# Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

**Submission Title:** Discussion on Channel Model for B4
**Date Submitted:** November 9, 2015
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**Re:** Agenda for Monday Nov. 9, PM2 session

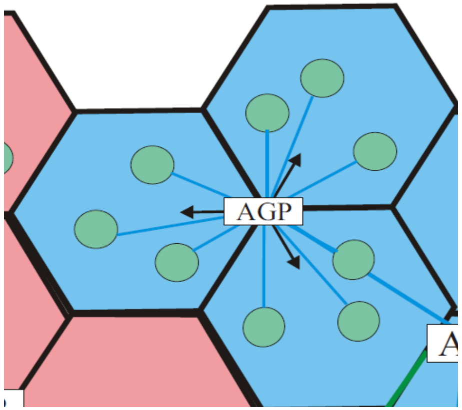
**Abstract:** Fudan University proposed that an additional channel model should be developed for scenario B4. Fraunhofer provides insights into recent work on that issue as a basis for discussion.

**Purpose:** Discussion

# Outline

- Low-cost short-range backhaul
- Initial results
- Long-term outdoor measurements
- Model for optimized link design
- Results with optimized link design
- Conclusions

# Low-cost short-range backhaul




- Increasing amounts of data over mobile networks
- Small cells are the main capacity scaling factor

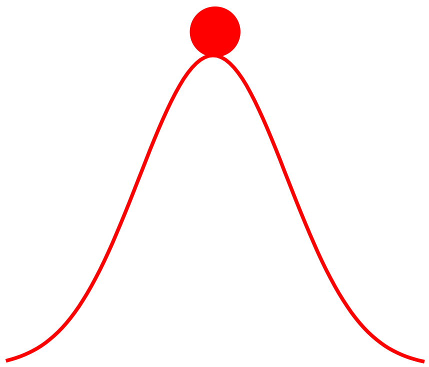
V. Jungnickel et al., "The role of small cells, coordinated multipoint, and massive MIMO in 5G," IEEE Communications Magazine, Special Issue on *5G Wireless Communication Systems: Prospects and Challenges*, vol.52, no.5, pp.44-51 (2014).

- 5G: Up to 50/10 indoor/outdoor small cells per sector
  - Urban areas (Germany): Typical inter-site distance is 500 m
  - Small-cell backhaul distance is 50-250 m
  - High line-of-sight probability
- New idea: Use LED-based optical wireless link as low-cost backhaul solution for small radio cells

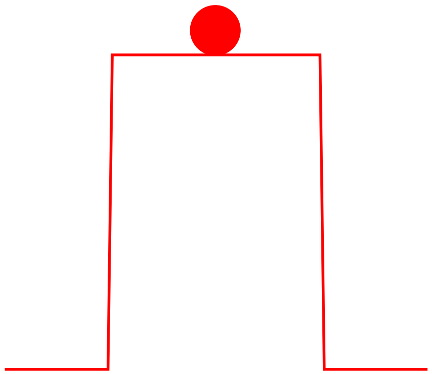
V. Jungnickel, D. Schulz, N. Perlot, K.-D. Langer, W. Störmer, „Optical Wireless as a Low-Cost Small-Cell Backhaul Solution," 8. ITG Fachtagung Photonische Netze und Systeme, Berlin, 1.-2. April 2014

