Wireless Communication Systems
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Lecture 10: Rate Adaptation

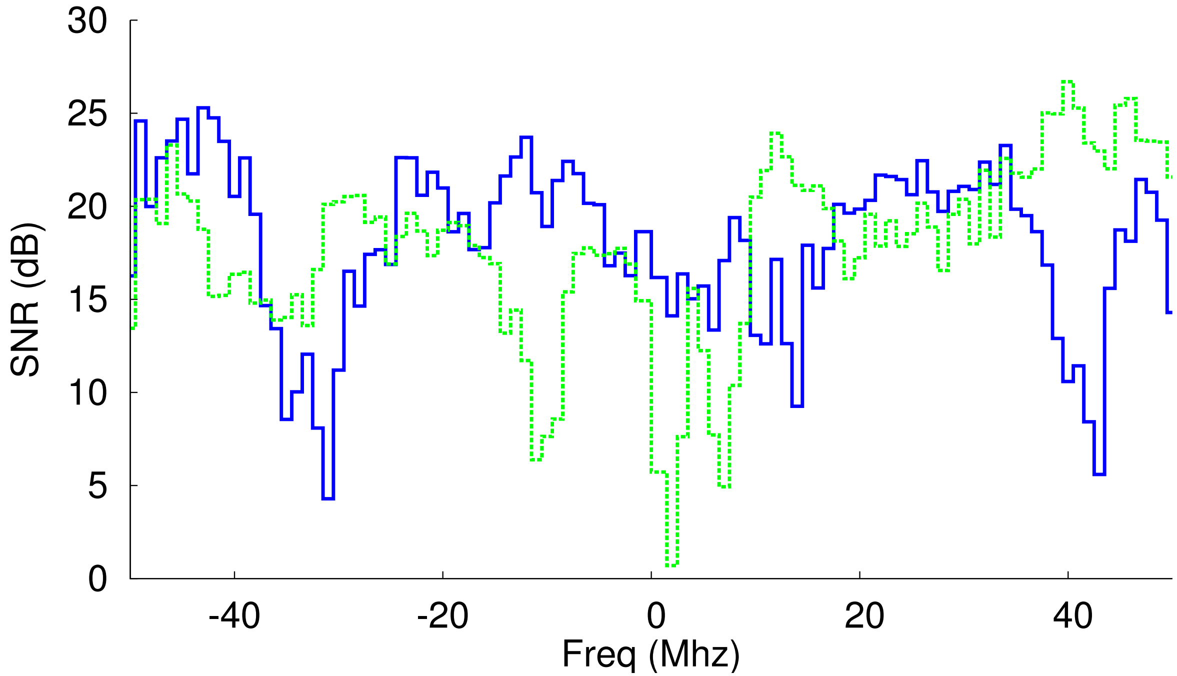
Frequency-Aware Rate Adaptation (MobiCom'09)

Lecturer: Kate Ching-Ju Lin (林靖茹)

