A wake-up strategy enabling GNSS-free NB-IoT links to sparse LEO satellite constellations

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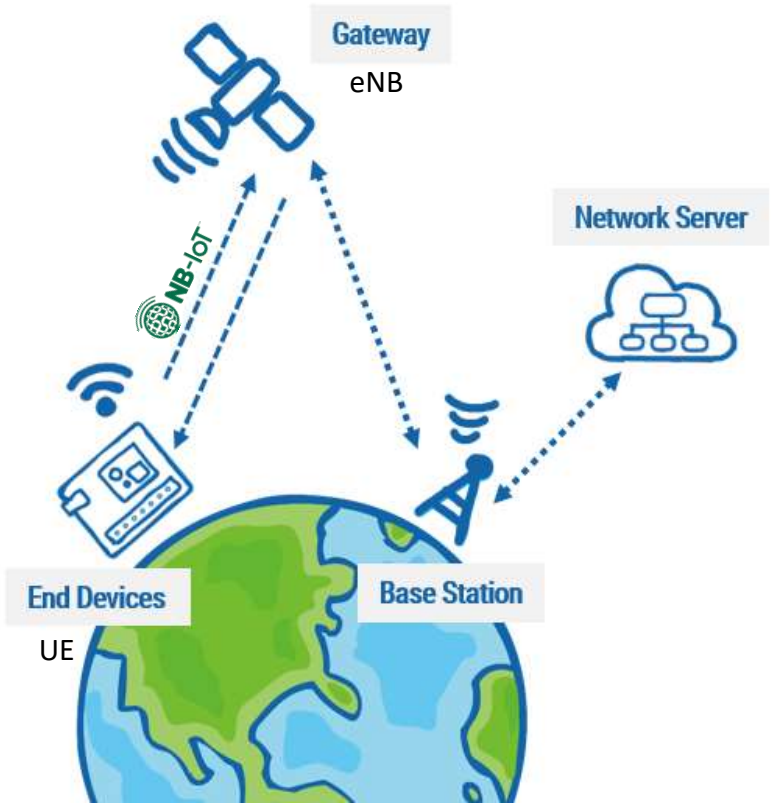
Background: Direct-to-Satellite protocol



LEO (Low Earth Orbit) Satellite:

- Time efficient
- Small-sized, low cost
- Low power

NB-IoT

- Licensed Spectrum -> **No duty cycle limitation**
- Resource allocation -> **Reliable**

UE: User Equipement
eNB: evolved Node B

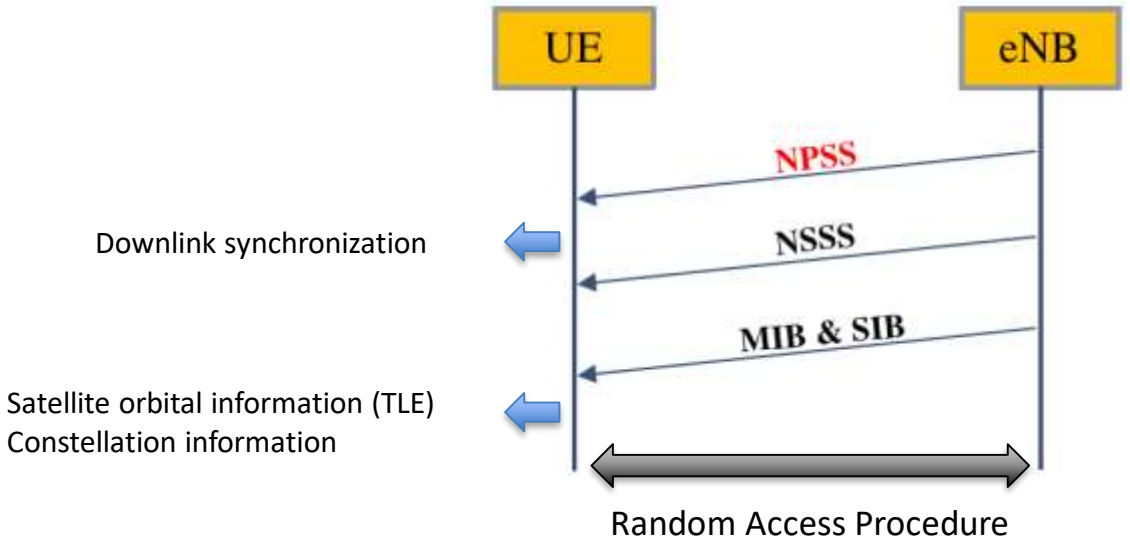
Narrowband Internet of Things

NB-IoT

- 3GPP Release 13 - Based on LTE standard (2015)
- Important steps of communication:

