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LabVIEW User Group Meeting

Long Island Chapter

December 3rd , 2009

Department. of Electrical & Computer Engineering

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Polytechnic Institute of New York University

Novel PAPR Reduction Algorithm in MIMO-OFDM Systems

(LabVIEW Prototype & Simulation)

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Keywords

- Peak-to-Average Power Ratio (PAPR),
- Orthogonal Frequency Division Multiplexing (OFDM)
- Multiple Input Multiple Output (MIMO)
- World Interoperability for Wireless Access (WiMAX) IEEE 802.16
- Inverse Fast Fourier Transform (IFFT),
- Fast Fourier Transform (FFT),
- Discrete Cosine Transform (DCT),

OUTLINE

- **OBJECTIVES**
- **INTRODUCTION**
  - **MIMO SYSTEMS**
  - **OFDM SYSTEMS**
- **MIMO-OFDM SYSTEMS**
- **IEEE 802.11**
  - **WiFi**
- **IEEE 802.16**
  - **WiMAX : 4th Generation Wireless Systems**
- **The need for PAPR Reduction in MIMO-OFDM**
- **Earlier PAPR Reduction Techniques**
- **PROPOSED NOVEL ALGORITHM**
- **CONCLUSION**

OBJECTIVES

Propose a novel MIMO/OFDM PAPR reduction algorithm that:

– Meets the basic requirements
– Has negligible or no sacrifice of bandwidth or data rate.
– Conforms to the IEEE 802.16 standards
– Could be optimized.

INTRODUCTION

The following three performance parameters may be used to describe the quality and usefulness of any wireless link :

- Range
- Speed
- Reliability.

Prior to MIMO, increasing any of the three parameters usually results in tradeoff for the other two parameters. MIMO techniques exploit the multipath characteristics of the wireless links and could be combined with any modulation and access techniques. MIMO-OFDM has proved to boost all the three parameters simultaneously.

It is also a technology of choice in multipath and hash environment and it is the foundation of all proposals for the IEEE802.11n (WiFi) standard and also used in IEEE802.16 (WiMAX).

Need for PAPR Reduction

Limitation of OFDM technique is the large PAPR!

- Which makes the designer in leaving high backoffs for amplifiers and hence limiting the power amplifier performance
- Increasing the cost of the systems
- Degrade the bit error rate (BER) due to inter-modulation noise occurring in the non-linear amplifier.
- use of higher resolution analog-to-digital-converters to prevent the signal from being clipped or carrier inter-modulation to occur.

Hence, the need to reduce the PAPR of such systems.

OFDM TRANCEIVER SYSTEM

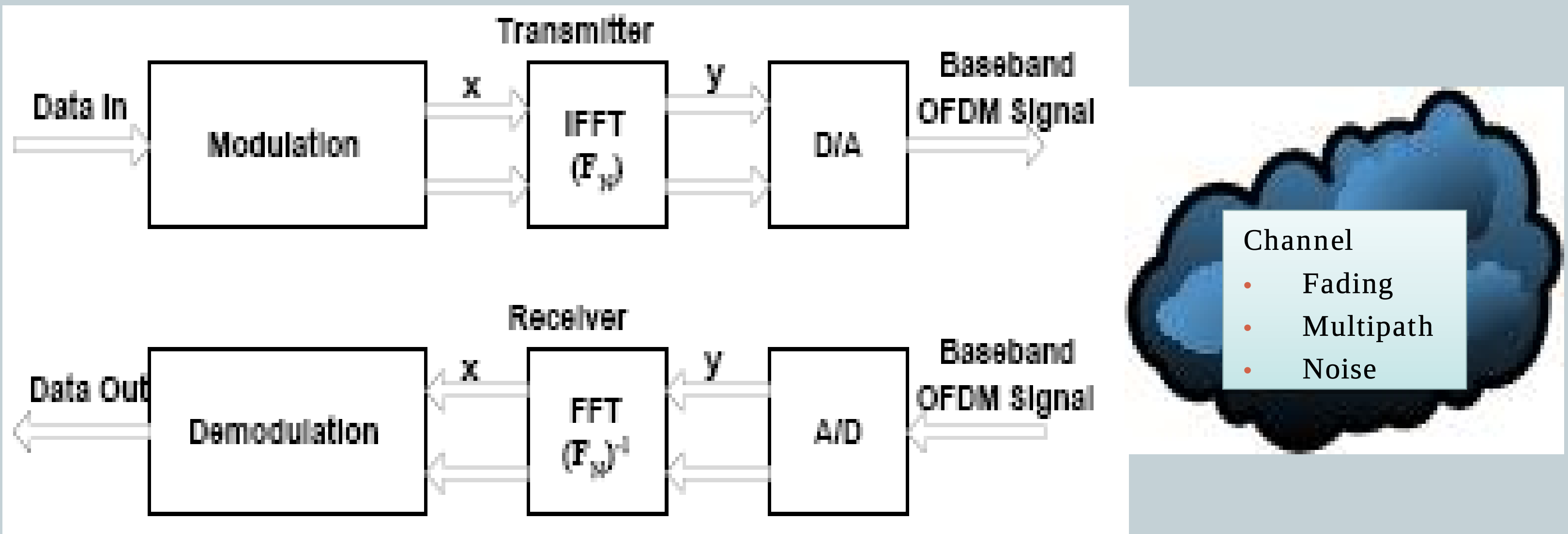


Fig 1: OFDM BLOCK [18]

Why Orthogonal Frequency Division Multiplexing (OFDM)?[18]

- **High spectral efficiency –**provides more data services.
- **Resiliency to RF interference –**good performance in unregulated and regulated frequency bands
- **Lower multi-path distortion –**works in complex indoor environments as well as at speed in vehicles.

