An OFDM-DCSK based Approach for D2D Emergency Communications

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ABSTRACT:
In a critical situation such as a flood, storm, and earthquake, where the communication infrastructures have been seriously destroyed, Device to Device (D2D) communications can be connected without the assistance of any operators. In addition, Equip the existing D2D systems to provide high reliability, robustness and other specific needs of the emergency services during the disasters seems to be unavoidable. In this paper an Orthogonal Frequency Division Multiplexing based Differential Chaos Shift Keying system (OFDM-DCSK) based approach is presented to overcome the problems in the emergency situations. An OFDM-DCSK receiver need no channel estimation for data detection. Moreover, the combination of a blind power allocation scheme with a non-coherent receiver is very desirable because these techniques save power, without the need for communication infrastructure like Base Stations (BSs). On the other hand, the proposed system benefits from the additional advantages of the DCSK-based systems such as reliability and robustness. We assign power coefficients to sub-carriers for guarantee a given level of outage probability. To this aim, we calculate the outage probability for a power allocated OFDM-DCSK system using instantaneous signal-to-noise ratio expression. The power that guarantees a given level of outage probability can be calculated by a simple numerical algorithm. Simulation results validate the feasibility of the proposed scheme.

KEYWORDS: Blind Power Allocation, Emergency Communications, OFDM-DCSK, Outage Probability.

1. INTRODUCTION

A major challenge in emergencies is access to a reliable, robust, and low power consumption with no need for communications infrastructure [1]. There are dedicated some communication systems for emergency conditions under radio access schemes like Bluetooth [2] and Wi-Fi [3]. However, in disaster situations, a short distance covered by Bluetooth is inadequate. Also, the Wi-Fi access points are mostly located in the same building where the users work and these locations will also damage due to the disaster event. Device to Device (D2D) direct communications provide several advantages such as higher energy efficiency, and infrastructure-less connectivity [4].

In this paper, we propose a novel D2D communication approach using OFDM-DCSK structure as a potential communication candidate in emergency conditions. An OFDM-DCSK structure has a non-coherent receiver that need no channel estimation for data detection. As the main contribution of this paper, we suggest a simple blind power allocation scheme that saves power, without the need for communication infrastructures like Base Stations (BSs).

Meanwhile, the proposed scheme benefits from inherent capabilities of a DCSK-based system including low power consumption, reliability, robustness, and low complexity. Therefore, it seems that the proposed scheme is fit for adoption in the emergency situations.

In the context of power allocation techniques, most of the researches are focused on the power allocation in coherent systems. Such systems, require a perfect knowledge of the Channel Side Information (CSI) at the transmitter and receiver side that is not applicable for many real scenarios. When the CSI is not available at the transmitter side, the practical approaches for power allocation are fixed power transmission or power randomization [5]- [7]. Non-coherent detection schemes such as Differential Chaos Shift keying (DCSK) scheme do neither need a complex channel estimator nor demand any complex synchronization processes [8] and [9]. In addition, DCSK is robust to multipath fading environments [10]. In the DCSK scheme, the reference signal is placed in the first time slot and information multiplied by the reference and is placed in the second part. Depending on the data value, the second part of the DCSK signal can be a copy or an inverse version of the reference part. Several methods have been proposed for performance improvement of DCSK modulation. In this paper, we focus on MC-DCSK in which some sub-carriers are dedicated to data and one sub-carrier is used for reference transmission [11]. The OFDM-DCSK system was proposed in [12] and multi-user version of OFDM-DCSK was presented in [13]. in OFDM-DCSK, the sub-carriers are divided into some groups and a chaotic reference is transmitted over the central sub-carrier of each group. In [14] and [15], power allocation is applied for performance improvement of MC-DCSK and MC-QCSK systems in presence of the Additive White Gaussian Noise (AWGN). But they assume that CSI is known at the transmitter side. Different with [14]-[15], the main contributions of this paper is the blind power allocation for the non-coherent transceivers has not been considered in the literature so far. We calculate a closed form expression for the outage probability of the OFDM-DCSK system and assign some power coefficients to the subcarriers for guarantee a given level of outage probability.

2. SYSTEM MODEL

We adopt a single user case of OFDM-DCSK structure in [13], in which the sub-carriers are divided into some groups and a chaotic reference $c(t)$ is transmitted over the central sub-carrier of each group (Fig.1). In this paper we consider one reference and one group for convenience. Information bit $s_i \in \{+1, -1\}$, multiplied by the chaotic reference x and transmit over M other subcarriers that called data-bearing subcarriers. After the IFFT operator, a cyclic prefix is added to the signal. The Fig.2 shows an example of the OFDM-DCSK frame.

