MULTIFRACTAL MODELING OF THE RADIO ELECTRIC SPECTRUM APPLIED IN COGNITIVE RADIO NETWORKS.

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AGENDA

1. Introduction
2. Analysis tools
3. Proposed Goals
4. Methods
5. Spectral Behaviour in Bogota
6. Background
7. Conclusions
8. Questions
INTRODUCTION
Initial Development
INITIATIVE

• Study the current state of the radio spectrum.

• Define methodologies to perform measurements in the radio spectrum of Bogotá.

• Lead Campaigns in specific areas of the city.

• Analyse the acquired data.

L. F. Pedraza, Hernández, Galeano, Rodríguez-Colina, & Páez, 2016
DATA COLLECTION

CUNDINAMARCA DEPARTMENT

L. F. Pedraza, Hernández, Galeano, Rodríguez-Colina, & Páez, 2016
UNDERUSED SPECTRUM

ISM2450, LTE, Mobile (Total Work duty 5.39%)
COGNITIVE RADIO

POWER

Occupied Spectrum

TIME

Dynamic Spectrum Access

FREQUENCY

Spectrum Hole
BACKGROUND
Related Work
PREDICTION IN COGNITIVE RADIOS

**Linear Prediction**
- The output is used to improve sensing accuracy and reduce costs.

**Markov Models**
- Such models work well under the assumption of low memory, which is a property of an evolving spectrum.

**Bayesian Inference**
- Used to predict the probabilities of a signal such as energy.
- Sayrac, Galindo-Serrano, Jemaa, & Riihijärvi, 2013

**Support Vector Machines**
- Applied in predictions where geospatial assumptions are made.
- Iliya, Goodyer, Gow, Shell, & Gongora, 2015; Y. Wang, Zhang, Ma, & Chen, 2014

**Artificial Neural Networks**
- Suitable for correlated prediction scenarios, ANN offer superior prediction accuracy compared to other models.
- Fleifel, Soliman, Hamouda, & Badawi, 2017; Iliya et al., 2015
TRAFFIC GENERATION

1989

- Traces collection (BELLCORE)

1999

- MWM (R. H. Riedi, et. al)

- Conservative Binomial Cascade
- Wavelet Transform

2012

- MFH (López, Alzate)

- Adjust: Mean, Hurst

2016

- MFHSW (Tuberquia, ET. AL)

- Adjust: Multifractal Spectrum Width

- Das & Ghosh, 2015; Hirata & Imoto, 1991
- (R.H. Riedi, Crouse, Ribeiro, & Baraniuk, 1999)
- (Chávez & Monroy, 2012)
- Tuberquia-David, Vela-Vargas, López-Chávez, & Hernández, 2016
ANALYSIS TOOLS
Multifractal Dimension Estimation
TRACE

![TRACE Diagram](Image)
FAST CALCULATION OF THE DETAIL COEFFICIENTS

SIGNAL $X[n]$

Octave $j=1$

Octave $j=2$

Octave $j=3$

...$

Octave $j=m$

Details $d_s(1,k)$ $d_s(2,k)$ $d_s(3,k)$ ... $d_s(m,k)$

Low Pass Filter & Sub sampler

High Pass Filter & Sub-sampler
VARIANCE ESTIMATOR

EQ. 1

\[ \mu_j = \frac{1}{n_j} \sum_{k=1}^{n_j} |d_x(j, k)|^2 \]

(Flandrin, Gonçalves, & Abry, 2009)

EQ. 2

\[ \mu_j \approx E[|d_x(j, \cdot)|^2] \sim 2^j (2H-1) C \]

(Sheluhin, Smolskiy, & Osin, 2007)

EQ. 3

\[ \log_2 \mu_j = (2H - 1)j + \log_2 C \]

(López, 2012)
LOG SCALE DIAGRAM

(0.52814 < H = 0.66603 < 0.80392)
LOG SCALE DIAGRAM

EQ. 4
\[ \mu_j^q = \frac{1}{n_j} \sum_{k=1}^{n_j} |d_x(j, k)|^q \]
(P. Abry et al., 2000)

EQ. 5
\[ H(q) = \frac{\alpha q}{q} + \frac{1}{2} \]
(P. Abry et al., 2000)
STATISTICAL MOMENTS