System Standards that use OFDM

Wireless

- IEEE 802.11a, g, j, n (WiFi) Wireless LANs
- IEEE 802.15.3a Ultra Wideband (UWB) Wireless PAN
- IEEE 802.16d, e (WiMAX), WiBro, and HiperMANWireless MANs
- IEEE 802.20 Mobile Broadband Wireless Access (MBWA)
- DVB (Digital Video Broadcast) terrestrial TV systems: DVB-T, DVB-H, T-DMB and ISDB-T
- DAB (Digital Audio Broadcast) systems: EUREKA 147, Digital RadioMondiale, HD Radio, T-DMB and ISDB-TSB
- Flash-OFDM cellular systems
- 3GPP UMTS & 3GPP@ LTE (Long-Term Evolution), and 4G

Wireline

- ADSL and VDSL broadband access via POTS copper wiring
- MoCA(Multi-media over Coax Alliance) home networking
- PLC (Power Line Communication)

The Multi-Path Problem

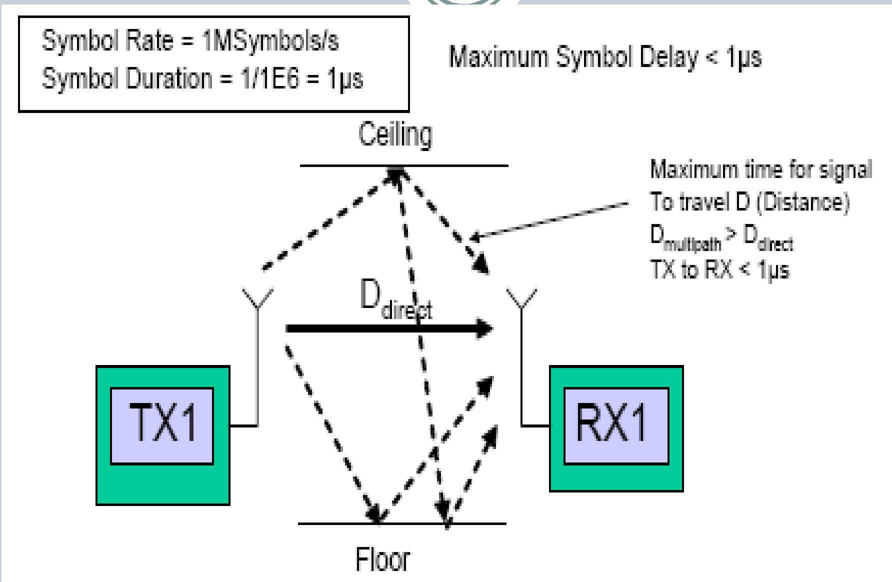


Fig. 2 - Example: Bluetooth Transmitter & Receiver [18]

Multi-path adds another layer of complexity to Error Vector Magnitude measurements. In this example, we can see the Bluetooth signal has a symbol rate of one mega-symbol per second.

Slow the Symbol Rate

That means that the receiver will expect a specific symbol within a window of one microsecond. If multi-path delays the signal by more than one microsecond, then this could result into inter-symbol interference, which may cause a significant symbol error.

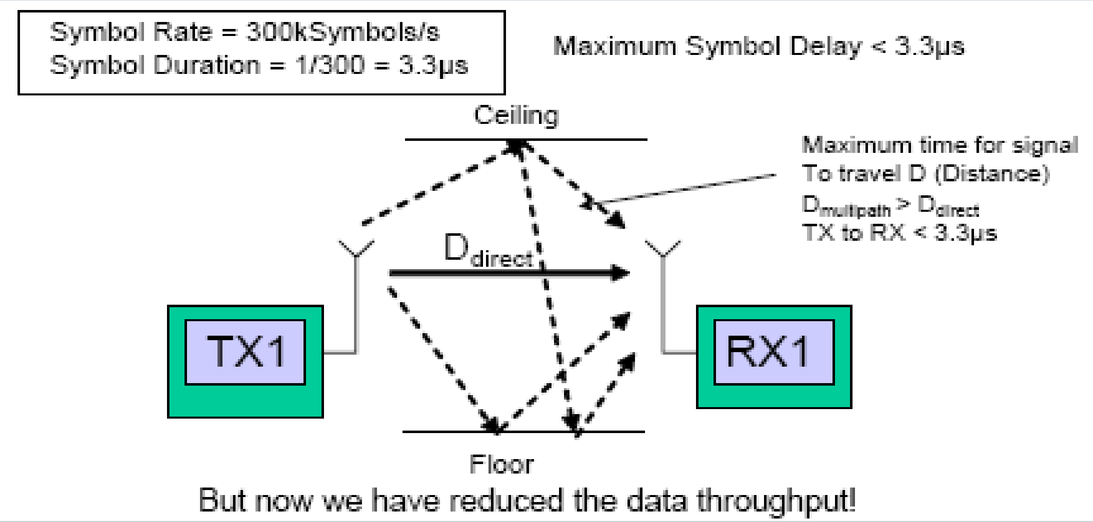


Fig.3 - Reduce the Previous Example's Symbol Rate by a Third [18]

Fig 3 showed that the symbol rate could be slowed by a third, thus improving the maximum time for the signal to travel. However, this will be a significant reduction in the data throughput if a single carrier scheme is used.

Why Orthogonal Frequency Division Multiplexing ?

- Instead of transmitting a single symbol at a time, OFDM transmits multiple symbols simultaneously on a number of carriers. This is the Frequency Division Multiplex component. The sub-carriers are distributed in carefully chosen multiples of frequency so that they are "orthogonal," so that the closely adjacent sub-carriers don't interfere with each other.

