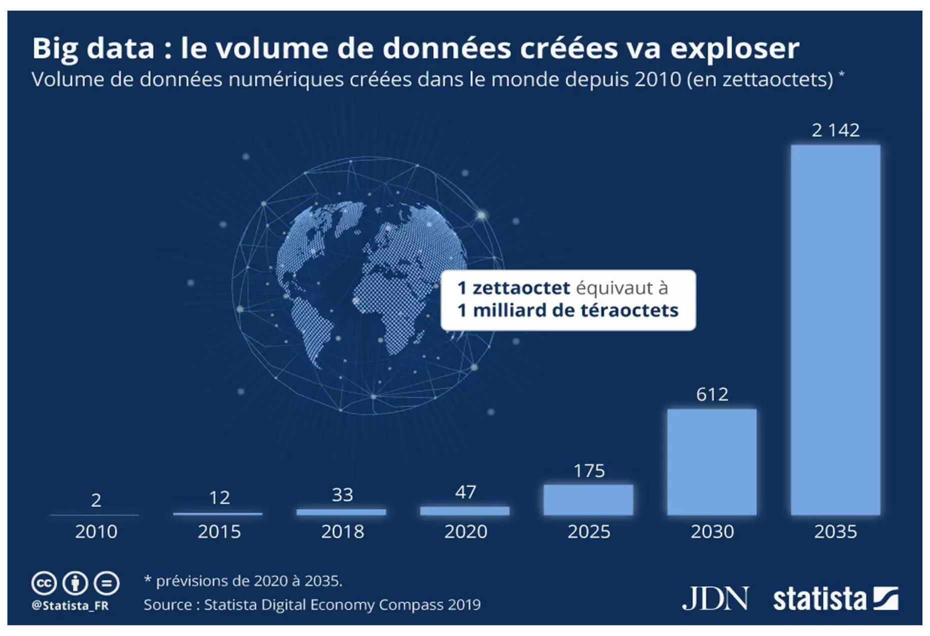
Secure data storage into DNA molecules compliant with biological constraints

Ensuring the confidentiality of data stored into DNA molecules

Institut Mines-Télécom



Volume of data created or replicated in the world, projection for 2020 to 2035 - Source : Statista