Motivation

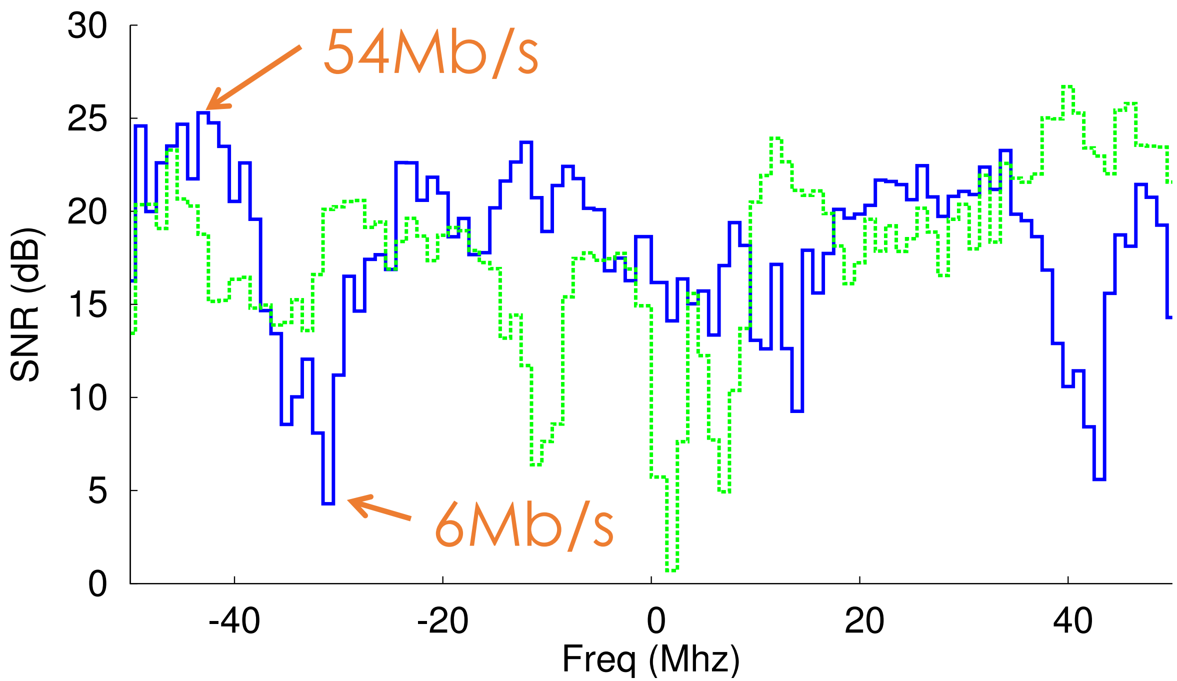
- The bandwidth supported in 802.11 is getting wider
  - 20MHz in 802.11a/b/g
  - 40MHz in 802.11n
  - 80-160MHz in 802.11ac
- 802.11 adopts OFDM, which partitions the wideband channel to subcarrier
- Frequency-selective fading
  - Different subcarriers experience independent fading due to the multipath effect
  - Different frequencies exhibit very different SNRs
  - But the transmitter can assign one rate to the entire band

Frequency Diversity



- The SNRs of different frequencies can differ by as much as 20dB
- Different receivers prefer different frequencies

Key Features of FARA



- Allow a receiver to measure the SNR of each sub-channel
- Instead of assigning the same rate to the entire band, allows each sub-channel to pick the optimal rate matching its SNR

SNR-based Adaptation

Minimum Required SNR	Modulation	Coding
<3.5 dB	Suppress subband	
3.5 dB	BPSK	1/2
5.0 dB	BPSK	3/4
5.5 dB	4-QAM	1/2
8.5 dB	4-QAM	3/4
12.0 dB	16-QAM	1/2
15.5 dB	16-QAM	3/4
20.0 dB	64-QAM	2/3
21.0 dB	64-QAM	3/4

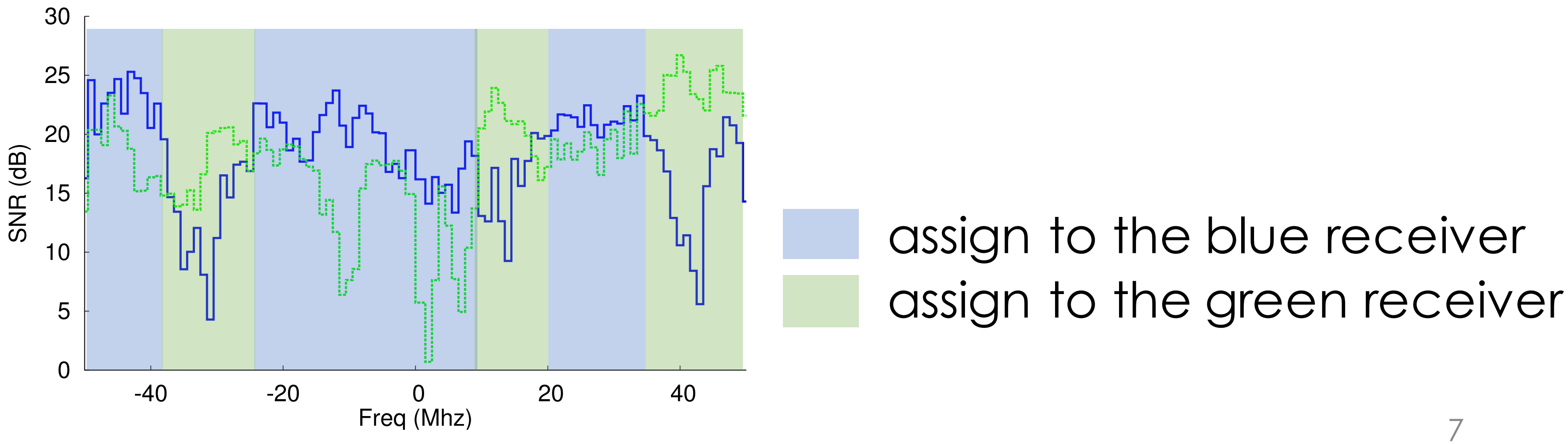
- Maintain a SNR-to-rate lookup table
- The sender transmits few symbols at the lowest bit-rate for all sub-channels
- The receiver selects the highest rate for each sub-channel corresponding to the SNR of that sub-channel
  - Discard the sub-channels if SNR is too low to support the lowest rate

