Molecular Communication: Review of Forward error correction for molecular communications

by Leeson and Higgins

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Outline

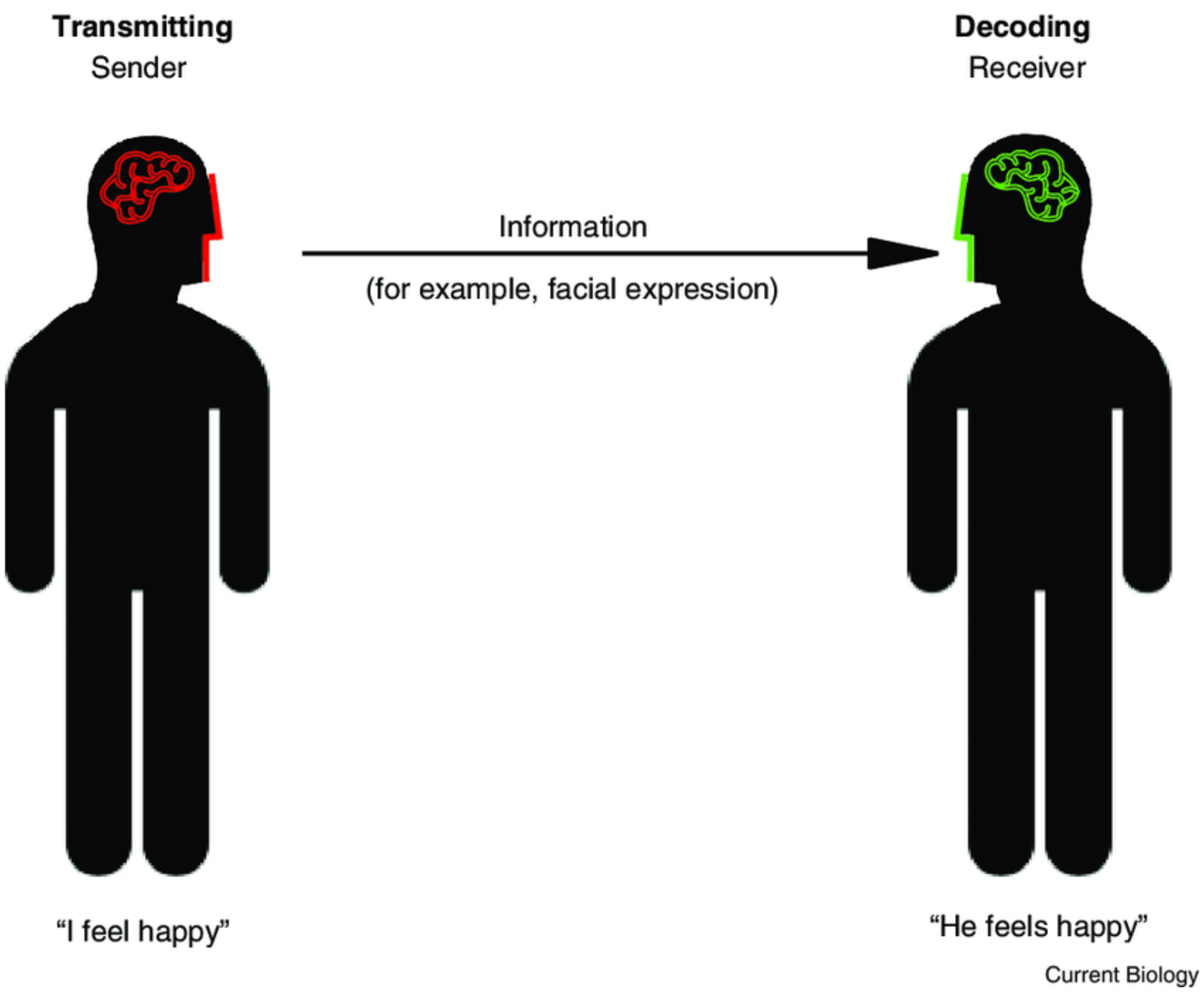
1. Introduction to Communication
    a) What is communication
    b) Computer Communication
    c) Molecular Communication