Considering the security of a promising storage medium

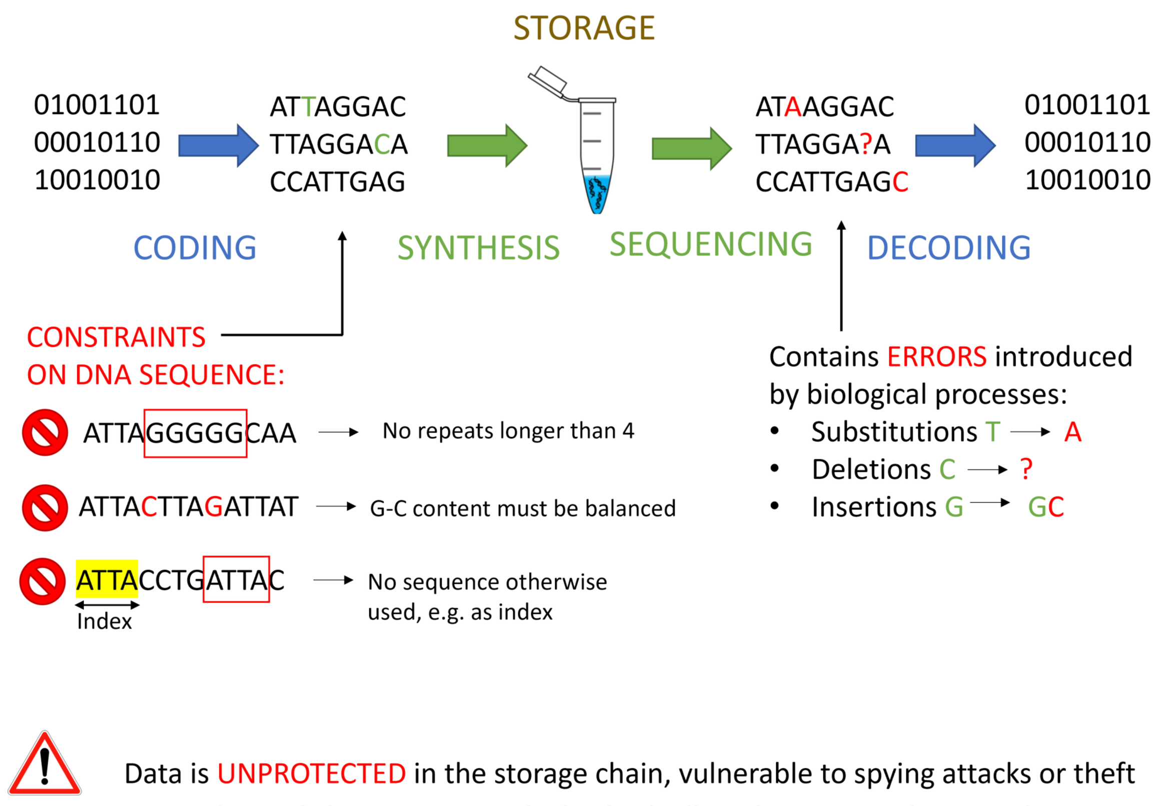
Introduction and motivation

- ▶ **Context** – Actual storage technologies (flash memory, hard drives, magnetic tapes,..) are outpaced by the exponential rise of digital data production [1]
- ▶ **Advantages of DNA storage [2]** – Density of 10^{21} bytes in one gram (10^6 times more compact than hard disks), durability for centuries, energy cost close to zero (molecules kept at room temperature with no maintenance)
- ▶ **Motivation** – Introducing security to ensure the confidentiality of the data stored into DNA molecules

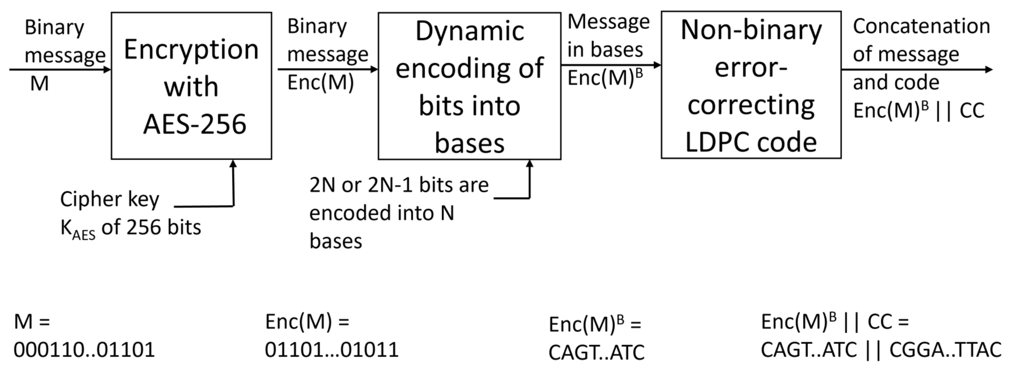
A new data storage medium

DNA data storage

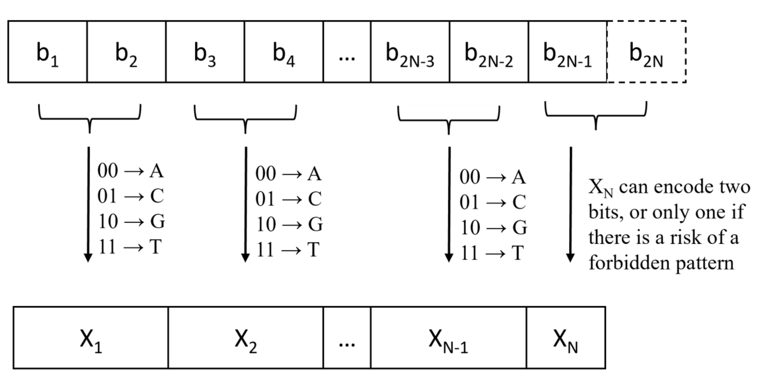
- ▶ **Principle** – [**WRITING**] Encode binary data into 4-base sequences following the DNA structure, transfer this data into synthetic DNA molecules. [**READING**] Amplify encoded sequences of interest and get several reads of them with a sequencing device. Reads are then processed and decoded back to binary data
- ▶ **Constraints** – i) Biological DNA synthesis and sequencing are imperfect and introduce errors. ii) devices have structural DNA requirements when generating 4-base sequences
- ▶ **Vulnerabilities** – This chain is notably vulnerable to: theft or cloning of molecules; spying attacks on the sequencing or synthesis devices; DDoS attack by adding fake DNA sequence to confuse sequencing