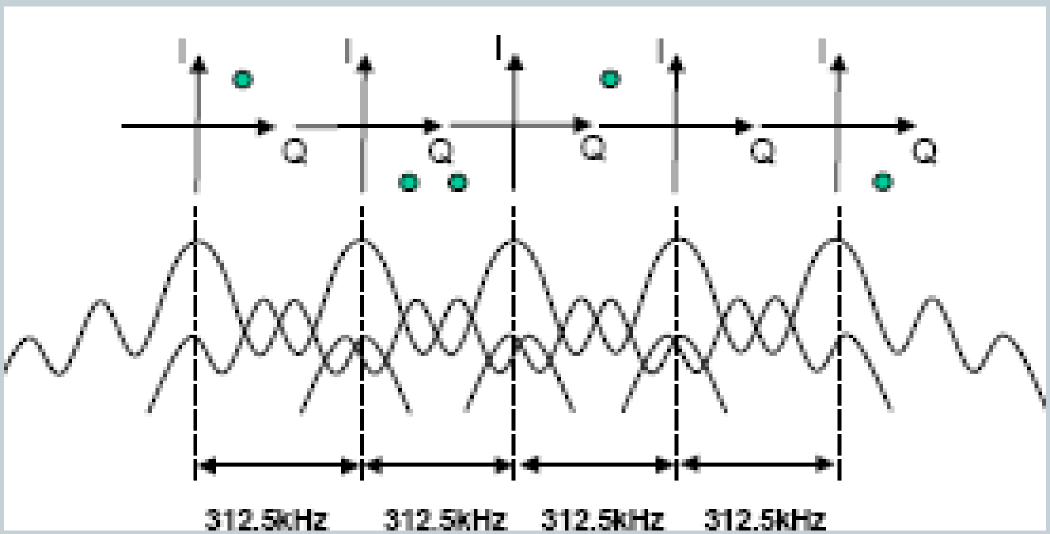


Fig 5: OFDM signals [18]

– Fundamentally, the objective is to slow down the symbol rate, while maintaining a high data rate by using an Inverse FFT to facilitate the transmission of slow symbols in parallel rather than fast symbols in serial as discussed in the previous slide.
– Each sub-carrier symbol contributes to the time domain waveform, but can be separated by the FFT at the receiver.

Conforming IEEE 802.16 Proposal & Recommendation

Peak-to-Average Power Ratio Reduction

As there are various methods of PAPR Reduction, there are various places to introduce this block into the transmit chain. The choice of the best methods needs to be investigated. Example options are various coding algorithms, carrier scaling, clipping, usage of peak reduction carriers, companding techniques etc.

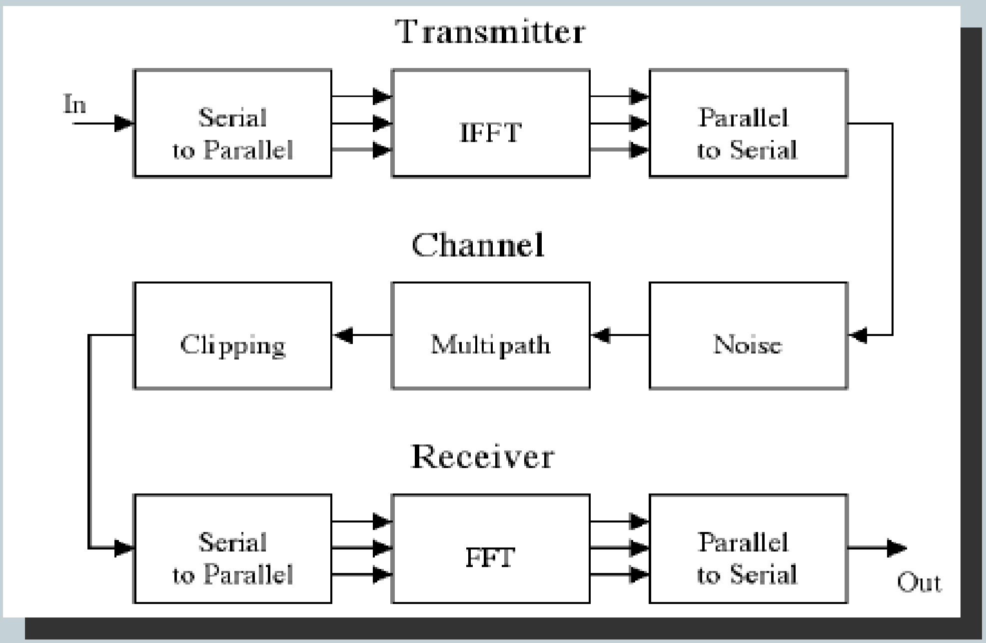


Fig 7: OFDM Spectral Efficiency [13]

Basic Requirements for PAPR Reduction Techniques

Basic requirement of practical PAPR reduction techniques include

1. The compatibility with the family of existing modulation schemes,
2. High spectral efficiency (negligible or no redundancy)
3. Low complexity

Earlier PAPR Reduction Techniques

Several techniques have been proposed in the literature to reduce the PAPR.

These techniques can generally be categorized into the following two:

1. Signal scrambling techniques
2. Signal distortion techniques.

Specific Classifications

- Clipping [1]
- Partial transmit sequence (PTS) [3-4]
- Selective mapping (SLM)[2-3]
- Tone reservation [5-7]
- Tone Injection
- Constellations Manipulations[8,24]
- Coding [9-10]

Earlier PAPR Reduction Techniques cont..

Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR.

Coding techniques can be used for signal scrambling. More practical solutions of the signal scrambling techniques are block coding, Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS).

