Dynamic Bit Loading with the OGFDM Waveform Maximises Bit-Rate of Future Mobile Communications

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Abstract. A new Dynamic Bit Loading (DBL) scheme with the Orthogonal Generalized Frequency Division Multiplexing (OGFDM) is, for the first time, proposed, discussed and assessed. The key concept of this hybrid modulation format depends substantially on the adaptive distribution of the bit stream to be more compatible with the gained capacity of the realistic channel state. Due to the negative impact of employing the fixed schemes of digital modulation on the performance of the conventional telecommunications systems, the influence of using the multilevel modulation system is investigated for the future applications of mobile communications. Utilising the DBL in the physical layer (PHY), a flexible range of modulation formats can be optimally assigned for each applied frequency sub-carrier in accordance with wireless channel circumstances. In addition, depending on the supportive features of the proposed modulation system, the performance in terms of channel capacity can be maximised at the acceptable limit of the Bit Error Rate (BER). As such, an extra enhancement can be achieved in the spectrum efficiency (SE) of the adaptively modulated wireless signal. Thus, an adjustable boost of the transmission range of used modulation formats can be reached with the introduced adaptation system. The performance of the DBL system through a wireless mobile channel under the Additive White Gaussian Noise (AWGN) is evaluated according to a various level of the Signal to Noise Ratio (SNR). Ultimately, regarding the numerical simulation, a MATLAB code is employed to simulate the performance (channel capacity & BER) of the proposed DBL that is fundamentally accommodated by the recent candidate waveform of future mobile technology (OGFDM).

Keywords: Orthogonal Generalized Frequency Division Multiplexing (OGFDM); Dynamic Bit Loading (DBL); modulation formats; channel capacity; Signal to Noise Ratio (SNR); Bit Error Rate (BER); physical layer (PHY); mobile communications; Spectrum Efficiency (SE).

1 Introduction

The ever-growing demand of higher bit-rate and the predicated applications of the future mobile generation make researchers focus their attention on evolving the applied bit loading system from the conventionally fixed schemes towards a more dynamic, scalable, and smarter configuration. Thus, the flourishing development of mobile communications systems can help to offer improved data rates which can convoy with the fast change of traffic patterns from voice to video-based services in wireless access networks [1].

Despite the rapid progression in the digital signal processing (DSP) domain, optimisation of the transmission resources, particularly, that is directly related to the bandwidth (BW) efficiency, is yet a key issue for future wireless communications of mobile [2].

Its worth noting that the fixed modulation methods which are already employed in the traditional mobile communication system, are not quite matching with the developed requirements of the wireless transmission channel that experiences diverse types of complicated characteristics like dispersive fading and time-variant phenomena [3]. Thus, the BER performance of the system can be improved whenever the circumstance of the incompetent channel is enhanced [4].

Generally speaking, as the wireless channel suffers from frequency selective fading and time-varying phenomena, the system performance of channel capacity can be limited according to the worse channel condition [5]. Thus, with the fixed modulation, the above undesirable factors can principally impact the system performance in terms of maximum bit-rate.

To mitigate this issue, it is necessary to adopt a different scheme of modulation which is assigned adaptively for different frequencies of sub-carriers according to the characteristics of the applied channel [6]. This hybrid scheme of modulation/de-modulation which merges different kinds of formats in one appropriate modulation shape is called herein as Dynamic Bit Loading (DBL).

The orthogonal generalized frequency division multiplexing (OGFDM) which is considered recently as a promising waveform for the future generation of mobile (5G) [7], is applied here as an accommodating environment for the DBL technique.

Utilising a more flexible level of the digital modulation/de-modulation system with the future candidate waveform OGFDM, a further efficient spectrum allocation of the wireless BW resources is achieved. As such, the newly introduced DBL can be exploited for improving the performance of channel capacity for future mobile technology. Hence, depending on the physical layer (PHY) of the proposed DBL over the OGFDM system, the wireless channel capacity can be maximised under key transmission constraints like reception power and Bit Error Rate (BER).