DNA-based data storage chain, including the constraints on the structure of DNA sequences to store, and types of errors caused by biological processes



Encoding solution to ensure data confidentiality in the entire DNA data storage channel



Dynamic encoding of bits into bases. In a block of N bases, each base X_i encodes two bits: b_{2i-1} and b_{2i}, except X_N, which encodes either b_{2N-1} only, or b_{2N-1} and b_{2N}

Method

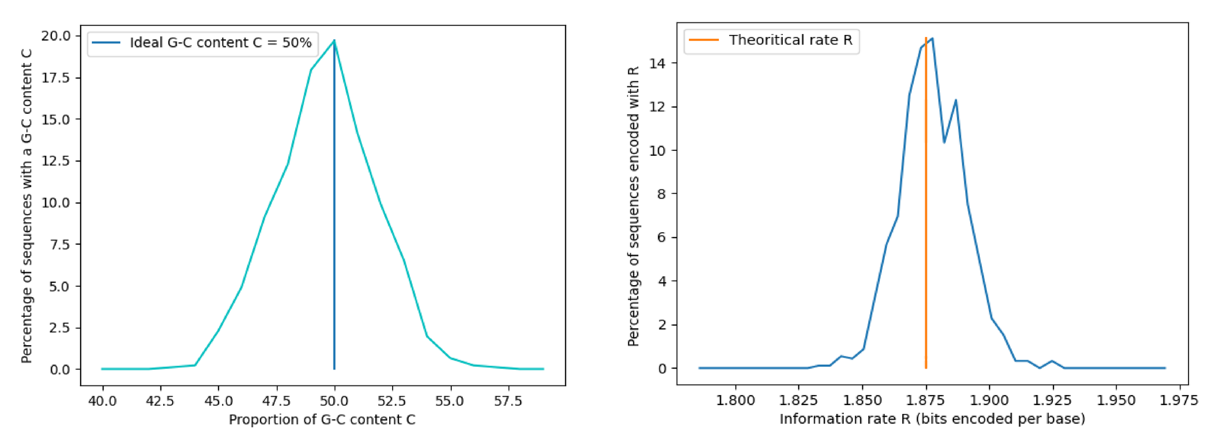
Encoding proposal to ensure data confidentiality

- ▶ **Challenge** - Ensure confidentiality under biological constraints while approaching the ideal information rate of 2 bits of information per base
- ▶ **Solution** – A three step coding process that includes encryption, dynamic data encoding and error-correction code
  - ➢ **Step 1:** Encryption with AES-256 to ensure confidentiality and to regulate the G-C base rate and homopolymers
  - ➢ **Step 2:** Dynamic encoding to manage unwanted base patterns; encoding based on the addition or not of one bit of data every *N* bases to avoid homopolymers longer than *N*
  - ➢ **Step 3:** Non-binary LDPC error-correction code to correct any base substitutions, deletions or insertions

Simulation and information rate

Experimental results

- ▶ **Simulation** of the biological processes using the simulator from [3]
- ▶ **Results:** information rate of 1,875 bits per base for *N*=4, no homopolymers longer than *N*, G-C content of 43-57%, data recovery without errors



G-C content (left) and information rate (right) for 1000 sequences of an image after encoding, for N=4 the maximal length of homopolymers authorized

Conclusion and future work

- ▶ **Confidentiality** in the entire storage chain that takes into account **biological constraints**
- ▶ Encoding solution **independent** from encryption algorithm and error-correction code, **adaptable** to the size of unwanted patterns
- ▶ Extend the approach to other synthesis and sequencing technologies

Contact: chloe.berton@imt-atlantique.fr, gouenou.coatrieux@imt-atlantique.fr

Parties prenantes

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

Auteurs

Chloé Berton
Gouenou Coatrieux
Dominique Lavenier

Partenaires

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References

[1] Rydning, D. R. J. G. J. (2018). The digitization of the world from edge to core. Framingham: International Data Corporation, 16.

[2] De Silva, P. Y., & Ganegoda, G. U. (2016). New trends of digital data storage in DNA. BioMed research international, 2016.

[3] Hamoum, B., Dupraz, E., Conde-Canencia, L., & Lavenier, D. (2021, August). Channel Model with Memory for DNA Data Storage with Nanopore Sequencing. In 2021 11th International Symposium on Topics in Coding (ISTC) (pp. 1-5). IEEE.

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