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# Short Distance Communication through 2-D barcodes for Low Data Rate Applications

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*Abstract-* **The practical areas of short distance optical wireless barcode technology can be improved manifold by the introduction of a temporally varying barcode method which can transfer large data files of any format. This method uses camera in smartphones as an alternative data channel. The data is encoded as a sequence of 2-D barcode images, displayed on a flat panel display, acquired by the camera, and decoded in real time by the software embedded in device. The decoded data is written to a file. The main advantage of such a scheme is that it does not require specifically developed hardware unlike other short range wireless technologies such as Bluetooth and Wi-Fi. Technical challenges to its implementation include correction of perspective distortion, compensation for contrast variation, and efficient implementation of small footprint software on handheld mobile devices. In this paper, we have developed a new data format for more efficient file transfer.**

***Index Terms*—Barcode, wireless optical communication, OFDM.**

## I. INTRODUCTION

A Barcode is a simple and cost-effective method of storing machine readable digital data on paper or product packages. The 2D barcode (e.g., QR code) or matrix barcode is an iteration of 1D barcode design and is used in more complex data transfer scenarios like storing contact information, URLs etc. Use of OFDM to modulate LCD pixels has proven to provide the highest data rates from experiments involving docked (fixed, stationary) devices. This is because while image blur and light leakage (between neighboring pixels) greatly reduce the performance of QR decoders they have a limited effect on OFDM modulation. This paper extends this idea through additional modifications on the modulation scheme to mitigate LCD-camera relative movements during the capture of a single frame, which results in motion blur distortion on the captured images. Thus, a combined DPSK-OFDM scheme is introduced. Though the performance of the system inherently depends on the quality of the LCD display and camera, and the processing power of the devices, an analysis of the limiting factors is essential. In this paper, Differential Phase Shift Keying was combined with Orthogonal Frequency Division Multiplexing in order to modulate data stream into visual two dimensional barcodes. It was shown that QPSK-OFDM modulation has serious shortcomings in the mitigation of camera LCD movements where the phase of each element changes
continuously.

On the other hand, addition of a differential phase modulator before OFDM to modulate the data stream into phase differences of adjacent elements (DPSK-OFDM) causes the motion effect to increasingly weaken because of its gradual change from element to element, contributing to a small deviation from the ideal phase in the received signal. It was observed that under relative LCD-camera motions that generate error rates in excess of 30% in PAM and QPSKOFDM, the proposed system of DPSK-OFDM will maintain an error rate less than 8% which is practically correctable using error correction coding.

## II. DETAILS EXPERIMENTAL

### *A. Related Work*

In this section, we analyze the existing methods and proposed methods to make an overall idea. Though the performance of a system inherently depends on the quality of the LCD display and camera, and the processing power of the devices, an assessment of the limiting factors which affect the transfer rate is essential. Considering a standard LCD display, the theoretically achievable data rate is calculated. The maximum data capacity of an LCD, for a single image,as

$$Ci = M_i \times N_i \times L_i \times B_i \text{ bits per image} \quad (1)$$

where Md: number of rows; with a standard value of 1136 Nd: number of columns; with a standard value 640 Ld: number of channels; Ld = 3 generally, for red, green & blue; Bd: color bit depth per channel; generally, a value 8. A screen refresh rate of R gives a total data rate of R x Ci (i.e., for a series of images). Data rate of time varying QR code = R x Ci, with a standard value R = 60 Hz. This would be equal to ~1 Gbps for standard displays, considering standard values, although not achievable in practice due to the following limitations:

***Camera Limitations:*** For correct sampling of consecutive frames in time, camera capture rate should be 2 times the display refresh rate. If the camera capture rate is, for example, Rc = 8 Hz, then the display refresh rate should be limited to maximum of 4Hz.

***Power Limitations*:** Increasing the intensity/optical power from the transmitter, in general, would improve signal to interference and noise ratio (SINR) in the receiver. In LCDs, the power is limited by the intensity of light it can generate leading to Peak to Average Power Ratio (PAPR) limitation. Since the maximum value of PAPR occurs when Average Power is small, if maximum power is fixed; a trade-off is required between average transmitted power and distortion due to clipping of the peaks.