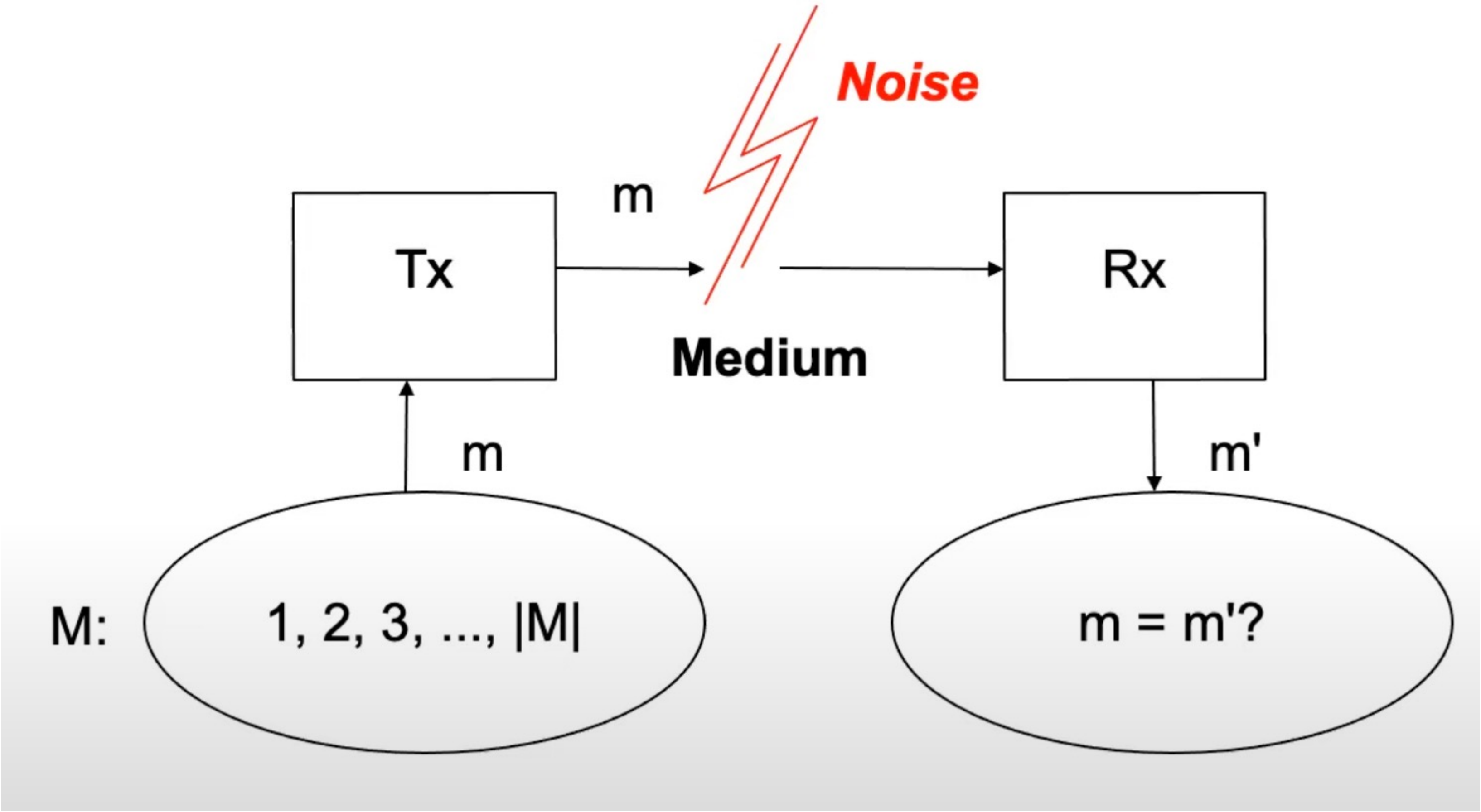
2. Why error occurs?

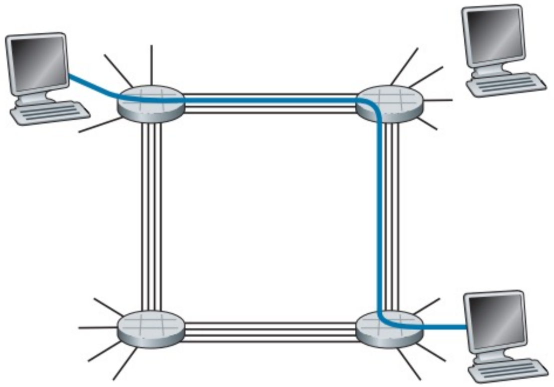
3. How to fix error

4. Further topics

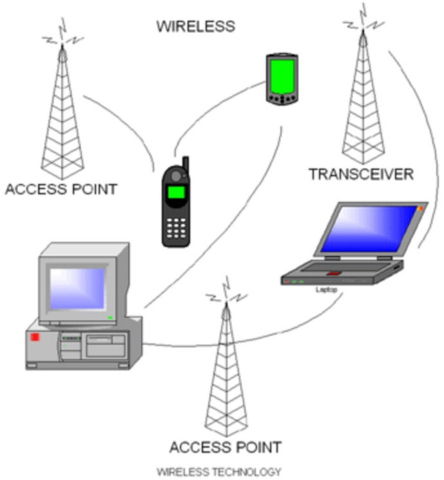
1. Introduction to Communication




Noise
m
Tx
Rx
Medium
m
m'
M:
1, 2, 3, ..., |M|
m = m'?

