The Effects of Nanosensors Movements on Nanocommunications

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Motivations

- There is no problem if humans move while speaking (sound waves)
- In molecular communication, molecules move, and this poses no problem as well it seems
- In elmagn communication, antennas are not alive, they do not move (GWNoC for ex.)
  - but if they are put inside other thing (such as human body or nanorobot), they *could* move even during the same communication
- But... is there any problem if they move?! Let's dig into this...

The problem: TS-OOK modulation peculiarities

- Nanonodes have size and power constraints => very challenging to generate a carrier => TS-OOK pulse-based modulation proposed
- In Time Spread On-Off Keying modulation, bit 1 is a pulse, bit 0 is silence (*Jornet & Akyildiz, TrComm 2014*)
- In order for this to work, nodes need to be **tightly** synchronised, is that fine if nodes move?!

```
On sender:
Signal:   /\____/\____.____/\____
Bit sent: 1      1      0    1

Signal on receiver:
Expected:   /\____/\____.____/\____
```

- Direct effects of receiver movement taken into account in the following:
  - change in timing (**when** pulses arrive at receiver, pulse time-shift)
  - change in frequency of the signal (Doppler effect)
  - change in distance => change in bit error rate and information rate

Pulse time-shift

On sender:
Signal: `/\____/\____.____/\____`
Bit sent: `1      1      0    1`

Signal on receiver:
Expected: `/\____/\____.____/\____`
Received: `/\_____/\_____._____/\____`

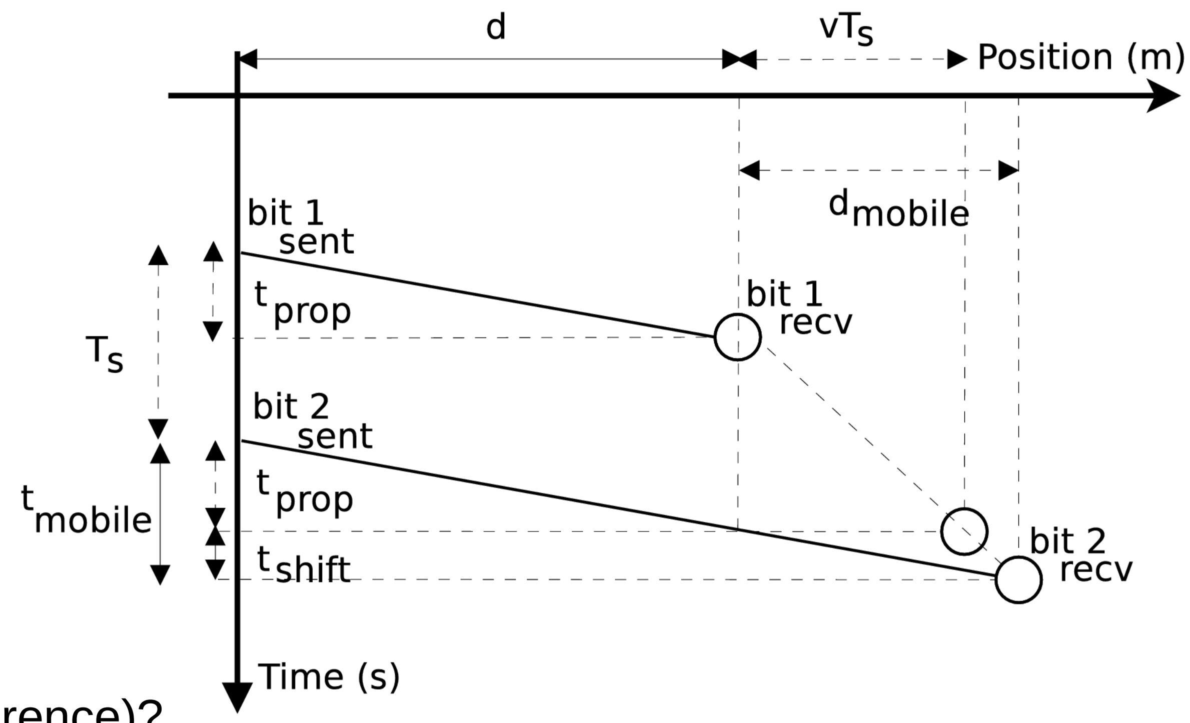
$$d_{\text{mobile}} = v(T_s + t_{\text{shift}})$$
$$d_{\text{mobile}} = ct_{\text{shift}}$$