Rx-based Adaptation

- The receiver is in charge of
  - Measuring the channel
  - Selecting the rate
  - Responding to the AP
- To decrease the feedback overhead, embed the rate information in ACK
- Perform some optimization to reduce the size of the embedded information

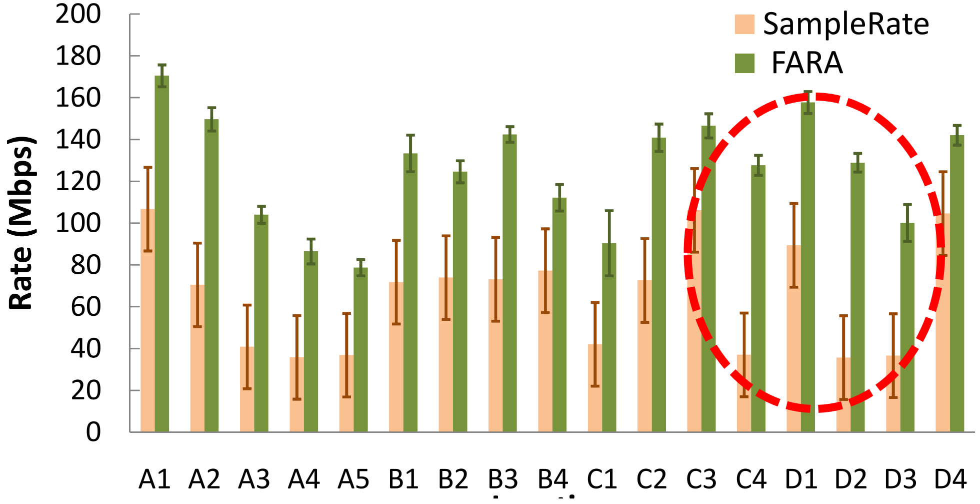
FARA in Frequency-Aware MAC

- Further combine FARA with the frequency-aware MAC protocol to leverage frequency diversity
- Instead of communicating with one receiver at a time, serve N (2-5) receivers concurrently
  - Randomly select N receivers with queued packets
  - Assign each sub-channel to a proper receiver
  - All the N receivers occupy the entire band