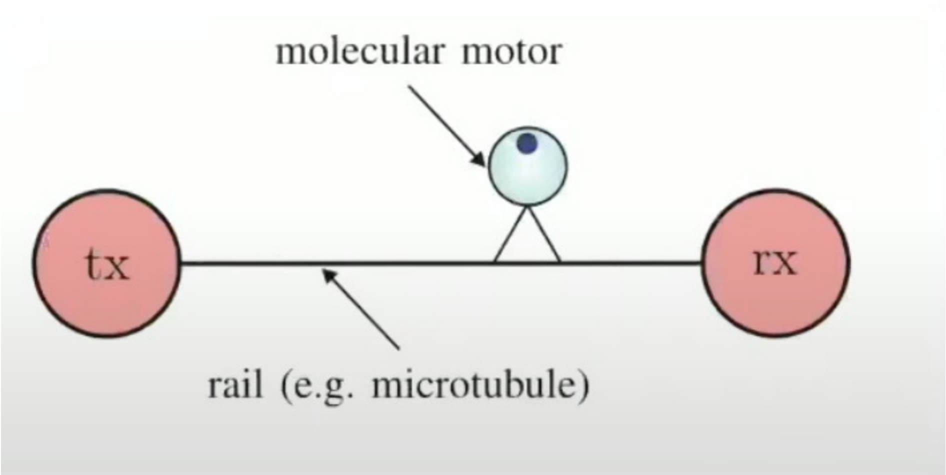


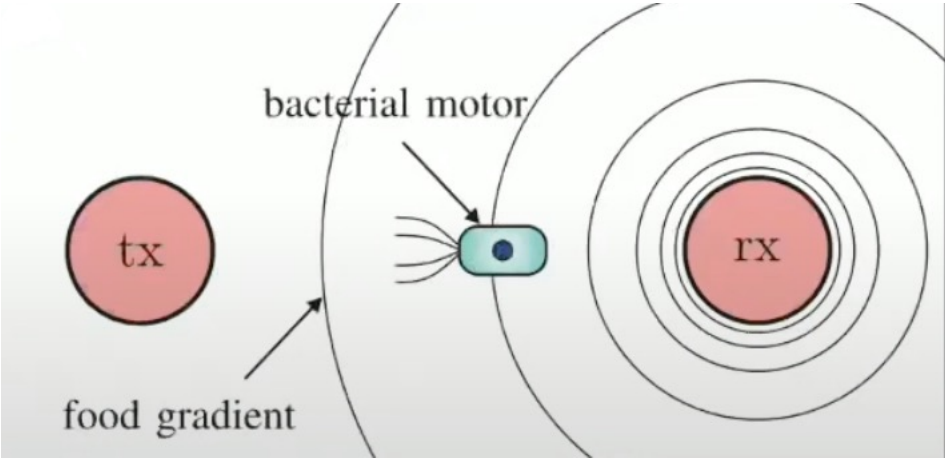
In computer networks:
Communication occurs via cable or wireless systems.

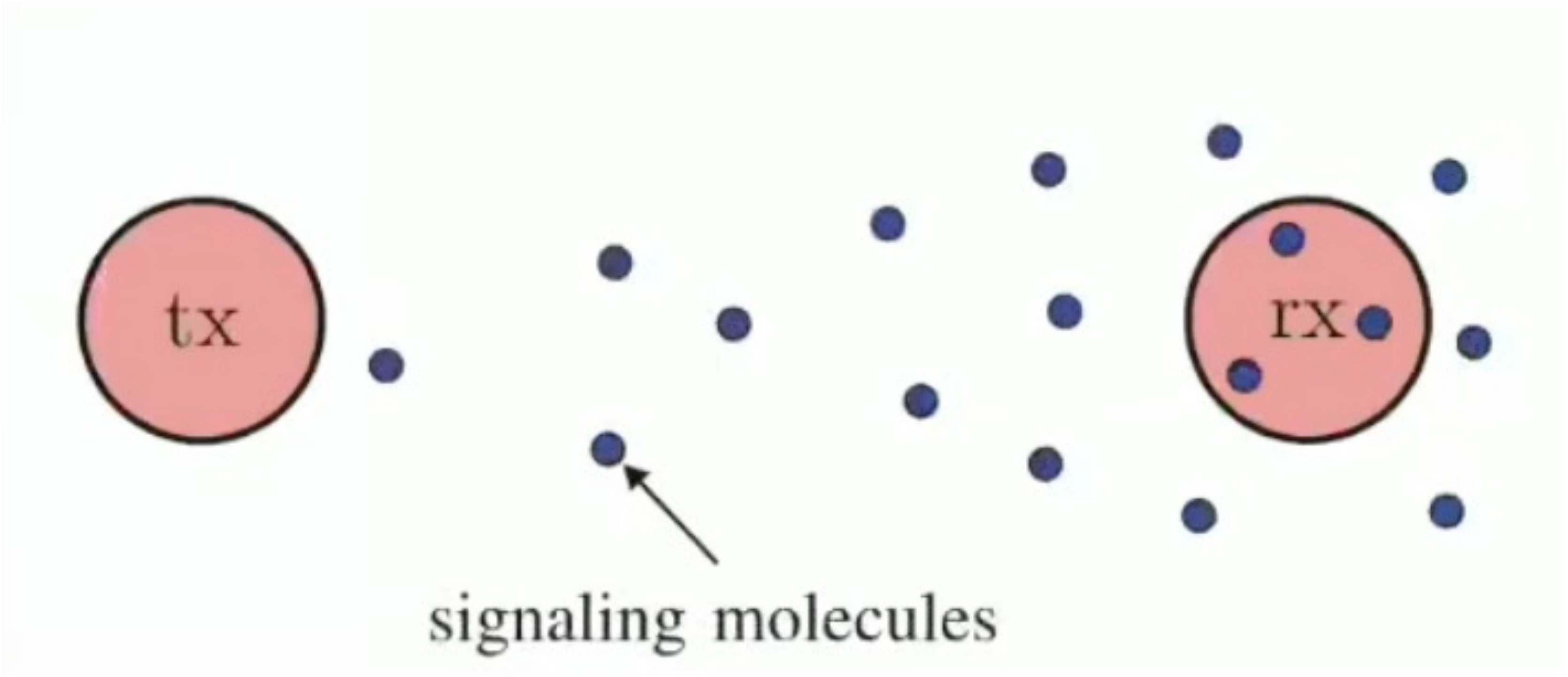


The main point is sending a coded information from point A to point B.

And decoding it to create some meanings.