Narrowband Internet of Things - Release 17 and 18

- **Devices listen first** -> Synchronization signals (NPSS)



TLE: Two-Line Elements
SIB: System Information Block
MIB: Master Information Block
NPSS: Narrow Band Primary Synchronization Signal
NSSS: Narrowband Secondary Synchronization Signal

Challenge with LEO satellites

Availability:

- Global **continuous** coverage
  -> Dozens to hundreds of satellites
- Global **discontinuous** coverage
  -> No satellite when the device wakes up

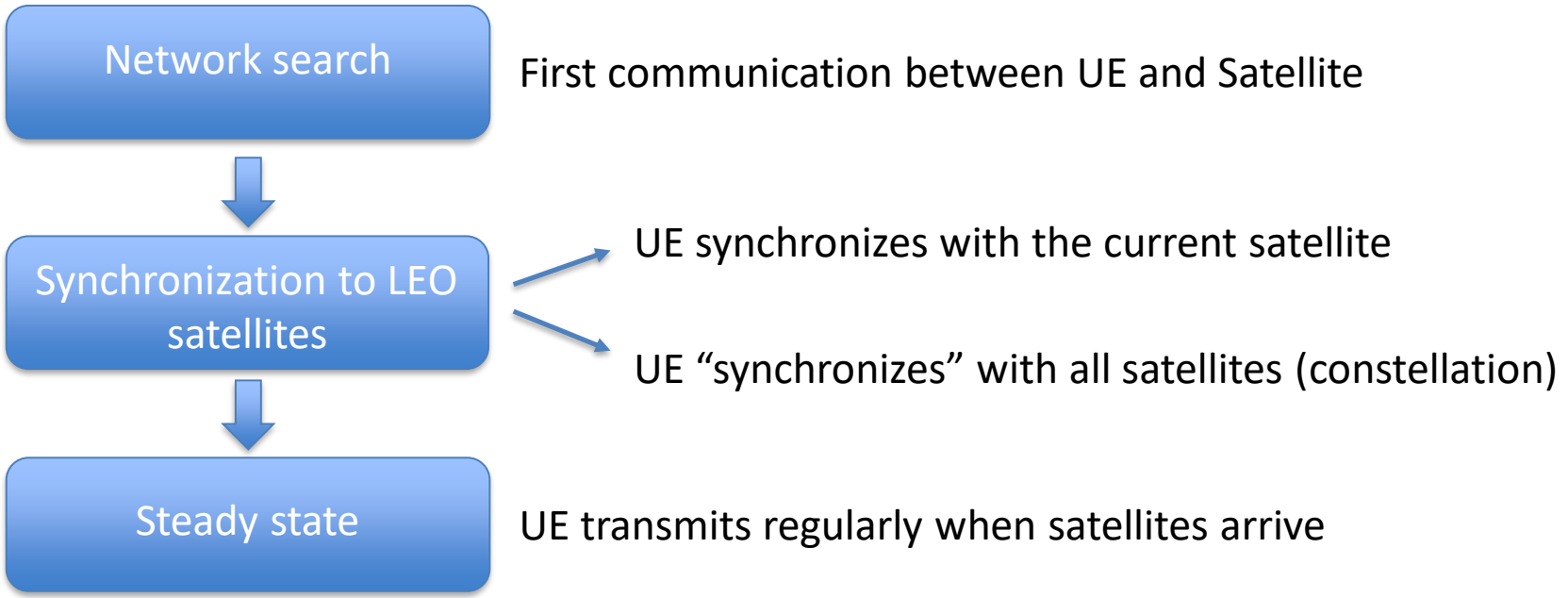
Current solution (3GPP standard):

