Drahtlose Breitbandkommunikation – Link Budget

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Vorlesung Drahtlose Breitbandkommunikationssysteme

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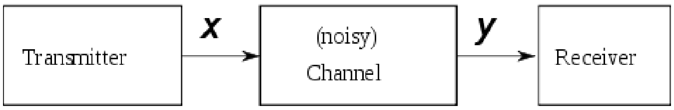
Channel Capacity: Shannon Theorem [Wikipedia]



- The **Shannon limit** or **Shannon capacity** of a communications channel is the theoretical maximum information transfer rate of the channel, for a particular noise level.
- Stated by Claude Shannon in 1948 (with sketchy proof)
- The first rigorous proof by Amiel Feinstein in 1954.
- The Shannon theorem states that given a noisy channel with channel capacity *C* and information transmitted at a rate *R*, then if R<C there exist codes that allow the probability of error at the receiver to be made arbitrarily small.
    - ➢ This means that, theoretically, it is possible to transmit information nearly without error at any rate below a limiting rate, *C*.

Link Budget Calculation

Path loss (PL) in free space (Friis equation):

$PL(a)= (4*\pi*d*f/c)^2$ (direct form)

$PL(\log)= 10*\log_{10}(4*\pi*d*f/c)^2= 20*\log_{10}(f) +20*\log_{10}(d) +20*\log_{10}(4\pi/c)$

(logarithmic form)

- d: Distance between Sender and Receiver
- f: Carrier Frequency
- c: Speed of light (~ 300 000 km/s)

Shannon channel capacity:

d_0

$C= B \log_2 (1 + S/N)$

Path Loss Exponent

Path loss (PL) in free space (Friis equation):

$$PL(a)= (4*\pi*d*f/c)^{2}$$ (direct form)

- The additional losses caused by fading, blockage … can be simply modeled by modifying the path loss exponent E_{PL}
- The path loss exponent $E_{PL} = 2$ for free space, line-of sight scenario
- For indoor and urban areas the path loss exponent can range from $E_{PL} = 2…4$
- In some lossy environment, the path loss exponent can reach even $E_{PL} = 6$
- In a specific tunnel scenario the lath loss exponent can be $E_{PL}<2$

Link Budget Calculation

- TX-Power	P_{TX}	
- Friis equation (path loss)	L_{FS}	(=PL)
- Antenna gain TX	G_{TX}	
- Antenna gain RX	G_{RX}	
- RX Losses (cables, connectors, …)	L_{RX}	
- Miscellaneous losses (Implementation losses)	L_M	
- RX-Noise Figure	NF	
- Shannon channel capacity	C	

Received Power (all in dB):

$$P_{RX}\ (dB) = P_{TX} + G_{TX} + G_{RX} - L_{FS} - L_{RX} - L_M$$

Required Signal/Noise at the Receiver

- During transmission and reception noise will be added to the signal
  - Thermal noise (Boltzmann noise)
  - Receiver Noise (Noise Figure)
  - Transmitter Noise caused by non linearities
  - etc.
- The effect for the received signal is that, in the constellation diagram, not a single point but a cloud of points around the expected point are received.
- Due to these noise and distortion impacts, the signal/noise (S/N) ratio to receive a signal correctly is at least around 6 dB (in the case of BPSK).
- The required SNR is dependent on the modulation and the transmission type
  - For 64 QAM, the SNR is at least 4 dB higher than for 16 QAM etc.

Receiver Sensitivity

The receiver sensitivity S_{min} is the minimum input signal power required at the receiver input to provide sufficient SNR at receiver output to do data demodulation for a specific modulation scheme

- S_{min} depends on:
  - Required SNR for desired modulation = SNR_{req}
  - Thermal noise floor at RX antenna = kT_oB
  - Noise Figure of the receiver = N_F

$S_{min} = SNR_{req} * kT_oB * N_F$ (all in absolute numbers)

$S_{min}\ (dB) = SNR_{req}\ (dB) + 10*\log_{10}(kT_oB) + N_F\ (dB)$

- In some (generic) cases: $SNR_{req} = 0$ dB

SNR <-> E_b/N_o

For the evaluation of the efficiency of a specific implementation, the parameter E_b/N_o is often used.

$E_b/N_o = SNR * (B_T/R)$

$SNR = (E_b/N_o) * (R/B_T)$

- SNR = Signal-to-noise ratio
- E_b = Energy required per bit of information
- N_o= thermal noise in 1Hz of bandwidth
- R = system data rate
- B_T= system bandwidth
- (R/B_T) = spectral efficiency

Source: Intersil, Tutorial Link budget Analysis 1998

Required Signal/Noise at the Receiver

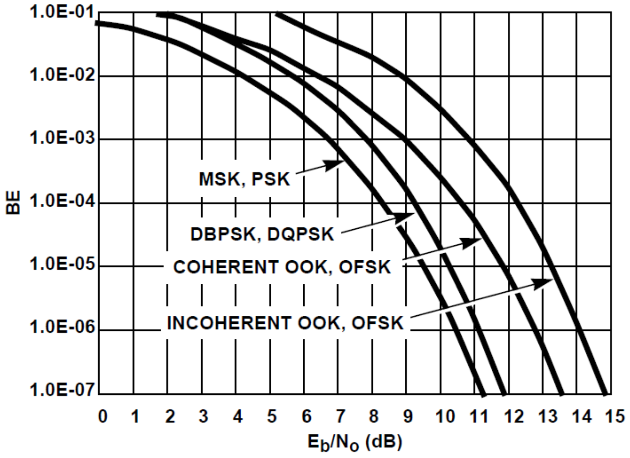


FIGURE 4. PROBABILITY OF BIT ERROR FOR COMMON MODULATION METHODS

Source: Intersil, Tutorial Link budget Analysis 1998

Link-Budget Calculator

- Excel Sheet

OFDM System Parameter Choice

Channel Parameters (T_{RMS}, Mobility, …)

- Strong multipath propagation and high bit rate
  - ➢ OFDM (otherwise single carrier scheme sufficient)
- Delay spread of channel T_{RMS} determines :
  - ➢ guard time (cyclic prefix): $T_{CP} \sim 2 \ldots 4 \times T_{RMS}$
  - ➢ $T_{OFDM} \sim > 5 \times T_{CP}$ -> ($T_{sym} = T_{CP} + T_{FFT}$)
  - ➢ $T_{FFT} \sim > 4 \times T_{CP}$
- Number of subcarriers:
  - ➢ $N_{sub} = B * T_{FFT}$
  - ➢ N_{sub} = target bitrate / (bitrate/subcarrier) (-> modulation scheme)
- Channel Coherence Time T_C determines:
  - ➢ Pliot scheme (time axis)
- Channel Coherence Bandwidth B_C
  - ➢ Pilot scheme (frequency axis)

OFDM System Parameter Choice II

Example Parameters for OFDM-parameter choice (@ board)

Channel properties / target parameters:

- Application scenario:
  Large office; metal coated windows
- Delay spread of channel: $T_{RMS} = 200$ ns
- Available bandwidth: $B = 20$ MHz
- Target data rate: $R = 50$ Mb/s
- Coherence time of channel: $T_C = 5\ \mu s$
- Coherence bandwidth of channel: $B_C = 5$ MHz