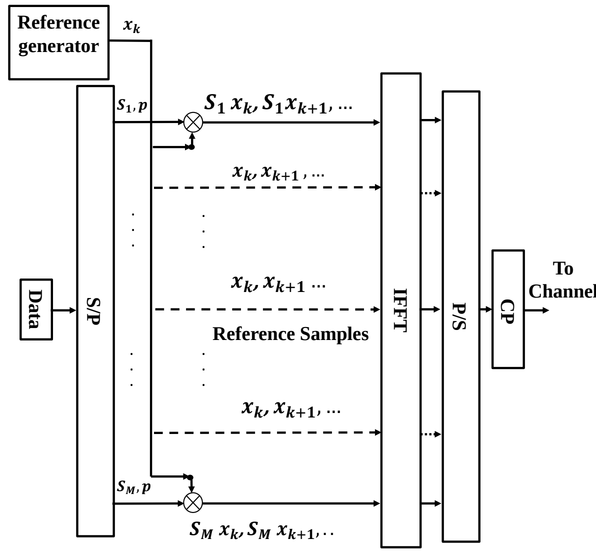

Fig. 1. The transmitter of OFDM-DCSK system.

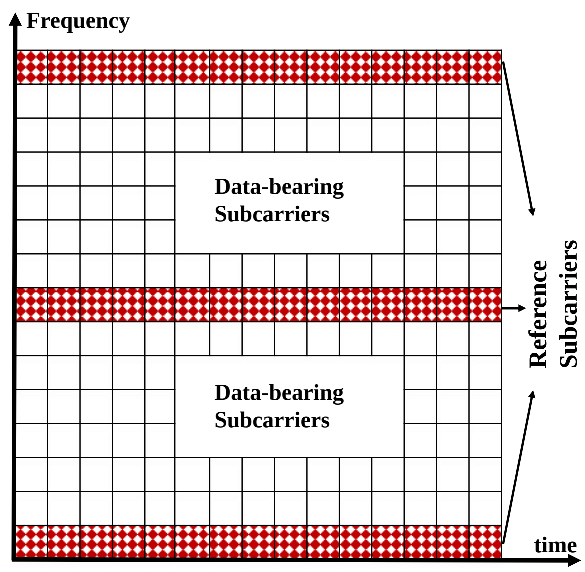

Fig. 2. An example for a transmitted OFDM-DCSK frame.

2.1. BER Derivation for Power Allocated System

In this part, we derive BER expression and instantaneous SNR of the power allocated OFDM-DCSK system for calculating the outage probability in the next step. The total required bit energy for DCSK systems is $E_{b,DCSK} = E_{data} + E_{ref}$, where E_{data}, E_{ref} are the needed energy for the data and reference sequence respectively. While, the necessary energy for transmission of one bit in a typical OFDM-DCSK system with single group is reduced to:

$$E_{b,DCSK} = E_{data} + \frac{E_{ref}}{M} = \left(\frac{M+1}{M}\right) T_c \sum_{k=1}^{\beta} c_k^2 \qquad (1)$$

Where β represents the spread factor, c_k is k^{th} sample of the reference sequence and the chip duration is assumed $T_c = 1$ for convenience. Now, consider power coefficient $\sqrt{P_1}$ for the reference signal and power coefficients $\sqrt{P_i}$, $(i > 1)$ for the data bearing signals. Hence, for the power allocated OFDM-DCSK system we have:

$$E_b = \frac{\sum_{m=1}^{M+1} P_m}{M+1} \left(\frac{M+1}{M}\right) \sum_{k=1}^{\beta} c_k^2 = \frac{\sum_{m=1}^{M+1} P_m}{M} \sum_{k=1}^{\beta} c_k^2 \qquad (2)$$

where P_m is the power assigned to each of the $M + 1$ sub-carriers. On the receiver side, the detection process performs by calculating the following decision variable for $i > 1$:

$$D_i = R\{\sum_{k=1}^{\beta} (\sqrt{P_i} s_i c_k h_l + N_{sk}) \,.\, (\sqrt{P_1} c_k h_l + N_{Pk})^*\}, \qquad (3)$$