- **GNSS** devices combine with TLE to predict the arrival of satellite
  -> High energy consumption and complexity for IoT devices

3GPP: The 3rd Generation Partnership Project
GNSS: Global Navigation Datellite System

Proposed solution: A wake-up strategy

- **Objective**: Devices predict satellite arrivals without using GNSS

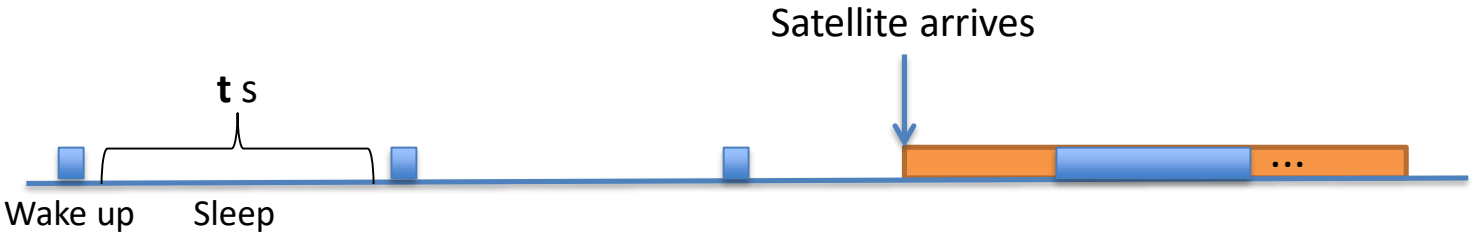


Network search - Introduction

At the beginning:

- UEs have no own position information and satellite information

The devices wake up periodically to search for sync signals (NPSS)



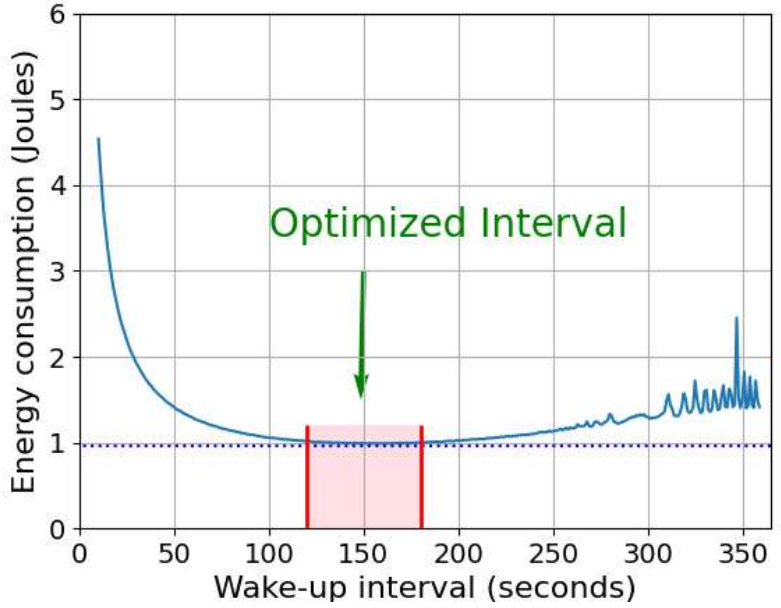
Network search - Simulation results

Time of sleeping (interval t)?

- Interval **t** too short: Wake up too often
- Interval **t** too long: Miss satellite arrivals