Depending on the DBL scheme, the same frequency sub-carrier is possibly reused in various ways by allocating varied modulation schemes to each located user based on transmission conditions [8]. Thus, according to diverse channel circumstances, variable bit stream of employed sub-carriers are allocated dynamically [9].

The proposed technique can back a variety of modulation formats for adjusting the key throughput parameters according to the channel quality. As a result, the flexible assignment of channel modulation can significantly enhance the bit-rate and Spectrum Efficiency (SE) by adjusting the bit distribution of the sub-carriers according to nature of sub-scribers' channels [10]. It is also worth pointing out that, under a varying selection of the modulation shapes, a more accurate bit-rate and a better spectral feature usage of transmission channel are obtained.

To adequately deal with the present channel conditions, signal propagation parameters are adaptively adjusted by the developed scheme of modulation format. Hence, the DBL enables the propagation system to optimise the performance based on the wireless link conditions [10]. Thus, via adaptively allocating the suitable modulation shape, the wireless transmission waveform can be maintained in all possible situations. Besides, exploiting the diversity of the sub-carrier quality in frequency domain comes up with allocating different levels of the quality of boosting [11].

It's worth noting that knowing state information of employed wireless channel can allocate efficiently the bits for each used sub-carrier in the OGFDM system.

Assuming the instantaneous states of the channel for all sub-scribers are recognized by the Base Station (BS), the DBL system can employ a higher modulation scheme with the frequency sub-carrier which physically has a large gain (high priority) to transfer more bits per sample and vice-versa [12]. Hence, a high order modulation can be chosen to support the good condition channel where a maximum limit of channel capacity and best SE are reached at acceptable limits of the BER. Thus, a preferable modulation format is allocated by the BS for each subscriber in accordance with the strength of the wireless signal interference [13].

The key principle of the flexible modulation is, its ability to bend to the real fading conditions in comparison with the fixed scheme which is essentially intended for the worst circumstances [14]. This, nevertheless, causes in the power diversity of constellation table which can be addressed by the normalisation process [15].

This paper is structured as follows: Section I is the introduction. Section 2 demonstrates the system model of the DBL that explains briefly the PHY of employing the proposed scheme in both the transmitter and the receiver sides. Section 3 presents the simulated work including the results and discussion. The conclusion is presented in Section 4.

2 System Model

Making use of the wireless channel conditions, the proposed adaptive format can expand the gained channel capacity at the intended limit of errors. To apply this, the dynamic bit loading system is utilised alternatively to mitigate the downside of the conventional loading of bits.

As is seen in Fig. 1, at the transmitter side, a wide range of the most common modulation formats can be employed for each used sub-carrier adaptively. Hence, depending on a variant size of bit token (N), assorted constellations can be introduced. Thus, varies average power limits for each dynamic constellation table is achieved. This is, as such, can come up with introducing a multi-level modulation scheme instead of the flat one. In addition, an extra number of bits can be obtained from this flexible shape of modulation increasing the bit-rate of transmission.

The hybrid scheme which is essentially used for transforming the assigned bits to its corresponding complex numbers can improve the freedom level of digital modulation. Hence, in the frequency domain, every sub-carrier can have a specifically different power consumption according to the modulation format employed. This, however, can result in an irregular power constellation map due to diverse schemes of bit loading. Nevertheless, utilising the normalisation process of scaling stage, the average energy of the combined Gray coded bit mapping is set to one.