The signal distortion techniques introduce both In-band and Out-of-band interference and complexity to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification.

Earlier PAPR Reduction Techniques - CLIPPING

CLIPPING

Clipping the OFDM signal before amplification is a simple method to limit PAPR. Complex baseband hard clipping is given by:

$$g(m) = \begin{cases} m & m < m_{\max}, \\ m_{\max} & m \geq m_{\max}, \end{cases}$$

Where m_{max} denotes the clipping magnitude. The behavior of a real solid state HPA is described the following equation.[20]

$$g(m) = \frac{m}{\left(1 + (m/m_{\max})^{2p}\right)^{1/2p}}$$

However, clipping may cause large out-of band (OOB) and in-band interference, which results in the system performance degradation.

Earlier PAPR Reduction Techniques - PTS.

Partial Transmit Sequences (PTS)

PTS exploited the linearity of IDFT by dividing the information bearing subcarrier blocks into disjointed carrier subblocks. A rotation vector is introduced for each subblock that modifies the amplitude vector. The subblocks are transformed by separate IDFTs to produce the partial transmit sequences.

Peak value optimization is then performed so as to transmit the sequence with the least PAPR of all the alternative transmit sequences. PTS may introduce some transmitter redundancy and complexity [4]

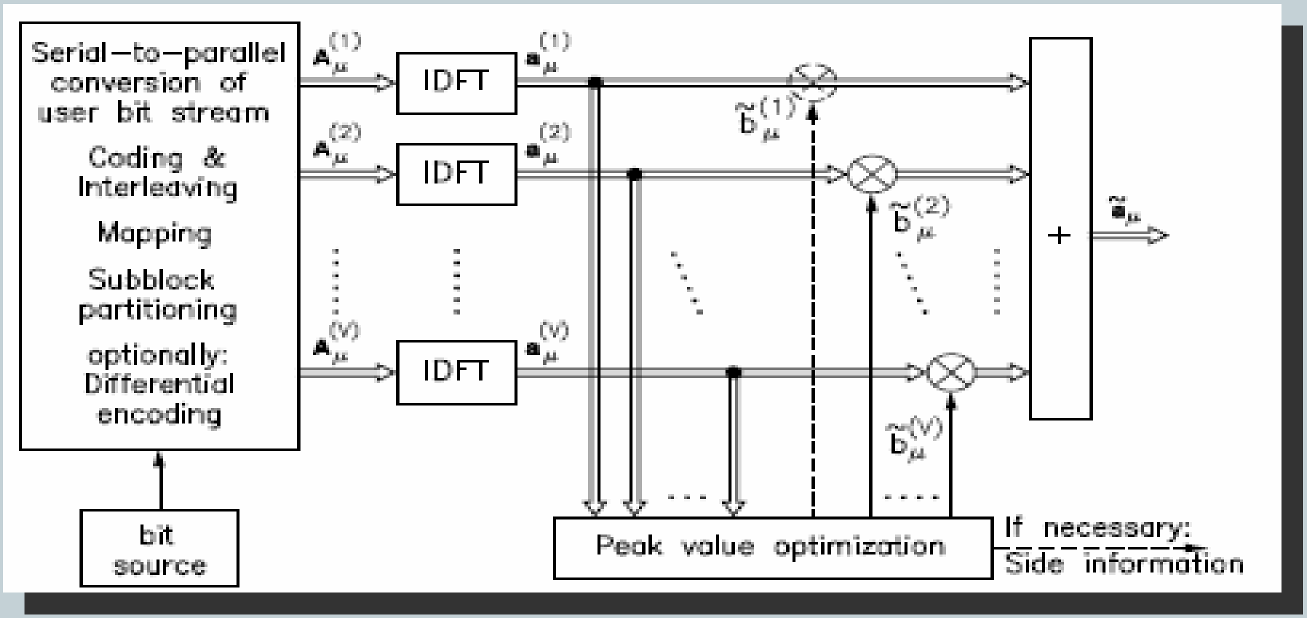


Fig 8 – PTS Reduction Technique in OFDM [4]

Earlier PAPR Reduction Techniques – SLM & PRC.

SeLected Mapping (SLM)

SLM technique generates several OFDM symbols as candidates and then select the one with the lowest PAPR for the actual transmission. Conventionally, the transmission of side information is needed so that the receiver can use the side information to determine which candidate is selected in the transmission and then recover the information. SLM technique do introduced some additional complexity, but with loss in efficiency [3]

Peak Reduction Carriers (PRC)

A modified form of SLM technique was also proposed that combines selective mapping technique and cyclic coding that could achieve 5dB reduction in the PAPR. Extra carriers referred to as Peak Reduction Carriers (PRC) were added for this purpose. [21] Lawrey's assumption (suggestion) is that further work will allow for more efficient algorithm to be found.

Earlier PAPR Reduction Techniques – Coding .

Coding

Coding method relies on using several bits or bit sequences which would carry a properly chosen code (sometimes with error correcting capabilities) that minimizes the PAPR of the resulting transmitted signal. The PAPR is reduced, but so is the data rate.

NOTE: Those methods with high complexity or those that require coded side information to be transmitted raises problems in terms of compliance to standards.

Earlier PAPR Reduction Techniques – Tone Reservation .

Tone Reservation

Tone Reservation propose inserting anti-peak signals in unused or reserved subcarriers. The method does not cause any in-band distortion, but it reduces the useful data rate. Although suited in some implementations (IEEE 802.16e for example), it is not always standard compliant (the bandwidth sacrifice required by this method is not acceptable in IEEE 802.16d).