High energy consumption

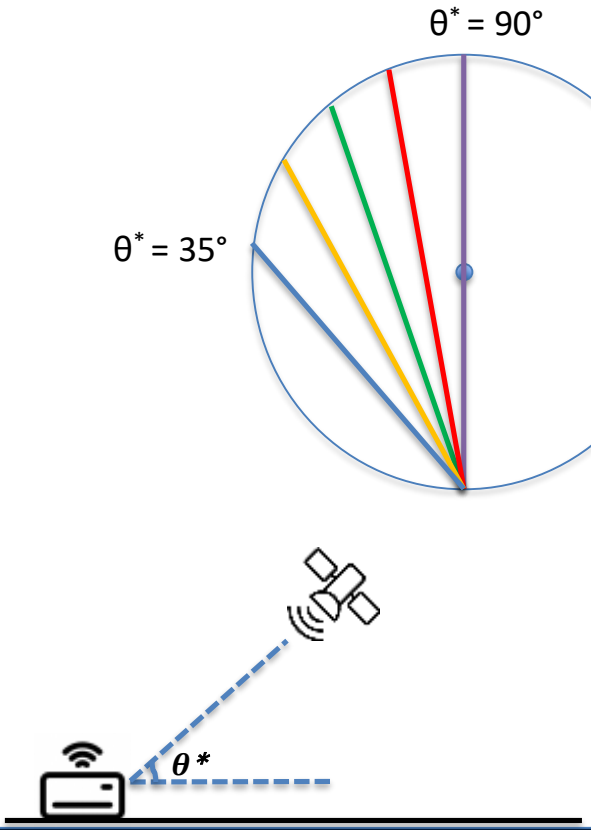
Simulation results with one single 600-km LEO satellite

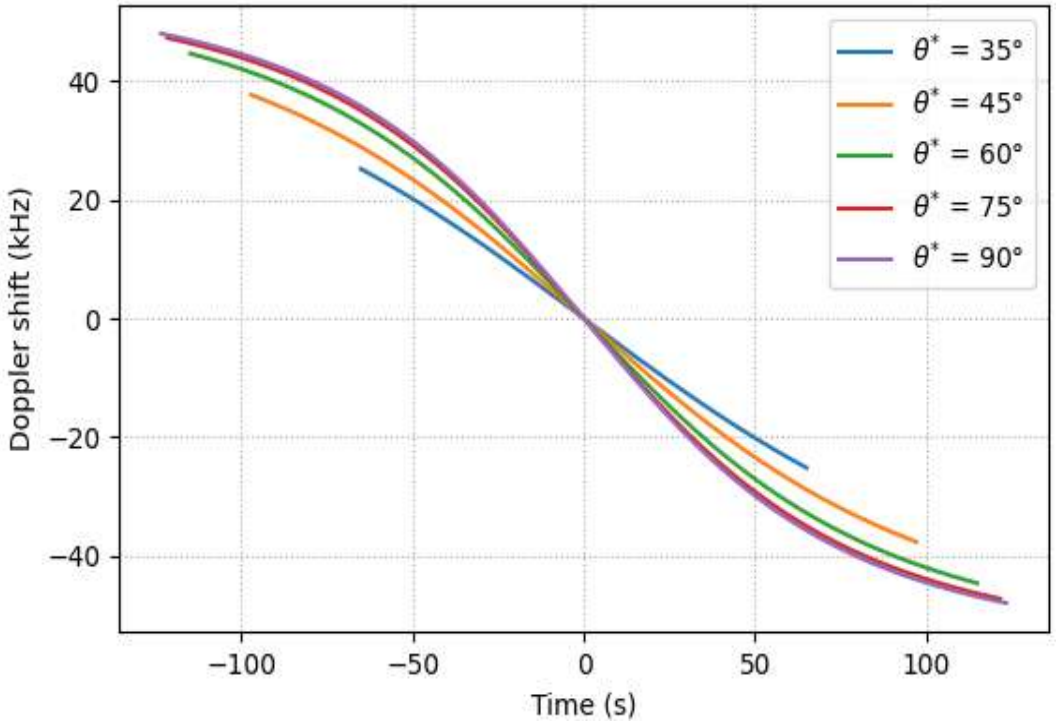


Synchronization to LEO satellites - Introduction

Step 1: **Synchronize time and frequency through NPSS (synchronization signals)**

