Seizure propagation analysis by means of a complex network approach

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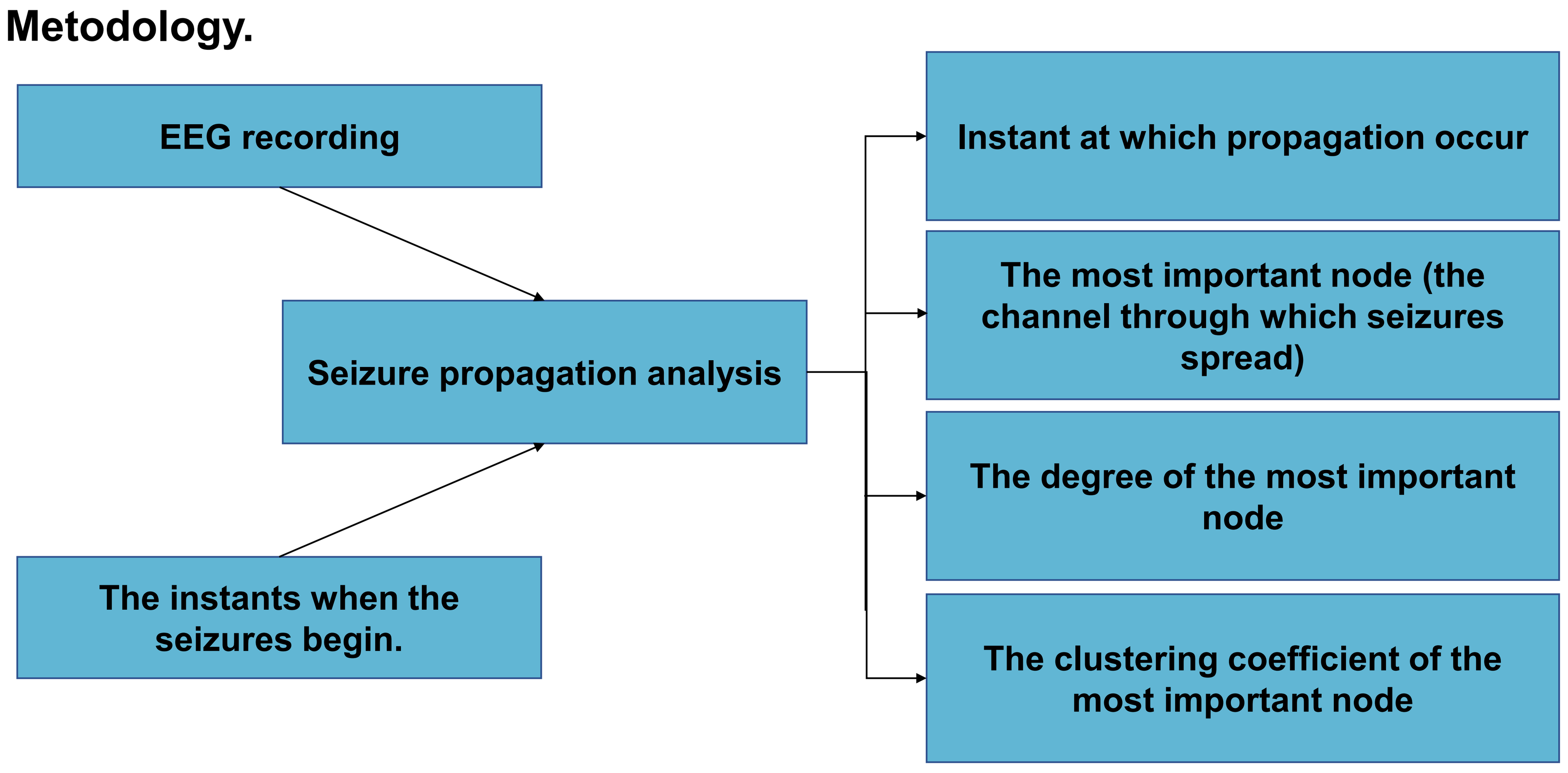
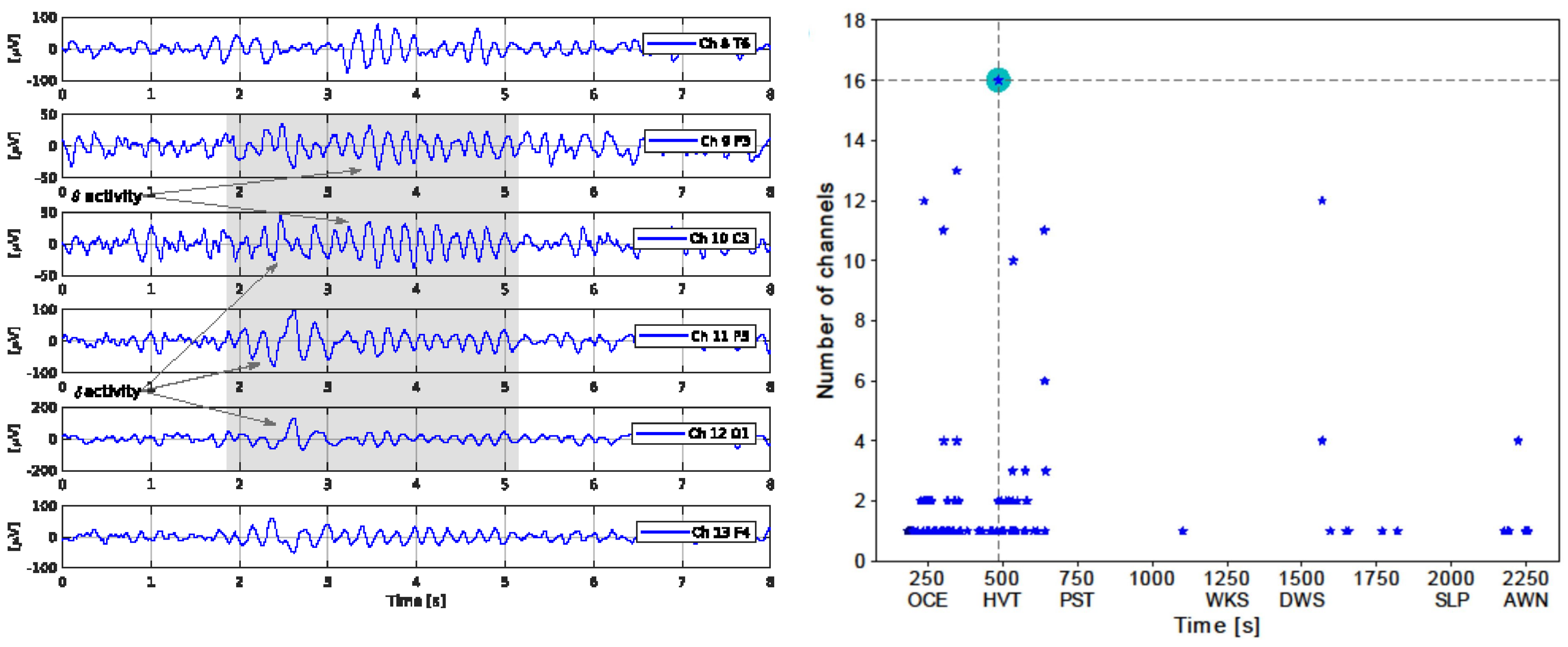
Abstract: The epileptic focus is an area of the cerebral cortex that is essential for the generation of seizures. It is the region where epileptic seizures begin, or the site with the most ictal activity. In this work we present a methodology to determine the propagation of seizures using linear techniques, and identify the EEG channels of the cerebral cortex where seizures spread as well as determine their dynamics from a complex network approach. Our approach leads to estimate the connectivity parameters of the cerebral networks generated during seizure events such as the degree and clustering coefficient of the network's nodes with the highest prevalence. This methodology allows to determine the dynamical characteristics of the zone with the highest ictal activity. This information could help neurologists in the diagnosis and analysis of the dynamics of epileptic seizures in case the primary studies were non-conclusive.

