WORK FLOW

1.TRANSIENT DETECTION

Method:

Threshold/Bayesian Step Change Detector Utilizing ***Amplitude-Based Variance Detection***

NB: Phase-Based Variance Detection *Could Be Used Under This Method On The Premise That Variance of The Phase Remains Constant Until Start of Transient*

Procedure:

Captured Waveform is First Normalized, Transient is Then Extracted using Amplitude –Based Variance Detection Algorithm by Defining a New Discrete Variance Signal V,

$$V_i = K\frac{1}{W-1}\sum_{n=1}^{w} (Si_{m-n} - \bar{X}_w)^2 \text{ ………………Eq 1}$$

Where:

V_i is a New Variance Signal Created From The Input Signal S (Captured Waveform)
w = The Sliding Window Size
$\bar{X}_w$ = Mean Of Sample Values $S_i - w, \ldots\ldots\ldots S_i - 1$
k = Scaling Factor For Making V Comparable To S

The Variance Signal V, Can be Viewed as a Measure of How Much The Incoming Signal S Deviates From The Average of The Last *w* Sample, Therefore, When The Transient Occurs, S Will Rapidly Increase Causing The Deviation to be High and Thus Detect The Transient

Once The Signal is Detected and its Variance Computed, Start and End of Transient Becomes a Change Point Problem

Thus For Transients; Variance of The Signal For a Giving Window Size *w* Would Increase Rapidly as compared to The Variance of The Last Measured *w* Sample

For Start of Transient, The Change Point is Where The V Signal Starts to Rise Rapidly, and End of Transient Being The Point Where V Flattens Out

These Two Change Point Problem is Solved Using The CUSUM (Cumulative Sum) Algorithm:

$CUSUM(V_i)=max(CUSUM(V_{i-1})+(V_i - V_{i-1})-\alpha,0)$, Where CUSUM(0)=0 ………..…Eq2

Now, Further Define The Detection Signal D, as:

$$D=CUSUM (V) \text{ ……………………….Eq3}$$

START POINT DETECTION

This Signal only Begins to Rise When The Signal Variance V Rises Significantly, Indicating The Start of Transient
The Detection Signal Falls Back To Zero When The V Signal Flattens Out
The Start of Transient is Located at The Point at Which D Rises Above a Pre-defined Threshold t.

Threshold Values of between $t=1.10^{-5}$ to $t=5.10^{-5}$ Found Experimentally to work well.Due to the Likelihood of False Detection of Start of Transient, the Final Decision is Made When End Point is Detected, The Starting Point is Then Chosen as The Last Point at Which D Rises above t

END POINT DETECTION

For Transient End Point, a Look-Ahead of Length ɭ is used to see if The Signal D Has Reached Its Peak End of Transient is Located at The Point That Satisfy The Equation:

$$D_i \geq \max((D_{i+1} \ldots\ldots D_{i+l})) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq4}$$

ɭ Refers to The Distance from the Transient Start Point to its End Point Along The X-Axis

End Point is Therefore Determined Experimentally to Satisfy Equation 4

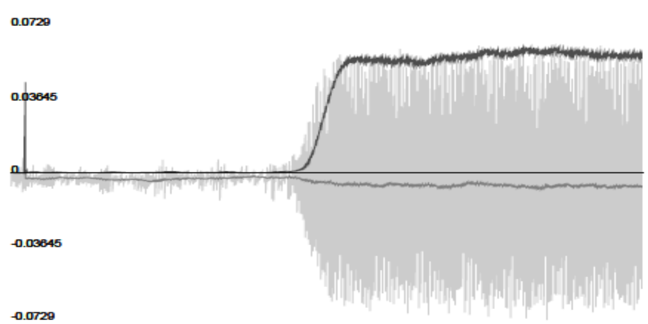


Fig. 2. Radio signal transient. The light gray signal represents the radio signal from the sensor node S, the dark gray signal is the variance signal V whereas the thin medium gray signal is the mean of S over a window of size $w = 50$ i.e., $\overline{X}_{50}$. The scaling constant is $k = 30$

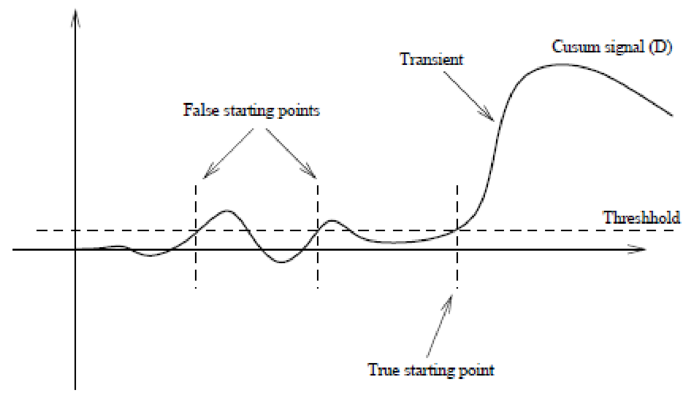


Fig. 3. An illustration of the detection of the starting point of the signal transient.