Challenge: Timing-varying frequency offset and propagation delay



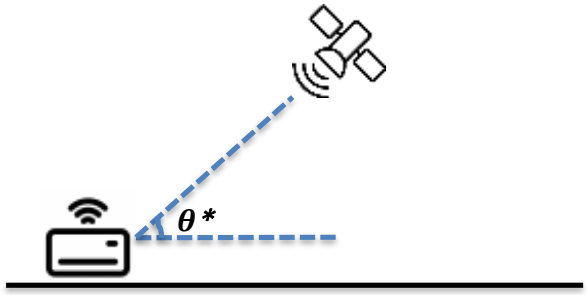


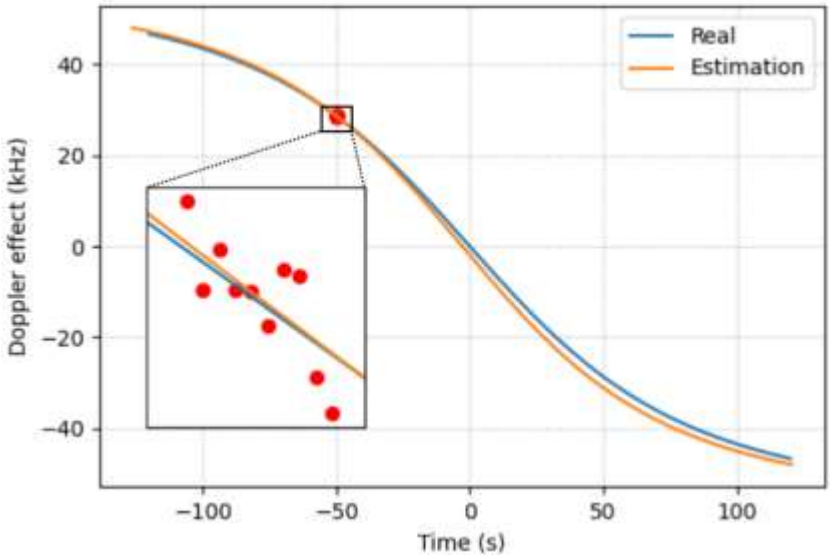
Synchronization to LEO satellites - Introduction

Step 1: **Synchronize time and frequency through NPSS (synchronization signals)**

➡ *Least squares method*

- Estimate the Doppler curve with **maximum elevation angle θ^*** using multiple NPSS signals





Simulation results (AWGN)

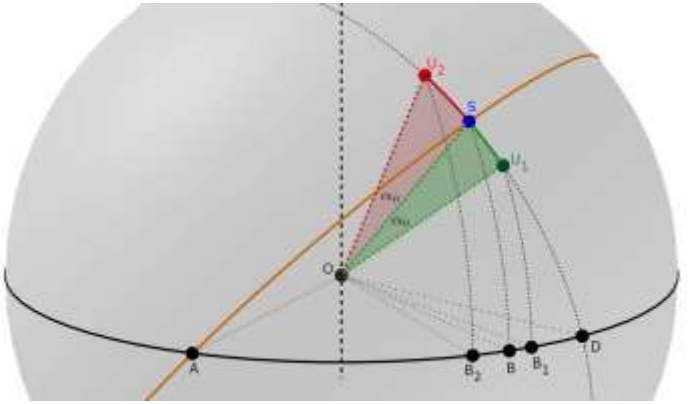
[1] *Z. Zhou, N. Accettura, R. Prévost and P. Berthou, "Lightweight synchronization to NB-IoT enabled LEO Satellites through Doppler prediction," 2023 19th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Montreal, QC, Canada, 2023, pp. 218-223*

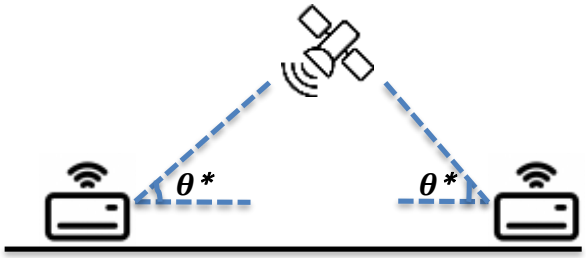
Synchronization to LEO satellites - Introduction

Step 2: **Estimate two potential positions of UE**

➡ *Geometry method*

- Based on $\boldsymbol{\theta}$*, and **TLE** sent in SIB
- Devices can predict the next passes for both two potential positions