So:

$$\begin{aligned} ct_{\text{shift}} &= v(T_s + t_{\text{shift}}) \\ (c-v)t_{\text{shift}} &= vT_s \\ t_{\text{shift}} &= \frac{1}{\frac{c}{v} - 1} T_s \end{aligned}$$

Finally:

$$t_{\text{shift}} \approx \frac{v}{c} T_s$$



Does it prevent communication,
i.e. create ISI (inter-symbol interference)?

$$t_{\text{percentage}} = \left(\frac{t_{\text{shift}}}{T_p}\right) \times 100\%$$

Pulse time-shift – numerical example

On sender:
Signal: `/\____/\____.____/\____`
Bit sent: `1      1      0    1`

Signal on receiver:
Expected: `/\____/\____.____/\____`
Received: `/\_____/\_____._____/\____`

An example:
- fastest blood speed is aorta, 0.4 m/s
- patient moves away with 2 m/s
- => v = 2.4 m/s
- $T_p = 10^{-12}$ s, $T_s = 10^{-9}$ s (spreading factor β=1000)

$$t_{\text{shift}} = 0.8 \times 10^{-17} (s)$$
$$t_{\text{percentage}} = 8 \times 10^{-4} \%$$

Conclusions:
- too small for 1 bit transmission, hence **no problem**
- reaches 100% (creates ISI) at the 125000th bit, i.e. at the 16th kB or after 0.125 ms or after 0.3 meters => **countermeasures need to be taken**

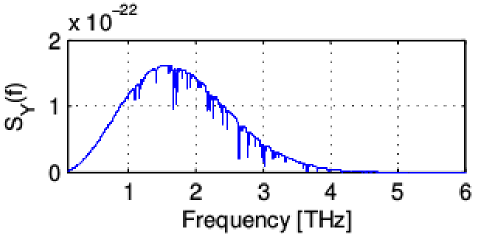
Doppler effect

- "Change in frequency because of movement"

$$\Delta f = \frac{v}{c} f_0$$

  where f_0 is the frequency, v receiver speed and c speed of the light

- Numerical example:
  - v = 2.4 m/s
  - first derivative of Gaussian TS-OOK pulse, signal is centered at around f_0 = 1.6 THz
  - then $\Delta f \approx$ 10 kHz



- So **change in frequency is negligible**

Bit error rate increase

Receiver moves away => distance snd/rcv increases => BER should increase

$$BER = P(e|X=0)P(X=0) + P(e|X=1)P(X=1)$$

Probability of error when bit x is transmitted:

$$P(e|x=0) = P(y=1|x=0) = 1 - \int_A^B P(Y|x=0)\,dy \quad (26)$$

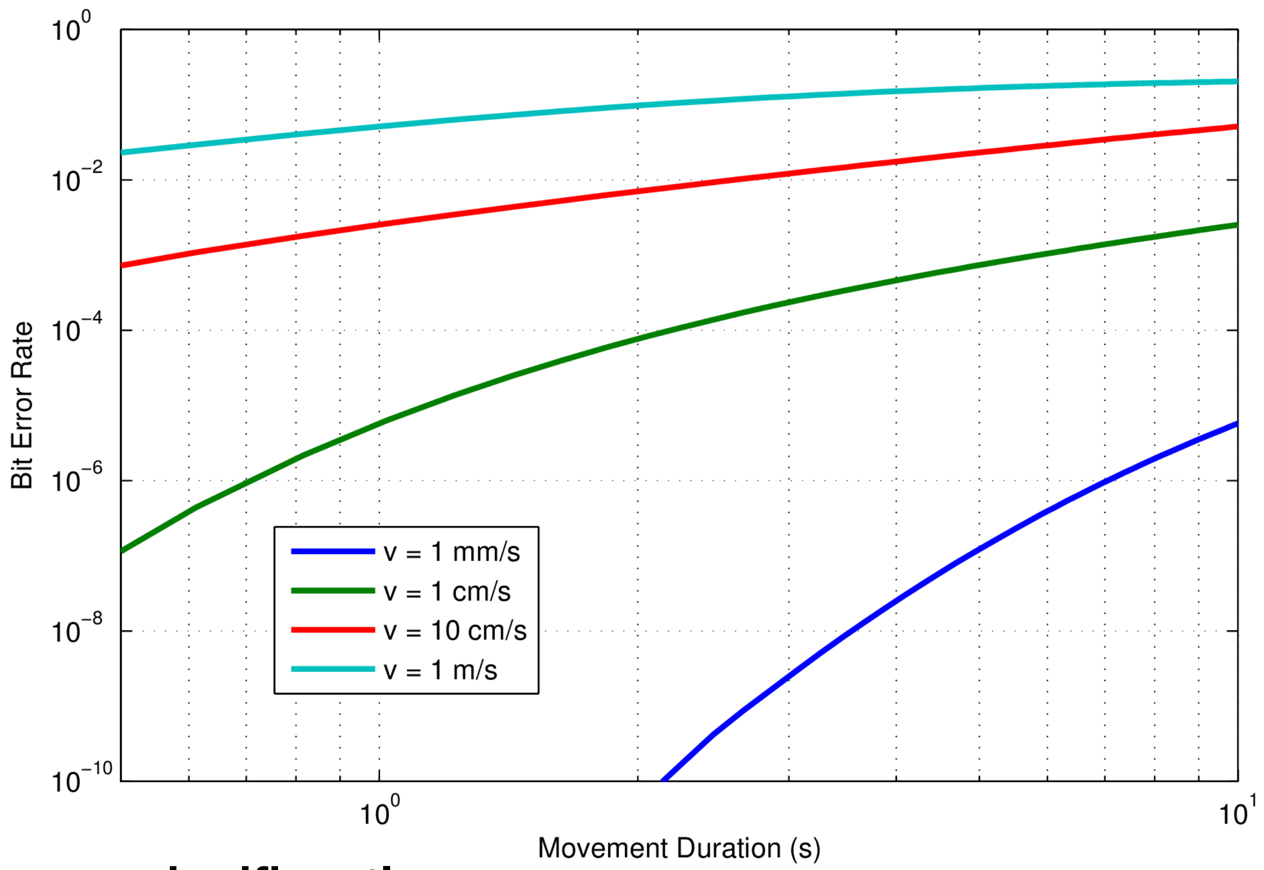
$$P(e|x=1) = P(y=0|x=1) = \int_A^B P(Y|x=1)\,dy \quad (27)$$

$$P(Y|X=x_i) = \frac{1}{\sqrt{2\pi N_i}} e^{-\frac{(y-a_i)^2}{2N_i}}$$ (*Jornet & Akyildiz, TrComm 2014*)

where:

- N_i total noise power for transmitted signal x_i
- a_i amplitude of the received symbol