***Inter-Symbol Interference (ISI)*:** When data is shown on an LCD, light that is passing through white pixels may leak into neighboring black pixels making them look grey. This is solved by increasing the size of the pixels so that they have minimal effects on each other. The sizing of the pixel is called barcode granularity. But, this greatly decreases the transfer-rate because the amount of information that can be encoded into the 2D code is reduced. Further, movements between camera and LCD during the capture of an image for barcode processing results in motion blur which is translated into ISI as neighboring pixels affect each other in the captured image. Another source of error is perspective distortion which occurs if the camera is not held parallel to the LCD display. But its effects are not much pronounced.

***Interference, Distortion, and Noise:*** Artifacts may be introduced due to the following reasons:

- Distance and angle between camera and LCD (perspective distortion);
- camera and subject relative motion;
- out of focus lens;
- compression distortions;
- unwanted ambient light sources;
- dirt and permanent marks on the LCD;
- noise (primarily additive Gaussian noise).

The most recent system implementations and modulation techniques use Orthogonal Frequency Division Multiplexing (OFDM) to mitigate some or many of these issues. In such systems, the main limiting factor to performance is the sub-carrier modulation method employed. Thus, the proposed system is aimed at overcoming those issues, especially the most detrimental factor – the screen-camera relative motion.

### *B. Proposed System*

In the proposed system section an overview of the implementation of a combined DPSK-OFDM modulation scheme that can be used for optical wireless data transmission using a temporally varying barcode is produced. The advantages and drawbacks of the proposed method over existing OFDM-based modulation schemes is also provided.

***DPSK-OFDM**:* Advances in LCD technology have resolved pixel-to-pixel isolation problem which was the earlier cause of Inter Channel Interference (ICI). But, some form of image capture distortion introduces ISI due to the mix up of adjacent pixels of the barcode in the image detected by the portable device camera, mainly due to LCD-Camera relative motion. Thus, the barcode image is interpreted as a wireless radio signal for which ISI reduction techniques have already been proven successful. OFDM is adopted— due the band-limited, power-constrained and multipath properties of the channel— which transfers multiple narrow-band signals in parallel instead of a single high bandwidth signal. DPSK is used to modulate the sub-carriers of each OFDM channel.

***Similarities between Barcode and Wireless RF Channel**:* For simplicity, the 2D barcode is thought of as a combination of multiple 1D rows of pixels. Each row can be considered as a time domain signal which has Pulse Amplitude Modulation where, zero represents black and 1 represents white pixels. Considering the barcode as a time domain radio signal, OFDM method is used to essentially divide the channel into multiple orthogonal low bandwidth channels and the low rate data is sent into these channels in parallel. Thus, inverse Fourier Transform is used for displaying the data instead of PAM modulated process. In this method, most artifacts only affect the high frequency components leaving low frequency components intact for data transmission. In older methods, each sub-carrier in an OFDM signal is modulated using M-quadrature amplitude modulation (M-QAM). Thus, proper phase shift of each element needed to be estimated and compensated for before demodulation. When using OFDM for transmission of data as images, all the channel equalization calculations are based on a single OFDM frame due to the independent channel response between subsequent frames, since the frame rate is very low. Each frame is distorted by LCD-Camera relative motion during its own capture time. To mitigate this problem, the phase difference between adjacent elements is used to convey data. Thus, DPSK modulation is used prior to applying the inverse Fourier transform in OFDM modulation, data would not have to be stored in the absolute phase of the received elements but rather in its phase difference to the neighboring element, which eliminates the requirement for channel estimation and equalization if the channel response does not vary abruptly between adjacent subcarriers.

***Transmitter:*** The basic advantage of using OFDM is its effective computation method which uses the Inverse Fast Fourier Transform (IFFT) to modulate input data into orthogonal frequencies. This implies that the computationally efficient IFFT algorithm can be used to modulate the data stream into orthogonal components. The input data to the DPSK modulator is decomposed into 2-bit symbols. Each symbol is converted to a complex phase – first bit modulates the real component and the second bit modulates the imaginary component of the phase.

$$11 \rightarrow e^{j\pi/4}, 10 \rightarrow e^{j7\pi/4} \rightarrow 01 \rightarrow e^{j3\pi/4}, 00 \rightarrow e^{j5\pi/4} \quad (2)$$

The modulated signal should be real-valued in order to be shown on an LCD, so the input to the IFFT algorithm should satisfy the Hermitian symmetry condition shown by:

$$T(M-m, N-n) = T(m,n)^* \quad (3)$$

where m lies between 0 and M and n lies between 0 andN.