Tone Injection

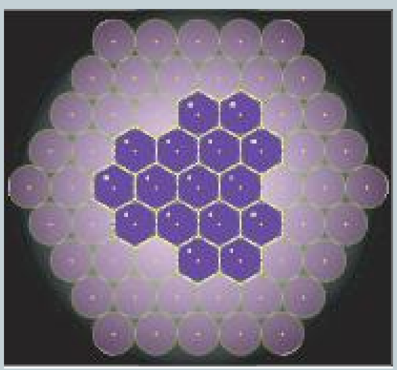
Another family of methods proposes altering the QAM constellation in order to reduce high signal peaks. The first method relying on the principle of constellation expansion was Tone Injection. However, using this technique for systems with high number of carriers usually involve complex optimization process.

Earlier PAPR Reduction Techniques – Constellation Shaping.

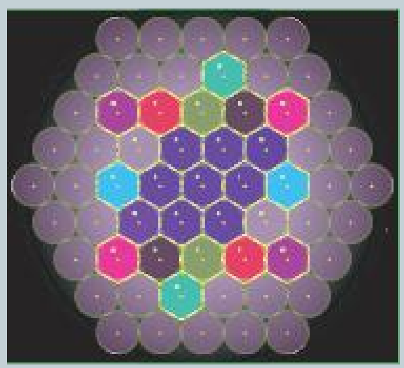
Constellation Shaping

Constellation in the frequency domain is performed such that the resulting shaping region in the time domain has a low PAPR. Example include Hadamard constellation shaping, constellation extension (see Figure 9) and active constellation extension (ACE) techniques . Each data symbol s, is chosen from the set of signaling alphabet Q = $\{\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_M)$ of *M* distinct elements. The set Q is called the signal constellation and M is the number of elements of Q is the order.

The set Q is called the signal constellation.



(a) A normal 16-QAM



(b) An extended 16-QAM

This technique, like PTS are actually of exponential complexity, rendering the method useless as the number of channels increases. [24]

Fig. 9 Hexagonal 16 Symbol QAM Constellations [24]

WiMAX

WiMAX is acronym for Worldwide Interoperability for Microwave Access, and it is also known as IEEE 802.16. In practical terms, WiMAX would operate similar to WiFi but at higher speeds, over greater distances and for a greater number of users. WiMAX - Leading edge of the fourth generation (4G) of wireless WAN.

- WiMAX ' specifications are set by the WiMAX forum (www.wimaxforum.org/home) and based on the standards developed by the IEE 802.16 Working Group (grouper/groups/802/16).
- Two existing standards are:
  - IEEE802.16d for fixed (both ends stationary)
  - IEEE802.16e for mobile broadband technology.
- A WiMAX system consists of two parts; a WiMAX tower that could provide coverage upto 3,000 square miles (~8,000 square km) and the WiMAX receiver in form of a PCMCIA card, or built into a laptop the way WiFi access is today.

DCT & IDCT

- A discrete cosine transform (DCT) expresses a sequence of finitely many data points in terms of a sum of cosine functions oscillating at different frequencies.
- A DCT is a Fourier-related transform similar to the discrete Fourier transform (DFT), but using only real numbers. DCTs are equivalent to DFTs of roughly twice the length, operating on real data with even symmetry.
- The DCT is used in JPEG image compression, MJPEG, MPEG, DV, and video compression.

DCT of a 1-D sequence of length N is

$$C(u)=\alpha(u)\sum_{x=0}^{N-1} f(x)\cos\left[\frac{\pi(2x+1)u}{2N}\right]$$

IDCT for 1-D Inverse transformation is

$$f(x)=\sum_{u=0}^{N-1} \alpha(u)C(u)\cos\left[\frac{\pi(2x+1)u}{2N}\right]$$

for u =0,1,..,N-1 and α =0,1,..,N-1

WHY USING DCT?

Energy compaction properties of the DCT [11]

- The energy compaction properties of the DCT make it useful in applications, including data communications.
- DCT concentrates the energy of the original signal into few coefficients.
- Reduction in the autocorrelation between the components of each OFDM signal will result into a reduced PAPR

Low cost DCT could be implemented using FGPAs

- An FPGA example is the Xilinx Virtex FPGA[23]