2. FEATURE EXTRACTION & FINGERPRINT GENERATION

Once The Transient is Detected, Discrete Wavelet Transform DWT is then Applied to Extract and Obtain Frequency Components From The Energy Envelop of The Non-Stationary Transient Signal

Simplified Morlet Wavelet $\quad \emptyset(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-i2\pi f_o t} e^{-t^2/2\sigma^2} \ , \sigma > 0$

RF Fingerprint (F) for instantaneous Amplitude (a), Phase (ϕ) and Frequency (f) are computed from the Complex I/Q Characteristics of The Signal as Follows:

$$a[n] = \sqrt{I[n]^2 + Q[n]b^2} \ \ldots\ldots\ldots\ldots(1)$$

$$\phi[n] = tan^{-1}\left[\frac{Q[n]}{I[n]}\right] \text{ for } I[n] \neq 0 \ldots\ldots(2)$$

$$f[n] = \frac{1}{2\pi}\left[\frac{d\emptyset[n]}{dt}\right] \ldots\ldots\ldots\ldots\ldots(3)$$

Statistical Fingerprint are then Generated as variance σ^2, Skewness γ, and Kurtosis, k

Equally

Power Spectral Density (PSD) Coefficients May be Used to Generate The RF Fingerprint as:

$$\Psi x(k)= \frac{|(X(k)|^2}{\sum_{k=1}^{K} |(X(k)|^2}$$

Where *X(k)Are The Coefficients of Discrete Fourier Transform For The Input Signal X(m)Given By:*

$$X(k)= \frac{1}{N_F} \sum_{m=1}^{N_F} x(m) e^{\left[\frac{-2\pi j}{N_F}(m-1)(k-1)\right]}$$

ALTERNATIVELY

The Following Signal Features Of Interest Could Also Be Observed and Extracted:

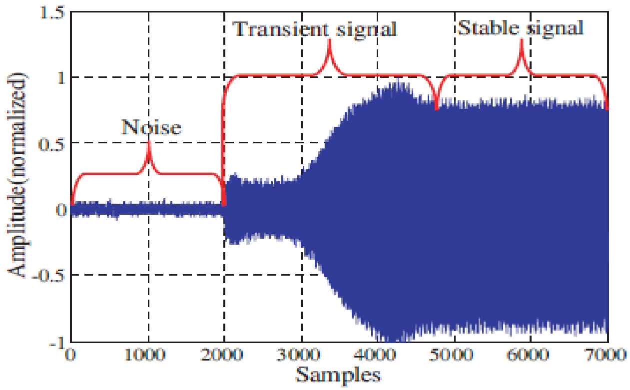
1. Length of Transient Along The X-Axis *(len)*
2. Variance of The Normalized Amplitude of Transient *(var)*
3 Skewness of the Transient curve
4 Kurtosis of the Transient Curve
5. The Number Of Peaks (Periods) of The Carrier Signal in Transient *(Peaks)*
4. The First Part of a Discrete Wavelet Transform of Transient *(dωt0)*
7. Difference Between The Normalized Mean and Normalized Maximum Value of Transient *(ndi f)*
8. Area Under The Normlized Energy Curve
9. Maximum Slope of The Transient Energy Curve

3.MACHINE LEARNING & FINGERPRINT CLASSIFICATION

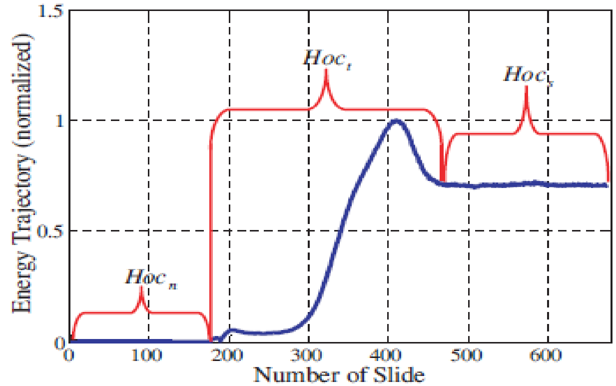
A 4:1 Ratio of Test and Training Samples Shall Be Used in a Support Vector Machine (SVM) Classifier For The Authentication & Classification Test

A Total of Fifty (50) Transmissions From Each Transceiver Under Test Shall Be Processed and Used For The Authentication & Classification Test