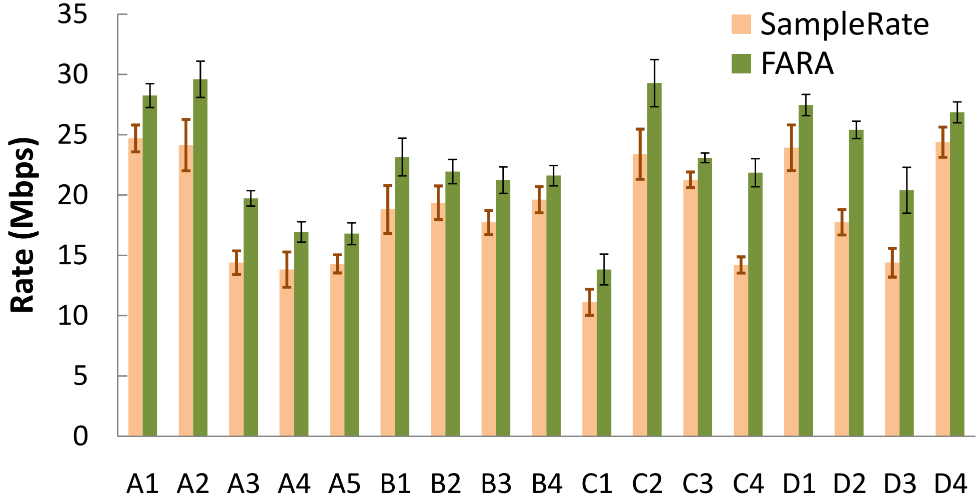


Performance

- Compare with SampleRate in 20MHz and 100MHz channel



100MHz



20MHz

Throughput gain is especially large as the band is wider

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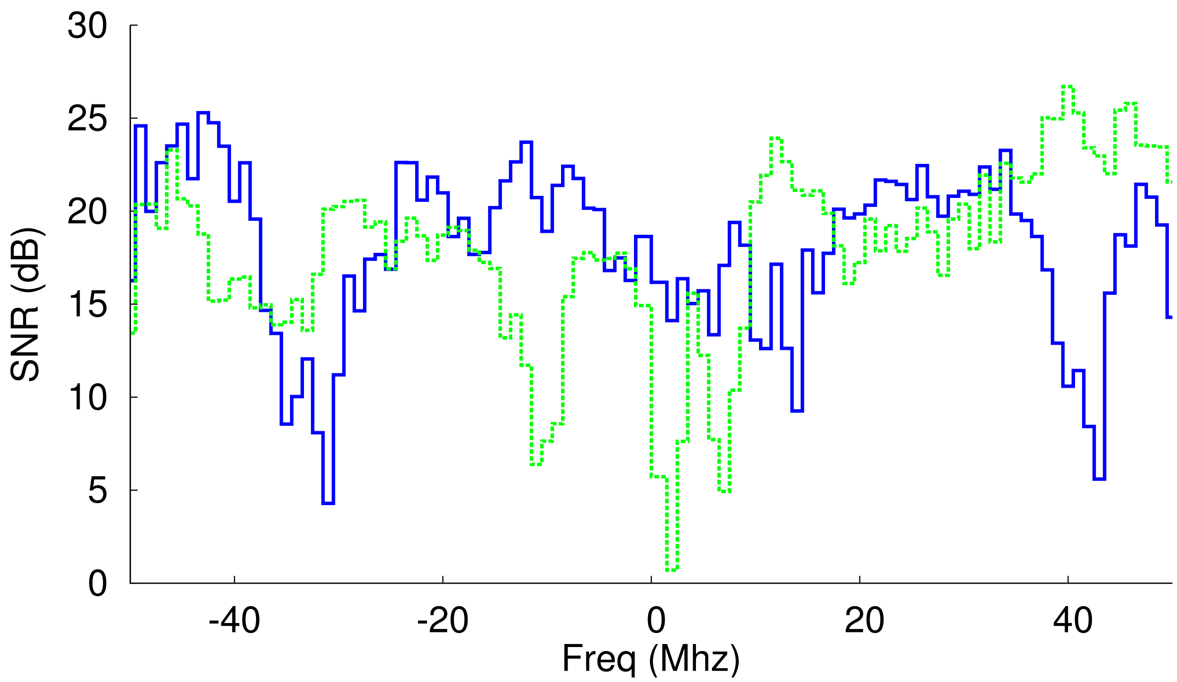
Predictable 802.11 Packet Delivery from Wireless Channel Measurements (SIGCOMM'10)

Kate Ching-Ju Lin (林靖茹)

Motivation



- Again, different frequencies experience different channel condition → frequency-selective
- Why not FARA?
  - Need hardware modification