Time Series

q=-3
Negative Moments

q=-1

q=1
Positive Moments

q=3

Monofractal
Multifractal

Periods with small Fluctuations

Periods with small Fluctuations
STATISTICAL MOMENTS

EQ. 6

\[ T(q) = qH(q) - 1 \]

(Meakin, 1998)

EQ. 7

\[ D(q) \equiv \frac{T(q)}{q - 1} = \frac{qH(q) - 1}{q - 1} \]

(Kantelhardt et al., 2002)
MULTIFRACTAL SPECTRUM

Graph showing Dq against hq for monofractal and multifractal cases.
PROPOSED GOALS
OBJECTIVE

Establish a tool that can estimate traffic with similar characteristics to those found in the radio spectrum of Bogotá.
METHODS

Adjusting Traffic as Multifractal Traces
MFHW

1. INPUT PARAMETERS
2. MULTIFRACTAL ALGORITHM
3. WAVELET ANALYSIS
4. MULTIFRACTAL SPECTRUM WIDTH
5. TRACE
STEP 1

INPUT PARAMETERS → MULTIFRACTAL ALGORITHM → WAVELET ANALYSIS → MULTIFRACTAL SPECTRUM WIDTH → TRACE

INPUT

Radioelectric Spectrum

Threshold
Noise Floor
Fixed BW
Multichannel

Decision-Making System

OUTPUT

Availability Matrix

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BEHAVIOUR OF THE RADIO ELECTRIC SPECTRUM AFTER COUNTING
STEP 2

INPUT PARAMETERS ➔ MULTIFRACTAL ALGORITHM ➔ WAVELET ANALYSIS ➔ MULTIFRACTAL SPECTRUM WIDTH ➔ TRACE

\[ i=n \]

\[ i>16 \]

Si

\[ k_1 = \frac{2^{2k-1} - 1}{2 - 2^{2k-1}} \]

Construction Binomial Cascade ➔ i++

No

Estimation of \( H_2 \) based on Linear Regression

\[ k_2 = \frac{2^{2k-1} - 1}{2 - 2^{2k-1}} \]
STEP 3

INPUT PARAMETERS → MULTIFRACTAL ALGORITHM → WAVELET ANALYSIS → MULTIFRACTAL SPECTRUM WIDTH → TRACE

Estimation of the detail coefficients $dx(j,k)$

Estimator

Log-Scale Diagram and Estimation of $H$ and Sample $H$ ($Hs$)

$|H-Hs| < 0.005$

$i = 0$
STEP 4

INPUT PARAMETERS → MULTIFRACTAL ALGORITHM → WAVELET ANALYSIS → MULTIFRACTAL SPECTRUM WIDTH → TRACE

Dq & Hq

Spectrum Calculation

Estimation of Width (Ws)

$|W - W_s| < 0.01$

i=0
STEP 4

INPUT PARAMETERS → MULTIFRACTAL ALGORITHM → WAVELET ANALYSIS → MULTIFRACTAL SPECTRUM WIDTH → TRACE

Resulting Trace

Inter-Arrival Time

Packet Number

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BEHAVIOR OF THE SPECTRUM IN BOGOTÁ
How the spectrum in Bogota works?
HURST PARAMETER OF THE RADIO SPECTRUM

LD Diagram

$H < 0.5 = 25; H > 1 = 2; 0.5 < H < 1 = 434$
ADJUSTING THE SAMPLING PROCESS

![Graphs showing optimal samples and corrections of multifractal spectrum](image-url)
SYNTHESIS OF THE 461 CHANNELS

Multifractal Spectrum for all channels

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CONCLUSIONS

After comparing both algorithms exposed in this investigation, the MaF method delivered more significant results offering the best routes. When $H$ is calculated for all channels, not all of them have $0.5 < H < 1$ which indicates that some channels have short range dependence while others do not. However, over 90% of the channels are in the $[0.5; 1]$ range, indicating a long-range dependence in the traces found.
CONCLUSIONS

► In fact, the sampling correction of the MD and the realignment of the values of $H(q)$ improves accuracy in the multifractal spectrum width of radio channels. Although the readjustment of the coefficients $H(q)$ improves width response, there is no method for checking new samples.

► In conclusion, the data collected from the radio spectrum of Bogotá reveals that Wi-Fi traffic has a multifractal behavior.
REFERENCES


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QUESTIONS

Thank you