# Laser vs. LED



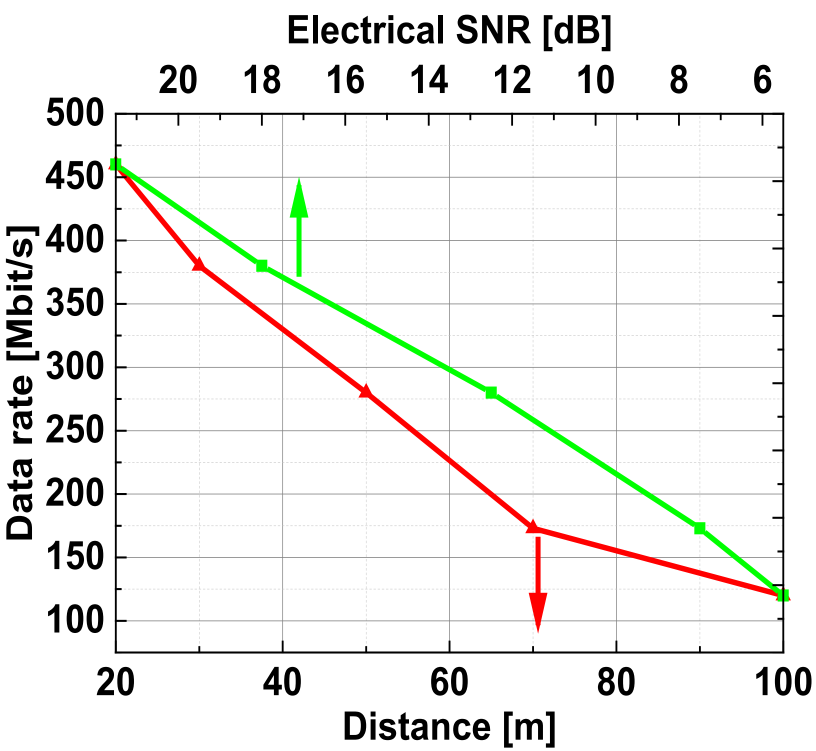


- Laser: Gaussian beam profile
  - Sensitive against misalignment
  - Needs tracking



- LED: Flat-top beam profile
  - Easy alignment
  - No more tracking is needed
  - Very robust link
  - Lamp posts, etc.

# Initial results

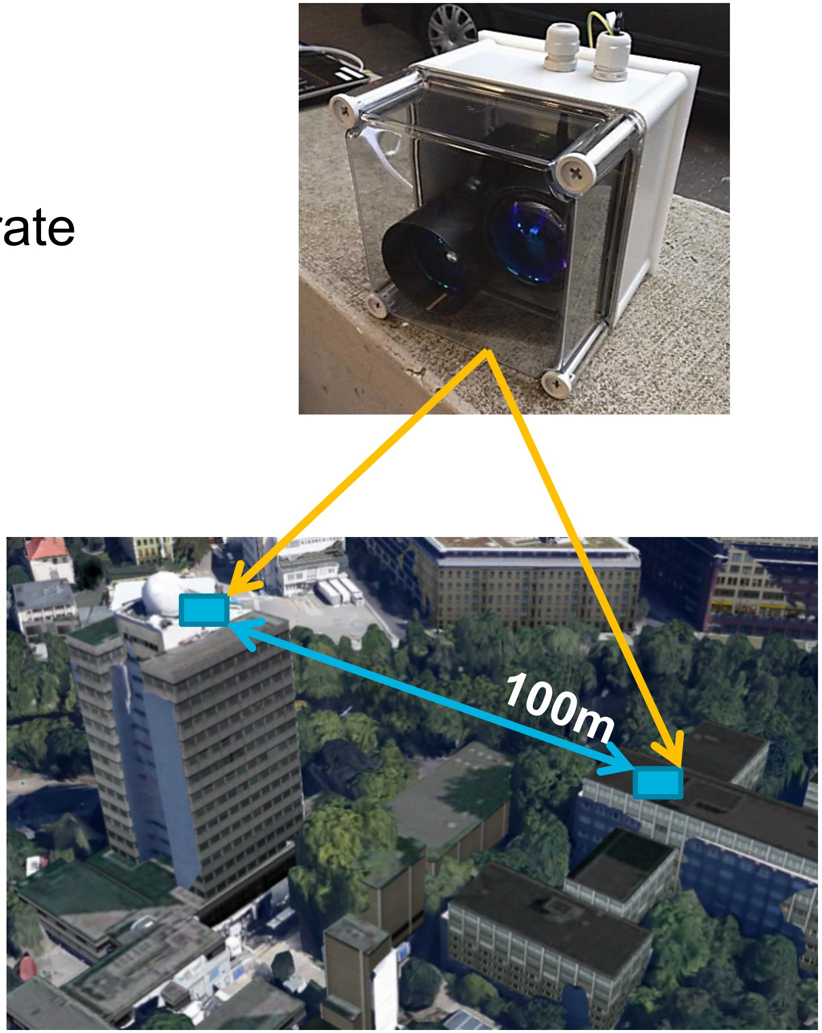



- 3”, f=10/8,5 cm lens at Tx/Rx
- Single-color infrared LED
- 7x7 mm² emitting area
- 14 mm effective PD diameter
- 7x7 m² beam area at 100 m

