Single-folded quadrifilar helix antennas for land mobile satellite MIMO receiver

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Abstract

A compact dual circularly polarised single-folded quadrifilar helix antenna (SFQHA) array has been proposed to be used in mobile terminal for land mobile satellite (LMS) MIMO system. The antenna performance in terms of its MIMO capability was evaluated by conducting an outdoor measurement campaign with the antennas at the mobile terminal and emulated satellite at the transmitter where minimum capacity increase of 0.8 b/s/Hz at 10% outage probability can be achieved. The results also show that the receive antenna orientation and design plays significant role in determining the capacity of LMS MIMO system. Comparison between SFQHA and dipole array in LoS and NLoS environments was conducted using a novel LMS MIMO channel model which includes the receive antennas properties. The SFQHA is shown to outperform the dipole array in both channel conditions especially in LoS area where a difference of 0.7 b/s/Hz at 10% outage capacity between the two antennas.

Key words: Quadrifilar helix antenna, land mobile satellite MIMO

1. Introduction

Implementation of the spatial-based multiple-input multiple-output (MIMO) technique in mobile satellite system is more restrictive due to significant differences in terrestrial and satellite channel characteristics such as huge path loss and asymmetric scatterer distribution. Instead of spatial-based MIMO, circular polarisation-based MIMO has been proposed as a practical utilisation of the MIMO technique for a land mobile satellite system [1]. Such a system requires the receiver to be equipped with compact dual circularly polarised antennas. We propose an orthogonally polarised array of novel miniaturised single-folded quadrifilar helix antenna (SFQHA) to be used at the receiver terminal for this system.

The resonant quadrifilar helix antenna has been extensively researched and used for mobile satellite communication and global positioning system applications. Its main advantages are wide circularly polarised pattern, good axial ratio across the beamwidth and ability to shape the radiation pattern by adjusting the QHA structural parameters. However, for a QHA to be fitted in today’s mobile handheld receiver, it has to be miniaturised since its conventional form is too large and bulky. Therefore, the antenna size needs to be reduced without severely affecting its radiation and impedance characteristics. Several methods have been proposed to reduce the size of QHA and they can be categorised into two groups: helical element adjustment and dielectric loading. The first miniaturisation method reduces the axial length of the QHA by meandering, folding or coupling of the helical element [2] while the second method introduces a dielectric rod with a high relative permittivity in the centre of the QHA to reduce the effective length of the helical element, hence reducing the QHA size and changing the QHA impedance characteristic [3]. Although different folding methods have been demonstrated in [4], our technique provides better percentage of size reduction while maintaining the antenna impedance bandwidth at the intended frequency.

2. Technical Approach

Although the QHA has many desirable properties when compared with other antennas, its conventional form is too bulky for a mobile terminal. In this paper, we propose a simple method of miniaturisation where its helical arms are folded into several segmented arms where each vertical segmented arm will have the same length and spaced from each other by specific angular distance. In this work, a miniaturised single-folded half-wavelength QHA was designed and fabricated for carrier frequency of 2.45 GHz which corresponds to element length of 61.5 mm. The antenna radius and element track width are fixed at 5 mm and 1 mm respectively. Based on the radius, element length and helical pitch angle, α of 62°, the axial length of the antennas is 22 mm which is 60% less compared to conventional QHA axial length of 55 mm. Fig.1 shows the fabricated conventional and single-folded QHAs for frequency of 2.45 GHz.

Based on the compact design of QHA, a dual circularly polarised array of SFQHA was constructed where it consists of two SFQHAs with orthogonal circular polarisation and separation of 6 cm between the two elements. The feeding network of the array was fabricated on a substrate with high relative permittivity (εr=10.3) in order to reduce the overall size of the antenna system.