Where N_{sk} and N_{pk} are k^{th} sample of the Gaussian noise added to the k^{th} bit of data-bearing and reference sub-carriers, respectively. $R(.)$ denotes real part operator. The variable h_l is related to l^{th} path. Expanding Eq. (3) yields:

$$D_i = R\{\underbrace{\sqrt{P_i P_1} s_i \sum_{l=1}^{L}\sum_{k=1}^{\beta} |h_l|^2 c_k^2}_{U} + \underbrace{\sqrt{P_1}\sum_{l=1}^{L}\sum_{k=1}^{\beta} c_k (h_l^* N_{sk})}_{A_1} + \underbrace{\sqrt{P_i}\sum_{l=1}^{L}\sum_{k=1}^{\beta} c_k h_{lv} s_i N_{Pk}^*}_{A_2} + \underbrace{\sum_{k=1}^{\beta} N_{Pk}^* N_{sk}}_{B} , \quad (4)$$

where L is the number of the paths and s_i indicates information bits replaced in i^{th} subcarrier. The first term is the useful signal other terms are interference created by noise. Furthermore, h_l^* is the complex conjugate of the channel coefficient. Now we focus on the instantaneous mean and variance of the decision variable expression. The instantaneous mean value may be expressed as:

$$E(D_i) = \sqrt{P_i P_1} s_i \sum_{l=1}^{L}\sum_{k=1}^{\beta} |h_{lv}|^2 E(c_k^2) . \quad (5)$$

Replacing (2) in (5) yields:

$$E(D_i) = \sqrt{P_i P_1} \frac{s_i M E_b}{\sum_{m=1}^{M+1} p_m} \sum_{l=1}^{L}\sum_{k=1}^{\beta} |h_{lv}|^2. \quad (6)$$

Since all terms in (4) are independent, by assuming transmission of bit +1, the conditional variance of the decision variable of the i^{th} bit is:

$$V(D_i) = E({A_1}^2) + E({A_2}^2) + E(B^2). \quad (7)$$

where $V(.)$ denotes variance operator. Because N_k^*, N_{sk}, c_k are independent variables and the channel coefficients are independent zero mean variables, the conditional variance of the interference terms can be written as:

$$V(A_1) = P_0 \frac{M E_b}{\sum_{m=1}^{M+1} p_m} \frac{N_0}{2} \sum_{l=1}^{L}\sum_{v=1}^{\beta} |h_{lv}|^2, \quad (8)$$

$$V(A_2) = P_i \frac{M E_b}{\sum_{m=1}^{M+1} p_m} \frac{N_0}{2} \sum_{l=1}^{L}\sum_{k=1}^{\beta} |h_{lv}|^2. \quad (9)$$

$$V(B) = \frac{\beta N_0^2}{4} . \quad (10)$$

As a common assumption, we assume that the transmitted bit energy in a chaos based communication is constant. Thus, we can derive BER expression by the Gaussian approximation method [16]:

$$\text{BER} = \frac{1}{2} erfc\left(\frac{E(D_i|s_i = +1)}{\sqrt{2Variance(D_i|s_i = +1)}}\right). \quad (11)$$

We set $\sum_{l=1}^{L_p}\sum_{v=1}^{\beta} |h_{lv}|^2 = \delta$ for convenience. simplification of the above equations yields the BER expression as:

$$BER = \frac{1}{2} erfc\left(\left[\frac{(P_i+P_1) N_0 \sum_{m=1}^{M+1} p_m}{P_{ig} P_{1g} M \delta E_b} + \frac{\beta {N_0}^2 (\sum_{m=1}^{M+1} p_m)^2}{2 P_1 P_i M^2 \delta^2 {E_b}^2}\right]^{-\frac{1}{2}}\right) . \quad (12)$$

2.2. Blind Power Allocation for OFDM-DCSK

In this paper, we assume that we do blind power allocation for a flat Rayleigh multipath fading channel using BER expression of Eq. (12). In other words, we assign power to the subcarriers to guarantee a given level of outage probability. The BER expression of Eq. (12) can be simplified as:

$$BER = \frac{1}{2} erfc\left(\left[\frac{1}{\gamma_i} + \frac{\beta (P_i + P_1)}{2{\gamma_i}^2}\right]^{-\frac{1}{2}}\right) \quad (13)$$

where we define instantaneous signal to noise ratio γ_i for i^{th} data bearing sub-carrier as:

$$\gamma_i = \frac{P_i P_1 M \delta E_b}{(P_i + P_1) N_0 \sum_{m=1}^{M+1} P_m} \quad (14)$$