- More focused beam
- Better usage of optical bandwidth

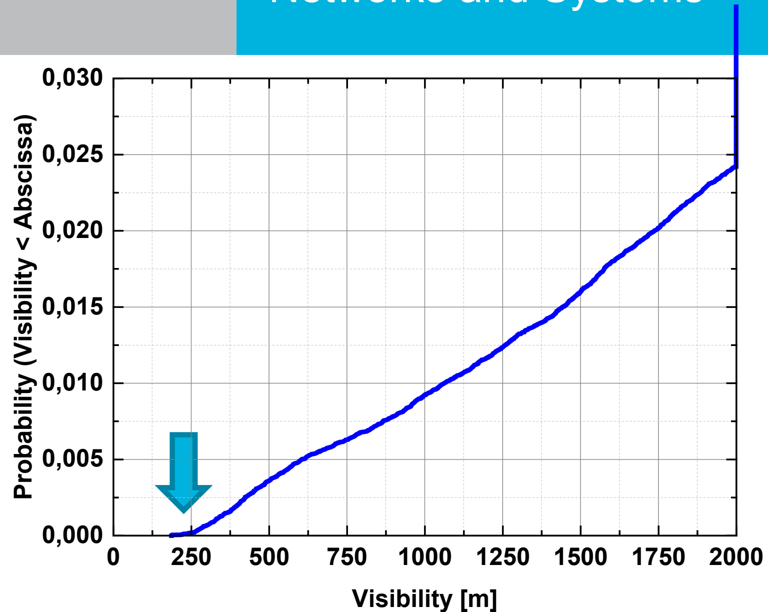
# Long-term outdoor experiment

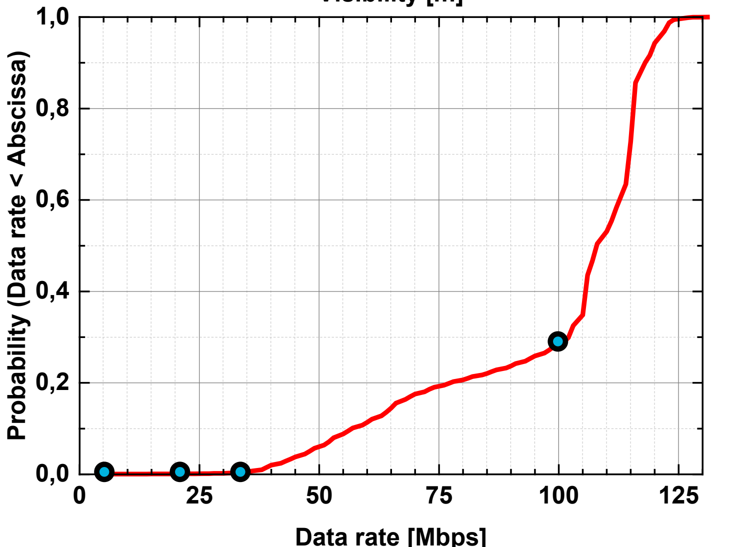
- Evaluate the impact of fog and sunlight
- Measured both, visibility range and data rate
- 5-month trial during winter term
  - Nov. 2014 – April 2015

# Cumulative long-term statistics

- Cumulative statistics of visibility and data rate for 5 months
- Visibility was never below 180 m
  - High availability for short distances
- Rate adaptation: Data rate was for
  - On average more than 100 Mbit/s
  - 99% more than 39 Mbit/s
  - 99,9% more than 22 Mbit/s
  - More than 6 Mbit/s at any time
- No outage at all
  - Thanks to rate-adaptive system concept

