A Fast Computation without Divisions for Combiners in Carrier Interferometry OFDM System

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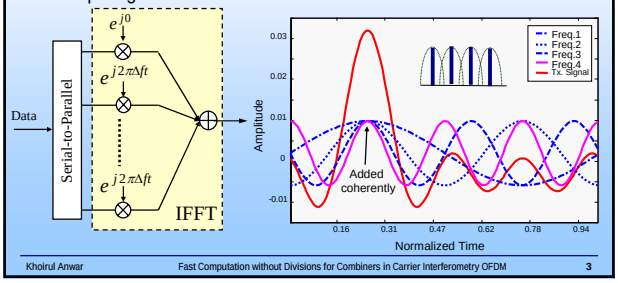
Presentation Outline

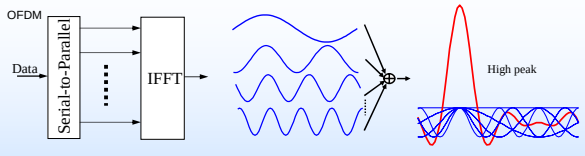
- Orthogonal Frequency Division Multiplexing (OFDM)
- Peak-to-Average Power Ratio (PAPR) Problem
- Carrier Interferometry OFDM (CI/OFDM)
- Multipath Fading Effects
- Frequency Domain Equalization
- Proposed Combiners
  - Make Efficient of FFT Spreading at the receiver
  - Fast Computation with Improved Newton-Raphson
- Conclusions

OFDM and High Peak Problem

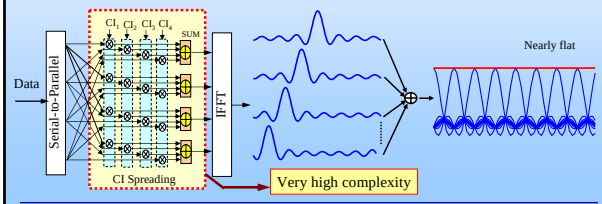
- OFDM : Technology for high-data rate applications and robust to against frequency selective fading effects.
- One disadvantage of OFDM is its high PAPR.
- Low PAPR → Safe Battery Power → Suitable for Ubiquitous Computing.



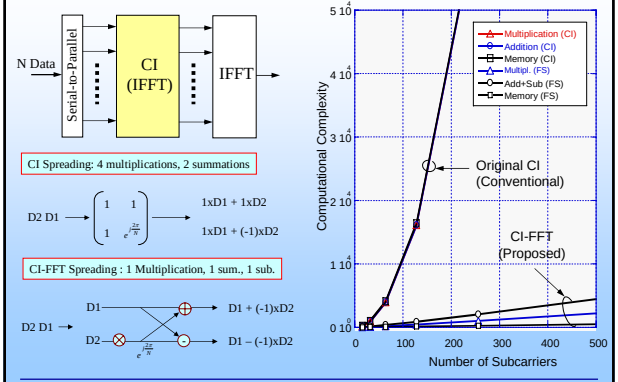
The Idea of Peaks Reduction



CI/OFDM [D.A Wiegandt et. al., "Overcoming PAPR issues in OFDM via Carrier Interferometry Codes", 2001]



Proposed FFT Spreading



Complexity Reduction by CI-FFT

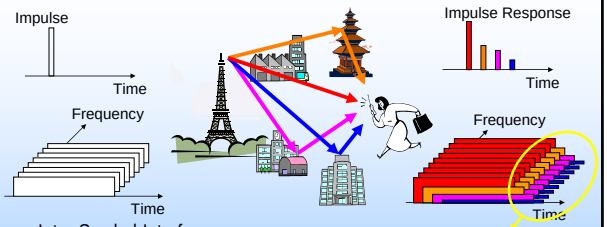
- IFFT is very efficient for replacing the CI
- IFFT can do both of CI generating and CI spreading at the same time

Computational Complexities of Generating CI Codes and Spreading Process*)

