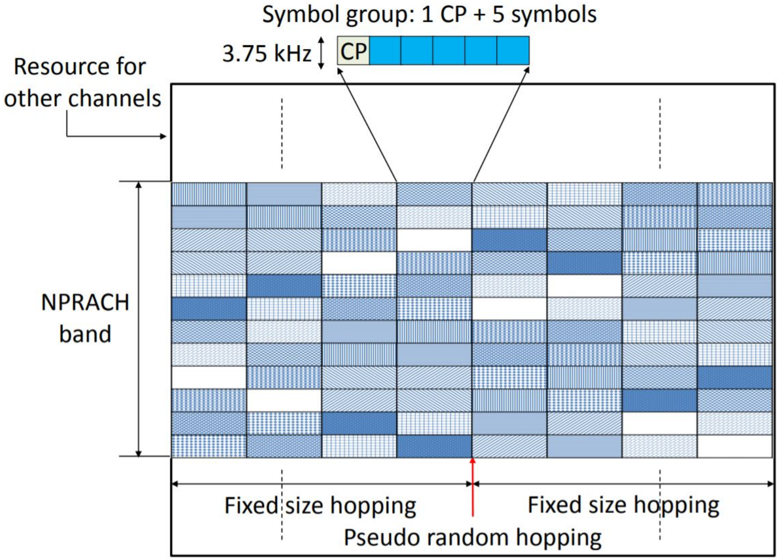
NPRACH Detector

Random Access Preamble Detection for Narrowband IoT (NB-IoT) Systems

- YASHWANTH R

Preamble Design, Hopping Pattern and Baseband Signal Generation

According to 3GPP Release 36.211 v13.4 (Feb 2017)



Coverage Area 1

- 8 Symbol Groups
- SNR: 14.25 dB
- Distance: upto 10 KM

Coverage Area 2

- 32 Symbol Groups
- SNR: 4.25 dB
- Distance: upto 40 KM

Coverage Area 3

- 128 Symbol Groups
- SNR: -5.25 dB
- Distance: upto 120 KM

$$s_i(t) = \beta_{\text{NPRACH}} e^{j2\pi\left(n_{\text{SC}}^{\text{RA}}(i)+Kk_0+1/2\right)\Delta f_{RA}(t-T_{\text{CP}})}$$

NPRACH: Preamble Signal Analysis and Detection

X. Lin, A. Adhikary and Y. -. Eric Wang, "Random Access Preamble Design and Detection for 3GPP Narrowband IoT Systems," in IEEE Wireless Communications Letters, 2016

UE Transmit Signal

$$s[n;m] = \frac{\sqrt{E}}{N} \sum_{k} S[k;m] e^{j2\pi \frac{k}{N} n}, n = -N_{cp}, ..., N-1,$$

Spectrum of Received Signal

$$\tilde{y}[i;m] = B(\Delta f, D) a[m] u[m] e^{j2\pi \Delta f (m(N_{cp}+\xi N)+iN))} \times e^{-j2\pi \frac{\Omega(m)}{N} D} + \tilde{v}[i;m].$$

PREAMBLE FORMAT 0: $N_{cp} = N/4$

PREAMBLE FORMAT 1: $N_{cp} = N$

Detection using 2D Fast Fourier Transform

$$W_g[p,q] = \sum_{n=0}^{M_1-1} \sum_{k=0}^{M_2-1} w_g[n,k] e^{-j2\pi \frac{n}{M_1} p} e^{-j2\pi \frac{k}{M_2} q}$$

$$z[i;m] = \tilde{y}[i;m] u^*[m].$$

$$w_g[n,k] = \begin{cases} z[i;m] & \text{if } n = (m-gQ)(\xi+1)+i,\ k = \Omega(m); \\ 0 & \text{otherwise.} \end{cases}$$

NPRACH: 2D FFT Algorithm for Detection

X. Lin, A. Adhikary and Y. -. Eric Wang, "Random Access Preamble Design and Detection for 3GPP Narrowband IoT Systems," in IEEE Wireless Communications Letters, 2016

Adding Correlation over Multiple Repetitions

$$\tilde{J}[p,q] = \sum_{g=0}^{L/Q-1} |W_g[p,q]|^2$$

$(p^\star, q^\star)$ Point of Maximum Correlation

Estimating CFO and ToA

$$\Delta f^\star = \begin{cases} \frac{1}{NM_1} p^\star & \text{if } p^\star < \frac{M_1}{2}; \\ \frac{1}{NM_1}(p^\star - M_1) & \text{otherwise.} \end{cases}$$

$$D^\star = \begin{cases} -\frac{N}{M_2} q^\star & \text{if } q^\star < \frac{M_2}{2}; \\ -\frac{N}{M_2}(q^\star - M_2) & \text{otherwise.} \end{cases}$$

Pseudocode

```
Algorithm 1: NPRACH Detection: 2D FFT Method
Result: Residual Frequency Offset and Time-of-Arrival Estimation
y = Received Signal;
y = removeCP(y);
Y = FFT( Received Signal );
Z = Y * conj(U);
W = PickUserSpecificSpectralComponents(Z, Nsc);
J = FFT2(W, M1, M2);
(P, Q) = maxIndex(J);
```

if $P \geq \frac{M_1}{2}$ **then**

$$\Delta F = \frac{(P - M_1)}{N * M_1}$$

else

$$\Delta F = \frac{P}{N * M_1}$$

end

if $Q \geq \frac{M_2}{2}$ **then**

$$D = \frac{-(Q - M_2) * N}{M_2}$$

else

$$D = \frac{-Q * N}{M_2}$$

end

if $J[P, Q] \geq threshold$ **then**

$$UAD = 1$$

else

$$UAD = 0$$

end

NPRACH: Time-of-Arrival Estimation Error

X. Lin, A. Adhikary and Y. -. Eric Wang, "Random Access Preamble Design and Detection for 3GPP Narrowband IoT Systems," in IEEE Wireless Communications Letters, 2016

Simulation Parameters

CP Length	66.7 and 266.7 us
Subcarrier Spacing	3.75 kHz
Symbol Group	1CP + 5 Symbols
NPRACH Band	12 Subcarriers
Channel Model	EPA
Doppler Spread	1Hz
Antenna Config	1Tx; 2Rx
Timing Offset	0 - CP (Random)
Frequency Offset	-200 to 200 Hz (Random)