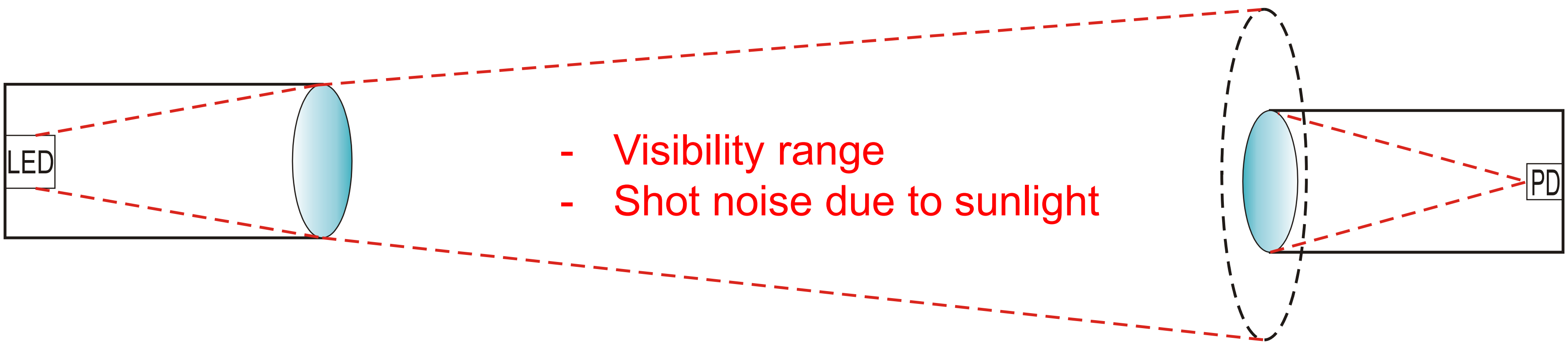


# Model for optimized link design

- Received power
- PD area, sensitivity
- Focal length and diameter of lens
- Rx bandwith

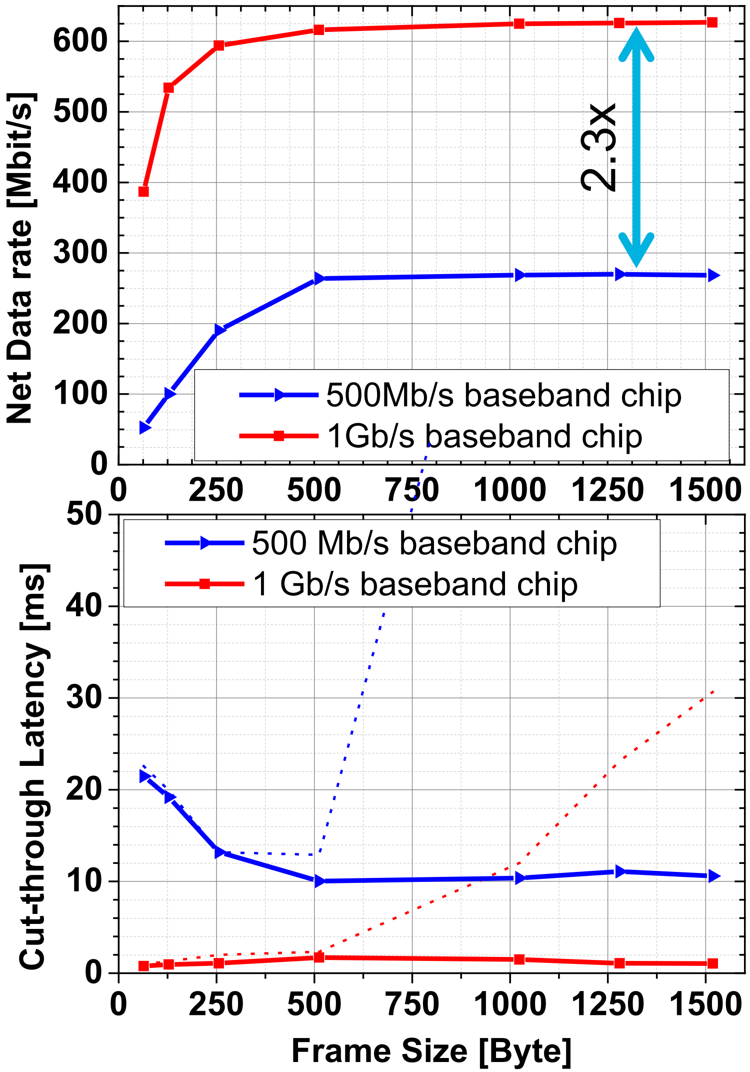
- LED power, active area, beam width
- Focal length and diameter of lens




- Model computes finally the electrical $SNR_{el}$ at the receiver
- Use modified Shannon's formula $C = B * \log_2(1 + SNR_{el} / \Gamma)$
- Determine empirical parameter $\Gamma$ from system measurements