PAPR Reduction System

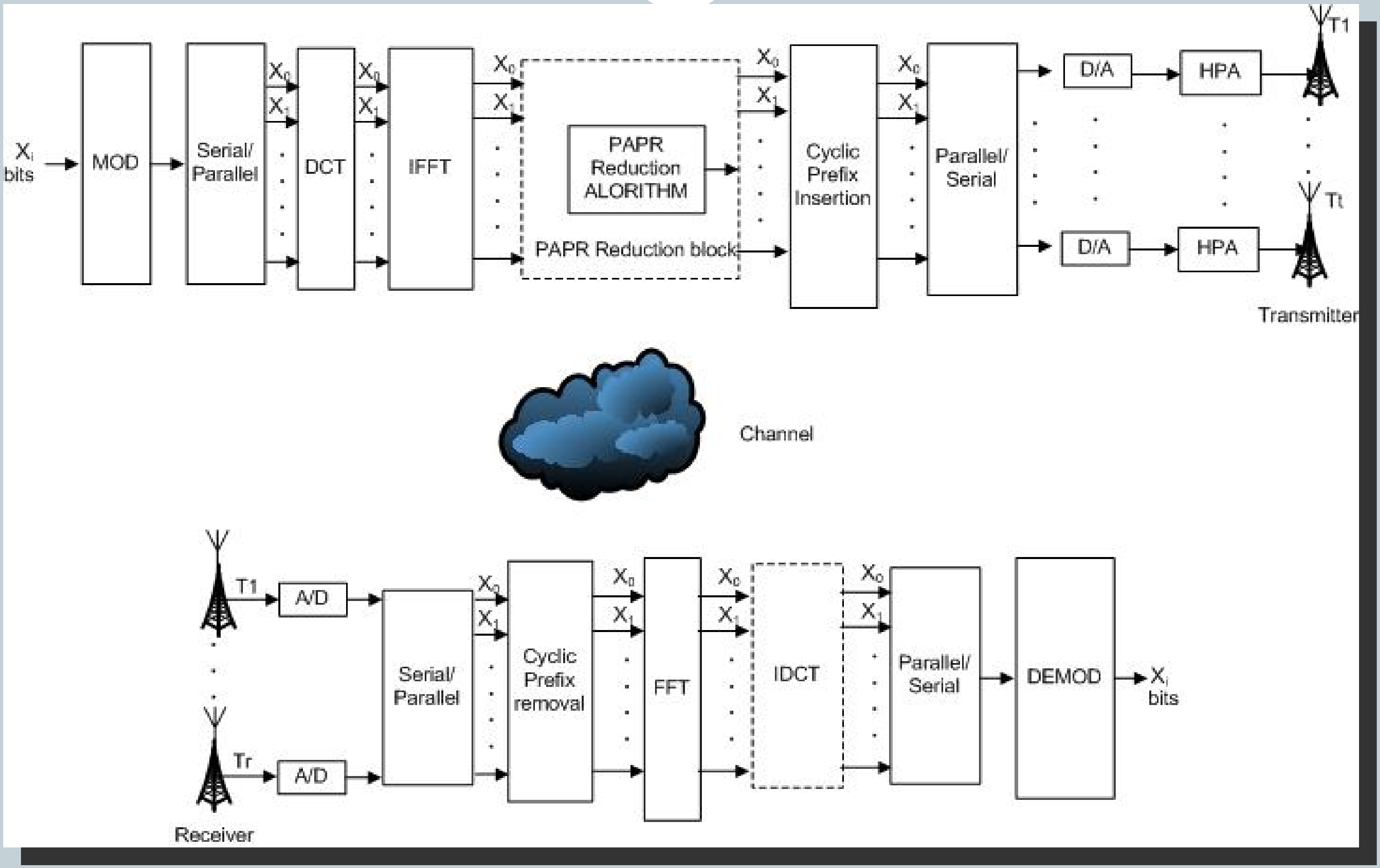
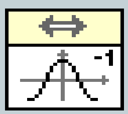
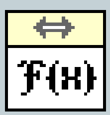
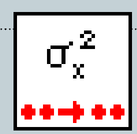


Fig. 9: PAPR Reduction tranceiver in MIMO-OFDM

PAPR Reduction Flowchart

LabVIEW already has built-in functions for the following building routines for the algorithm:

– DCT 
– IDCT
– IFFT 
– FFT
– MEAN *(μ)* 
– VARIRANCE *(σ2)*

*PAPR=Max[x*x]/E[x*x]*

*where E[x*x]= σ2+(μ*μ)*

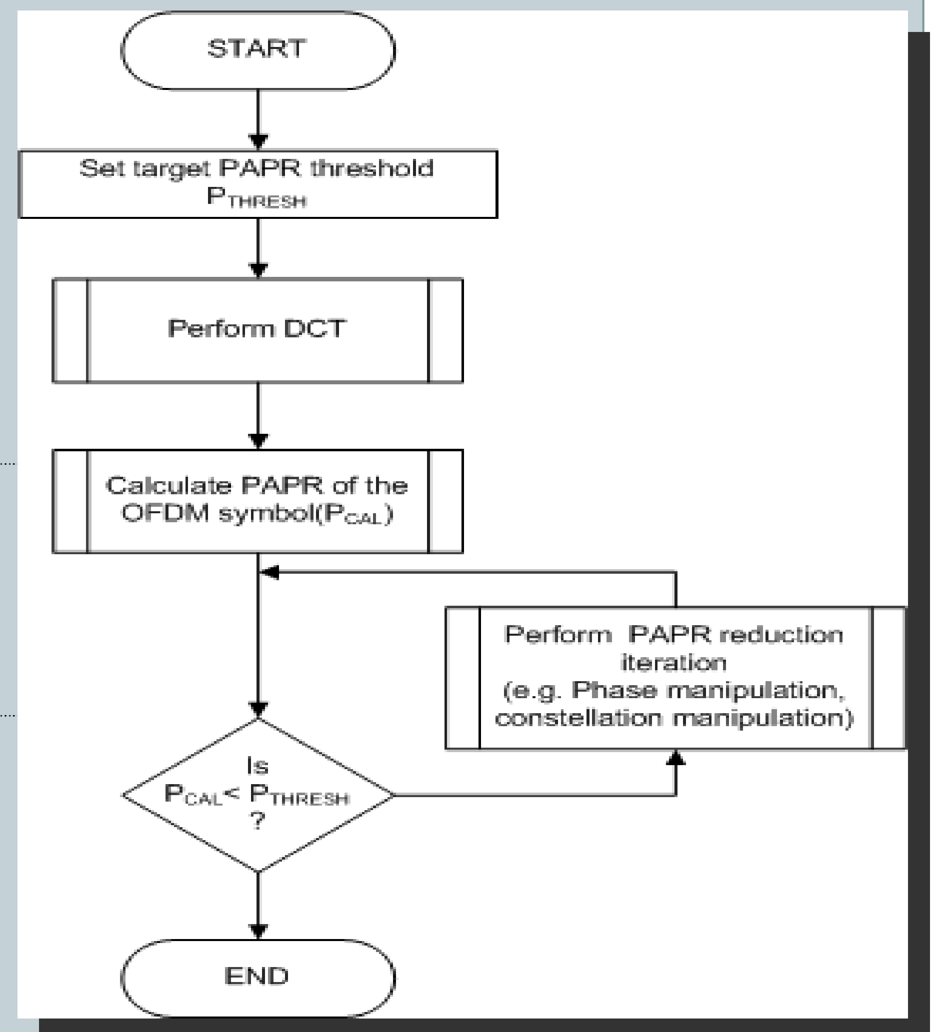


Fig 10 – Top Level Flowchart

Computation of the PAPR of a single cosine tone

The PAPR for a signal $x(t)=A\cos(2\pi F_c t)$ is defined as $\boxed{\dfrac{P_{peak}}{P_{avg}}}$