Since we considers blind power allocation we have to assume that all P_i's are equal to P for convenience. Without loss of generality, with normalizing the reference's power to 1, we can obtain a ratio between power of data-bearing subcarriers (P) and normalized reference power $P_1 = 1$. Thus, equation (14) can be written as:

$$\gamma = \frac{P M \delta E_b}{(P+1)(MP+1) N_0} \ . \quad (15)$$

For L independent and identically distributed Rayleigh channels, the PDF of the γ can be written as [17]:

$$f(\gamma) = \begin{cases} \frac{\gamma^{L-1}}{(L-1)! \lambda^L} e^{-\gamma/\lambda} & \gamma \geq 0 \\ 0 & else \end{cases} \quad (16)$$

where $\lambda = \bar{\delta}$, presents the mean channel gain. We assume that the receiver is in outage whenever it's SNR is less than a predefined threshold γ_{th}. Thus, the outage probability can be calculated by the following equation:

$$P_{out} = Pr\{\gamma \leq \gamma_{th}\} \quad (17)$$

We use normalized channel gain with separation of δ , λ .Thus, With replacing Eq. (15) in Eq. (17) , the outage probability can be written as:

$$P_{out} = Pr\left\{\delta \leq \frac{(P+1)(MP+1) N_0 \gamma_{th}}{P M \delta E_b \lambda}\right\} \quad (18)$$

We define a variable ζ as the following for convenience:

$$\zeta = \frac{PM\delta E_b \lambda}{(P+1)(MP+1)N_0\, \gamma_{th}} \tag{19}$$

The outage probability can be written as $F(\zeta^{-1})$, where $F(\mathrm{x})$ denotes the CDF of the channel gain. Using the Eq. (16) the CDF is derived as the following expression:

Algorithm 1 : Compute P^* for a given P_{out}

Initialize: $\gamma_{th}, \lambda, P_{out}, \varepsilon\ (stopping\ criterion)$ $,\Delta P\ (a\ smal\ number)$

$$\zeta = \frac{PM\delta E_b \lambda}{(P+1)(MP+1)N_0\, \gamma_{th}}$$

$$P^0 = P^{min} > 0\ (Initial\ seed\ )$$

$$Metric = P_{out} - \left[1 - \left((e^{-\zeta})(\sum_{m=0}^{L-1} \frac{(\zeta)^m}{m!})\right)\right]$$

While $|Metric| > \varepsilon$

$P^{k+1} = P^k + \Delta P$

Compute Metric

End while

$P^* = P^{k+1}$

End

$$P_{out} = \frac{1}{(L-1)!}\int_0^{\zeta^{-1}} v^{L-1} e^{-v} dv\,. \tag{20}$$

By the closed-form expression of the incomplete Gamma function [18], we get the equivalent of Eq. (20):

$$P_{out} = \left[1 - \left((e^{-\zeta})(\sum_{m=0}^{L-1} \frac{(\zeta)^m}{m!})\right)\right]. \tag{21}$$

According to the Eq. (21) we can extract necessary power for a given level of the outage probability. Calculation of P^* from Eq. (21) is hard because of the nonlinearity nature of the obtained expression. Hence, we propose a simple iterative algorithm1 to compute P^* for a given P_{out}.

3. RESULTS AND DISCUSSION

Consider a two-path Rayleigh channel in which the channel state does not change during each frame transmission. We set the total 21 sub-carrier and the $\beta = 40$. Fig. 3 shows the outage curves for different values of the power P={0.0476, 0.238 , 0.476, 0.714, 1} and $\gamma_{th} = 7\ dB$. As an interesting result, when we do not know CSI without a proper strategy, each of these curves may happen and such a system has an unreliable behavior. We can adjust the needed power to support a requested level of the outage probability. Moreover, one can see that increasing of the power from 0.0476 to 0.238 results in an improvement in terms of outage probability and increasing the power from 0.238 to 1 causes to performance degradation. For example, when $E_b/N_0 = 15\ dB$ and $\lambda = 1$, we have $P_{out} \le 0.05$.

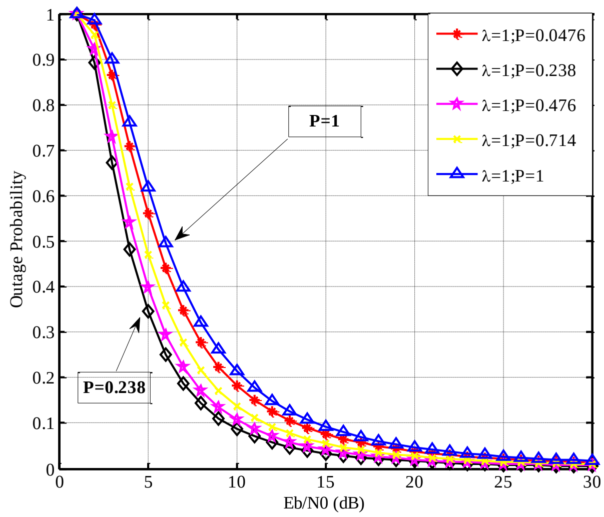

Fig. 3. Outage probability for different values of power and E_b/N_0.