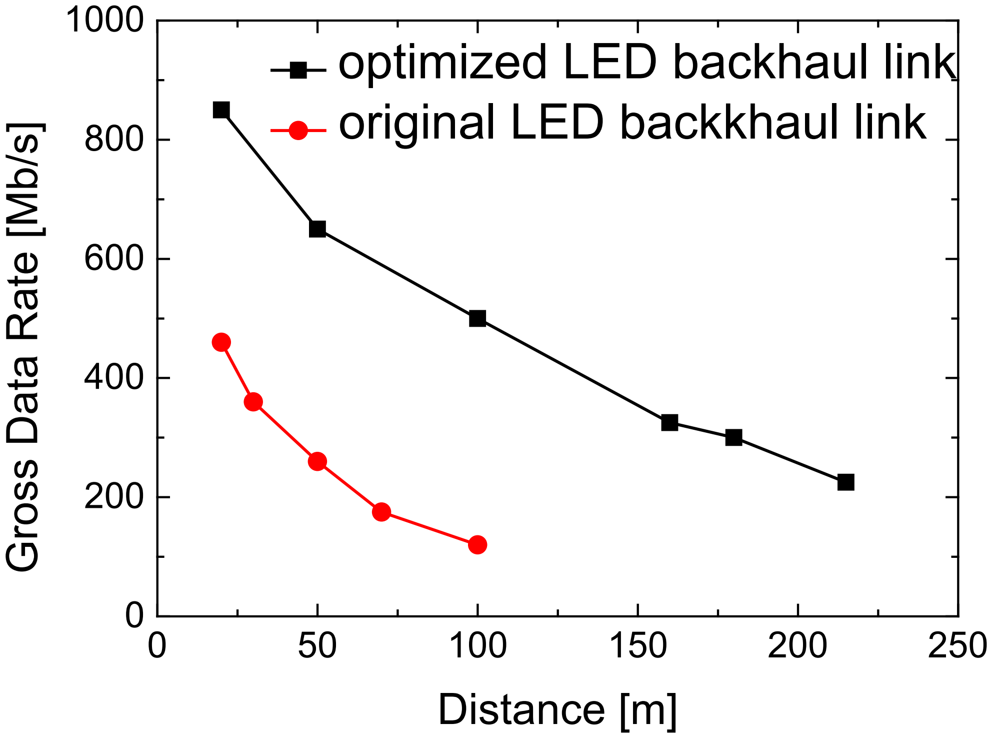
# New 1 Gb/s baseband chip

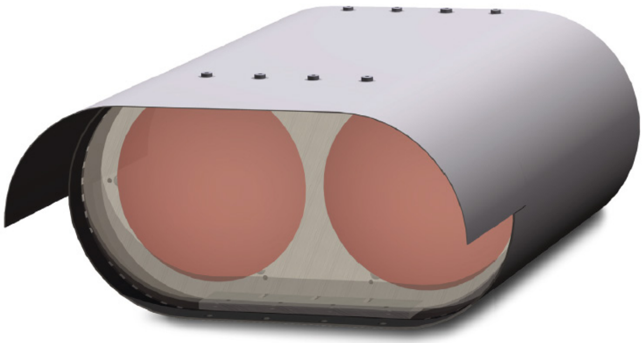





- Standard RFC 2544 test
  - electrical back-to-back measurements
  - Electrical gross data rate ~950 Mb/s
  - Optical gross data rate ~850 Mb/s
- Throughput results
  - Is smaller for smaller frame sizes
  - Max. reached for frame size ≥ 512 byte
  - 230% more net throughput
- Latency results
  - (10±1) ms for 500 Mb/s chip for frame size ≥ 512 byte
  - < 2 ms for 1 Gb/s chip, independent of the frame size

# Results with optimized backhaul link



- 4” f=10 cm lenses at Tx and Rx, single-color IR LED
- 1x1 m² at 100 m → higher SNR
- New baseband chip → Higher throughput, lower latency

# Summary

- Initial work using LED-based optical wireless link for the backhaul of small radio cells (WiFi, LTE).
- Long-term outdoor trial indicates the impact of fog and sunlight.
- Mathematical model of the link was developed to figure out optimized link parameters, goal was 1 Gbps over 100 m within available analog bandwidth (180 MHz).
- Optimized link with new baseband chip (using 100 MHz bandwidth only) achieved around 500 Mbps over 100 m.
- Potential towards 10G lies in replacing LED with lasers (high bandwidth).
- WDM is regarded critical as it increases receiver complexity.