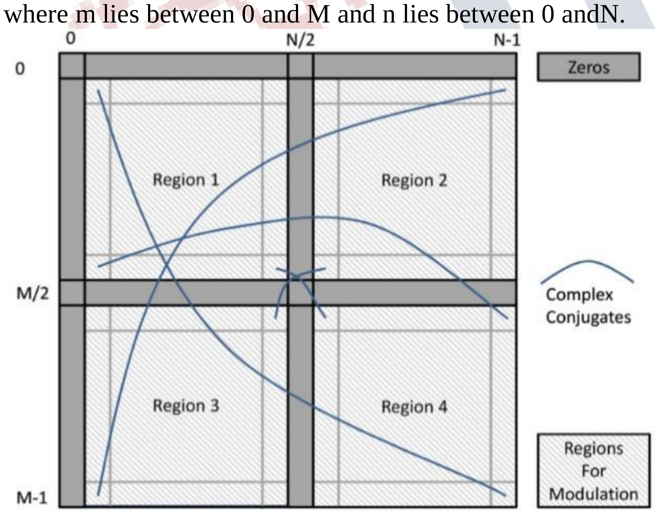


***Fig: 2.1: Hermitian symmetric matrix used for DPSK-OFDM modulation. The IFFT of this matrix would have real-valued output on display.***

Regions 1 and 2 of the Hermitian matrix are filled by the DPSK modulated data stream. Regions 3 and 4 are generated mathematically based on the Hermitian symmetry requirement to have a real-valued IFFT. The Hermitian symmetry matrix is a real valued 2D signal with high peak to average power ratio (PAPR). Statistically, the probability of having a high PAPR increases as the number of frequency components increases. Thus, soft-clipping is performed on the signal to limit the PAPR. Any components with higher amplitude than the clipping threshold are consequently clipped. Then, OFDM is applied to the clipped DPSK modulated signal. The pixel levels in the PAPR adjusted OFDM signal is then transformed linearly into LCD dynamic range levels for efficient utilization of transmission power. QR Code-like finder patterns are adopted due to its omni-directional readability and fast decoding.

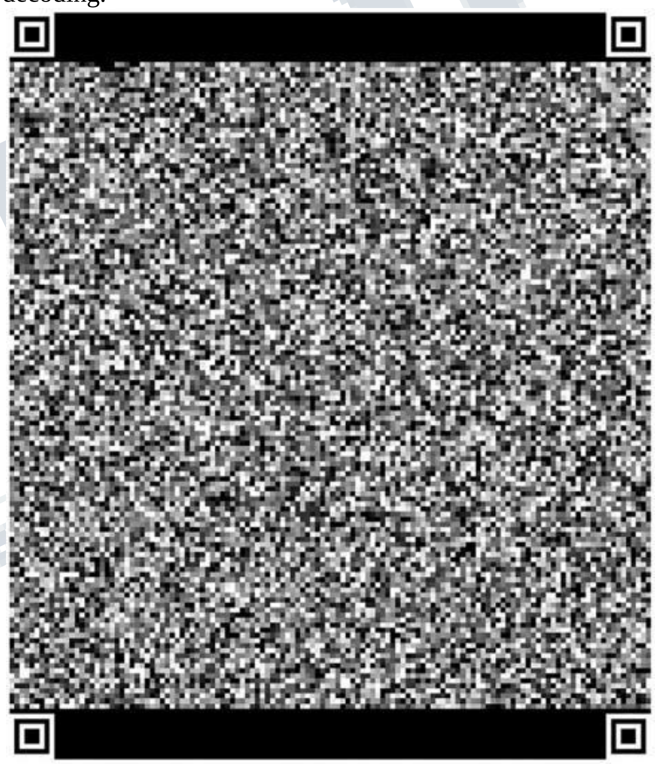

***Fig. 2.2: Final image shown on the LCD after applying the DPSK-OFDM modulation algorithm.***

After displaying the generated image, the receiver uses its camera for sampling and registering the acquired image so that a fairly acceptable copy is created at the receiver end. The effects of interference, noise and distortions encountered in this step are addressed by local processing within the receiver device.

