**Notation & constants**

* d : distance (meters) between interferer (AP site) and the incumbent receiver.
* f : frequency (Hz).
* c : speed of light ≈ 3.0×10^8 m/s.
* P\_tx : transmit power at transmitter port (dBm).
* G\_tx, G\_rx : transmit / receive antenna gains (dBi).
* L\_tx\_losses, L\_rx\_losses : Tx / Rx feedline and other hardware losses (dB, positive).
* EIRP (dBm) = P\_tx (dBm) + G\_tx (dBi) - L\_tx\_losses (dB).  
  (EIRP definition — including feedline loss; we avoid omitting losses)
* PL(d) : path loss (dB) (model-dependent; FSPL or log-distance, ITM, WINNER II, ...).
* I(d) : interference power at the incumbent receiver terminal (dBm).
* N : noise power in the incumbent receiver over its relevant Rx bandwidth (dBm).
* NF : noise figure of incumbent receiver (dB).
* B\_Rx : incumbent receiver noise bandwidth (Hz).
* I/N (dB) = I (dBm) - N (dBm).
* I\_thresh : maximum allowed interference power at the incumbent receiver (dBm) consistent with the regulatory criterion (e.g., for co-channel, I/N ≤ −6 dB → I\_thresh = N + (-6 dB)).
* All dB arithmetic uses the usual conversion rules.

**1) AFC layer — link budget → interference → protection distance**

**(A) Received interference power**

We start from EIRP:

EIRP(dBm) = P\_tx(dBm) + G\_tx(dBi) - L\_tx\_losses(dB)

Then the interference arriving at the incumbent receiver terminals (accounting receiver antenna gain and Rx losses) would be:

I(d) (dBm) = EIRP(dBm) - PL(d) + G\_rx(dBi) - L\_rx\_losses(dB) - L\_polarization(dB)

This is the dB form of Friis / link budget (Friis -> Pr = Pt + Gt + Gr +20 log10(λ/(4πd))). We use EIRP to avoid double counting G\_tx. See Friis / FSPL references.

**(B) Noise power and I/N**

Thermal noise PSD at T0 = 290 K is -174 dBm/Hz. Then

N(dBm) = -174 dBm/Hz + 10·log10(B\_Rx) + NF(dB)

and

I/N (dB) = I(dBm) - N(dBm).

So the regulatory condition I/N ≤ −6 dB means:

I(dBm) ≤ N(dBm) - 6 dB (equivalently I\_thresh = N - 6 dB).

This is the standard noise-floor formula; -174 dBm/Hz is the thermal reference.

**(C) Interference Margin (IM)**

IM(dB) := I\_thresh(dBm) - I(dBm).

* IM > 0 means incumbent is safe (headroom).
* IM = 0 borderline.
* IM < 0 means incumbent interference protection *violated*.

**(D) Protection distance**

For **free-space** (valid in far-field LoS):

Free-space path-loss (FSPL), in dB:

FSPL(dB) = 20·log10(4·π·d·f / c)

(ITU-R P.525 gives the recommended FSPL and constants in a convenient expanded form; explicit with units.)

We solve for distance d such that I(d) = I\_thresh. Rearranging:

1. From link budget I(dBm) = EIRP - FSPL(dB) + G\_rx - L\_misc. We put I(d) = I\_thresh and solve FSPL:

FSPL\_required(dB) = EIRP + G\_rx - L\_misc - I\_thresh.

1. We invert FSPL:

d = (c/(4π f)) · 10^{FSPL\_required(dB)/20}.

f in Hz, d in meters; FSPL\_required in dB.

**(E) Adjacent-channel handling (ACIR)**

When the AP is on an adjacent channel, the effective attenuation due to Tx out-of-channel leakage (ACLR or Tx out-of-band) and Rx selectivity (ACS or Rx out-of-band rejection) combine into an **ACIR**. The standard linear-domain combination is:

Let A\_tx(dB) = Tx out-of-channel attenuation (ACL R-like), A\_rx(dB) = Rx selectivity/ACS (both positive dB attenuation). Then the combined ACIR in dB is:

ACIR(dB) = -10·log10( 10^{-A\_tx/10} + 10^{-A\_rx/10} ).

Equivalently

ACIR\_lin = 1 / (10^{-A\_tx/10} + 10^{-A\_rx/10})

and ACIR(dB) = 10 log10(ACIR\_lin).

We use I\_adj(dBm) = I\_cochannel(dBm) - ACIR(dB) for adjacent-channel interference estimation. See ITU/3GPP/ETSI guidance on ACIR combination.

**2) PHY layer — SINR, OFDMA, MU-MIMO**

**(A) Single-stream received SINR (narrowband)**

If the desired signal power at the receiver terminal is S (dBm) and aggregate interference plus noise equals I\_agg(dBm) (interference from other APs after path loss + noise power), then:

SINR (dB) = S(dBm) - 10·log10( 10^{I\_agg/10} + 10^{N/10} ) [if we want linear combine],

but commonly we compute:

S\_lin = 10^{S/10} (mW), N\_lin = 10^{N/10}, I\_lin = 10^{I\_agg/10}

SINR\_linear = S\_lin / (I\_lin + N\_lin)

SINR\_dB = 10 log10(SINR\_linear).

**(B) Beamforming / MIMO single-user (narrowband) — vector form**

For single-user beamforming where AP uses beamforming vector v and channel vector h:

y = h^H v · s + Σ\_j (h\_j^H v\_j · s\_j) + n

SINR (linear) = |h^H v|^2 P\_s / ( Σ\_j |h^H v\_j|^2 P\_j + N0·B ). (we normalize v appropriately.) For details we refer to standard MIMO capacity references (Telatar, Foschini).

**(C) MU-MIMO capacity (multi-antenna matrix formula)**

Single-user MIMO capacity (bits/s/Hz) in the complex Gaussian channel:

C = log2 det( I + (1/N0) H Q H^H )

where H is the channel matrix, Q is the transmit covariance (power allocation), and N0 is noise power spectral density. See Telatar (1999) for rigorous derivation.

**(D) OFDMA — per-subcarrier (per-RU) capacity**

OFDMA sum capacity over assigned subcarriers n ∈ S\_k to user k:

C\_k = Σ\_{n ∈ S\_k} Δf\_n · log2(1 + SINR\_{k,n}),

with Δf\_n the subcarrier (RU) spacing. For implementation we compute SINR per RU including adjacent-channel leakage via ACIR where needed.

**3) MAC layer — collision probability, Bianchi saturated model (useful if AFC optimizes channel assignments)**

**Bianchi (2000)** saturated DCF model (canonical): let τ be transmit probability in a random slot, and p = collision probability seen by a packet. Then:

p = 1 - (1 - τ)^{N-1}.

τ is a function of p determined by the 802.11 binary exponential backoff. For a classic binary exponential backoff with m backoff stages and CWmin W (CWmin), the closed form is:

τ = [ 2 (1 - 2 p) ] / [ (1 - 2 p) (W + 1) + p W (1 - (2p)^m) ].

p and τ form a fixed-point system — we solve numerically. This is the standard Bianchi solution; the rough τ ≈ 2/(CW + 1) is only a first approximation (and ignores p and retransmissions). For Wi-Fi 6/6E with OFDMA and trigger-based uplink there are extensions to Bianchi — we use those if we want accurate OFDMA-aware MAC modeling.