**Motivation**
- To characterize efficient communication for a receiver with limited source of energy.

**System Model**
- Power is limited or stochastic at the receiver
  \[ \bar{W} = E[W] \]

**Applications**
- Wireless sensor networks.
- Short-range communication

**Power Consumption at the Receiver**
- **Fixed**
  \[ P_{\text{receiver}} = P_{\text{mix}} + P_{\text{sig}} + P_{\text{LNA}} + P_{\text{filter}} + P_{\text{IFA}} + P_{\text{ADC}} + P_{\text{D}} \]
- **Small**
  \[ P_{\text{ADC}} \approx 3V^2f_{\text{min}}(2B + f_{\text{foc}}) \]
  \[ E_{\text{sampling}} = \frac{1}{B}(3V^2f_{\text{min}}(2B + f_{\text{foc}}) + 105.8mW) \]
  (Shuguan Cui, A.J. Goldsmith, and A. Bahai 2005)

**Performance Metric**
- Reliable Communication Rate:
  \[ \rho(t) = \frac{1}{t} \sum_{i=1}^{N(t)} R_i I_i \]
  \( N(t) \) the number of codewords sent by time \( t \).
  \( R_i \) the code rate of packet \( i \).
  \( I_i = 1 \) if the receiver decodes the packet \( i \) reliably.

**Dropping a Sample: Erasure Channel**
- C = capacity of original channel
- \( \lambda = \) sampling rate =1- erasure rate
- CA = capacity of the new channel
  (S. Verdu and T. Weissman, 2008)
- Conjecture: Decoding energy is an increasing function of the code rate \( R \) that diverges as \( R \) approaches capacity:
  \[ O((n/\delta) \ln(1/\delta)) \]
  ([A. Khandekar and R.J. McEliece, 2001]
  [T. Richardson and R. Urbanke, 2003])

The gap to the capacity: \( \delta = 1 - R/CA \)

**Sampling and Decoding Energy Tradeoff**
- Total Energy Consumption:
  \[ nE = s + nE_D \left( \frac{R}{C\lambda} \right) = n \left[ \lambda + E_D \left( \frac{R}{C\lambda} \right) \right] \]

**Optimum Communication for a Fixed Code Rate**
- Outerbound:
  It can be shown that for a fixed code rate \( R \): \[ \rho \leq \frac{\bar{w}R}{E(R)} \]
- Achievability:
  Variable-Timing Transmission: \( Tx \) inserts idle periods between codewords to give the Rx time to decode and recharge its battery for sampling the next codeword.
  Fixed-Timing Transmission: \( Tx \) sends codewords without idle periods between transmissions. Rx may drop some packets to collect energy or do decoding.

**Code Rate Optimization**
- \( \hat{\rho} = \max_{R, \lambda} \frac{\bar{w}R}{E(R)} \)
  s.t. 0 < R < C \lambda

  \[ \lambda \leq \lambda_{\text{max}} \]

- \( \lambda_{\text{max}} = \min \{ \beta + \bar{w}, 1 \} \)

- \( \hat{\lambda} = \lambda_{\text{max}} \)
  \[ \hat{\rho} = \frac{\bar{w}C\lambda_{\text{max}}}{E_D(R/C\lambda_{\text{max}})} \]

**Summary**
- At low code rates, the receiver has tradeoff between sampling and decoding.
- Sampling energy, even if it is small, may limit the communication rate.
- Fixed-timing transmission may not achieve the energy constraint outerbound.