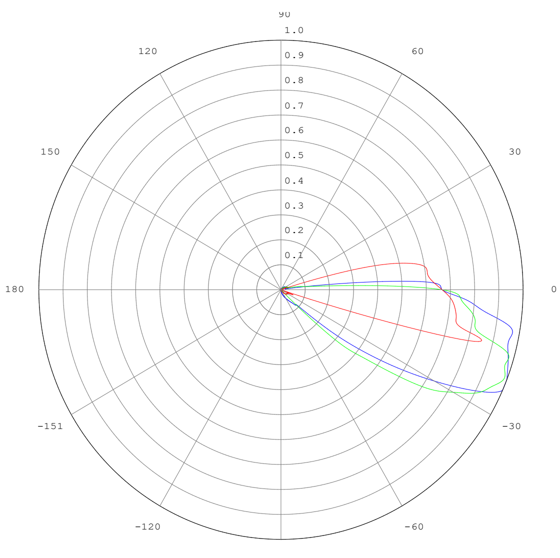
Headlamp Modeling

Spatial distribution of low-beam headlamp

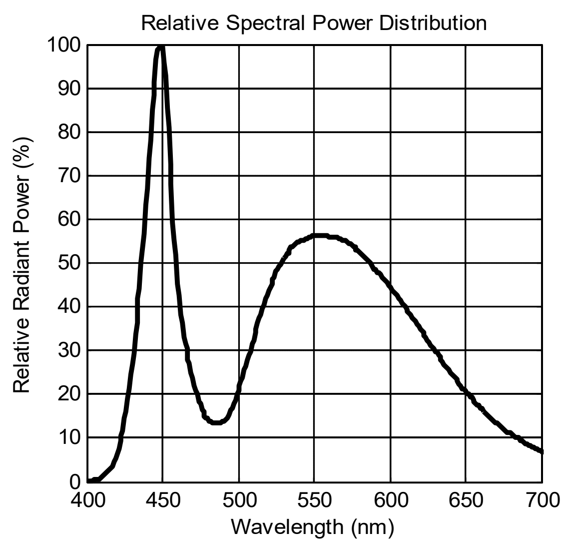


Spatial distribution of high-beam headlamp

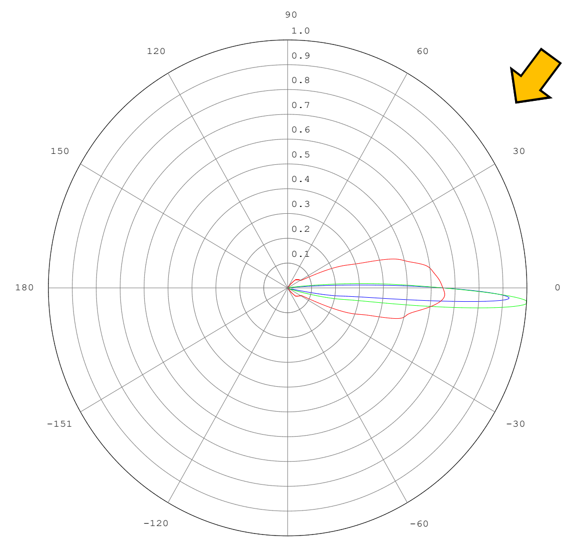




Relative intensity distributions of low-beam headlamp



Relative spectral power distribution of Philips LUXEON Rebel



Relative intensity distributions of high-beam headlamp

Modeling of Weather Conditions

- To model the interaction of rays with the air, Mie scattering is used to model rainy and foggy weather conditions with different visibilities.
- "Bulk scatter" method in the Zemax software allows providing the input parameters
  - "Particle index" (the refractive index of particles)
  - "Size" (the radius of the spherical particles)
  - "Density" (the density of particles). The characteristics of various weather types are listed in Table below.

	Particle Index	**Size (µm)**	**Density (cm^{-3})**
Clear	1.000277	10^{-4}	10^{19}
Rain	1.33	100	0.1
Fog, $V = 50$ m	1.33	10	124.6
Fog, $V = 10$ m	1.33	10	622.6

Channel Impulse Response (CIR)

- Based on Monte Carlo Ray Tracing.
- Sobol sampling is used for speeding up ray tracing.
- The Zemax® non-sequential ray-tracing tool generates an output file, which includes all the data about rays such as the detected power and path lengths for each ray.
- The data from Zemax® output file is imported to MATLAB® and using these information, the multipath CIR is expressed as

$$h(t) = \sum_{i=1}^{N_r} P_i \delta(t - \tau_i)$$

P_i = the power of the i^{th} ray
τ_i = the propagation time of the i^{th} ray
$\delta(t)$ = the Dirac delta function
N_r = the number of rays received at the detector

Effect of LED Response

- In addition to the multipath propagation environment, the low-pass characteristics of the LED sources should be further taken into account in channel modelling.