It is well established that isolated measurement is inadequate to evaluate MIMO antennas where the inclusion of channel properties are fundamental for accurate performance evaluation. Several methods that emulate channel behaviours such as reverberation chamber measurement and MIMO Over-The-Air testing have been proposed for evaluating MIMO antennas in terrestrial system. However, since the land mobile satellite channel differs substantially from terrestrial channels, it is considered that the MIMO antennas for this system need to be evaluated by conducting a field measurement campaign in the intended operating environment.
3. Results and Discussion

In order to evaluate the array performance, an outdoor measurement campaign was carried out where a satellite was emulated by a transmitter equipped with two co-located orthogonal circularly polarised directional antennas communicating with a mobile receiver equipped with a two element SFQHA array, one for left hand and the other for right hand circular polarisation. The measurement was conducted in a typical suburban environment and the elevation angle between transmitter and receiver was within 20° to 30° range during the whole measurement run. Analysis of the measurement results indicates significant capacity increase can be realised with an SFQHA array as the receive antenna. The effect of receive antenna orientation to the MIMO capacity was also studied by taking the SFQHA as an example. Fig. 2 shows the comparison of measured capacity distribution between two different orientations of the array where considerable increase of spectral efficiency can be obtained when the antennas are tilted 50° from the vertical plane towards the source.

Comparison between the SFQHA and dipole array in terms of their MIMO capability was investigated using a novel LMS MIMO channel which combines the effect of antenna with the propagation channel. By including the antenna effects such as radiation pattern and polarisation, the channel model can be used as a tool to compare various types and orientation of receive antennas in LMS MIMO system. In the channel model, the large scale fading and shadowing were modelled statistically while the small scale fading is modelled using 3D hemispheric geometric scattering approach. Apart from that, simulated or measured 3D polarised radiation pattern of the antenna is required for the use in the channel model. In Fig. 3 and 4, the capacity performance of the SFQHA and dipole array was compared in LoS and NLoS channel conditions using the developed simulation model. The results clearly show that the SFQHA outperforms dipole array in both conditions especially in the LoS channel.

Summary and Conclusion

A novel antenna system for mobile terminal to be used in land mobile satellite MIMO system has been presented. The measurement and simulation results have shown that significant capacity increase can be achieved by SFQHA in both LoS and NLoS channel conditions. The design clearly illustrates the benefits available when considering mobile terminal antenna design in LMS-MIMO applications, particularly on vehicles and the handset.
SNR Estimation for ACM in DVB-RCS Systems

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Abstract

A robust signal-to-noise ratio (SNR) estimation algorithm for future DVB-RCS systems using adaptive coding and modulation is presented. The estimator makes use of amplitude and phase values of the received signal to estimate SNR for constant envelope modulation schemes employed in the system under consideration. It achieves significantly lower complexity and higher accuracy as compared to the state-of-the-art estimators and, therefore, seems to be an attractive choice for use in the reverse link of broadband satellite systems.

Key words: Signal-to-noise ratio, DVB-RCS, Adaptive coding and modulation.

1. Introduction

Adaptive coding and modulation (ACM) is implemented in the satellite communication systems operating at Ku band and higher frequencies in order to overcome the effect of bad channel conditions arising from rain attenuation, which can render the system economically inefficient. The resulting potential for increase in the system capacity and availability has been demonstrated in the literature [1]. ACM procedures require signal-to-noise ratio (SNR) estimation as a measure of the channel quality. Hence, the accuracy of SNR estimation algorithms directly affects the efficiency of ACM. Therefore, SNR estimation efficiency is a major topic of interest for satellite systems such as DVB-S2 and DVB-RCS which employ ACM.