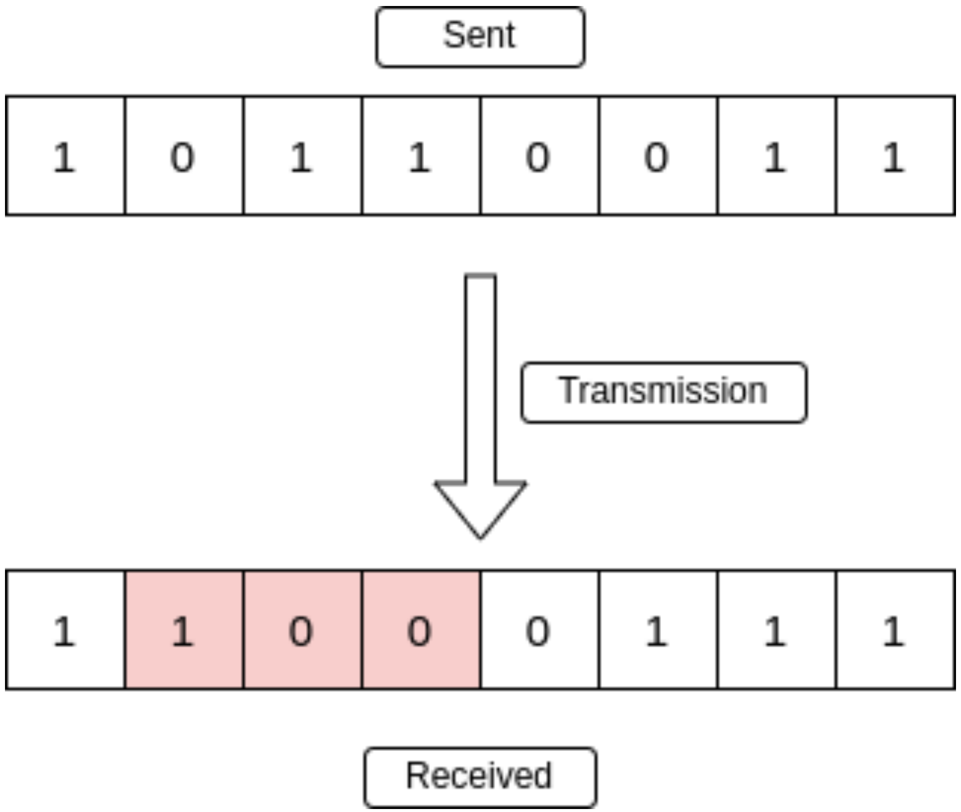

molecular motor
tx
rx
rail (e.g. microtubule)