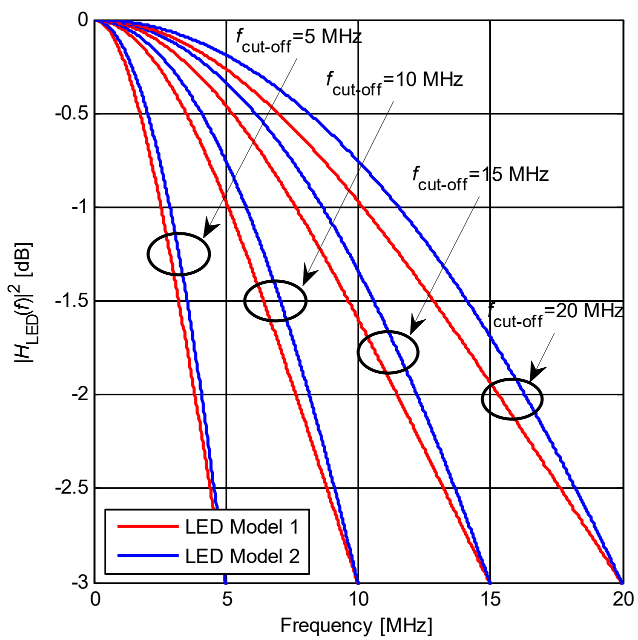
LED Model 1 [2]

$$H_{\text{LED}}(f) = \frac{1}{1 + j\dfrac{f}{f_{\text{cut-off}}}}$$

LED Model 2 [3]

$$H_{\text{LED}}(f) = e^{-\ln(\sqrt{2})\left(\frac{f}{f_{\text{cut-off}}}\right)^2}$$

$f_{\text{cut-off}}$: 3 dB cut-off frequency of the LED

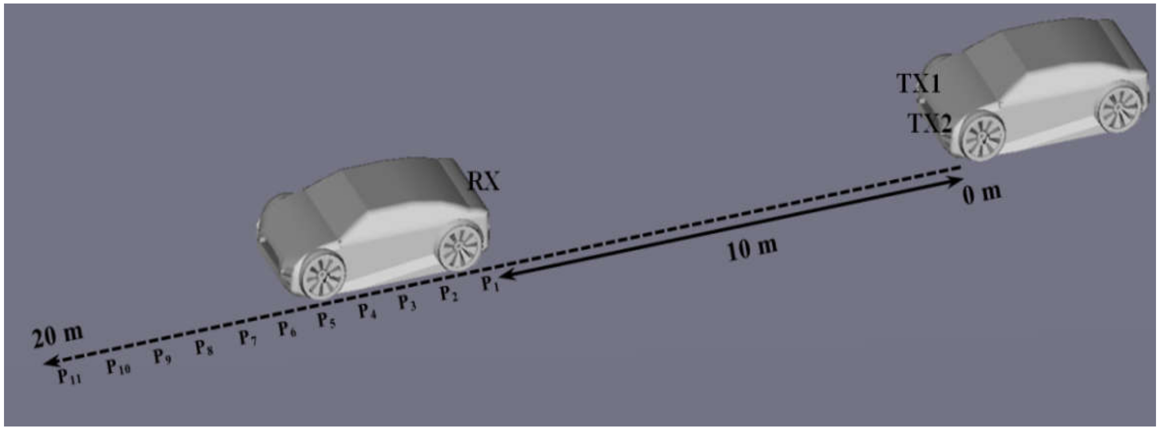


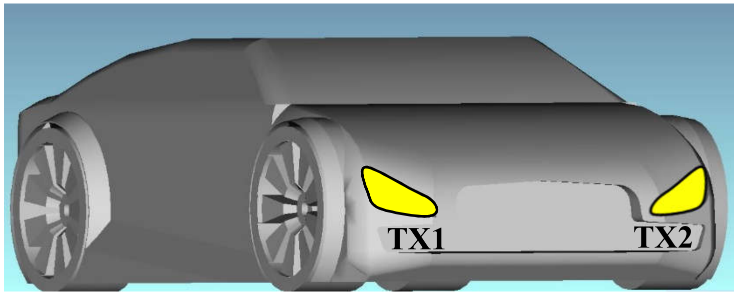
[2] L. Grobe, and K. D. Langer, "**Block-based PAM with frequency domain equalization in visible light communications**," In *IEEE Globecom Workshops (GC Wkshps)*, pp. 1070-1075, 2013.

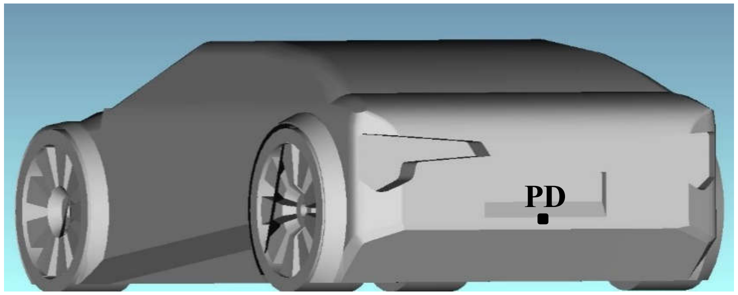
[3] M. Wolf, S. A. Cheema, M. Haardt, and L. Grobe, "**On the performance of block transmission schemes in optical channels with a Gaussian profile**," *In 16th International Conference on Transparent Optical Networks (ICTON)*, pp. 1-8, 2014.

Simulation Scenario

- We assume that the two vehicles are separated from each other initially at a distance of 10 meter.