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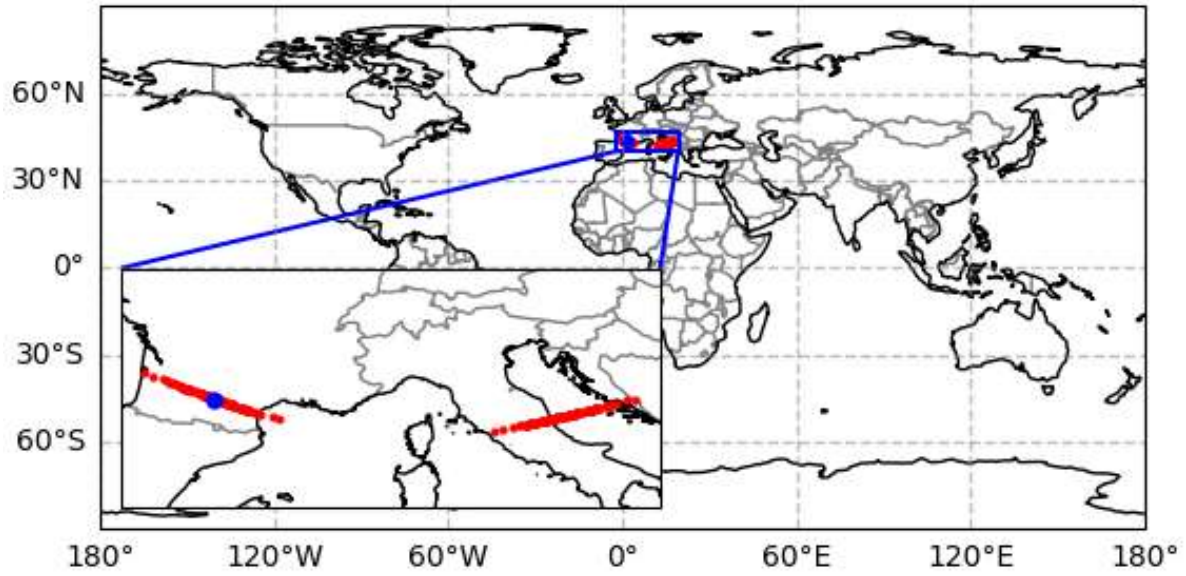
Synchronization to LEO satellites - Introduction