SNR estimation techniques can broadly be divided into two categories: (1) data-aided (DA) techniques that make use of training symbols in estimation and (2) non-data-aided (NDA) techniques that estimate SNR using information bearing portion of the received signal. Although various SNR estimation methods have been proposed in the literature, there is not much work done in this area from the system point of view. In [2], the performances of contemporary SNR estimation algorithms are quantified in terms of number of received symbols needed to obtain an estimate with a given error margin. Their suitability as channel quality indicators for a typical digital video broadcasting (DVB) type satellite system is analyzed by considering the various assumptions involved in the algorithms, the effect of noise due to interference and the fast fluctuations of the propagation channel during rainy conditions. It is concluded that the data-aided (DA) maximum-likelihood (ML) estimator is the best choice for the high speed forward link compliant with the DVB-S2 standard in a broadband Interactive Satellite System. This is because pilot symbols, periodically repeated within each frame in DVB-S2, enable DA estimation using the optimally efficient ML algorithm to estimate SNR with an error margin of 0.2 dB within few milliseconds. However, this level of accuracy cannot be achieved on the return link adhering to DVB-RCS standard due to absence of a repetitive pilot symbol structure and the use of a short preamble consisting of only 48 symbols for each burst transmission. In the above scenario and due to slot to slot variation in interference level resulting from sporadic nature of data traffic on the return link, it is necessary to perform SNR estimation within one traffic slot duration employing all available symbols (preamble and data) for reliable channel estimation with an acceptable error margin. Therefore, decision-directed (DD) and NDA estimators are of particular interest and the performance of DD ML and M2M4 estimators presented in [3] can be considered as the benchmark in this scenario.

Here, a proposed NDA/DD SNR estimator is presented [4] which can be used for full scale ACM, employing QPSK and 8PSK modulation schemes with different code rates, in future DVB-RCS systems providing interactive broadband services to fixed terminals.

2. Proposed Estimator

The new NDA estimator for QPSK is proposed based on the observation that the absolute values of the in-phase and quadrature components of the received signal have a close relationship with signal power, since these components have a constant amplitude in the transmit signal. Based on this observation, the signal power estimator is derived using the mean of absolute values of the in-phase and quadrature components of the received signal samples. Noise power is estimated using the conventional method by subtracting the estimated signal power from total received power.

The observed property of constant amplitude of the in-phase and quadrature components is not valid for 8PSK signals, which means that the above described estimator is not directly applicable. However, it is observed that the 8PSK constellation consists of one QPSK constellation and two orthogonal BPSK constellations dividing the signal into three subsets. In each subset, the absolute values of the amplitudes of received signal components remain fixed. Therefore, a DD estimator is proposed for 8PSK modulated signal wherein the received signal samples are partitioned into three subsets based on their phase values and the average signal power in each subset is estimated by averaging the amplitudes of received signal components. Finally, average signal power is
estimated by averaging the estimated power in the three subsets according to the fraction of samples in a subset with respect to the total received signal samples.

3. Simulation Results

Computer simulations were performed to identify the suitability of the proposed estimator as a channel quality indicator in a DVB-RCS type satellite system and to quantify its performance when the estimation is performed in duration of one slot only carrying an MPEG transport stream packet. Simulation results show that the proposed estimator achieves data-aided Cramer-Rao bound (CRBDA) at moderate/high values of SNR. This is a significant improvement in accuracy than \( M_2M_4 \) but similar to DD ML. However, the overall complexity of the proposed estimator is less than both estimators as can be seen from Table 1. It shows the number of real additions and multiplications required to estimate signal power using the three estimators assuming equiprobable distribution of transmitted 8PSK constellation. For \( M_2M_4 \) estimator, the number of computations required to calculate \( M_2 \) is not taken into account, since, it is required to estimate SNR in all the three algorithms. For a single MPEG transport stream (TS) packet carrying 8PSK-modulated symbols (i.e. 501 symbols), the proposed estimator requires only 11 real multiplications (it is independent of the number of estimation symbols \( 'L' \)) and 751 additions, whereas, DD ML requires 1001 multiplications and 1004 additions while \( M_2M_4 \) requires 1507 multiplications and 501 additions (both having a multiplication complexity which increases with \( L \)).

![Table 1. Complexity Comparison of the Estimators](image)

<table>
<thead>
<tr>
<th>Operation</th>
<th>( \hat{S}_{DOM} )</th>
<th>( \hat{S}_{\text{proposed}} )</th>
<th>( \hat{S}_{M_2M_4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real Multiplications</td>
<td>2( L+2 )</td>
<td>11</td>
<td>3( L+4 )</td>
</tr>
<tr>
<td>Real Additions</td>
<td>2( L-1 )</td>
<td>1.5( L-1 )</td>
<td>( L )</td>
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</table>

Fig. 1 NMSE of estimated SNR for QPSK in complex AWGN

As seen from the results in Fig. 1 and 2, \( M_2M_4 \) estimator has lower NMSE at low SNR values than the proposed estimator. Therefore, it is further proposed to use a hybrid algorithm that first estimates SNR according to the less complex proposed algorithm and if the estimated value is below a certain threshold, then the SNR is estimated according to the more complex \( M_2M_4 \) estimator. From the extensive computer simulations, the threshold levels were found to be 7dB and 12.5dB for QPSK and 8PSK modulation schemes, respectively.

