EE 484

FDMA Notes

Reference: R.M. Gagliardi, *Introduction to Communications Engineering*, 2nd ed., Wiley, 1988.

In an FDMA system each uplink carrier is assigned a frequency band within the RF bandwidth of the satellite.

Let the RF satellite bandwidth B_{RF} Hz be available to the carriers each using a bandwidth of B Hz. Then the number of carriers allowed by the satellite bandwidth is

$$K = \frac{B_{RF}}{B}.$$

Let P_{ui} be the ith carrier uplink power at the satellite amplifier input and let P_{un} be the corresponding uplink noise. The total input power is then

$$P_u = \sum_{i=1}^{K} P_{ui} + KP_{un}.$$

Let P_T denote the satellite downlink power. Then

$$G = \frac{P_T}{P_u} = \frac{P_T}{\sum_{i=1}^{K} P_{ui} + KP_{un}}.$$

The downlink receiver power of the ith carrier is then

$$P_{di} = LGP_{ui} = LP_T \frac{P_{ui}}{\sum_{i=1}^{K} P_{ui} + KP_{un}}$$

where L is the combined downlink power losses and gains from the satellite amplifier output to the receiver input.

The total receiver noise is the sum of the transponded uplink noise and the receiver noise. Thus, the downlink carrier-to-noise ratio (CNR) is

$$\text{CNR}_d = \frac{P_{di}}{LGP_{un} + N_{0d}B}$$

where N_{0d} is the receiver noise spectral level. We can write this as

$$(\text{CNR}_d)^{-1} = (\text{CNR}_u)^{-1} + (\text{CNR}_r)^{-1}$$

where

$$\text{CNR}_u = \frac{P_{ui}}{P_{un}} = \frac{P_{di}}{LGP_{un}}$$

and

$$\text{CNR}_r = \frac{P_{di}}{N_{0d}B} = \frac{P_T L}{N_{0d}B}\left(\frac{P_{ui}}{P_u}\right)$$

where CNR_u is the uplink CNR of a single carrier and CNR_r is the CNR measured at the receiver.

Using the above we can solve for K as

$$K = \left[\frac{P_T L}{N_{0d}B}\right]\left[\frac{1-(\text{CNR}_d/\text{CNR}_u)}{\text{CNR}_d}\right].$$

So we have two expressions for K: the first is based on bandwidth and the second on power. Hence, a linear FDMA system can be either power or bandwidth limited depending on which equation yields the smallest value of K (the number of allowed carriers).

The above analysis assumes linear operations. If a power amplifier on the satellite is operating close to saturation to maximize output power then nonlinearities will be present and the above equations would have to be modified to account for this. We will now add some analysis to account for this.

The most important nonlinearity is the power amplifier (e.g., TWTA) when it is being operated near saturation for maximum output power. When multiple FDMA carriers pass through a nonlinearity then (1) the carriers mix together to produce unwanted intermodulation products that fall into the FDMA bands as interference or noise and (2) the available output power decreases as a result of conversion of useful satellite power intermodulation noise. Let N_{0I} denote the peak intermodulation spectral level and let $P_T(K)$ denote the total carrier power available for the K carriers. Then including the intermodulation and power suppression we now get

$$\text{CNR}_d = \frac{P_T(K)L\alpha_s^2/K}{N_{0d}B + P_T(K)\alpha_n^2 L + N_{0I}BL}$$

where we have assumed a flat intermodulation spectrum over the band and

$$\alpha_s^2 = \frac{P_u}{P_u + P_{un}}, \quad \alpha_n^2 = \frac{P_{un}}{P_u + P_{un}}$$

are the limiting suppression factors. This is the downlink receiver CNR_d of a particular FDMA carrier. We can now write

$$(\text{CNR}_d)^{-1} = \left(\frac{\alpha_s^2}{\alpha_n^2}\text{CNR}_u\right)^{-1} + (\text{CNR}_r)^{-1} + (\text{CNR}_I)^{-1}$$

where

$$\text{CNR}_u = P_{ui}/P_{ni} \quad = \text{ uplink carrier CNR at the satellite limiter input,}$$

$$\text{CNR}_r = P_{di}/N_{0d}B \quad = \text{ downlink carrier CNR due to available satellite power,}$$

$$\text{CNR}_I = (P_T(K)/K)/N_{0I}B \quad = \text{ carrier-to-intermodulation ratio.}$$

When the uplink and downlink power levels are sufficient, the downlink CNR is mostly determined by the intermodulation and we can write

$$\text{CNR}_d \approx \text{CNR}_I = \frac{P_T(K)/K}{N_{0I}B}.$$

Note that the numerator term of CNR_I decreases with input backoff while the intermodulation level N_{0I} is also reduced with backoff. As backoff increases the intermodulation decreases and thus increasing CNR_I. however, the available satellite power also decreases producing a backoff point at which CNR_I is maximized. The desired operating point is strongly dependent on the characteristics of the amplifier used.