Step 3: **Determine the position of UE**

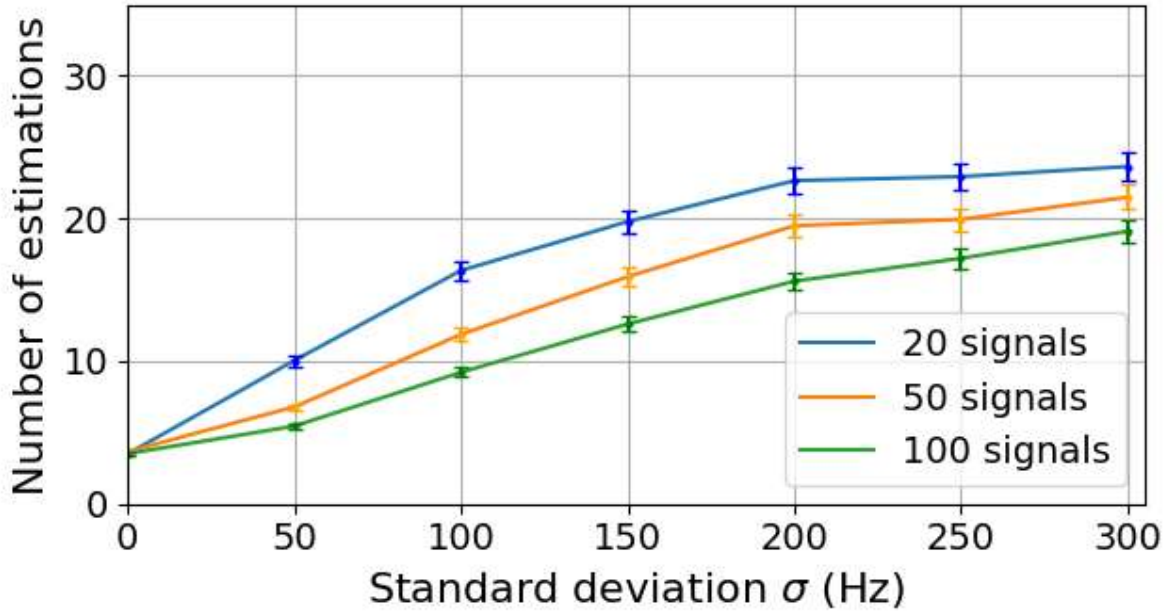
➡ *Optimized algorithm*

- Calculate its own approximate position through multiple satellite passes
  -> Considering two **potential positions** and **measurement errors**



Synchronization to LEO satellites - Simulation

- Number of passes needed to confirm the position of UE (50 km accuracy)



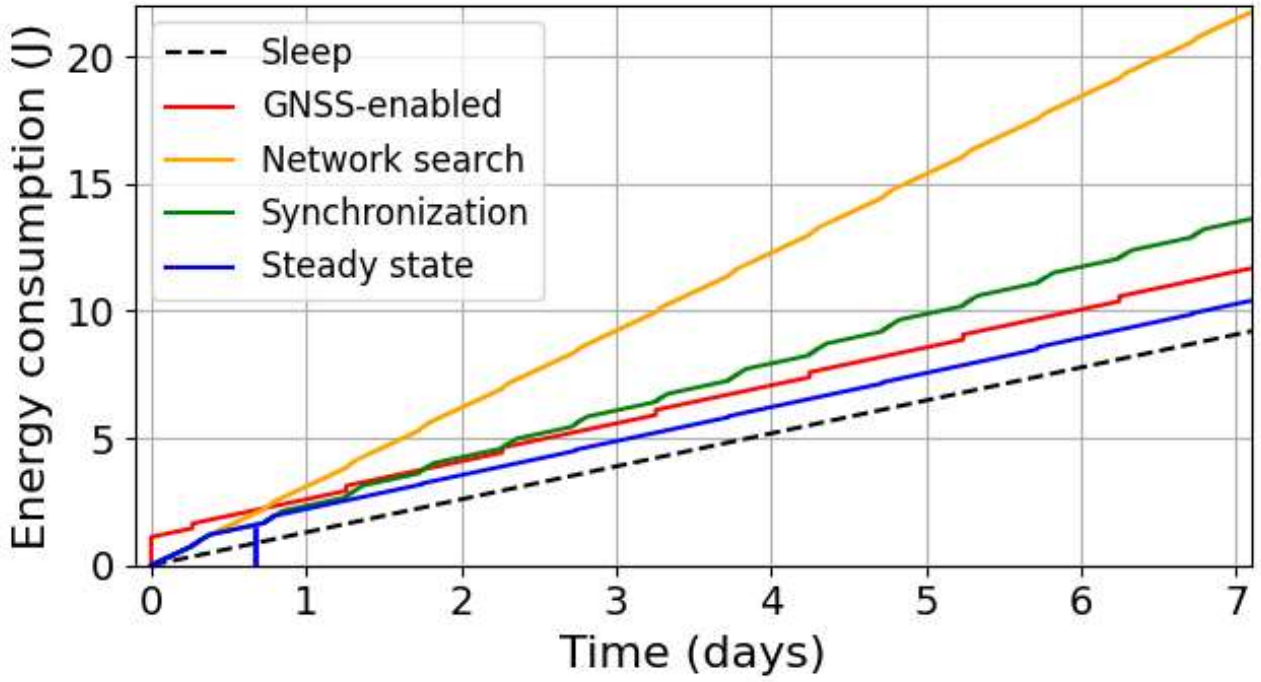
Steady State

- The UE knows where it is, and where are the satellites
- Start transmission regularly based on application requirements
- An easier **analytical method** to predict the arrivals of LEO satellite