bacterial motor
tx
rx
food gradient


tx
rx
signaling molecules

2. Why error occurs?

Bits may change or be corrupted due to external effects



2. Why error occurs?

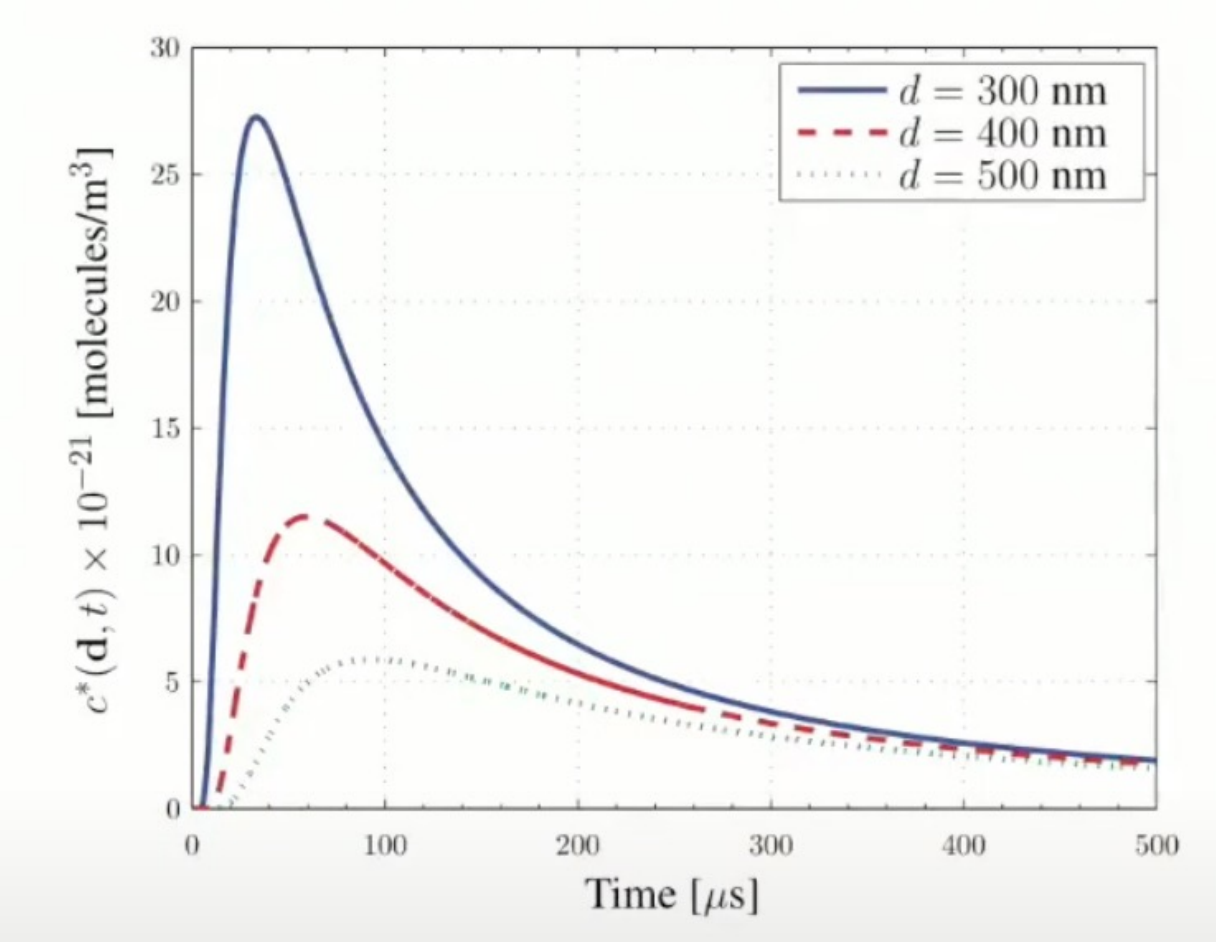
Fick's Second Law

$$\frac{\partial C(\mathbf{r},t)}{\partial t} = D\nabla^2 C(\mathbf{r},t)$$

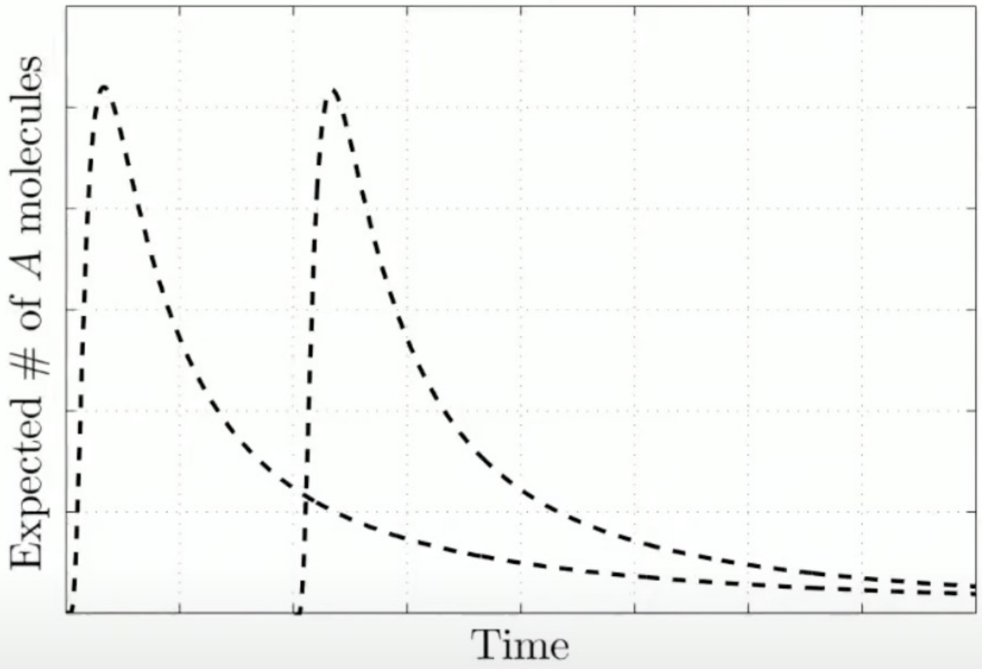
- C - concentration of diffusing molecule $(\mathrm{molecule} \cdot \mathrm{m}^{-3})$
- D - coefficient of diffusion $(\mathrm{m}^2/\mathrm{s})$
- A lot of literature on solving Fick's Second Law
- Solutions depend on the boundary conditions:
  - Shape of environment (infinite, rod, cylinder, sphere, etc.)
  - Source of diffusing molecules (point, surface, steady vs. impulse, etc.)
- Many environments have no analytical solutions or are represented with infinite sums

2. Why error occurs?

Concentration of signalling molecules receiver at distance d



2. Why error occurs?



- It takes a long time until molecules at the receiver diffuse away
- Molecules of successive emissions of TX overlap at RX

Previous bits has an influence on the current bit as there will be a number of residual molecules N_p from previous one bits during the current bit period at time t_s .

This means that the difference between Binomial distributions is needed to accommodate the probability that the received messenger molecule was sent some time slots ago but arrives now. In general, one should calculate

$$N_p \sim \sum_{i=1}^{\infty} B\left(N, P\left(r_0, \{i+1\} t_s\right)\right) - B\left(N, P\left(r_0, i t_s\right)\right) .$$

2. Why error occurs?

Fig. 2. Hit probability as $t \to \infty$ for receiver diameters of $R = 1, 5$ and $10\ \mu m$.