# Impact of visibility

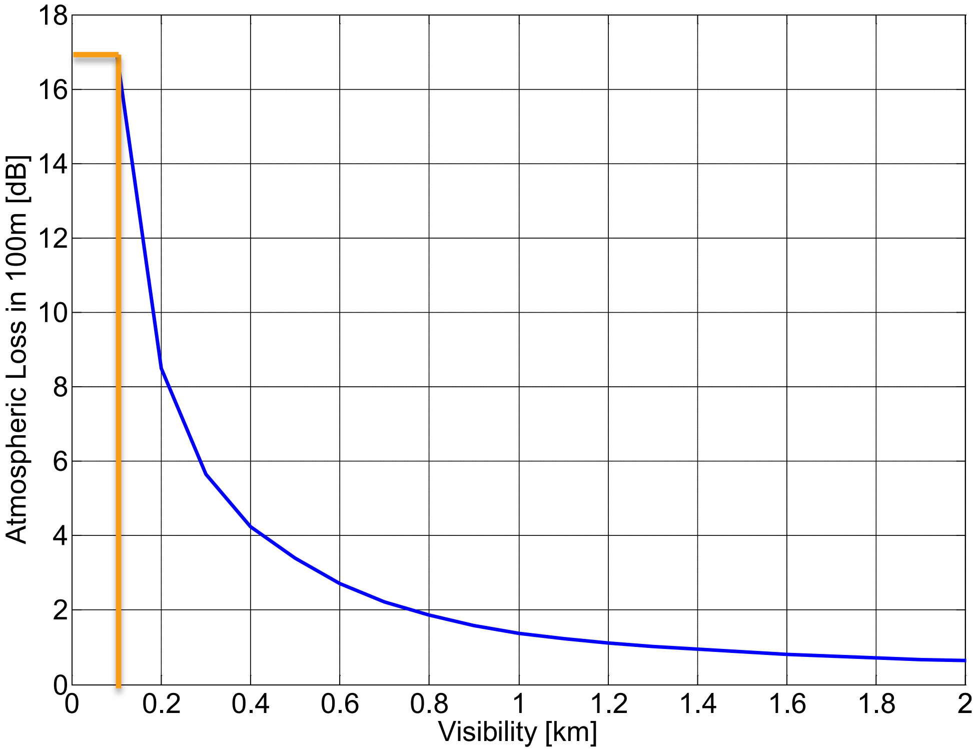


- Attenuation due to fog is main limiting factor
- Visibility is essential parameter
- Use well-known Kim‘s formula: 17 dB loss if visibility is equal to distance

$$G_{Atm}[dB] = 10\log(e^{-\gamma(\lambda)L})$$

$$\gamma(\lambda) = \frac{3.91}{V}\left[\frac{\lambda}{550}\right]^{-q} \quad [km^{-1}]$$

$$q = \begin{cases} 1.6 & V > 50km \\ 1.3 & 6km < V < 50km \\ 0.16V + 0.34 & 1km < V < 6km \\ V - 0.5 & 0.5km < V < 1km \\ 0 & V < 0.5km \end{cases}$$




*I. I. Kim, B. McArthur , E. Korevaar, "Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications".*