Metodology.



1. Identification of the instants at which propagations occur



2. Generation of adjacency matrices

$$\rho_{XY}(\tau) = \frac{1}{N-\tau}\sum_{i=1}^{N-\tau}\frac{(X_i-\mu_X)(Y_{i+\tau}-\mu_Y)}{\sigma_X\sigma_Y}.$$

Let

$$\mathrm{Cor}_{XY} = \max_{\tau\in[0,N-1]}\rho_{XY}(\tau)$$

$$\mathrm{Cor}(n) = \begin{pmatrix} \mathrm{Cor}_{1,1}^{(n)} & \mathrm{Cor}_{1,2}^{(n)} & \cdots & \mathrm{Cor}_{1,19}^{(n)} \\ \mathrm{Cor}_{2,1}^{(n)} & \mathrm{Cor}_{2,2}^{(n)} & \cdots & \mathrm{Cor}_{2,19}^{(n)} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{Cor}_{19,1}^{(n)} & \mathrm{Cor}_{19,2}^{(n)} & \cdots & \mathrm{Cor}_{19,19}^{(n)} \end{pmatrix}$$

$$\bar{x}_{\mathrm{Cor}}^{(n)} = \frac{1}{19^2}\sum_{i=1}^{19}\sum_{j=1}^{19}\mathrm{Cor}_{ij}^{(n)}, \quad \sigma_{\mathrm{Cor}}^{(n)} = \sqrt{\frac{1}{19^2}\sum_{i=1}^{19}\sum_{j=1}^{19}\left(\mathrm{Cor}_{ij}^{(n)} - \bar{x}_{\mathrm{Cor}}^{(n)}\right)^2}$$

$$a^{(n)} = \bar{x}_{\mathrm{Cor}}^{(n)} - \sigma_{\mathrm{Cor}}^{(n)}, \qquad b^{(n)} = \bar{x}_{\mathrm{Cor}}^{(n)} + \sigma_{\mathrm{Cor}}^{(n)}.$$

$$W(n) = \left(b^{(n)}, b^{(n)} - \Delta_n, b^{(n)} - 2\Delta_n, \ldots, a^{(n)}\right)$$

$$A(n) = \left(A_{ij}^{(n)}\right)_{i,j=1}^{19} \qquad \sum_{j=1}^{19} A_{ij}^{(n)} > 0$$

$$A_{ij}^{(n)} = \begin{cases} 1, & \text{if } W_k^{(n)} \le \mathrm{Cor}_{ij}^{(n)} < 1, \\ 0, & \text{if } W_k^{(n)} > \mathrm{Cor}_{ij}^{(n)} \text{ or if } \mathrm{Cor}_{ij}^{(n)} = 1 \end{cases}$$