Bit error rate increase – simulation results

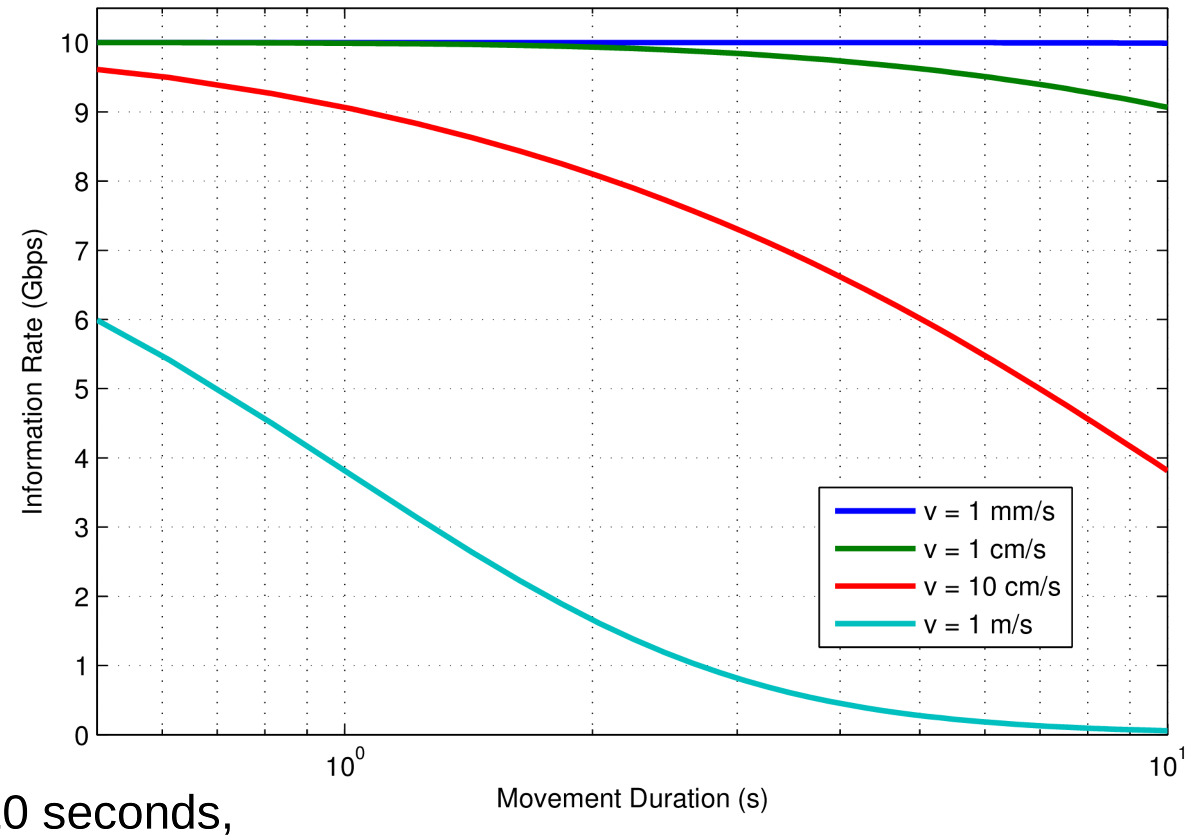


- **BER changes significantly**
- Some applications have BER constraints, e.g. video streaming needs BER < 10^{-4} (v should be smaller than 1 cm/s in the example)
- If BER is too high, error correction codes, ... are required

Information rate reduction

Receiver moves away => distance snd/rcv increases => IR should decrease

$$IR = C \times \frac{B}{\beta} \quad \text{(bit/second)}$$



Numerical results:

- B = 10^{13} (in THz band)
- β = 1000
- initial distance = 1 mm

- 10 sec movement with various speeds

Conclusion:

- if moving with 10 cm/s for 10 seconds,
  IR decreases from 10 to 4 Gb/s in this example
- **IR changes significantly**

Conclusions and perspectives

- **Node movement is worth taking into account**
- Without synchronisation, problems (such as ISI) can arise

  => there is a need for synchronisation algorithms used by nanonodes
- BER and IR could change significantly when moving

  => the type of motion should be taken into account in communication protocols
- Doppler effect is negligible

- All code to regenerate the results of the paper are available on my Web page (http://eugen.dedu.free.fr)