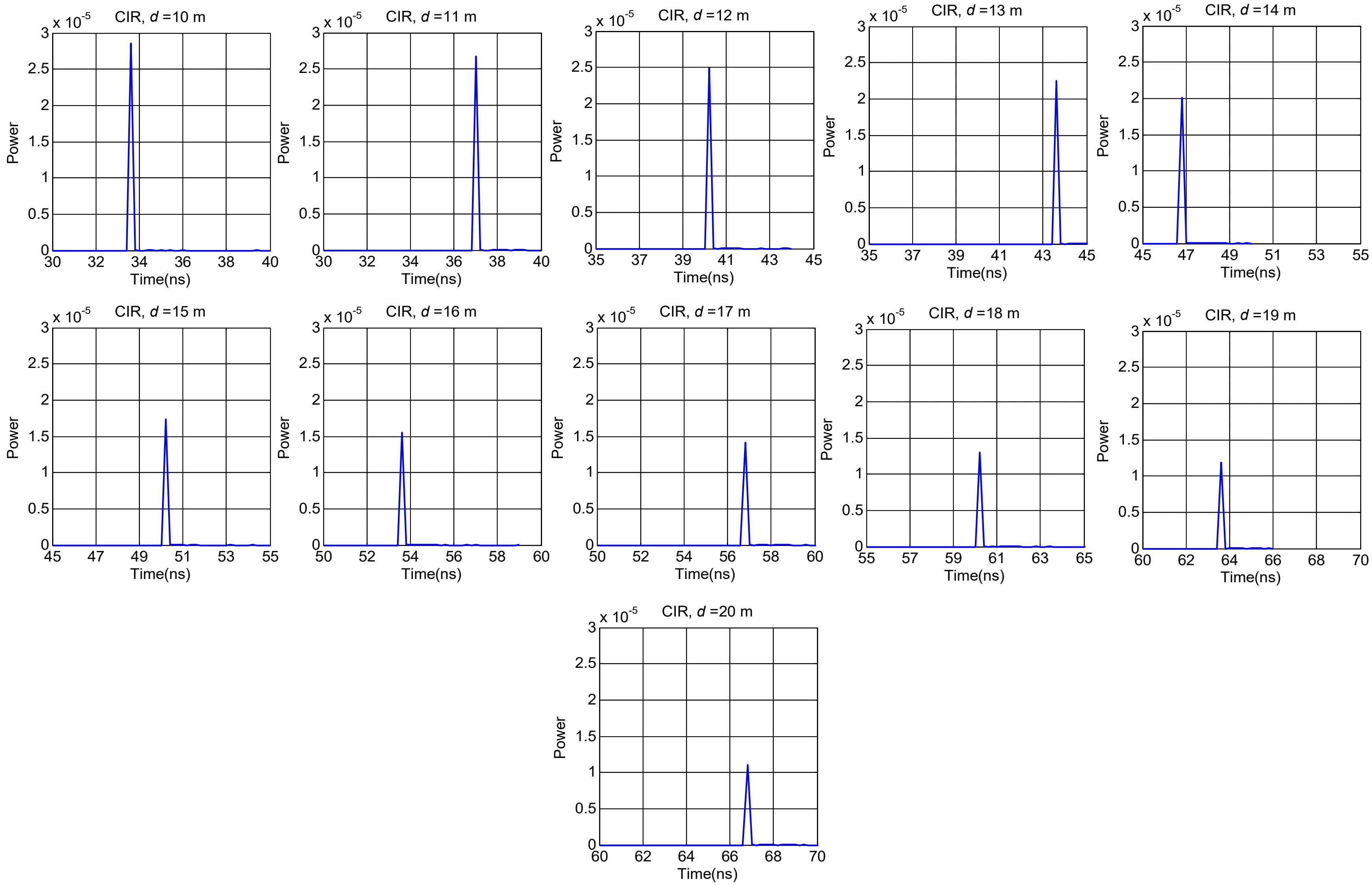




Simulation Parameters

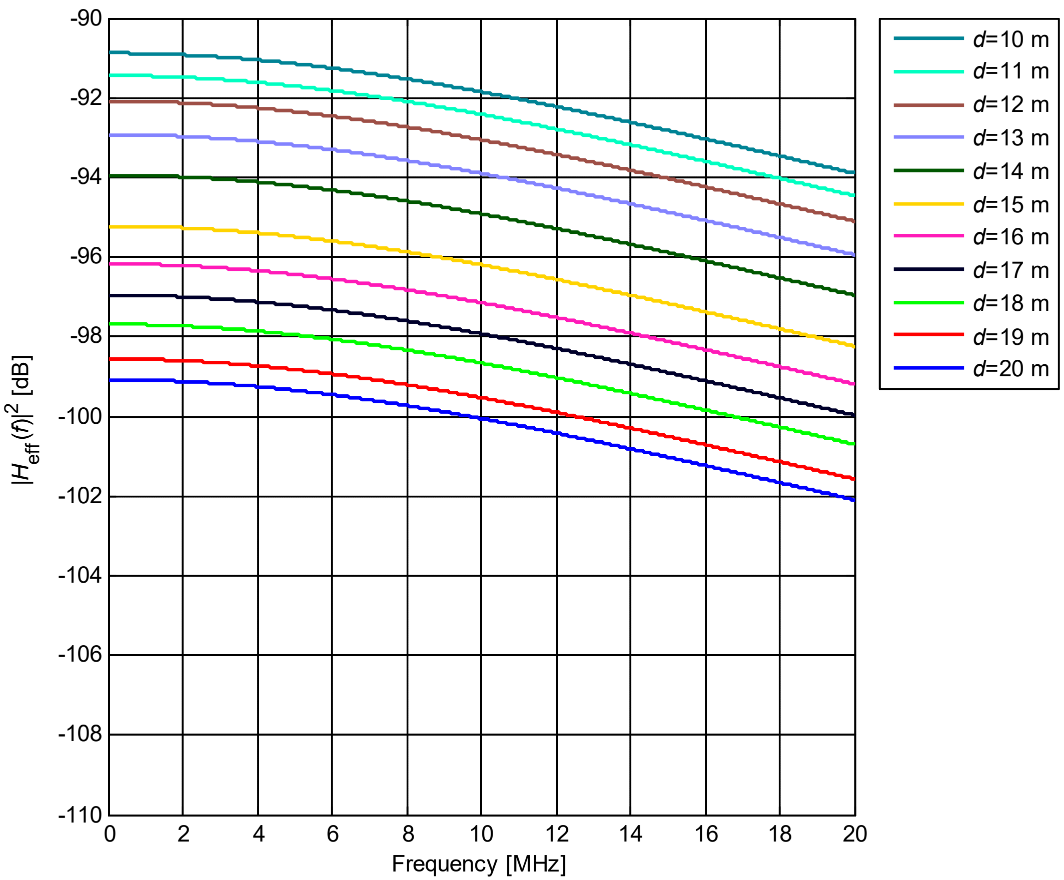
Transmitter specifications	Type: High-beam headlamp Brand: Philips Luxeon Rebel white LED Power: 1 Watt per each headlamp
Receiver specifications	Area: 1 cm^2 FOV: 180º
Coating material of vehicle	Black gloss paint
Road type	R2
Weather types	Clear Rainy Foggy with visibilities of $V = 50$ m and 10 m