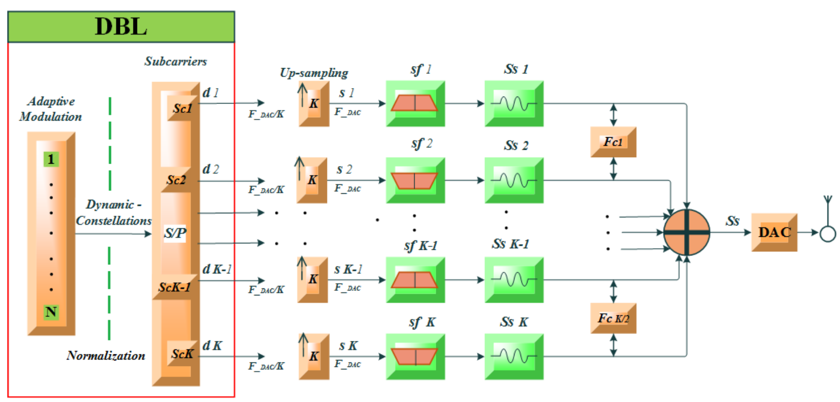

Fig. 1. The block diagram of the proposed DBL for the transmitter side of the OGFDM system.

In this paper, its worth noting that, all management operations of the bits loading scheme for both the transmitter and receiver are referred to as the DBL part.

From the time domain perspective, every generated complex number is equivalent to a sample, whereas, each group of samples with K length is equal to one OGFDM symbol. The normalized sub-carrier is subsequently up-sampled by a factor of K where $K - 1$ zeroes samples are inserted between any two adjacent points.

After that, each up-sampled frequency sub-carrier is convoluted with one of shaping Hilbert filters (cosine or sine) producing an orthogonally filtered sub-carrier. In addition, the digital filters are employed for multiplexing the shaped frequencies of sub-carriers into an obtainable BW. Employing the electrical adder, the carried samples of all utilised frequencies of sub-carriers are ultimately collected in one digital signal. To put this signal in the transmission mode, the Digital to Analog Converter (DAC) is used outputting the analog signal. The delivered signal which is exponentially denoted as ($e^{j2\pi f_c t}$) is transmitted by the antenna.

As is shown in Fig. 2, the detected signal at the antenna of the receiver side is delivered to an Analog to Digital Converter (ADC). As such, inverse operations are launched to retrieve the original transmitted signal. The digital signal is then distributed into a various set of sub-carriers (frequencies), where, every two orthogonal sub-carriers are recognized by an identical frequency centre (f_c).

After that, the formerly convoluted sub-carriers are extracted utilising the matching filters of Hilbert pairs, where, each matching filter is corresponding to it shaping filter. Subsequently, the de-multiplexed sub-carriers are down-sampled by a factor of K, eliminating the $K-1$ zeroes of neighbouring samples.

In the frequency domain, where every sample is represented by a complex number, a flexible de-modulation system is employed to convert adaptively complex numbers to binary digits. Thus, according to the channel conditions, a dynamic range of the most popular de-modulation schemes can be used with an applied frequency sub-carrier. Hence, based on the diversity of de-modulation formats, multi-levels of the de-modulation process can be applied for frequencies of sub-carriers. As such, a specific level of power is consumed differently by the adaptive sub-carriers in accordance with the channel state.

As a result, the average power of the receiver constellations table can be unstable. Even though, a uniform level of the constellations map power can be obtained by the normalisation operation. Each complex number in this hybrid de-modulation shape is translated dynamically to N bit token, where 2^N indicates the order of utilised modulation/de-modulation scheme for every used sub-carrier.

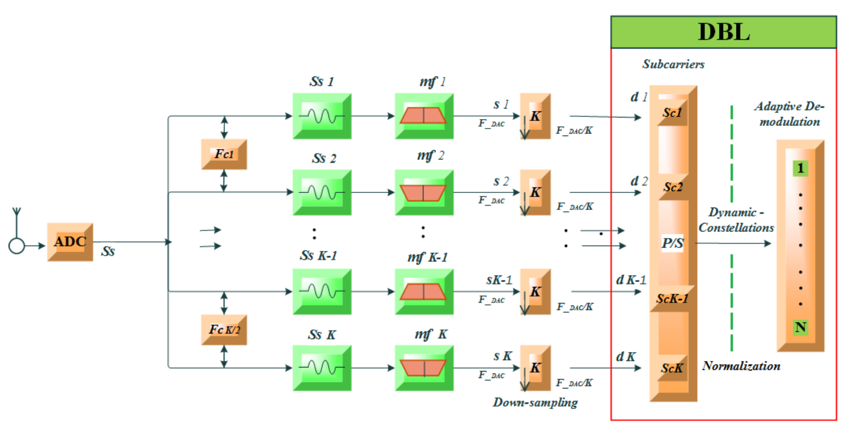

Fig. 2. The block diagram of the proposed DBL for the receiver side of the OGFDM system.