P_{peak} *is the peak power and* P_{avg} *is the average power of x(t).*

It could also be expressed as:

$$\boxed{papr = \frac{\max\left[x(t)x^*(t)\right]}{E\left[x(t)x^*(t)\right]}}$$

$E[x(t)x^*(t)]$ *is the statistical expectation of* $|x^2(t)|$,. Expressed in deciBels:

$$\boxed{papr_{dB} = 10\log_{10}(papr)} = \boxed{10\log_{10}\left(\frac{P_{peak}}{P_{avg}}\right)}$$

The **crest factor (C)** or **peak-to-average ratio** (**PAR**), is the square root of the **peak-to-average power ratio** (**PAPR**), and may be defined as:

$$\boxed{C = \frac{|x|_{\text{peak}}}{x_{\text{rms}}}}$$

$|x|_{peak}$ *is the peak value and* x_{rms} *is the root-mean-square value of x(t).*

Computation of the PAPR of a single cosine tone

Consider a sinusoidal signal having with *frequency* F_c, *i.e.*

$x(t)=A\cos(2\pi F_c t)$

The peak power, P_{peak} ,for the signal is: $\max\left\{\left|A^2\cos^2(2\pi F_c t)\right|\right\} = A^2$

The average power, P_{avg} , is:

$$
\begin{aligned}
P_{avg} &= F_c \int_0^{1/F_c} A^2 \cos^2(2\pi F_c)dt \\
&= F_c \int_0^{1/F_c} A^2 \left[\frac{1}{2} + \frac{1}{2}\cos(4\pi F_c t)\right] dt \\
&= \frac{F_c}{2}\left\{\frac{A^2}{F_c} + \underbrace{\int_0^{1/F_c} A^2 \cos(4\pi F_c t)dt}_{=0}\right\} = \frac{A^2}{2}
\end{aligned}
$$

Hence, the PAPR of the single cosine tone = $\frac{A^2}{A^2/2} = 2$

Or in deciBels, the PAPR = $10\log_{10}\left(\frac{P_{peak}}{P_s}\right) = 10\log_{10}\left(\frac{A^2}{A^2/2}\right) = 3dB$