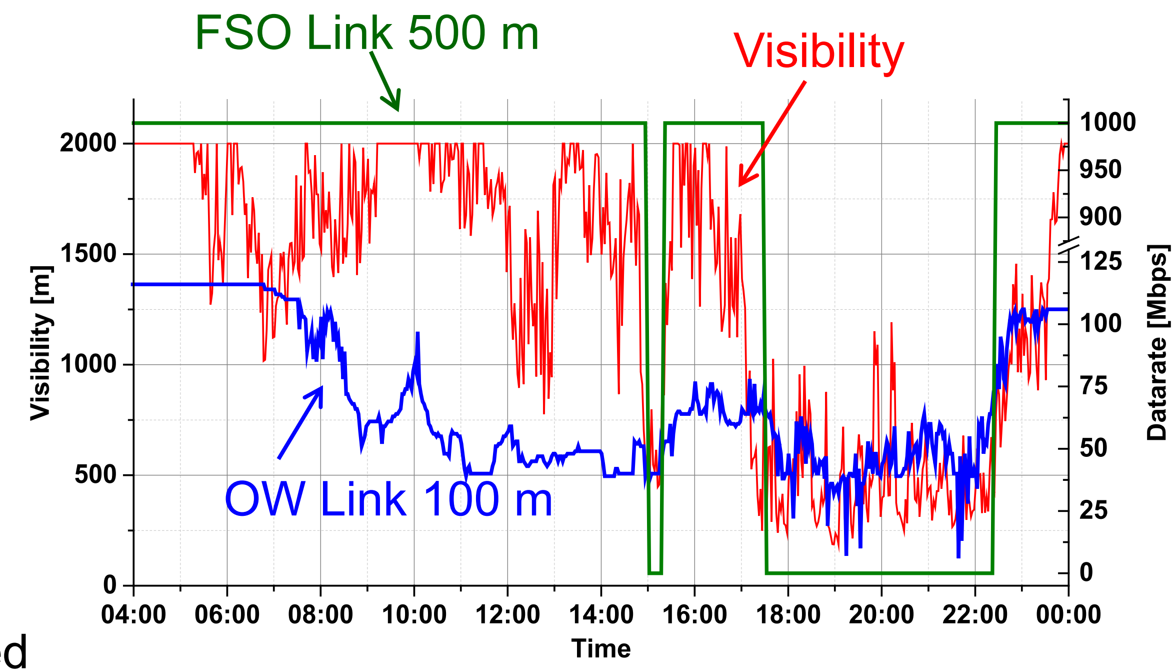
# Impact of fog



- Reduced visibility leads to higher atmospheric losses

- Fixed-rate FSO link
  - Total outage
  - Where link margin is not enough

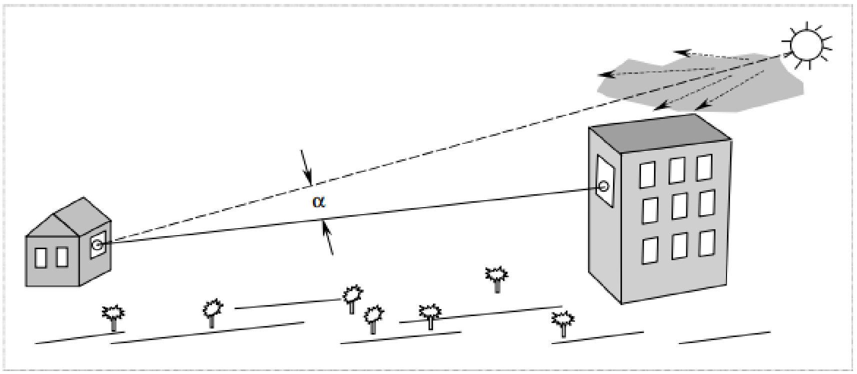
- Rate adaptive OW link
  - Reduced rate
  - No more outage is observed
  - Enhanced link availability