CIR Results (Clear Weather)

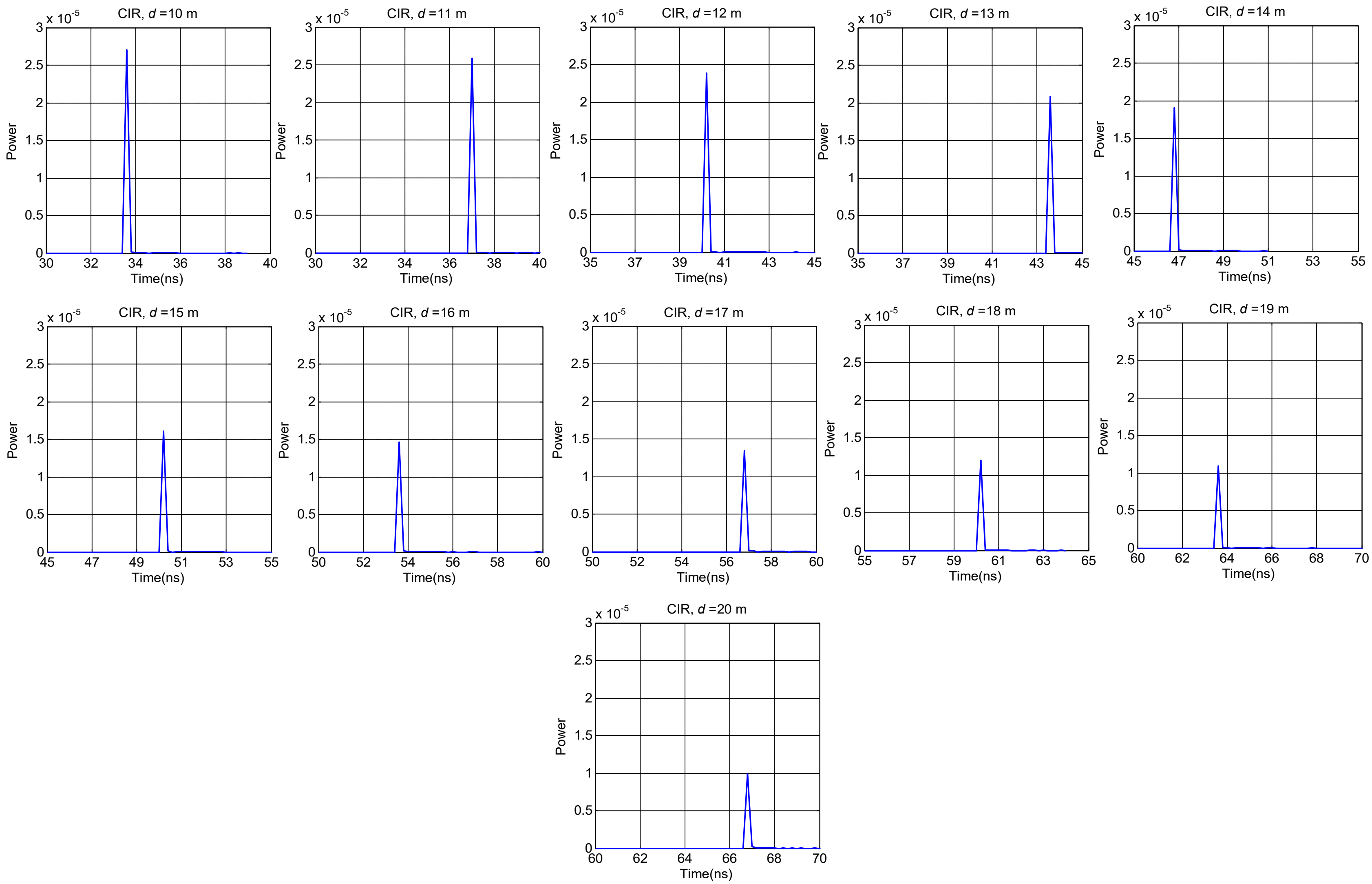


Effective Channel Responses (Clear Weather)