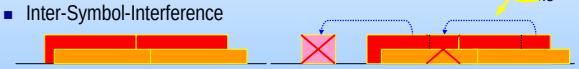
FFT	CI/OFDM			Proposed CI-FFT /OFDM			Saving (%)		
	Mul	Add	Mem	Mul	Add+Sub	Mem	Mul	Add+Sub	Mem
64	3,969	4,032	3,969	192	384	64	95.2	90.5	98.4
256	65,025	65,280	65,025	1,024	2,048	256	98.4	96.9	99.6
1,024	1,046,529	1,047,552	1,046,525	5,120	10,240	1,024	99.5	99.0	99.9
N	(*N*-1)x(*N*-1)	(*N*-1)x(*N*)	(*N*-1)x(*N*-1)	*N*/2log$_2$(*N*)	*N* log$_2$(*N*)		*N*		

*)K. Anwar and H. Yamamoto, "A New Design of Carrier Interferometry OFDM with FFT as Spreading Code", IEEE RWS 2006,

Multipath-Fading Effects

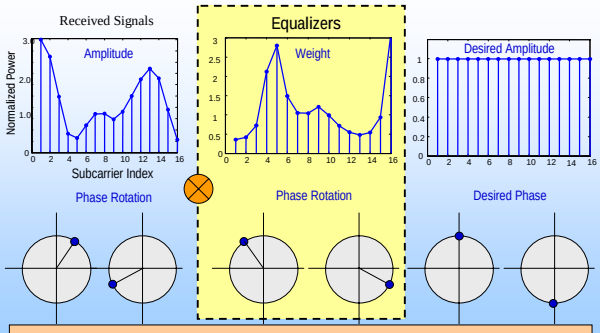


- Inter-Symbol-Interference



- Frequency Selective

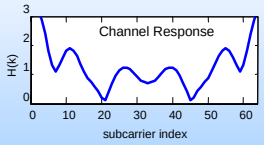
Frequency Domain Equalizations



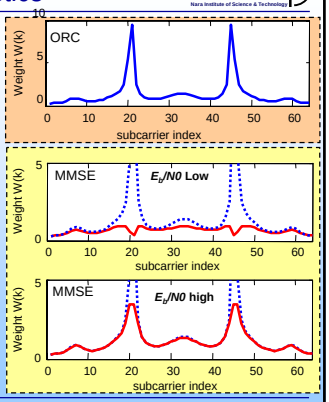
For Spread Signals, the equalized signals should be combined. Therefore, in CI/OFDM, this equalizer then called Combiner. In this Presentation we will focus on MMSE Combiners.

Equalizers Characteristics

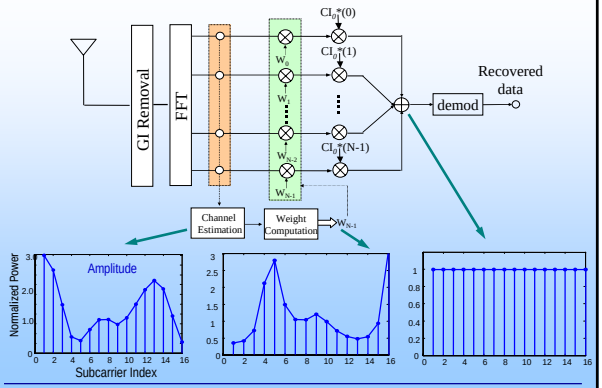
$$W(k)_{ZF} = \frac{1}{H(k)}$$



$$W(k)_{MMSE} = \frac{H^*(k)}{|H(k)|^2 + \sigma}$$



Equalizer → Combiner



Objectives of the Research

- Obtain fast and low complexity design of CI/OFDM
  - Replace the division operation in the computation of combiner weights.
  - Using the summation in FFT-spreading for performing Combiner.