3. Calculation of the network parameters and identification of the most important nodes.

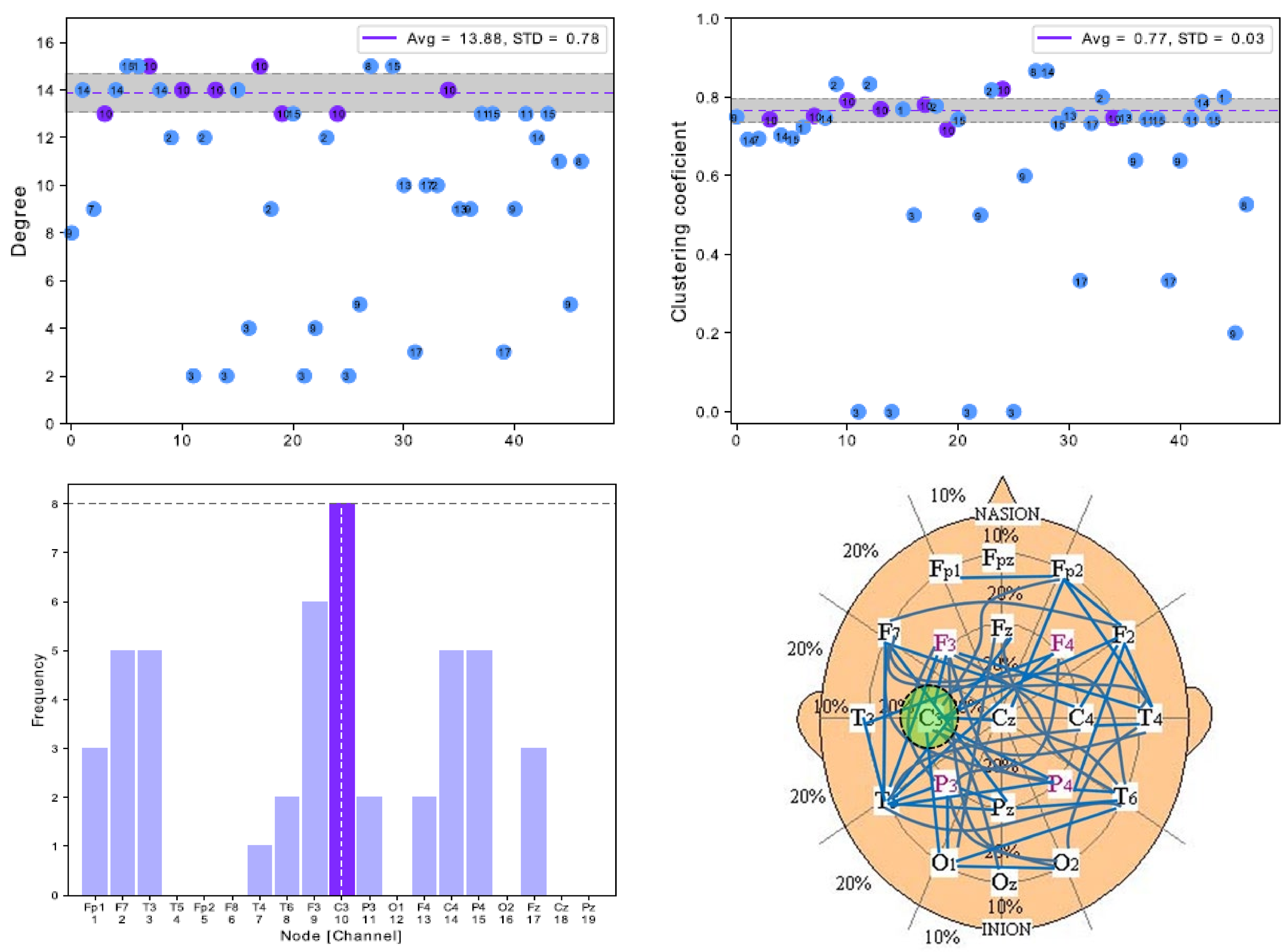
$$c_b(v) = \sum_{s,t\in V(G)}\frac{\sigma(s,t\mid v)}{\sigma(s,t)}$$

$$C_b(n) = \{c_b(v_1(n)), c_b(v_2(n)), \ldots, c_b(v_{19}(n))\}$$

$$c_b(v_i(n)) \ge (\mathrm{avg}(C_b(n)) + \mathrm{std}(C_b(n)))$$

$$k_v^{(n)} = \sum_{j=1}^{19} A_{vj}^{(n)}, \quad C_v^{(n)} = \frac{2L_v^{(n)}}{k_v^{(n)}\left(k_v^{(n)} - 1\right)}$$

Results.



Conclusions. With the implementation of the concepts of cross-correlation, shortest path, and betweenness centrality, it was possible to identify which EEG channels are more likely related to the propagation of seizures. Indeed, the important EEG channels through which propagations occur and the most important node (which corresponds to the node with the highest prevalence during the whole recording) can be well-identified.

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