![Fig. 2 NMSE of estimated SNR for 8PSK in complex AWGN](image)

4. Conclusion

A new signal-to-noise ratio estimator has been proposed for use in future DVB-RCS systems employing adaptive coding and modulation. The estimator makes use of only amplitude and phase values of the received signal in its estimation/decision process such as to achieve significant improvement in performance (i.e. lower complexity and greater accuracy) than the existing estimators for both QPSK and 8PSK. It shows promising results for the operating SNR region of ACM even in the worst case scenario of a single MPEG TS packet for each burst transmission.

References


How much multi-user diversity is required for energy-limited multi-user networks

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Abstract

In this work, we consider uplink multi-user (MU) wireless networks and we develop MU scheduling algorithms which aim at maximizing the multi-user diversity (MUDiv) gain. MUDiv is one of the central concepts in MU networks. In particular, MUDiv allows for scheduling among users in order to eliminate the negative effects of unfavourable channel fading conditions of some users on the network performance. Scheduling, however, consumes energy (e.g., for making users’ channel state information available to the scheduler). This extra usage of energy, which could potentially be used for data transmission, can be very wasteful, especially if the number of users is large. In this paper, we answer the fundamental inquiry of how much MUDiv is required for energy limited MU networks. Using asymptotic analysis and numerical simulations, we show that our approach benefits from MUDiv gains higher than that achievable by generic algorithm, which is the optimal scheduling method for energy unlimited systems.

Key words: Multi-User Diversity, Terminal Energy Usage, Bit Error Rate, Opportunistic Scheduling.

1. Introduction

For multipoint–to–point single–input single–output (SISO) wireless systems, the multiuser diversity (MUDiv) gain was first studied in [1]. The information theoretic results have shown that based on the optimal transmit power control, the overall network throughput can be maximized by allowing only the ‘best’ user in a network to transmit at each time slot.

As per the state of the art femtocell technologies by commercial standardization bodies (e.g., 3GPP’s LTE), femtocells also consist of multiple femto users accessing radio spectrum, assigned to their own femtocell. Accordingly, a careful study of MUDiv gain within/across femtocell(s) would be performed to enhance the femtocell performance as well as to provide mutual co-existence between femtocell(s) and the macro network [2,3].

Toward improving the MUDiv gain in a single cell, notice that, in the conventional approaches, the MUDiv has been investigated for the case of fixed transmit resources, e.g., fixed transmit energy and fixed number of active users (e.g., [4]).

Although it has rarely been discussed before, it is important to note that the MUDiv gain relies on the total energy available at the users and, therefore, depends on this energy, especially for the energy limited networks such as femtocell network. Particularly, such an energy issue in the femtocell context is very important. This is because as a result of an extensive femtocells deployment in the near future, one prime concern is the resulting substantial energy usage.

In this work, we develop methods which aim at maximizing the MUDiv gain in multuser (MU) networks by exploiting a realistic energy model. Unlike existing methods, we consider also the energy spent by users to exchange signalling symbols to the BS. By bringing this inherent energy usage into the picture, we find that it is better to choose (schedule for data transmission) the ‘best’ user from a subset of users (referred to as the set of active users) rather than among the entire set of users. Based on this approaches, it will be shown that a significant amount of energy usage can be saved from the terminal side at an acceptable performance level.

2. System Model and Problem Description

2.1 System Model

Focusing on the uplink in the single cell network, $K$ user equipments (UEs) each having a single antenna intend to communicate with the base station (BS) having $d$ receiving antennas via orthogonal channels in, for example, the frequency domain (e.g., 3GPP’s LTE). Suppose that the wireless channel between each UE and the BS is flat fading.