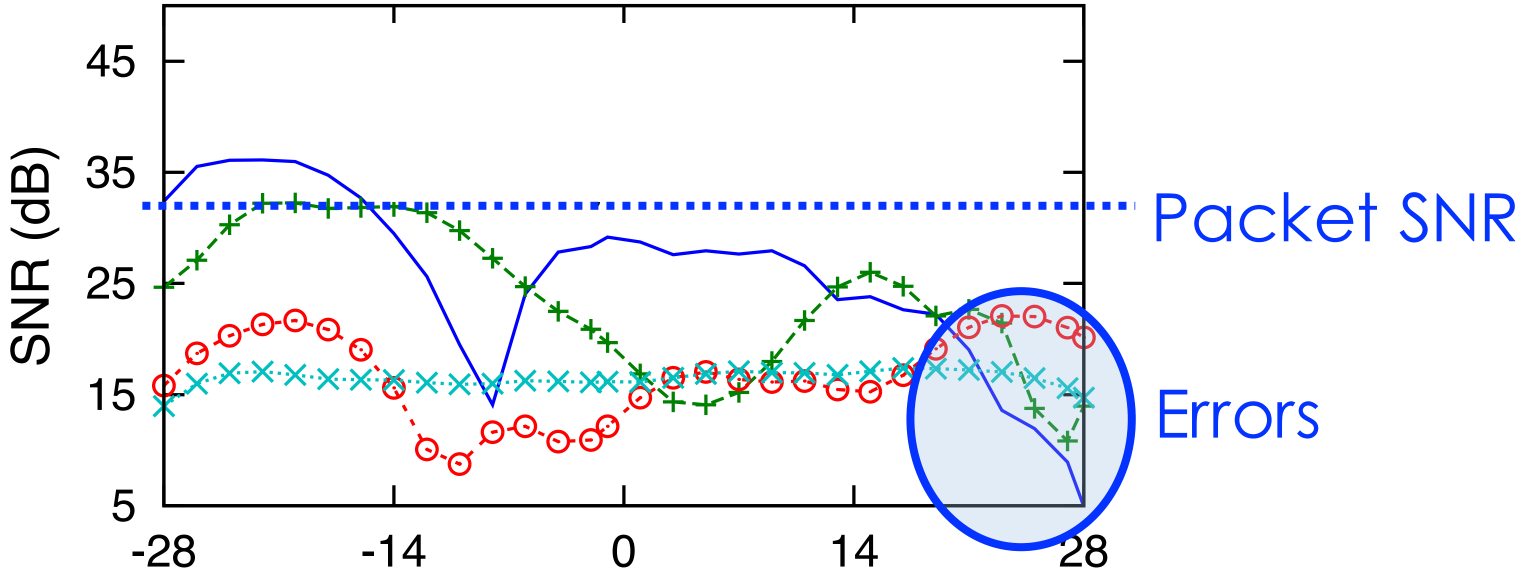
Traditional SNR-based Adaptation

- SNR-based rate adaptation is usually inaccurate because we
  - Assume frequency-flat fading
  - Select the bit-rate based on "average SNR" across subcarriers
- However, this will over-estimate the channel quality because
  - A packet will fail to pass the CRC check even if only a few bits are in error due to frequency-selective fading

Traditional model: Packet SNR

- Traditional theory well maps the channel condition (SNR) to the corresponding bit-error rate (BER)
  - e.g., $BER = Q\left(\frac{d_{\min}}{\sqrt{2N_0}}\right) = Q(\sqrt{2SNR})$ in BPSK
  - But, this only work for a narrow band channel
- The average SNR over all sub-carriers is not a good representation of a wideband channel
  - Why? The channel condition is not a linear function
  - The losses in a few subcarriers would lead to packet errors

