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Purpose :
Theoretical background used for assisting another submission about Ranging Process Analysis & Improvement Recommendations

Timing & Power Estimate Basics For Multi-user Ranging

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1. Math for Ranging Signal & Code Matrices

The M active users' superimposed ranging signal is demodulated by the BS FFT processor to produce L (the number of ranging carriers) complex outputs which can be represented by a L x M matrix $R_{L \times M}$ (for matrix multiplication purpose, or a simpler L x 1 vector will do).

$$\mathbf{R} = \begin{pmatrix} r_0 & r_0 & \cdots & r_0 \\ r_1 & r_1 & \cdots & r_1 \\ \vdots & & & \\ & & r_k & \\ & & & \\ r_{L-1} & r_{L-1} & \cdots & r_{L-1} \end{pmatrix}_{L \times M}$$

And, the M L-bit ranging codes from M users can be represented by a M x L matrix $B_{M \times L}$;

Cont'd

$$
\mathbf{B}_{M \times L} = \begin{pmatrix} b_{00} & b_{01} & \cdots & b_{0L-1} \\ b_{10} & b_{11} & \cdots & b_{1,L-1} \\ \vdots & & b_{ki} & \\ b_{M-1,0} & b_{M-1,1} & \cdots & b_{M-1,L-1} \end{pmatrix}_{M \times L}
$$

Where $r_k = \sum_{i=0}^{M-1} A_{ki} b_{ki} e^{j2\pi(d(i)n(k)/N) + \Phi ki}$, A_{ki} is the attenuation through wireless channel from the i^{th} SS to the BS at k^{th} ranging sub-carrier, b_{ki} is the k^{th} bit of the i^{th} ranging code (for i^{th} SS)converted in bipolar values (1, -1), d(i) is the round trip traveling delay between the i^{th} user SS to BS in units of BS FFT sampling period, k is the IFFT/FFT bin index for n(k), the k^{th} sub-carrier location of the common ranging channel

Cont'd

To detect all the active user's traveling time & power, R is multiplied (in frequency domain) with the ranging matrix B which contains M users' ranging codes (each is L–bit long) ;

$$P_{L \times L} = R_{L \times M} \times B_{M \times L} = \begin{pmatrix} p_0 & X & \dots & x \\ x & p_1 & \dots & x \\ \cdot & & & \\ \cdot & & p_k & \\ \cdot & & & \\ x & x & \dots & P_{L-1} \end{pmatrix}_{L \times L}$$

" x" means does not need to be calculated.

$$\text{Where } P_k = \sum_{l=0}^{M-1} \sum_{m=0}^{M-1} A_{kl} b_{kl} b_{km} e^{j2\pi(d(l)n(k)/N) + \Phi kl}$$

$$P_{km} = b_{km} \sum_{l=0}^{M-1} A_{kl} b_{kl} e^{j2\pi(d(l)n(k)/N) + \Phi kl}$$

Cont'd

For M terms in P_k .ie. P_{km} with m=i, and the angle small enough (e.g. ABS [(D(i) n(k)/N)] << ¼), P_k is always positive and will cause all L sine waves to be added constructively to generate a spike ($N^{1/2}$ above the other sets (L elements) of sine waves).

Ideally, to calculate the time delay (with respect to the BS FFT symbol timing) of m^{th} of the M SS/users, P_{km} is used for the n(k) bin location of an IFFT processor (as shown in the following equation) to generate a singular spike like impulse response among background noise floor.

$$x_{m\,i} = \frac{1}{N} \sum_{k=n(k)}^{N-1} P_{km} e^{-j2\pi (n(k)i)/N}$$

Where, P_{km} =0 for those n(k) not equal to any one of the ranging carrier locations.