Notice the fact that in conventional MUDiv mechanisms, there inevitably exist following two different main phases of energy usage:

i) Control signalling energy phase (denoted by Phase 0) in which signalling information is exchanged,

ii) Data-transmission energy phase (denoted by Phase 1) in which data transmission via the opportunistic scheduling occurs.

Unlike conventional approaches considering mainly energy usage at Phase 1, we take into account sum energy usage by all UEs at both the above control and data phases.

2.2 Problem Description

Two different objectives can be considered for selecting $K \leq K$ active UEs: (i) minimization of the network BER and (ii) minimization of the total energy ($E_T$) consumed by all users in the network.

To resolve this problem, we address the inherent trade-off of energy usages at the above phases while remaining the fixed total energy. Although the users are not connected to the same energy source, given the finite energies at individual users, the sum of individual user energies also determines the total.
energy consumed by all users. It is worth stressing that for network performance analysis in MU network, the total energy consumed by all users is more important than individual user energies because the MUDiv gain depends on the number of users participating in scheduling, and the energy which determines the MUDiv gain is the total energy consumed by all users, rather than the individual user energies.

3. Key Analytical and Simulation Results

3.1 Asymptotic analysis for the network BER minimization

We consider two cases of (i) large $K$ and (ii) high SNR and study the asymptotic behaviour of optimal $K^*$, minimizing the network BER. Here, the network BER is equivalent to the BER of the best UE as per our system model.

In the case when $K$ is large, we first determine how the system BER scales with $K$ while satisfying the finite energy constraint. When controlling the energy distribution among Phases 0 and 1, the achievable power gain is $G_p = (K - K)\alpha^2 + 1$, where $\alpha$ is the ratio of the energy in Phase 1 to Phase 0. And, the network BER can be asymptotically written as $P_{b_{GA}}^{K-GA}(K) = \Theta(K^{-G_p \text{SNR}^n})$, where SNR denotes the receiving signal-to-noise ratio of the best UE in the conventional opportunistic scheme.

In the case of high SNR, the asymptotic network BER expression can be obtained as $P_{b_{GA}}^{K-GA}(K) = \Theta(G_p^{-K \text{SNR}^n})$. It follows from this equation that the asymptotic network BER benefits from the MUDiv gain $G_p = (K - K)\alpha^2 + 1$ at the cost of having the diversity order $K < K^*$.

3.2 Simulation Results

Consider an MU system with Gray-coded square M-QAM of size $M \{4, 64\}$. Note that the parameter $\alpha = 2$ corresponds to the standard case when 280 pilot sub-carriers and 560 data sub-carriers are used per one sub-channel in 10 MHz uplink WiMAX (IEEE 802.16e).

Fig. 1 depicts the impact of the optimal $K$ on the network BER versus $P_T$. It can be seen from the figure that the BER is a decreasing function of $P_T$. Moreover, for $M = 4$ and $P_T \leq 30.5 \text{ dB}$, the generic GA scheme is optimal since it provides minimum BER and the optimal $K^* = K^*$, in this case. However, when $P_T \geq 30.5 \text{ dB}$, the optimal $K^* = K^*$ is obtained.

With regard to the energy minimization, Fig. 2 depicts the total energy usage on average by UEs versus transmit SNR. As can be seen, the delay-tolerant (DT) MU system requires less power (energy) than the delay-sensitive (DS) MU system while satisfying the system requirement on target BER.

4. Summary

A new realistic energy model which describes the distribution of the total finite users’ energy between signalling and data transmission phases is developed for the energy limited uplink MU wireless systems. Our analytical and numerical results show that with no extra energy usage, the proposed scheme can enhance the network performance significantly, compared to the conventional approaches.

Fig. 1 Total network BER using the optimal $K$ versus $P_T$ when $\text{SNR} = 5 \text{ dB}, M = 4, 64, \alpha = 2$.

Fig. 2 Average $P_T$ of K-GA in DS MU and DT MU when $K = 100, d = 1, \alpha = 1$ and $\text{BER}_i = 0.001$.