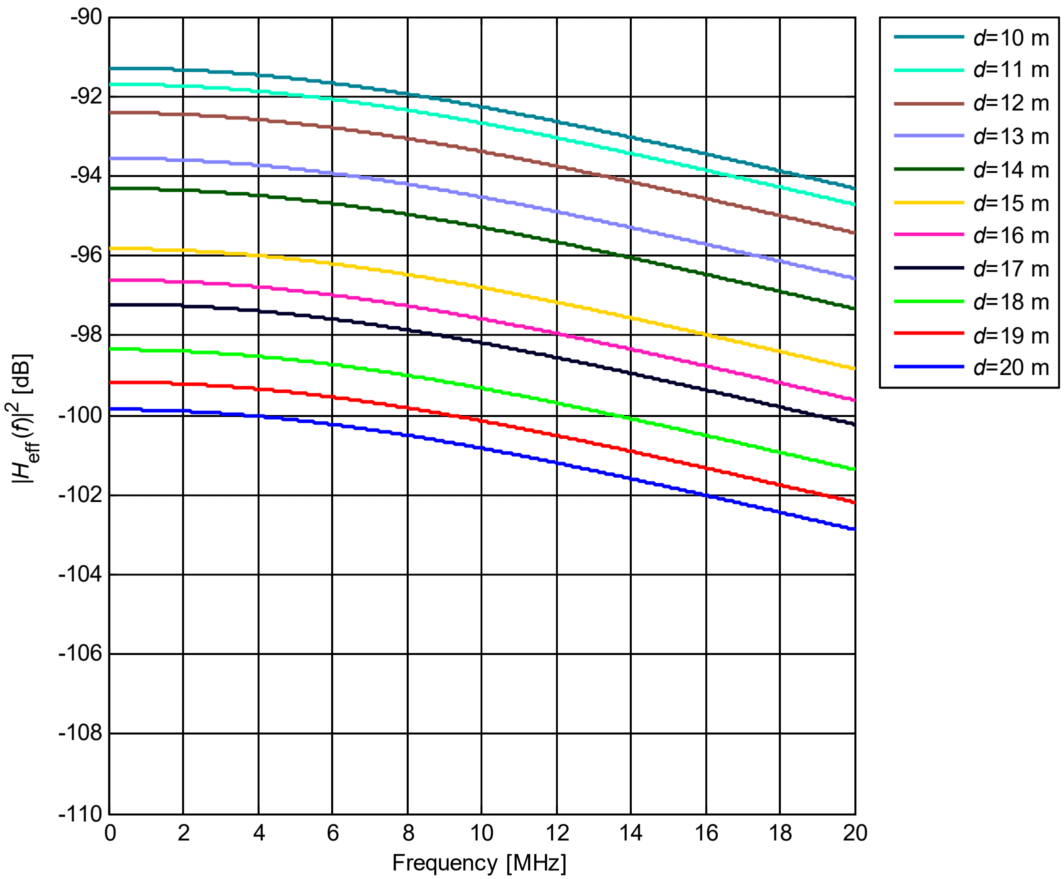
- For the effective channel responses, the "LED Model 1" with cut-off frequency of 20 MHz is considered.



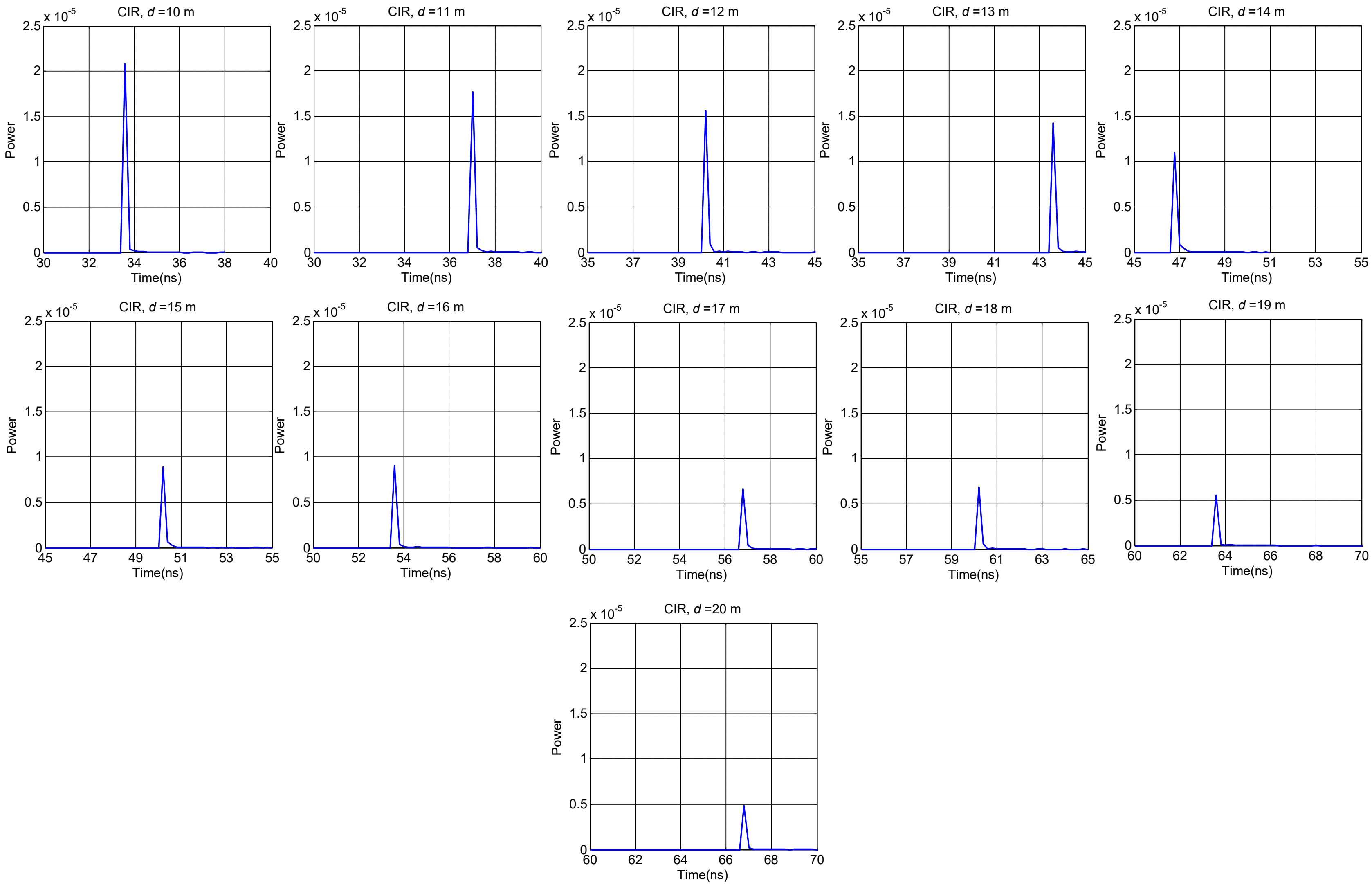
CIR Results (Rainy Weather)