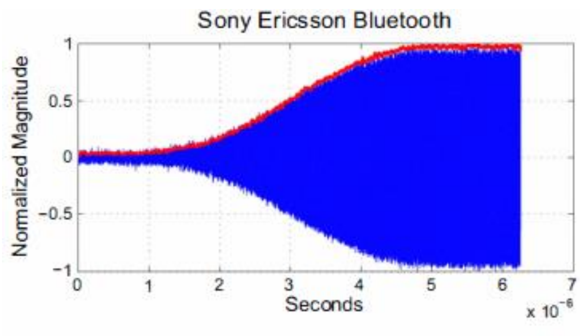
SAMPLE TRANSIENT SIGNALS

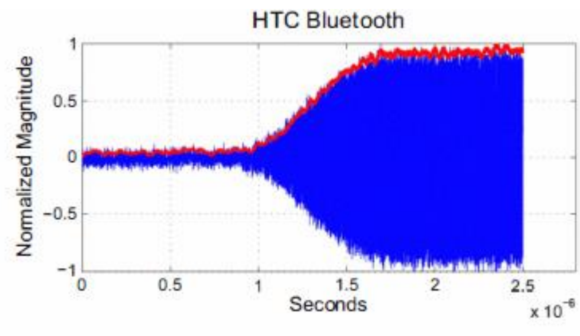


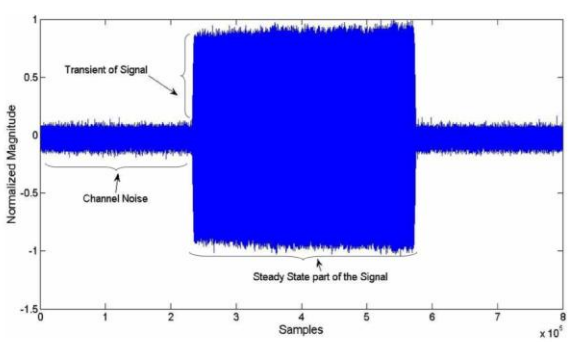
Transient From Nokia 5230 Mobile Phone



Energy Envelop







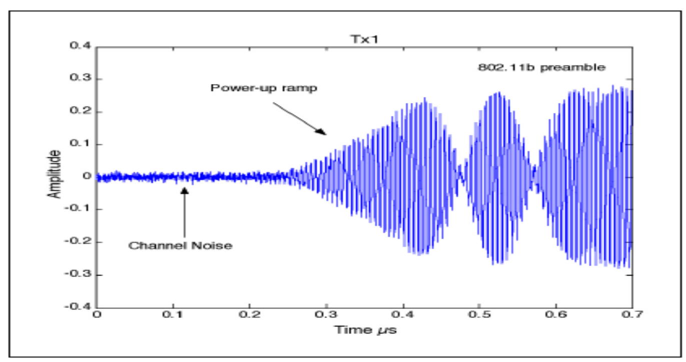
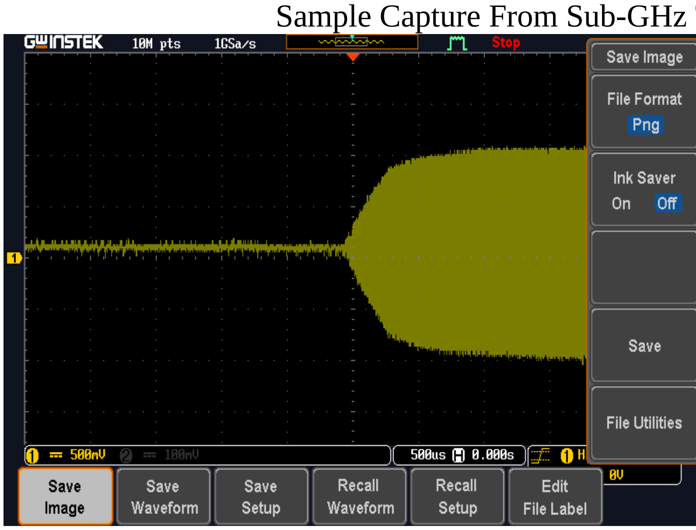
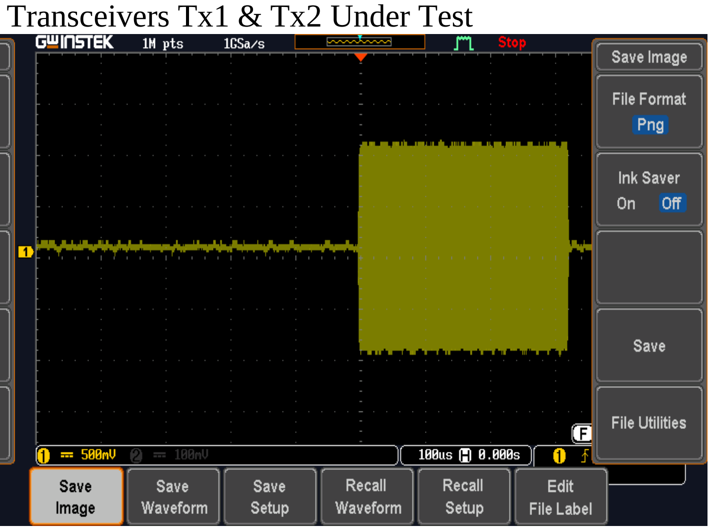


Figure 1: *Typical waveform captured from a WiFi device.*

Sample Capture From Sub-GHz Transceivers Tx1 & Tx2 Under Test



Tx 1



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