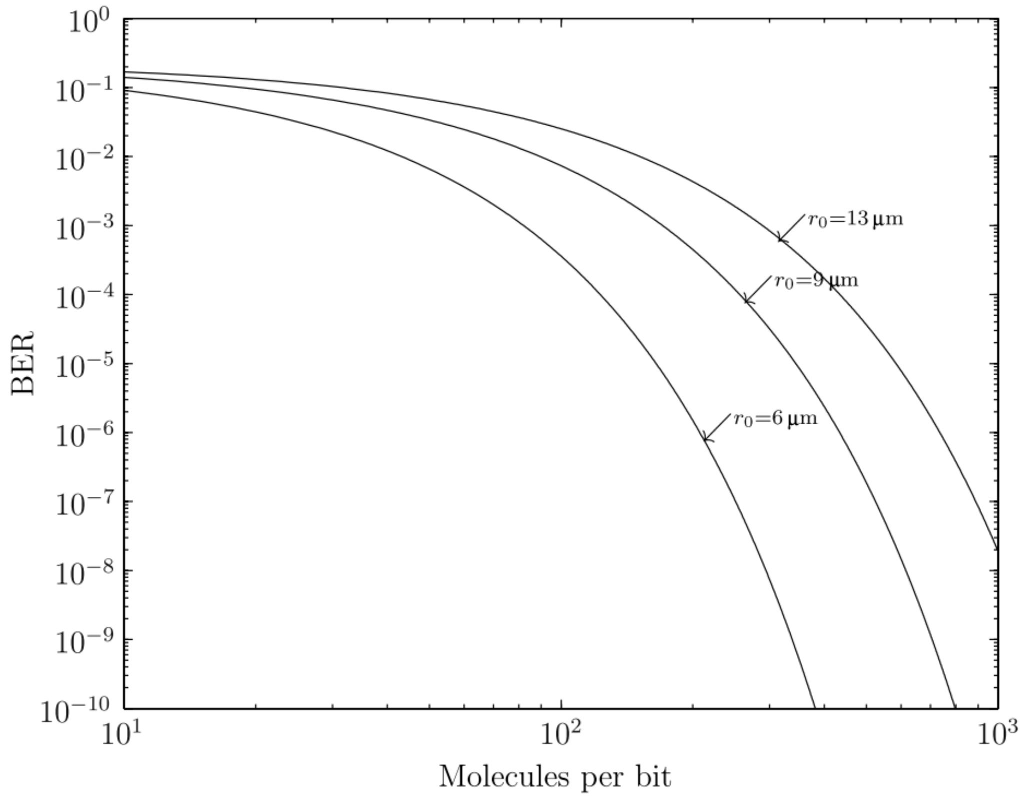
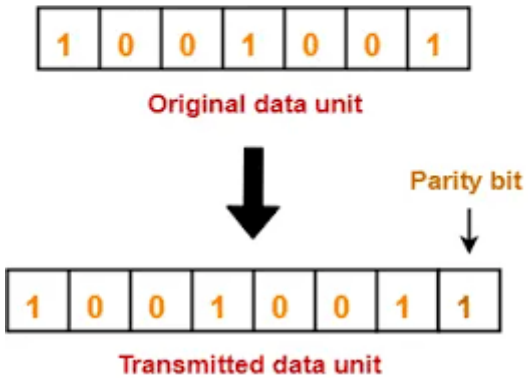


Fig. 3. Bit error rate versus molecules per bit for distances of $r_0 = 6, 9$ and $13\ \mu m$.

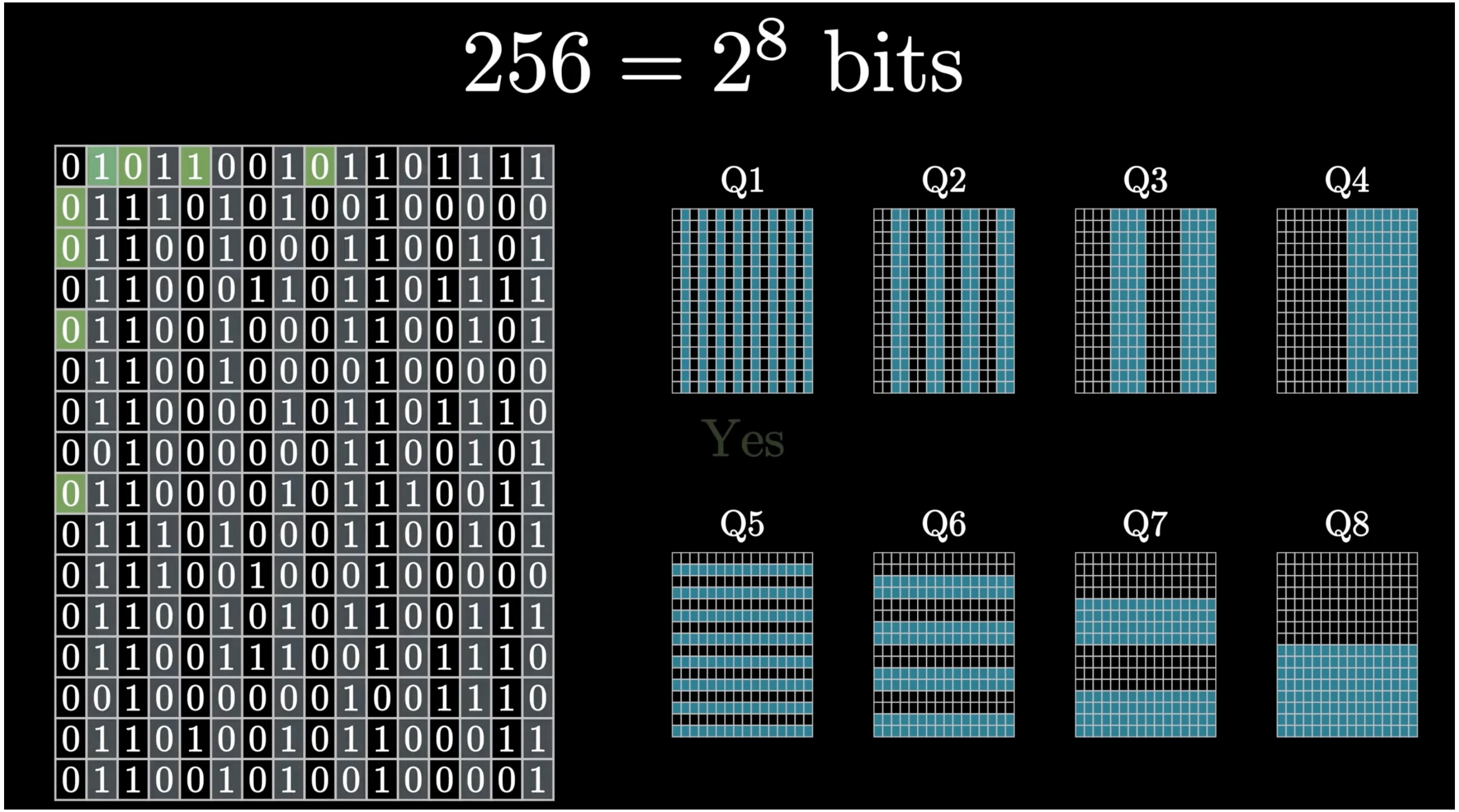
3. How to fix errors?