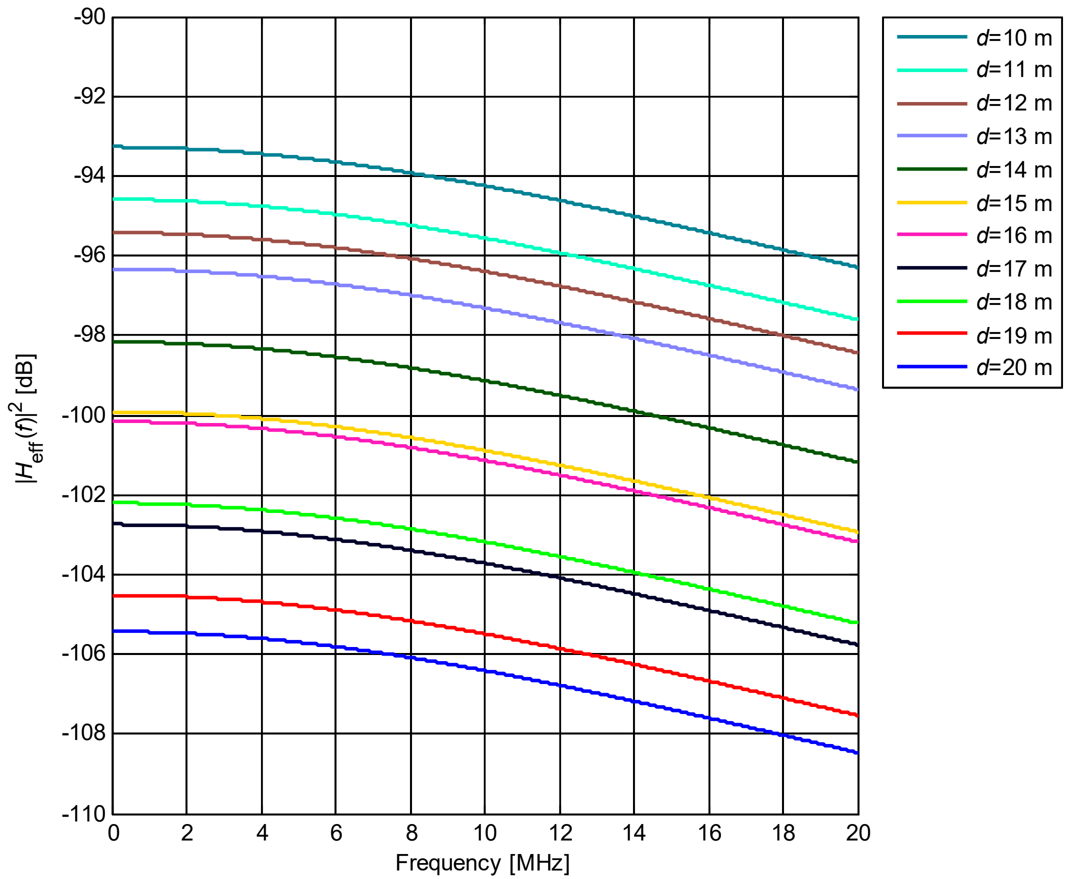
Effective Channel Responses (Rainy Weather)