Traditional model: Packet SNR

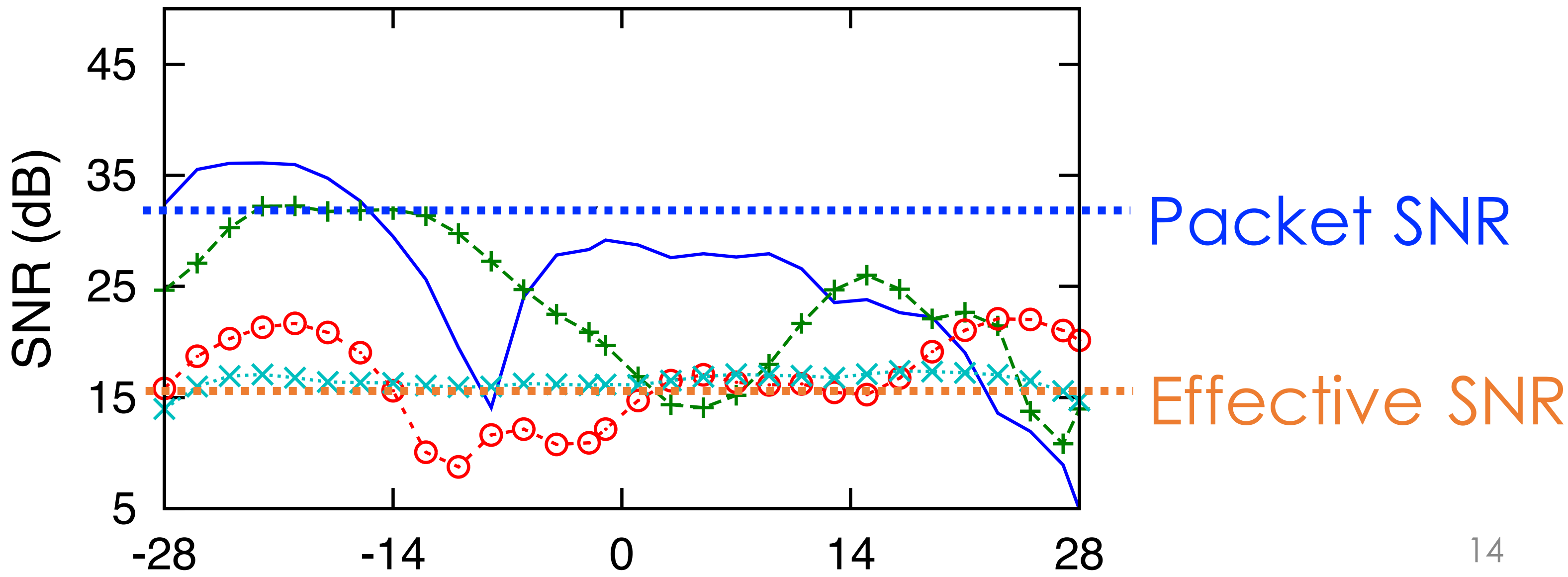


- Packet SNR: Average power of a link / Noise power
- Due to frequency-selective fading, a link could have a higher packet SNR, but also have a high bit-error rate

Effective SNR (ESNR)

- Can we find a metric that can be used to
  - Represent a wideband channel
  - Estimate the BER of the whole packet

  → **Effective SNR (ESNR)**
- Average SNR vs. Effective SNR
  - Total power of a link vs. Useful power of a link



Effective SNR (ESNR)

- Benefits
  - Can accurately estimate the packet delivery rate of packets
  - Pick a single bit-rate that maximizes the packet delivery rate or the effective throughput in a wideband channel
- How to calculate?
  - Reuse the theoretical channel model derived in the textbook
  - Find the expected BER of a link
  - Then, convert it back to the effective SNR

$$\text{narrow-band SNR} \Longleftrightarrow \text{narrow-band BER}$$
$$\text{effective SNR} \Longleftrightarrow \text{packet BER}$$

Effective BER and Effective SNR

- First calculate the average BER of a selected modulation *k* across all subcarriers *i*

$$\mathrm{BER}_{\mathrm{eff},k} = \frac{1}{N}\sum \mathrm{BER}_k(\mathrm{SNR}_i)$$

- Convert it back to the effective SNR

$$\mathrm{ESNR}_k = \mathrm{BER}_k^{-1}(\mathrm{BER}_{\mathrm{eff},k})$$

Modulation	Bits/Symbol (k)	$\mathrm{BER}_k(\rho)$
BPSK	1	$Q\left(\sqrt{2\rho}\right)$
QPSK	2	$Q\left(\sqrt{\rho}\right)$
QAM-16	4	$\frac{3}{4}Q\left(\sqrt{\rho/5}\right)$
QAM-64	6	$\frac{7}{12}Q\left(\sqrt{\rho/21}\right)$

$\mathrm{BER}_k^{-1}()$: the inverse function $\mathrm{BER}_k()$

ESNR-based Rate Adaptation

- ESNR can be thought of the equivalent SNR of a wideband flat-fading channel
- Hence, now we are able to use ESNR to find the optimal rate by looking up the SNR-to-rate mapping table