## III. RESULTS AND DISCUSSIONS

### *A. Performance Analysis*

OFDM transfers a bunch of narrow-band signals in parallel instead of a single high bandwidth signal. Then each of the sub-carrier is modulated using as DPSK. Since DPSK is used to modulate each data channel, data is not stored in the absolute phase of the received elements but in its phase difference to the neighboring element. DPSK is implemented by using the IFFT algorithm. The IFFT modulates input data into orthogonal frequencies. The method provides high capabilities in mitigating aggressive relative movements between transmitter and receiver. Error correction coding is often used in communication systems to correct for the different number of bits lost in the transmission process. For example, Reed-Solomon (RS) coding is used in QR codes, where depending on the level of error correction used, error rates of 7% up to 30% can be corrected at the receiver end. While the selection of error correction coding has a great influence on the overall performance of the communication system, they are generally used on top of the modulation-demodulation scheme and after source coding. Therefore, based on the achievable error rates without error correction coding, one can select an appropriate coding scheme to create a reliable communication channel. An important issue regarding the applicability of such a system would be the computational power required to implement the system. Although a thorough investigation of such requirements and any optimization process can be subject to further study, it should be noted that the proposed

DQPSK-OFDM system has a limited processing overhead compared to the equivalent QPSK-OFDM system which is already implemented and tested. More specifically, on the transmitter side, although the differential modulation is described by complex multiplications, it can be easily implemented using a small look-up table taking current phase and data to be modulated as inputs. High PAPR and limited peak power enforces a reduction in average power for the signal if it is going to be transmitted as is. Low average power means higher error rate in the presence of noise. To mitigate this problem, PAPR should be decreased as the maximum power is limited by physical constraints of LCD. Here soft clipping method is used. As the clipping increases, the average power also increases due to fixed maximum power and lower PAPR. However, this increased average power is at the expense of a more distorted signal which translates into more BER.

Inter symbol interference and out of focus lens may be modeled by applying low pass filtering on the captured image. To simulate this out of focus effect, the Butterworth low pass filter in the frequency domain is used with various cutoff frequencies and the resulting BER is measured. BER increases with lower cutoff frequencies. unless the cutoff frequency is less than 20%, frequency domain modulations have better error performance than the PAM method. In the proposed DPSK-OFDM method BER is maximized as reaches about. This is the case where the motion is perpendicular to the differential phase modulation path. Because vertical phase difference of the elements is what transfers data, may attenuate some elements resulting in SINR decrease or it may reverse the phase of the original elements resulting in constellation rotation and hence in error bits. Frequency attenuation in sub channels is something that affects both OFDM methods. This is where DPSK modulated OFDM shows its promising capabilities in mitigating aggressive relative movements between transmitter and receiver.

It was observed that under relative LCD-camera motions that generate error rates in excess of 30% in PAM and QPSK-OFDM, the proposed system of DPSK-OFDM will maintain an error rate less than 8% which is practically correctable using error correction coding. Future inquiries in a resolution to this problem have to address the best choice of differential pattern to optimize performance for various motion scenarios. Moreover, extension of the current two-bit per symbol constellations increases data transfer capacity, and its BER performance evaluation would be required.

### *B. Advantages*

OFDM uses multiple low data-rate channels instead of a wide high data-rate channel. Hence effects of ISI are reduced. The data stream to each of the low bit-rate channel is modulated by DPSK. Hence, the information is not stored in the phases (as is in the case of M-QAM), but rather in the phase difference between the symbols. Thus, errors during demodulation at the receiver due to phase errors can be eliminated. The proposed OFDM-DPSK combined method provides the highest resilience to distortion due to screen-camera relative motion as compared to existing methods of video barcode modulation. OFDM can be implemented by the computationally efficient IFFT algorithm which can be easily ported to work on devices with low processing power, although the achievable data transfer rate is proportional to other hardware specifications and the processing capability.

## IV. CONCLUSION

Differential Phase Shift Keying was combined with Orthogonal Frequency Division Multiplexing in order to modulate data stream into visual two dimensional barcodes. QPSK-OFDM modulation has serious shortcomings in the mitigation of camera LCD movements where the phase of each element changes continuously. On the other hand, addition of a differential phase modulator before OFDM to modulate the data stream into phase differences of adjacent elements (DPSK-OFDM) causes the motion effect to increasingly weaken because of it gradual change from element to element, contributing to a small deviation from the ideal phase in the received signal. Extension of the current two-bit per symbol constellations increases data transfer capacity, and its BER performance evaluation would be required.

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