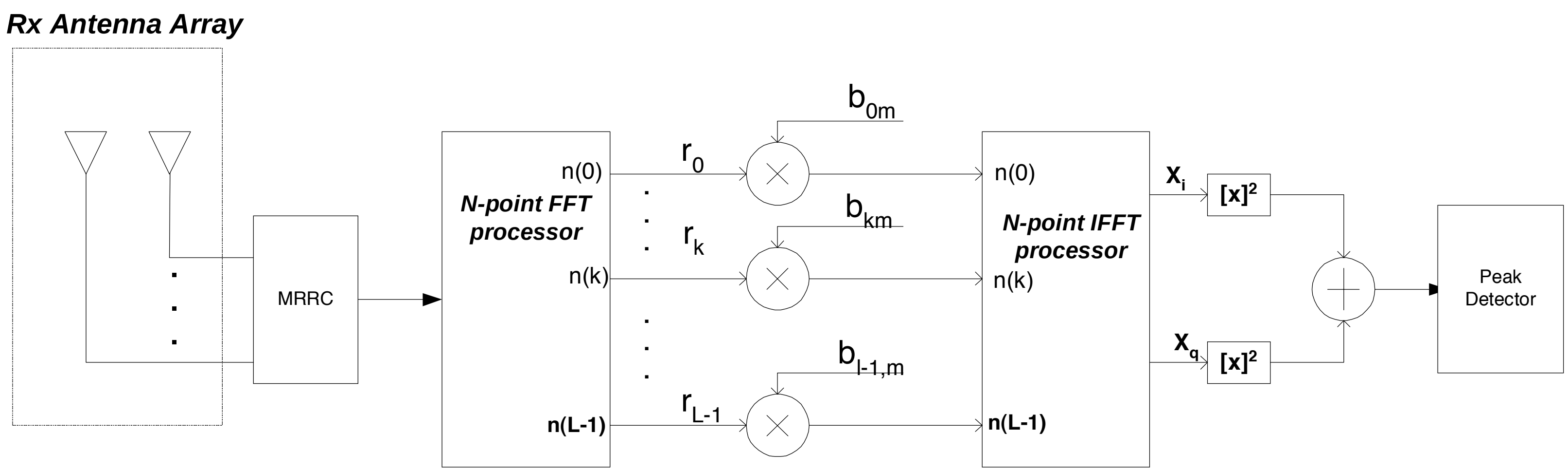
" i"is the sampling time index based on the N-point FFT sampling rate.

More local spikes will show up when the phase rotation of the ranging pilots gets bigger.

That is when ;

ABS [(D(i) n(k)/N)] ≈ ¼

Functional Block Diagram For Timing & Power Detection, Method 1 using IFFT & Peak Detect Circuit



2. How To Keep The Ranging Carrier Phase Angle Small

- Use clustered (allowed to be hopping around for a finite set of ranging channels) sub-carriers for the ranging channel.
- Generate dual tones (by FDPR) for each ranging carrier. (FDPR : Frequency Domain Partial Response)
- Add to ranging channel each of its carrier’s neighboring carrier as the new ranging channel.

Cont'd

2.1. Use IFFT to calculate each user's group (averaged over L ranging carriers) time delay (with respect to the BS symbol timing) :

Ranging Channel Composed Of Clustered Sub-carriers

For the m[th] user 's SS

$$X_{mi} = \frac{e^{-i2\pi n(0)i/N}}{N} \sum_{k=0}^{L-1} P_{km}\, e^{-j2\pi(ki)/N}$$

Assming all P_{km}(ranging amplitude of the detected user plus uncorrelate noise from M-1 other users) approximate a constant ;

$$|Xmi|^2 \sim \frac{1}{N} \frac{SIN^2(\pi Li/N)}{SIN^2(\pi i/N)}$$

The above displays single peak like waveform with respect to i the index of sampling time over s symbol time.

Cont'd

2.2 & 2.3 both use differential phase of two adjacent (by a sub-carrier spacing) ranging carriers to calculate the differential time delay $\tau = d\phi/df$ at each ranging carrier pair modulated by a pair of bits (d_{ki}, $d_{k-1,i}$) which represents the k^{th} bit, b_{ki} of the i^{th} user's ranging code by the following rule;

$b_{ki} = d_{ki}$ XOR d_{k-1i} where XOR means exclusive or

The phase difference of the K^{th} pair from the i^{th} user is $\Phi_{ki,}$ and

$$\Phi_{ki,} = b_{ki} \times \Phi_k \sim b_{ki} \times \mathrm{Im}\{ r_k \times r_{k-1}^* \} \sim b_{ki} \times \mathrm{Im}\{ \sum_{l=0}^{M-1} \sum_{m=0}^{M-1} A_{kl} A_{K-1,m} d_{kl} d_{k-1,m} e^{j2\pi d(i)/N} \}$$

$$\sim A_{ki} A_{k-1,i} b_{ki} b_{k,i} (2\pi d(i)/N)$$,Where $b_{ki} = d_{ki} \times d_{k-1,i}$

$$d(i) \sim N/(2\pi P_{ki}) \times \{ \sum_{k=0}^{L-1} \Phi_{ki} \}$$,Where $P_{ki} = \mathrm{ABS}(r_k \times r_{k-1}^*)$

And, $Pi = 1/L (\sum_{k=0}^{L-1} P_{ki})$ is the averaged power of the i^{th} user's Ranging signal.

Note that the same differential phase approach to find the group delay averaged over L ranging carriers can be used for 2.1 Ranging Channel of Clustered carriers.

Method 2 ,Using Differential Phase Delay Between Dual Ranging Carriers