- One division can replaced by 2 multiplications and 1 subtraction
- Simple combiners

Newton-Raphson Method

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

Calculate 1/*h*, *h* = channel response

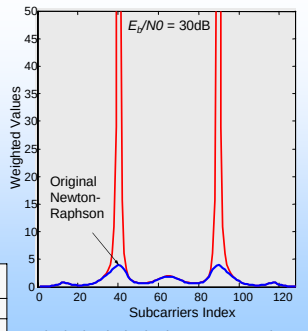
$$f(x) = \frac{1}{x} - h = 0 \qquad f'(x) = -\frac{1}{x^2}$$

$$x_{n+1} = x_n - \left(\frac{1}{x_n} - h\right) \Big/ \left(-\frac{1}{x_n^2}\right)$$

$$= x_n + (x_n - hx_n^2)$$

$$x_{n+1} = x_n(2 - hx_n)$$

Input (*h*)	Register	Expected value	Output (x_n)
1	0000 0001	1	1
2 - 3	0000 001X	1/2 – 1/3	0.4
4 -7	0000 01XX	1/4 – 1/7	0.2
…	…	…	…



To Obtain the desired value, Newton-Raphson need more than 15X iterations

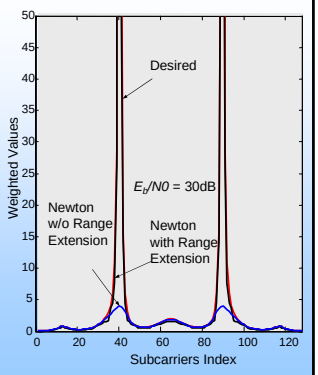
Proposed Range Extension

$$w = \frac{1}{h} \qquad w' = \frac{1}{h'}$$

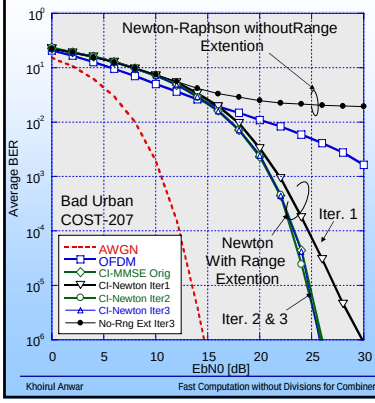
$$w' = \frac{1}{h'} = \frac{1}{h \times c} = \left(\frac{1}{h}\right) \cdot \frac{1}{c} = \frac{w}{c}$$

$$w = w' \times c$$

Input x 2^7 *(h)*	Register	Expected value	Output
128x(1)	000 0000 0001	128	128
128x(2–3)	000 0000 001X	128/2–128/3	51
128x(4-7)	000 0000 01XX	128/4–128/7	26
128x(8–15)	000 0000 1XXX	128/8–128/15	12
…	…	…	…

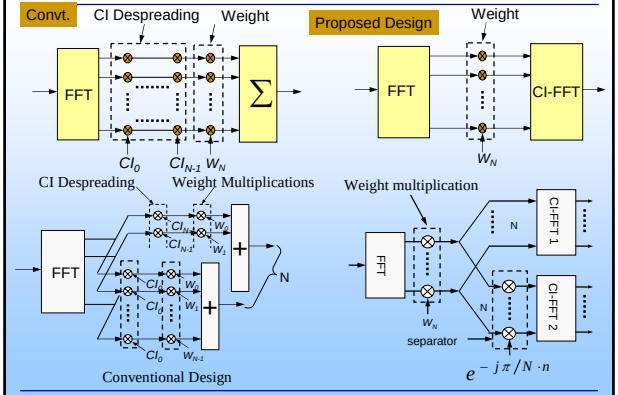


Bit-Error-Rate Performance



Arithmetic Operations	Original Computations	Proposed Computation	
		1 iteration	2 iterations
Div.	1	0	0
Mul.	2	4	6
Add/Sub.	1	2	3
Error	-	2dB at BER or 10^{-5}	0

Simple Combiner for CI & POCI/OFDM



Conclusions

- PAPR of OFDM can be reduce by CI-FFT/POCI-FFT
  - Simple Combiners, low computational complexity
  - Suitable for future ubiquitous computing with low power transmission
- Improvement of Newton-Raphson Method
  - One division can be replaced by 2 multiplications and one subtraction.
  - Range extension can reduce the number of iterations significantly from 15x → 2x