The vital idea of this proposed system is utilising the DBL process to combine different types of modulation/de-modulation formats adaptively. Consequently, the major parameters of this method (complex numbers and bit stream) and their relational impacts are mathematically considered here. Accordingly, in terms of the complex numbers usage, the basic formula of the flexible modulus (M_i) for each recorded point at the mapping table can be defined as follows [16]:

$$M_i = \sqrt{X_i^2 + Y_i^2} \tag{1}$$

where X_i, Y_i the real and imaginary parts of i_{th} constellation point respectively.

Also, the phase effect (ϕ) of intended constellations is calculated as the following [16]:

$$\phi_i = \arctan(Y_i/X_i) \tag{2}$$

In addition, depending on the gained value of modulus (M_i), the average power of the transmitted signal (AP) with length (L) is illustrated as follows [17]:

$$AP = \frac{1}{L}\sum_{i=1}^{L} M_i^2 \tag{3}$$

Moreover, the consumed power of the constellation table (P_{CT}) for a fixed format of modulation is represented by the following [18]:

$$P_{CT} = \frac{2}{3} * (Z - 1) \tag{4}$$

where Z indicates the order of modulation format.

It's worth mentioning that under the DBL scheme, multi-levels of power are obtained for the hybrid Gray mapping table. Hence, every utilised sub-carrier is treated differently based on the modulation shape used. This, however, can be unified to one level of consumption power via dividing every complex number ($X + Yj$) belong to an applied sub-carrier by the square root of its constellation table power. Thus, the normalisation process (N_P) is employed with each point to adjust the average power of the dynamic mapping table to one as follows [18]:

$$N_P = \frac{X + Yj}{\sqrt{P_{CT}}} \tag{5}$$

The system performance in terms of the maximum bit-rate of transmission (Br) for a symbol slot of time (t) at the accepted limits of the BER, is obtained as the following [19]:

$$Br = \frac{\sum_{i=1}^{K} b_i}{t} \tag{6}$$

where b_i denotes the number of transmitted bits through K available frequencies of sub-carriers.

Based on this equation, the upgraded channel capacity can be reached under the satisfactory bounds of errors.

Moreover, the influence of assumed wireless channel (Es) on the received signal (Rx) can be illustrated as the following [19]:

$$Rx = Es * Tx + N \tag{7}$$

where Tx represents the impacted transmitted signal in the presence of a noise (N).

A related point to consider here is the relation between the mean value of the expected signal (μ) to the standard deviation of the undesirable signal (σ) can be shown as follows [19]:

$$SNR = \frac{\mu}{\sigma} \tag{8}$$

Accordingly, in terms of improved bit-rate, the DBL scheme can be more compatible with the dynamic range of the SNR than the fixed formats of modulation which is recommended with the static SNR (calculated for worst channel condition).

3 Experimental Work

To explore the proposed DBL of the future candidate waveform (OGFDM), a numerical simulation is applied at the PHY of an electrical back-to-back (B2B) transmission system.

As is clear in Fig. 3, three key regions are essentially exploited based on the channel transmission circumstances. Hence, for a dynamic SNR range, several important spots are mainly introduced for every two adjacent shapes of the fixed modulation. Thus, various power thresholds are manipulated between the minimum levels of required SNR for both the first and second proposed styles of modulation (128 QAM & 256 QAM). Besides, the emerging improvements of the SNR which basically result from the enhanced status of the transmission channel are optimally employed by the DBL system.