$$T_{k,o,j} = T_0 + (j-1)P_N + \frac{(k-1)F}{T}P_N + \frac{(o-1)P}{T}P_N$$

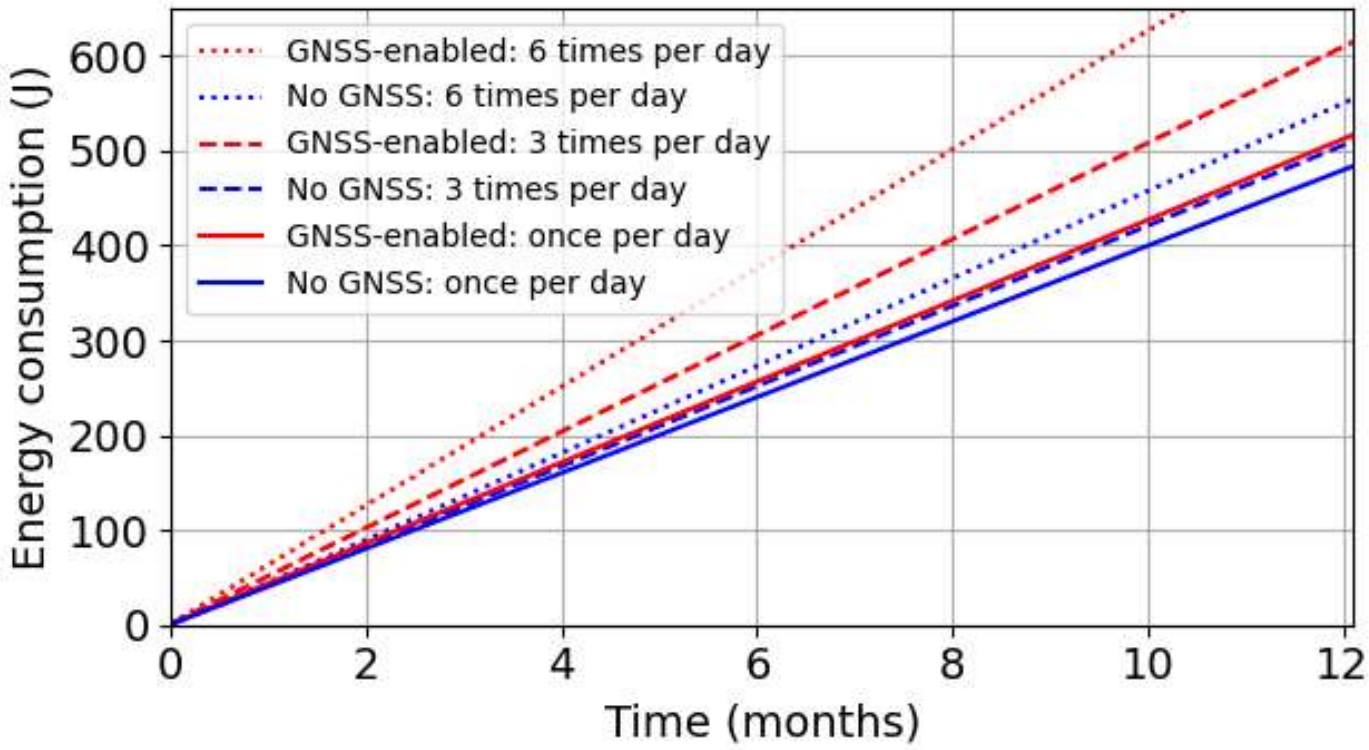
Simulation results - Energy consumption

- Short-term energy consumption (7 days)



Simulation results - Energy consumption

- Long-term energy consumption (1 year)



Conclusion

- A **lightweight** wake-up strategy
  - No GNSS or TLE implemented in devices -> Low energy consumption
  - Low complexity for both satellite and ground devices
  - No modifications in the NB-IoT protocol

Thank you for your attention.
Any questions?

[2] *Z. Zhou, N. Accettura and P. Berthou,* "A wake-up strategy enabling GNSS-free NB-IoT links to sparse LEO satellite constellations," *IEEE IoT journal (under review)*