PAPR Computation in LabVIEW

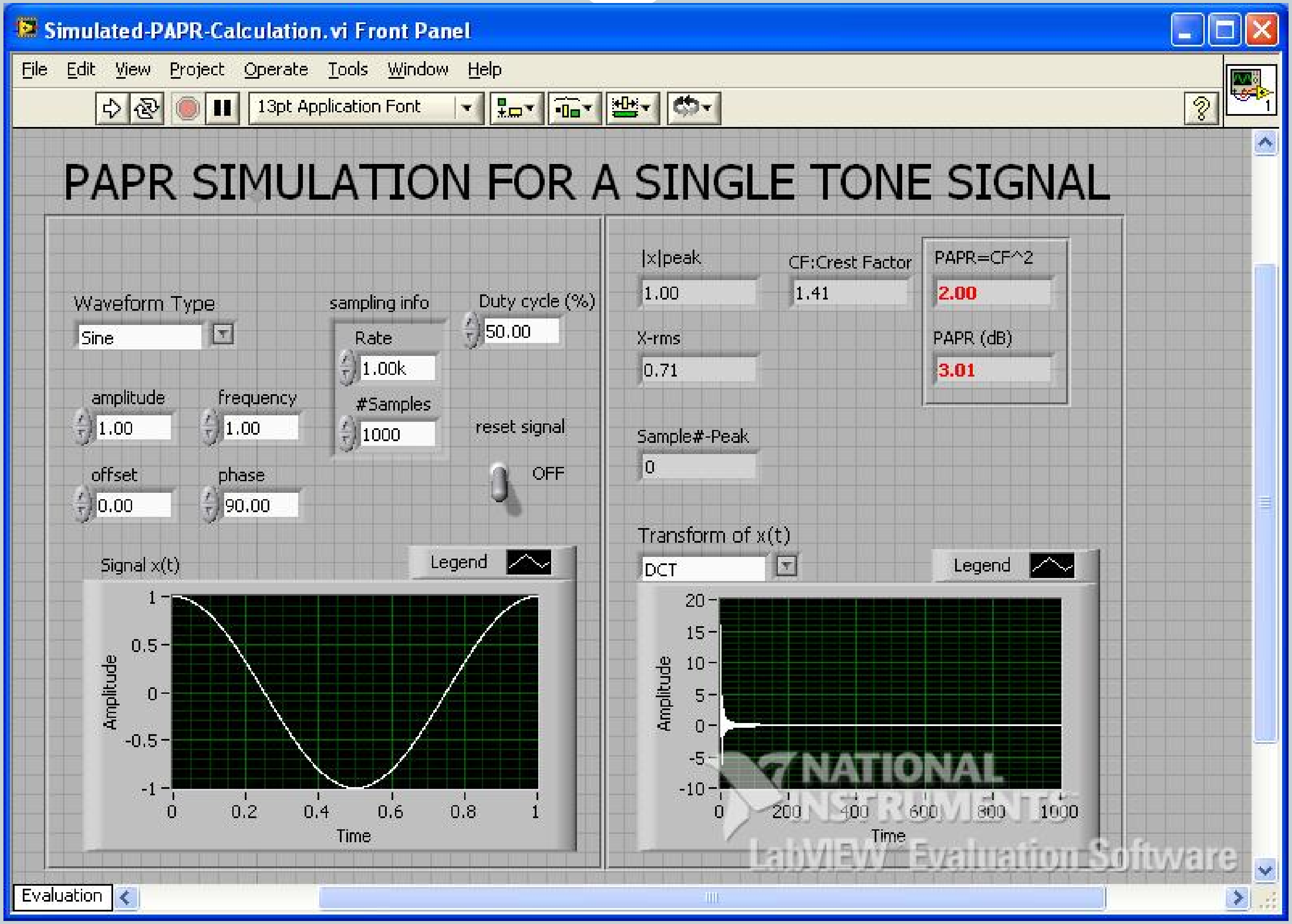


Fig. 11: PAPR Calculation for a single cosine tone – Front Panel

PAPR Computation in LabVIEW

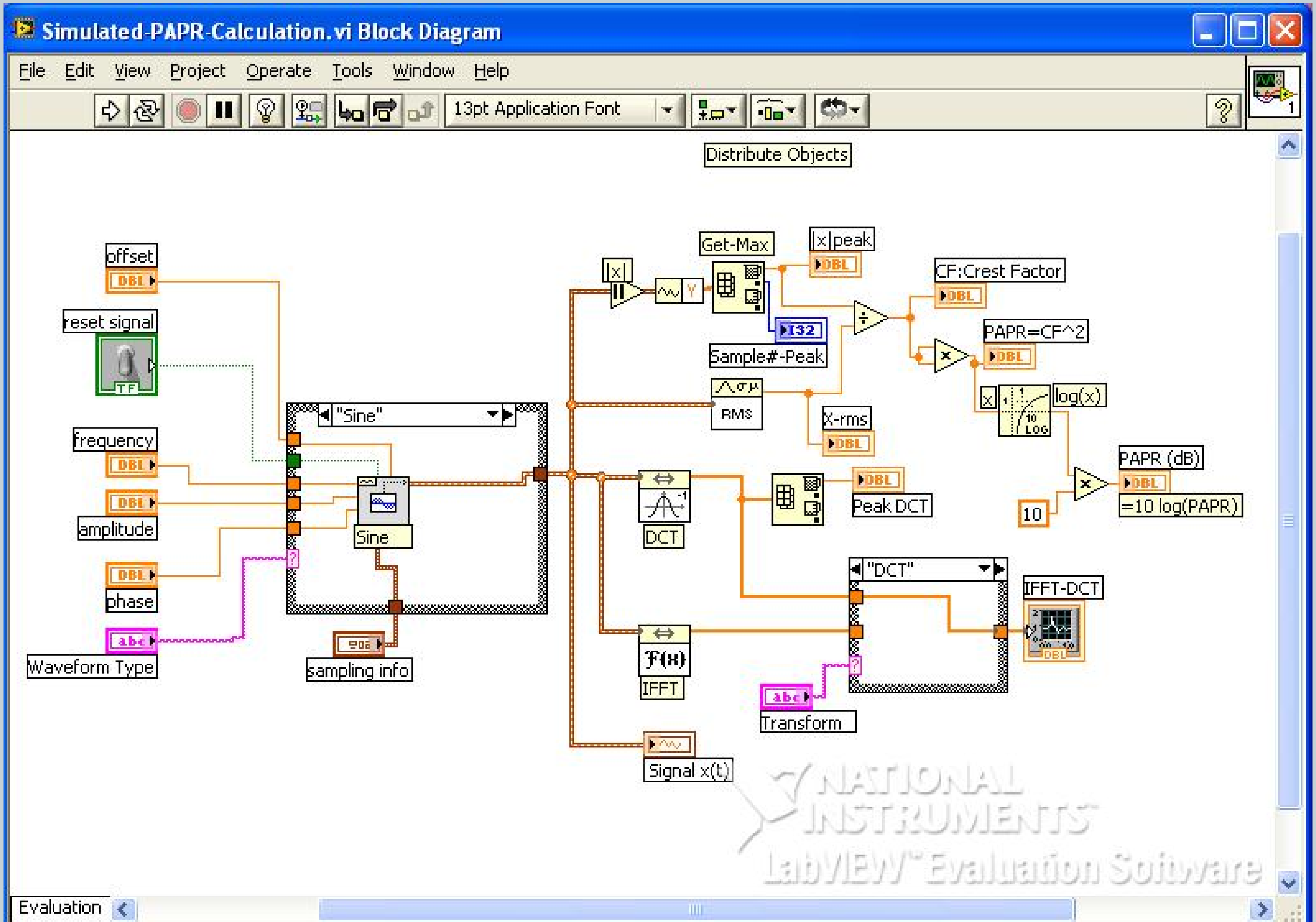


Fig. 12: PAPR Calculation for a single cosine tone – Block Diagram

Conclusion

- This Research work is in progress to propose a MIMO/OFDM PAPR reducing technique that meets the basic requirements and will exceeds earlier reduction achievements and the simulation is being programmed in Labview.
- WiMAX (IEEE 802.16) is being used as a case study.
- Labview could easily be used to implement the simulation of the OFDM System to test the proposed PAPR reduction technique.

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