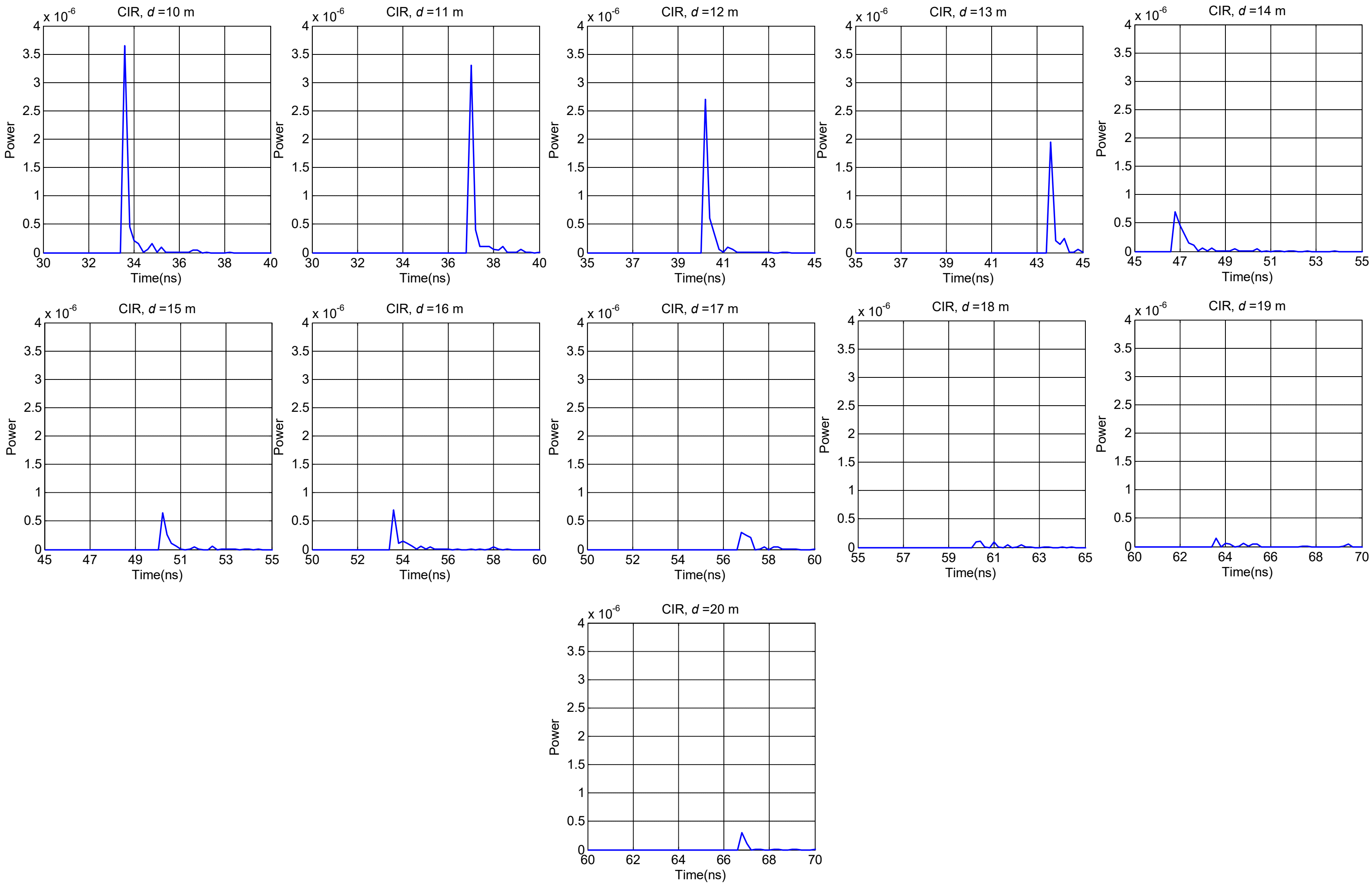
CIR Results (Foggy Weather, *V*=50 m)



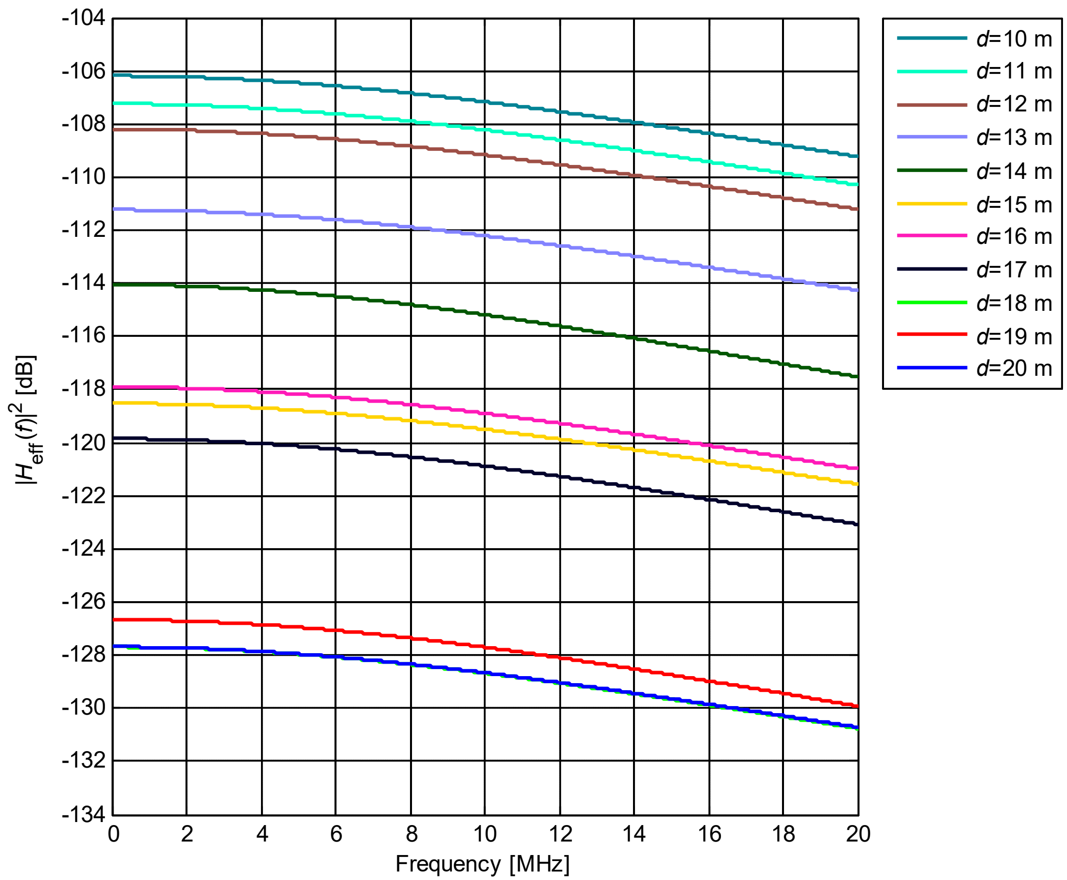
Effective Channel Responses (Foggy Weather, *V*=50 m)