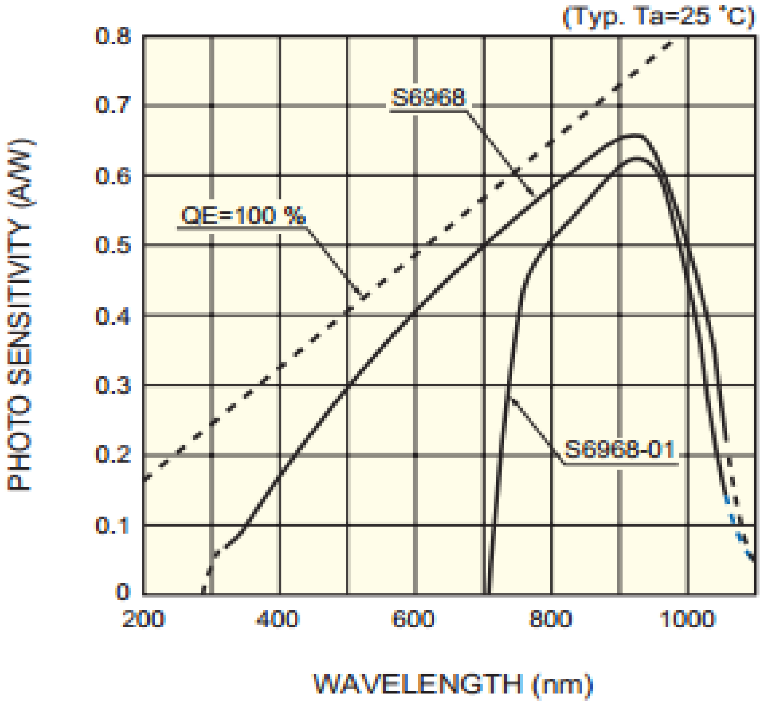


# Impact of sunlight



$$P_{b,\lambda} = L_\lambda(\lambda) A_r \Omega_{pr} = L_\lambda(\lambda) A_r \pi \sin^2(\frac{FOV}{2})$$




Max. spectral radiance

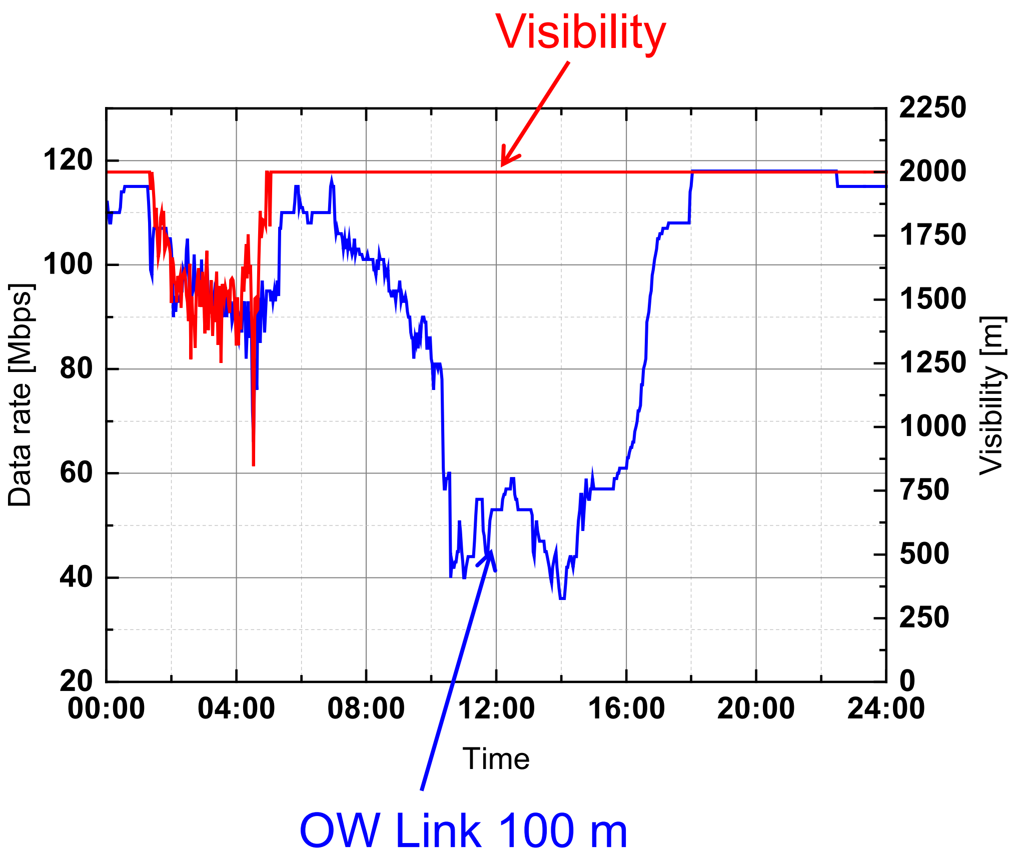
at 780-830 nm: $L_\lambda = 2\ Wm^{-2}sr^{-1}nm^{-1}$

*Example:*

*Ø 75mm , FOV=9°, $E_p$(780-830nm)=0,6 A/W, $L_\lambda = 2\ Wm^{-2}sr^{-1}nm^{-1}$*

*$P_b$=8.5 mW* *$I_b$=5,1mA*

# Impact of sunlight




- Scattered sunlight leads to
  - Shot noise
  - Rx saturation (if strong)
  - Use sun cap
- Direct sunlight leads to outage
  - Rare event
  - If both, Tx and sunlight are inside the Rx field-of-view (FOV)
  - Minimize the FOV
  - Use optical band-pass filter