Regarding the investigated cases, the first one is the "Low Boost" (LB) case, which is counted for the SNR threshold that is typically a higher than the first fixed threshold with the 128 QAM but less than the central point of both decided modulation formats. The LB case can come from different scenarios of Bit Loading Map (BLM). As such, depending on the ratio of enhancements in the utilised frequency sub-carriers, the BLM is obtained. For example, for eight sub-carriers, when the rate of improvement is equivalent to 25%, the BLM is equal to one of the following probabilities, [8,7,7,7,7,7,7,8], [7,8,7,7,7,7,8,7], [8,8,7,7,7,7,7,7], etc. This, as a result, can come up with a slight increase in the capacity of the channel due to the growing ability of about 25% of the sub-carriers to carry added bits.

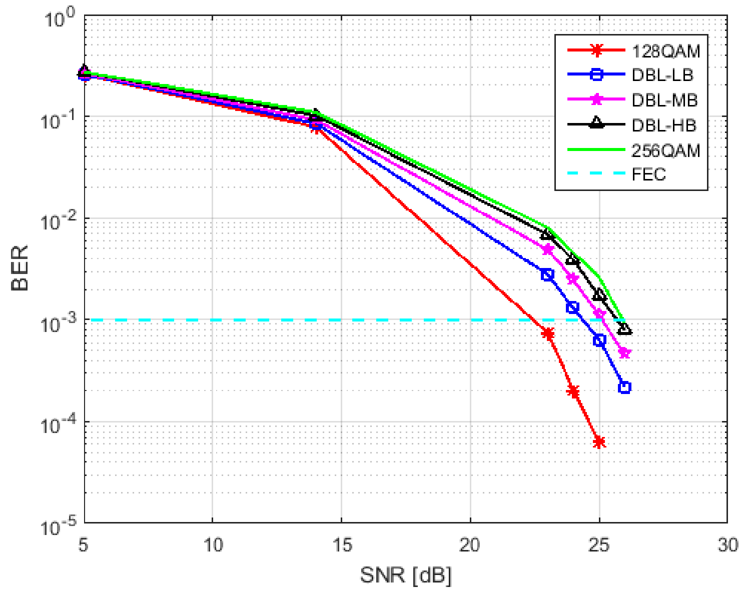

Fig. 3. Apply the DBL system for induced SNR between two successive modulation formats.

Regarding the second case "Medium Boost" (MB), the SNR threshold herein is acquired in the middle distance between the first and the second threshold of both 128 and 256 QAM respectively ($SNR_{128QAM} < SNR_{MB} < SNR_{256QAM}$). Moreover, a fair rise in the channel capacity results from the amended ability for approximately 50% of the utilised sub-carriers. The BLM of this situation, where the proportion of increment is averaged, equivalents to one of the next prospects, [8,8,7,7,7,7,8,8], [8,8,8,8,7,7,7,7], [7,7,8,8,8,8,7,7], etc. Thus, according to the intermediate improvement of the channel circumstance, half of the sub-carriers are capable to carry further bits. Hence, the gained channel capacity of case two is higher than case one due to the increased number of promoted sub-carriers.

Regarding the third case "High Boost" (HB), due to an extremely improved circumstance of the channel, the SNR threshold is recorded herein near to the second fixed threshold with the 256 QAM. Thus, most of the employed sub-carriers (around 75%) are furthered giving an extra ability to carry more bits. As such, the BLM for this advanced state counterparts to one of the following diagnoses, [8,8,8,7,7,8,8,8], [7,8,8,8,8,8,8,7], [8,8,8,8,8,8,7,7], etc. This, as a result, comes up with a higher channel capacity in relative to the formerly mentioned cases (MB, LB).

It's worth noting that all these achieved thresholds of the SNR are allocated for upgraded statuses of the channel condition that are fundamentally bounded by two successive modulation formats ($SNR_{MF}<SNR_{DBL}<SNR_{MF+1}$).