Simply we can send same message more than one time and do bitwise comparisons. However this adds huge redundancy, and causes to big energy losses.

In the case of nanoscale communications, the energy budget is severely constrained since the nodes will usually scavenge their energy from the surrounding environment. The achieved output of energy harvesting devices is only likely to be in the pW range



Therefore, relatively simple block codes are considered that add parity check bits to enable the correction of errors. One of the simplest families is that of the Hamming codes, defined for an integer $m \geq 2$ such that blocks of $k = 2^m - m - 1$ data bits are used to form coded output blocks of length $n = 2^m - 1$ having m party check bits.


$256 = 2^8$ bits
0101100101101111
0111010100100000
0110010001100101
0110001101101111
0110010001100101
0110010000100000
0110000101101110
0010000001100101
0110000101110011
0111010001100101
0111001000100000
0110010101100111
0110011100101110
0010000001001110
0110100101100011
0110010100100001
Q1
Q2
Q3
Q4
Yes
Q5
Q6
Q7
Q8

3. Bit Error Rate with Hamming Codes

M.S. Leeson, M.D. Higgins / Nano Communication Networks 3 (2012) 161–167

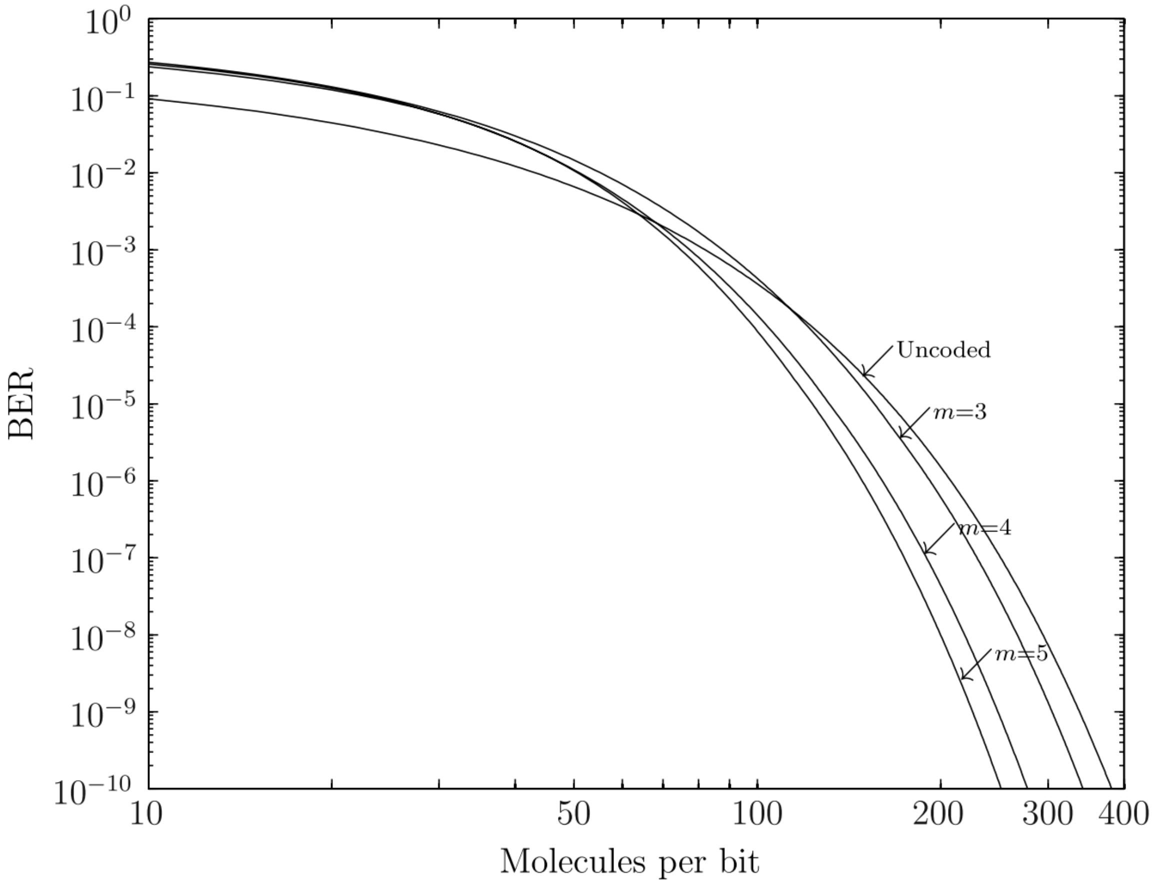
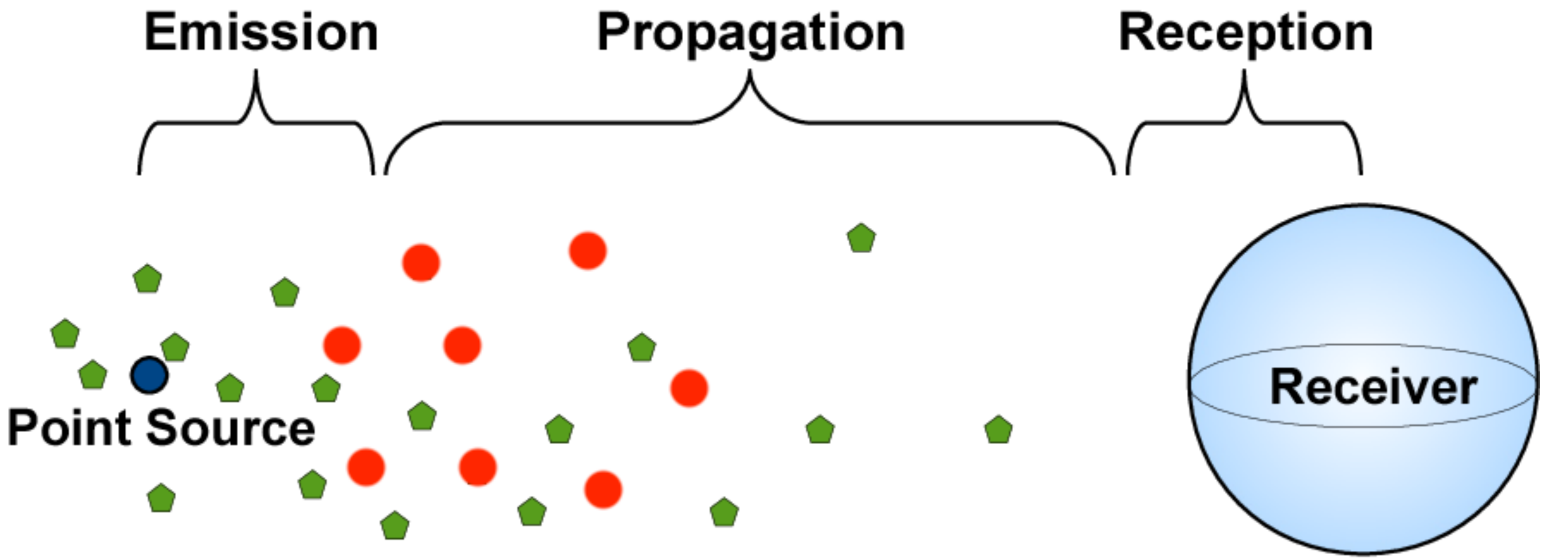