References


EXIT Chart Analysis for Turbo LDS-OFDM Receivers

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Abstract

In this paper, the mutual information transfer characteristics of turbo Multiuser Detector (MUD) for a novel air interface scheme, called Low Density Signature Orthogonal Frequency Division Multiplexing (LDS-OFDM) are investigated using Extrinsic Information Transfer (EXIT) charts. LDS-OFDM uses Low Density Signature structure for spreading the data symbols in frequency domain. This technique benefits from frequency diversity besides its ability of supporting parallel data streams more than the number of subcarriers (overloaded condition). The results show that at $E_b/N_0$ as low as 0.3 dB, LDS-OFDM can support loads up to 300%.

Key words: EXIT Chart, turbo mutliuser detector/decoder, low density signature.

1. Introduction

In recent years, there has been considerable interest on improving the efficiency of modulation and coding techniques to be used for broadband wireless services. Future wireless communication systems are expected to provide a range of high speed services with different Quality of Service (QoS) requirements. In this regard LDS-OFDM has recently been introduced as an efficient multiple access technique. LDS-OFDM approach combines benefits of OFDM based multicarrier transmission with a recent idea on Low Density Signature (LDS) based spreading proposed for CDMA systems in [1].

In LDS-OFDM, due to low density signature structure, every data symbol will only be spread over a small subset of subcarriers (effective processing gain) and also every subcarrier will only be used by a small subset of data symbols that could belong to different users. The LDS structure can be captured by a low density graph, thus, similar to the application of LDS for CDMA system, the detection of LDS-OFDM could be based on message passing algorithm (MPA) presented in [1] for LDS-CDMA systems. This new technique can be viewed as a system which applies LDS as multiple access technique and OFDM for multicarrier modulation. In [2], it was shown that LDS-OFDM could improve the performance if compared to OFDMA but with the cost of increased complexity. It is noticeable that the complexity of LDS-OFDM is higher than the conventional OFDMA but it is still affordable.

In order to increase the spectral efficiency of LDS-OFDM, the loading or modulation order must be increased while keeping the performance near single user bound. However, this requires efficient MUD receiver to decode overloaded parallel data streams. To keep the complexity low these receivers usually operate on iterative decoding principle and their convergence analysis becomes important. In this paper we provide the framework and tools to perform this analysis. Inspired by the message passing analysis presented in [3] [4], this paper proposes the evaluation of the extrinsic information transfer characteristics to describe the flow of information through the soft-input soft-output (SISO) components of the turbo MUD for the LDS-OFDM scheme. The Extrinsic Information Transfer chart (EXIT chart) is used for finding the effect of loading on convergence of turbo MUD which gives us insights about the maximum load that the LDS structure can tolerate.

The LDS-OFDM’s turbo receiver is made of two basic components: LDS multiuser symbol detector and a bank of users’ SISO FEC decoders. The extrinsic information is iteratively exchanged between the two components towards a solution with less number of bit errors. Noticeable performance improvement is observed compared to the conventional receiver that does not benefit from this iterative exchange of information. EXIT chart analysis is employed to evaluate the convergence of the considered turbo MUD [4]. For both of its components, the detection/decoding trajectory is derived to visualize the evolution of extrinsic information in their detection/decoding process. Simulation results suggest that the derived EXIT charts are able to accurately predict the convergence behaviour of the turbo MUD for LDS-OFDM.

2. Technical Approach

In the LDS-OFDM technique, the original data streams are first multiplied with their low density spreading sequences and then modulated on different sub-carriers. The conceptual block diagram of an uplink LDS-OFDM system is shown in Fig. 1. To further explain and clarify, in this system, each chip represents a subcarrier of OFDM modulation and the data symbols using the same subcarrier will interfere with each other. The amount of interference will depend on the allocated power of data symbols on each subcarrier and user’s
corresponding channel gain. Without loss of generality all users are assumed to take their symbols from the same binary constellation alphabet. Also users are assumed to have the same number of data symbols $M$ so the spreading signature for user $k$ will be $S_k = (s_{k,1}, \ldots, s_{k,M}) \in \mathbb{C}^{M \times M}$ that has only $d_v$ nonzero components on each column. Let $\mathcal{J} = \{(k,m) : s_{k,m}^2 \neq 0 \}$ be the set of different users’ data symbols that share the same chip $n$ or in other words be the set of nonzero positions in the $n^{th}$ row of the signature matrix $S$. So the received signal at $n^{th}$ chip (subcarrier) is:

$$y_n = \sum_{(k,m) \in \mathcal{J}} h_{k,m}^n x_{k,m} + v_n$$

(1)

where $v_n$ is the additive white Gaussian noise of subcarrier $n$ and $x_{k,m}$ is the $m^{th}$ data symbol of user $k$. At the receiver side, after performing OFDM demodulation operations the signal is passed to a near-optimum MUD based on Message Passing Algorithm (MPA) [1]. The turbo receiver of LDS-OFDM is based on iterative detection/decoding between LDS data symbol detector and users’ FEC decoders. This is realized by iterative exchange of extrinsic information between detection and FEC decoding stages. The block diagram of LDS-OFDM’s turbo MUD is illustrated in Fig. 1. In the turbo MUD, there exist two iterative processes: inner and outer iterative processing for MUD and the turbo-style processing, respectively. Considering now that two iterative processes are involved, the message update algorithm should be addressed accordingly. In this paper the main focus is on Additive White Gaussian Noise (AWGN) channels, however, it can be extended to multifading fading channels.

3. Key Results and Discussion

Extrinsic Information Transfer (EXIT) chart is a useful tool to analyse the information transfer between the two components of a decoder with iterations. Inspired by the message passing analysis, in this section the extrinsic information transfer characteristics are evaluated to describe the flow of information through the Soft-Input Soft-Output (SISO) components of the turbo multiuser detection algorithm for the turbo receiver of LDS-OFDM scheme. So the extrinsic L-values are passed on and interpreted as $a$ priori information by the other detector or decoder. We use the notation of [3] and write $I_s$ for the average mutual information between the bits sent to the detector/decoder (which are the bits about which extrinsic L-values are exchanged) and the $a$ priori L-values. Similarly, $I_e$ refers to the average mutual information between the bits sent to the detector/decoder and the extrinsic L-values.

Using EXIT chart analysis we will be able to find the maximum load that the LDS-OFDM system can handle for a target BER. In this section, we present the simulation results for LDS-OFDM systems over different loading conditions. LDSOFDM’s signatures are generated randomly. We denote the $a$ priori information and extrinsic information of the MUD by $I_{MUD}$ and $I_{MUD}$, respectively, while the corresponding quantities of the channel decoder by $I_{FEC}$ and $I_{FEC}$, respectively.

Fig. 2 illustrates the EXIT chart for the turbo MUD with different loaded condition over AWGN channel. The iterative process starts with $I_{MUD} = 0$ which means no prior information for the MUD. Next, the output L-values are fed into decoder while their output L-values are then fed back to MUD and so forth. Considering the mentioned results we can say that LDS-OFDM is able to tolerate up to 300% load at $E_b/N_0$ as low as 0.3 dB. For the 350% loaded case, the two curves intersect at low mutual information level which results in high BER. Fig. 2 also shows that the curves related to MUD for different overloaded conditions meet at $I_s = 1$, which is because for perfect a priori information, the MUD is able to remove the multiple access interference (MAI) completely and overloading effect will be cancelled. This result also implies that more number of iterations is needed to achieve convergence when the system is more heavily loaded.

It is also shown that since the simulated decoding trajectories closely follow the EXIT curves of the receiver components, the validity of EXIT chart analysis can be verified. The analysis can be extended to higher order modulations. So a better spectral efficiency can be achieved by finding the trade-off on tuning modulation level and loading factor.

4. Summary of the work, potential impact & Conclusion

Using EXIT charts the convergence behaviour of the turbo MUD was analysed, and we were able to show how loading affects the performance of LDS-OFDM system as the curves intersect at points where mutual information is lower for higher loading values. The results shows that at $E_b/N_0$ as low as 0.3 dB, the receiver of LDS-OFDM is able to detect parallel data streams up to 300% more than the number of subcarriers.

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