As is seen in Fig. 4, graduated amounts of channel capacity can be obtained between any consecutively applied schemes of fixed modulation. Thus, three channel capacities are elected mainly to give a good example of the diversity in transmission bit-rate for enhanced statuses of channel condition. The gained channel capacities are varied herein from low increment with the LB, to medium increment with the MB and to high increment with the HB. In addition, with

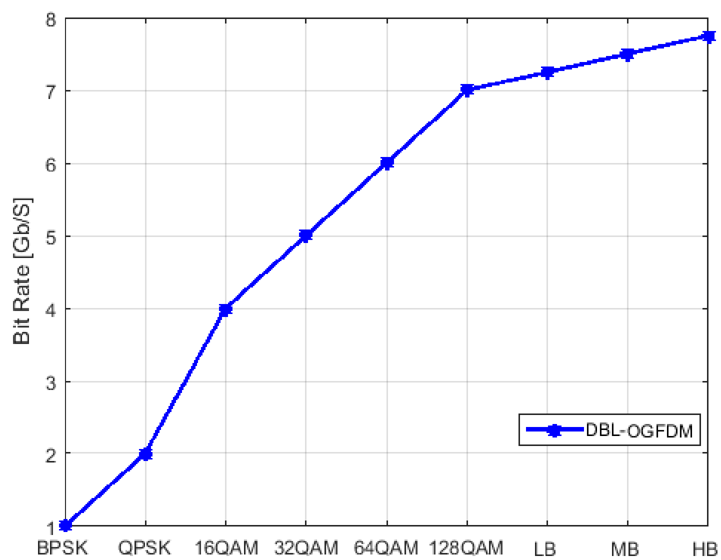

Fig. 4. Maximise achieved bit-rate with the DBL system (LB, MB, HB) and BER equals to (10^{-3}).

the DBL system, the bit-rate of transmission can be maximised in accordance with the grade of the channel condition improvement. Thus, herein, the raised level of the SNR can play a big role in promoting the capacity of the channel rather than the BER performance. Hence, when the provided SNR is developed, only the achieved bit-rate can be enlarged keeping a stable case of the BER (10^{-3}) for all dynamic gains between two adjacent shapes of fixed modulation.

As a result, comparing with the fixed modulation schemes, the improved channel capacities are obtained using the DBL with a changeable channel status. Thus, except for the worst channel condition, achieved channel capacities with the DBL system can outweigh the gained channel capacity of a fixed SNR threshold. Hence, in contrast with the fixed modulation, the transmission bit-

Table 1. System parameters for the DBL-OGFDM

Parameter	Value
No. of frequency centres	4
$F_{DAC/ADC}$	4 GHz
SNR	Static & Dynamic
Modulation Format	Fixed & Adaptive
OGFDM symbols	2000
Filter type	Hilbert filter

rate can be maximised up to an extra 14%, i.e. 114% of the original channel capacity with a similar level of error. The performance of transmission, in terms of the channel capacity is examined under the condition stated in Table I.

4 Conclusion

In this paper, a novel way of mapping bits among utilised sub-carriers of frequencies in the OGFDM system is introduced, explored and evaluated. The proposed DBL scheme comes from substituting the conventionally fixed bit loading system of the OGFDM with another flexible design. The main feature of this optimised technique is the preferably adaptive allocation of the applied stream of bits in accordance with the instantaneous channel status. The multi-levels adjustment comes up with maximising the performance capacity of the wireless channel without the need for employing a higher fixed modulation scheme. Thus, the hybrid modulation/de-modulation mechanism of future mobile generation leads to an extra enhancement in the efficiency of BW usage with maintaining a suitable level of the BER. The implemented work clarified that utilising the DBL with changeable channel cases, several better channel capacities can be achieved in comparison with the conventional fixed modulation format. Hence, depending on the typically supposed circumstances of the transmission channel, three key exploiting regions (low, medium, high) can be declared for any dynamic SNR area of each two adjacent fixed modulation shapes. Thus, apart from the worst condition, all gained channel capacities of the DBL configuration exceed the threshold channel capacity of the used fixed scheme of modulation.

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