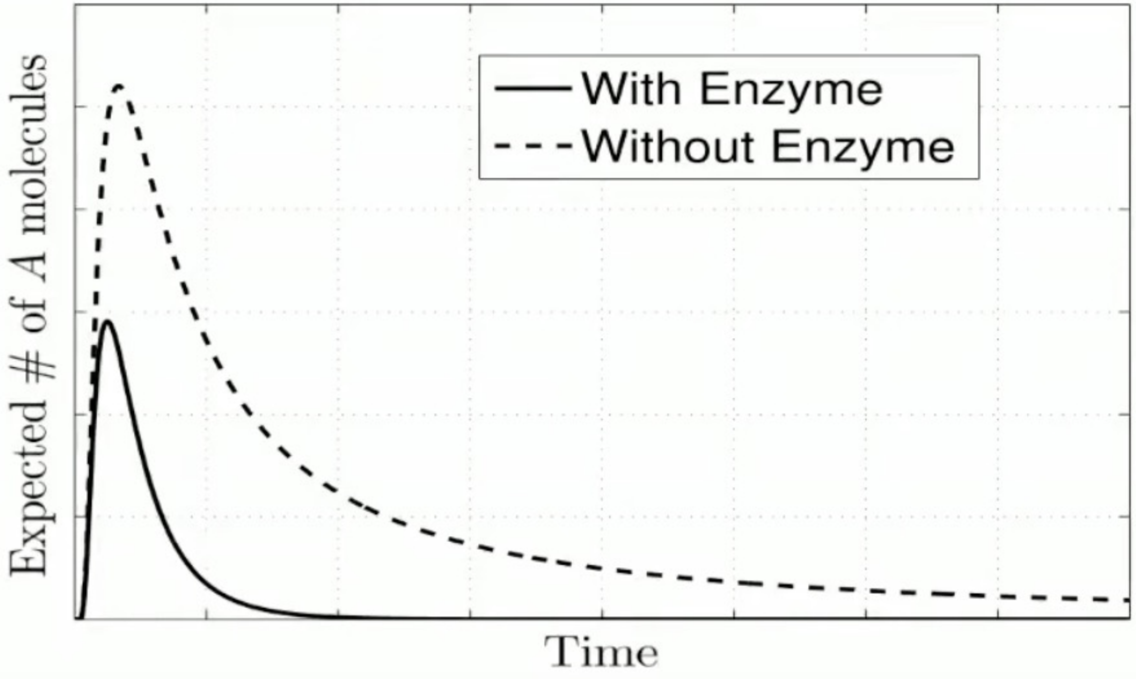
Fig. 4. BER for coded and uncoded transmission using Hamming codes having $m = 3, 4, 5$ with $r_0 = 6\ \mu m$.

Let’s also release absorver particles that is bigger than our regular particles

Our enzymes will absorb communication particles. So that the effect of the current particles for the next time frame will be smaller.



4 – Enzymes or absorber particles



Concentration at distance r from TX is now

$$C(r,t) \approx \frac{N}{(4\pi D t)^{3/2}} \exp\left(-kt - \frac{r^2}{4Dt}\right)$$

where k is a constant that depends on k_1 and the enzyme concentration

- We may try to simulate the bit error rate with enzymes without any correction mechanisms.

- If we approximate particles as spheres, we have the formula

$$D = \frac{k_B T}{6\pi r \eta_0}$$

- Because enzymes are bigger particles, their diffusion coefficient will be higher, therefore they will diffuse slower.
- But still they diffuse, so once a while we may need to release same enzymes again.

We expect the following results for this setup.

- Enzymes will absorb some of the particles.
- Particles' effect for the next time frame will be smaller.
- Therefore, BER will be released.
- But because we need to release enzymes, the energy requirement for this process will be higher.