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Title: COMBINED LOSS OF COHERENCE AND NETWORK COVERING METHODS TO IMPROVE I17CI DETECTIONS BY ADDING DUMMY SENSORS.

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INTRODUCTION AND MAIN RESULTS

Infrasound networks are highly dependent on their geometry, which influences coherence, coverage, and SNR.

Multi-criteria optimization of the I17CI network, by adding dummy sensors, improves directional coherence, expands coverage, and homogenizes SNR. The network thus becomes more reliable, sensitive, and robust in the face of noise and atmospheric conditions.

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Abstract : In the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Côte d'Ivoire benefits from two primary stations: seismic (PS15) and infrasound (I17CI) respectively for monitoring underground and airborne nuclear tests. Upgrading the infrasound station I17CI from four to more sensors is part of the CTBTO's medium term objectives. Thus, this research project is part of the preliminary studies prior to the implementation of this major CTBTO project. We combined coherence and network covering methods to take part of the similarity of signals across all sensors and also network sensitivity to event detection by adding dummy sensors.

Introduction

- Infrasound (< 20 Hz) can detect large-scale events at long distances (Andry, 2019).
- Infrasound networks, capable of capturing these waves, depend not only on the sensor configuration but also on the spacing between them (Blandford, 1997).
- The I17CI infrasound network in Côte d'Ivoire, like any network of this kind, experiences reduced capability when inter-sensor distances are large (approximately 3 km), particularly for detecting higher-frequency waves (> 1 Hz) (Bowman et Lees, 2008).
- In this context, the I17CI network should be enhanced through the addition of optimally placed fictitious sensors.
- The objective is to maximize data quality by identifying the optimal positions for **2 to 5 new sensors**, using MERRA-2 data (2010–2018).

Methods / Data

- Optimization criteria :
  - Spatial coherence (Le Pichon et al., 2005): Measures the similarity of signals recorded between sensors.

$$w^{dist}_{m,b} = e^{-\frac{r_m}{r_{w,b}}} \; ; \; w^{dir}_m = |\cos(\phi_m - \theta_{wind})| \; ; \quad (1)$$

as : $C_{m,b} = w_b . w^{dist}_{m,b} . w^{dir}_m$

  - Spatial coverage (Kay, 1998): Represents the region covered by a sensor. (2)

$$p_i = \eta\, p_i^{dist} + (1-\eta)\, p_i^{SNR} \quad \text{et} \quad p_{cov} = 1 - \prod(1 - p_i)$$

  - SNR (Kinsler et al., 2000): Indicates the signal-to-noise ratio, i.e., the quality of the signal relative to the noise. (3)

$$SPL(r, f_b) = SL_b - TL(r, f_b)\ , \ SNR_b(r) = SPL(r, f_b) - NL_b$$

$$\text{Avec } TL(r, f_b) = 20\log\left(\frac{r}{r_{ref}}\right) + \alpha_b r$$

- **NSGA-II** (*Non-dominated Sorting Genetic Algorithm II*) : multi-objective optimization and determination of solutions via Pareto fronts.
- Atmospheric reanalysis MERRA-2 (NASA), averaged over **2010–2018**.

Results

1. Obtained optimal position

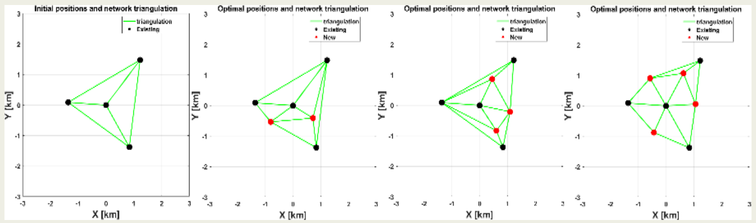

Figure 1 : Initial sensor positions of the I17CI network (black). Optimal positions of the added fictitious sensors (red).

2. Impact of adding fictitious sensors at the optimal positions

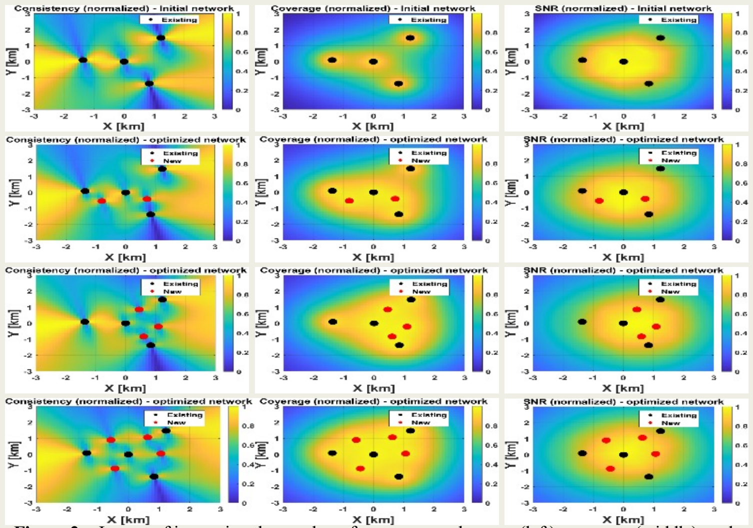

Figure 2 : Impact of increasing the number of sensors on coherence (left), coverage (middle), and SNR (right) for the I17CI network for 2 sensors (top), 3 sensors (middle) and 4 sensors (bottom)

- Optimization on three criteria → the trade-off is represented by a Pareto front (Deb et al., 2002).
- The approach yields (i) improved extraction of weak signals, (ii) an expanded detectable zone, and (iii) enhanced measurement quality.
- The results demonstrate seasonal stability and robustness to atmospheric variability.
- Moreover, network characteristics improve with an increased strategic deployment of sensors.

Conclusion

The multi-objective NSGA-II approach is effective for optimizing infrasonic networks. Solutions provided via the Pareto front for 2 to 5 sensors are adaptable to budget constraints, with proposed positions simultaneously maximizing coherence, coverage, and SNR, yielding improved detection performance.

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