Fig. 4 shows the outage curves for different values of power and different states of the channel gain when $\gamma_{th} = 7\ dB$. We may achieve different levels of outage probability (blue circles) for a predefined available power (P = 0.6, for example). For minimum Outage probability, we need to compute the derivative of Eq. (21) with respect to P:

$$P'_{out} = \left(m - \frac{1}{P^2}\right) f(\zeta^{-1}) \tag{22}$$

Setting the Eq. (22) equal to zero, result in the optimal power coefficient $P^* = \sqrt{\frac{1}{M}}$. Also, normalizing to the total power, leads to the simpler scaling:

$$P^* = \frac{P^*}{\sum_{i=1}^{M} P^*} = \frac{\sqrt{\frac{1}{M}}}{\sum_{i=1}^{M}\sqrt{\frac{1}{M}}} = \frac{1}{M} \tag{23}$$

The obtained optimal power value in (23), shows an agreement with the results of the optimal power allocation in [14] and [15], when we have a perfect knowledge of CSI.

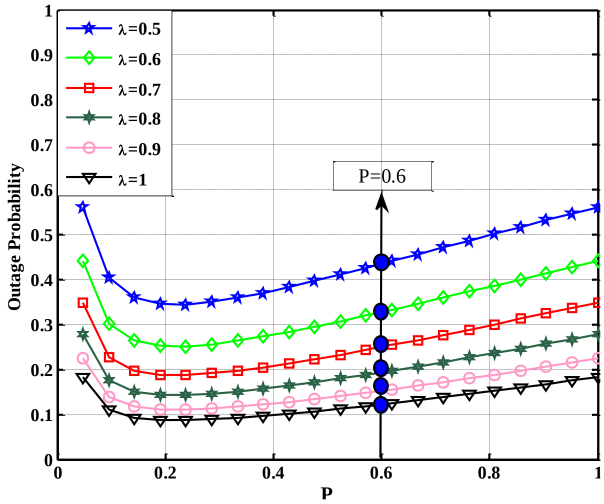

Fig. 4. Outage probability for different values of power in a constant E_b/N_0.

Fig. 5 shows the analytical outage probability for different values of the mean channel gain when $\gamma_{th} = 7\,dB$, $P = 1$. We can see that for the high SNR condition and high channel gain values, the outage performance of the system is in an acceptable range.

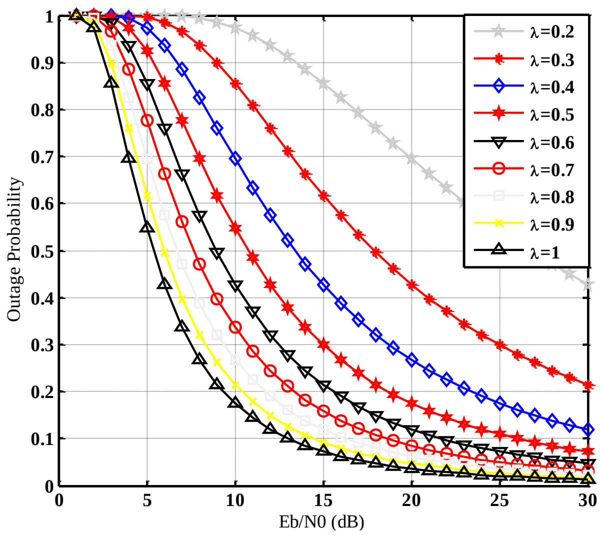

Fig. 5. Outage probability for different values of the mean channel gain.

4. CONCLUSION

In this paper, a blind power allocation scheme introduced for Non-Coherent OFDM-DCSK system in Multipath Rayleigh Fading Channel that do neither need complex channel estimation for the detection process nor demand CSI for power allocation at the transmitter side. This scheme guarantees a given level of outage probability and the necessary power can be calculated by a simple numerical algorithm. Simulation results validate the feasibility of the proposed scheme and it gives the idea that when a communication system do not have CSI, our proposed scheme can be a low complexity and practical scheme.

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