CIR Results (Foggy Weather, *V*=10 m)



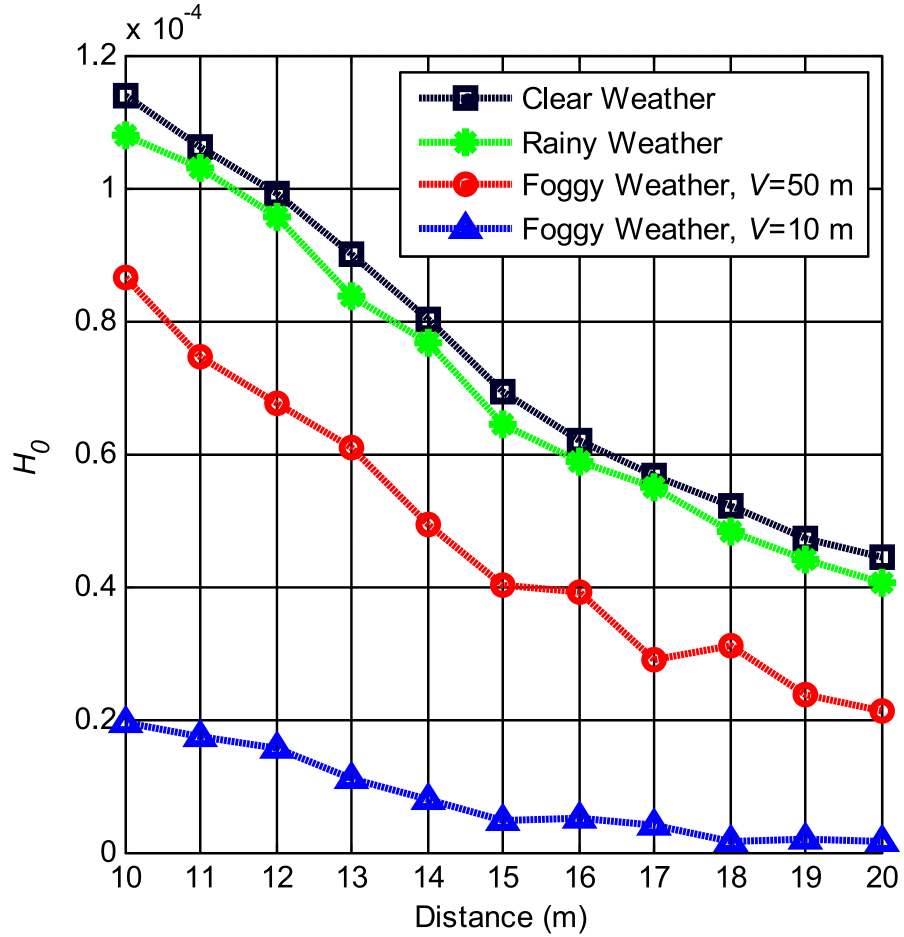
Effective Channel Responses (Foggy Weather, *V*=10 m)



Channel Characteristics (1/2)

d (m)	τ_{RMS} (ns)				H_0			
	Clear	**Rain**	**Fog (V=50 m)**	**Fog (V=10 m)**	**Clear**	**Rain**	**Fog (V=50 m)**	**Fog (V=10 m)**
10	7.95	7.95	7.95	7.97	1.14×10^{-4}	1.08×10^{-4}	8.66×10^{-5}	1.95×10^{-5}
11	7.95	7.95	7.95	7.99	1.06×10^{-4}	1.03×10^{-4}	7.44×10^{-5}	1.73×10^{-5}
12	7.95	7.95	7.95	7.95	9.92×10^{-5}	9.56×10^{-5}	6.76×10^{-5}	1.55×10^{-5}
13	7.95	7.95	7.95	7.97	9.01×10^{-5}	8.38×10^{-5}	6.08×10^{-5}	1.09×10^{-5}
14	7.95	7.95	7.95	8.56	8.01×10^{-5}	7.68×10^{-5}	4.93×10^{-5}	7.91×10^{-6}
15	7.95	7.95	7.95	7.97	6.92×10^{-5}	6.45×10^{-5}	4.03×10^{-5}	4.73×10^{-6}
16	7.95	7.95	7.95	8.02	6.20×10^{-5}	5.89×10^{-5}	3.91×10^{-5}	5.08×10^{-6}
17	7.95	7.95	7.95	8.14	5.66×10^{-5}	5.50×10^{-5}	2.91×10^{-5}	4.06×10^{-6}
18	7.95	7.95	7.95	7.99	5.21×10^{-5}	4.82×10^{-5}	3.09×10^{-5}	1.64×10^{-6}
19	7.95	7.95	7.95	8.16	4.71×10^{-5}	4.39×10^{-5}	2.37×10^{-5}	1.85×10^{-6}
20	7.95	7.95	7.97	7.96	4.43×10^{-5}	4.05×10^{-5}	2.13×10^{-5}	1.64×10^{-6}

Channel Characteristics (2/2)



Conclusions

- This contribution proposes LiFi reference channel models for vehicular communications to assist the IEEE 802.11bb.