Multi-stage multi-user detection assisted fast-FH/MFSK

K. Hamaguchi, Lie-Liang Yang and L. Hanzo

A multi-stage multi-user detection (MUD) scheme designed for a fast-FH/MFSK system is proposed, in which the received signal level is attenuated by a constant scaling factor when the signal is deemed to be overwhelmed by multi-user interference. In the investigated scenario a substantially reduced bit error rate is achieved.

Introduction: In [1] an efficient multi-stage multi-user detection (MS-MUD) scheme has been proposed for improving the performance of a fast frequency-hopping/multilevel frequency shift keying (fast-FH/MFSK) system [2]. This MUD successively eliminates the interfering signals by exploiting the knowledge of the users' MUD addresses. Recently, a further improved MS-MUD scheme was proposed [3], where the contribution of the estimated interfering signal is cancelled from the received composite signal by exploiting both the knowledge of all users' MUD addresses as well as that of their received signal powers, i.e. MS-MUD is capable of successfully mitigating the effects of interference, provided all users' received signal powers are known. In practice, however, the received signal is typically contaminated by multi-user interference (MUI) and hence it may be an arduous task to accurately determine the individual users' received signal powers.

In our proposed MUD, a constant weighting factor is invoked for mitigating the effects of the interferers. Specifically, in the proposed system both the matrix of the desired signal and that of the interference are constructed similarly to the procedure used in the MS-MUD of [3], but we eliminate the requirement of knowing the received signal powers.

Fast-FH/MFSK system: Let us consider a time-frequency coded system [2], where K number of users are supported and the transmitted signal of each user is constituted by a sequence of L-chips, selected from Q-possible frequencies. Furthermore, we assume that the L-chip sequences of all the users arrive at the same instant, i.e. that we employ a synchronous system. The possible received signals of the system are described by a matrix having Q rows and L columns, representing the legitimate frequencies and time slots, respectively.

We assume that $x_k(m) = \{0, 1, 2, \ldots, Q-1\}$ represents a data symbol of the kth user transmitted at the time instant of $t = mL\Delta + t_0$, where m, Δ, and t_0 represent the transmitted symbol index, the chip duration and the initial time offset, respectively. Let $\boldsymbol{a}_k = (a_{k,1}, a_{k,2}, \ldots, a_{k,L})$ be the MUD address assigned for user k and let us denote the received signal of user k by $\boldsymbol{y}_k(m) = (y_{k,1}(m), y_{k,2}(m), \ldots, y_{k,L}(m))$, which may be written as

$$\boldsymbol{y}_k(m) = x_k(m) \cdot \mathbf{1} + \boldsymbol{a}_k \tag{1}$$

where we have $\mathbf{1} = (1, 1, \ldots, 1)$, which represents a unit-vector, while '+' indicates addition over the Galois field GF(Q).

The receiver processes the received signal for the sake of constructing the $(Q \times L)$-element received signal matrix of $\mathbf{R}(m) = \{r_{q,l}(m)\}$, in which each matrix element stores the corresponding received signal components, each having a different detected power level, where we have $1 \le q \le Q$ and $1 \le l \le L$. Given the received signal matrix, the data symbol may be estimated using the detection scheme described below.

Proposed MUD scheme: Fig. 1 shows the block diagram of the proposed MUD. To simplify its description, we omit the transmitted symbol index m. First, the elements of the received signal matrix, $\mathbf{R}^{(i)} = \{r_{q,l}^{(i)}\}$, valid for detection stage i are compared to a constant-valued positive threshold δ, for the sake of generating $\hat{\mathbf{R}}^{(i)} = \{\hat{r}_{q,l}^{(i)}\}$, where we have $\hat{r}_{q,l}^{(i)} = 1$ for $r_{q,l} > \delta$, and 0 otherwise. Next, $\hat{\mathbf{R}}^{(i)}$ is used for generating the data of user k with the aid of subtracting $\boldsymbol{a}_k$ from $\hat{\mathbf{R}}^{(i)}$ on a chip-by-chip basis over GF(Q), producing the decoded data matrix $\mathbf{D}_k^{(i)} = \{\hat{r}_{(q-a_{k,l}),l}^{(i)}\}$ as seen in Fig. 1. If the received signal does not suffer from any noise or other channel impairments, $\mathbf{D}_k^{(i)}$ contains a complete row of binary one values at the received signal matrix positions corresponding to the desired user's symbol $x_k(m)$. In practice, however, the received signal suffers from both MUI imposed by the undesired users as well as from AWGN and other channel impairments. Hence the received signal matrix may contain incomplete rows, as well as multiple nonzero rows, which renders the detection process prone to detection errors. By contrast, in a perfect reception scenario one and only one complete row having nonzero values exists, which allows us to unambiguously estimate the data symbol, $\hat{x}_v^{(i)}$, for $1 \le v \le K$, $v \ne k$.

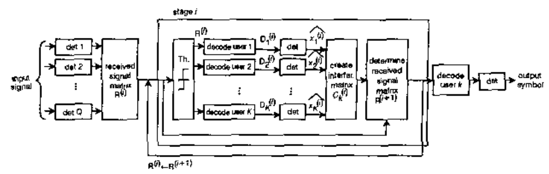

Fig. 1 *Block diagram of proposed MUD*

In the next detection step we construct the estimated interference matrix, $\mathbf{C}_k^{(i)} = \{c_{q,l}^{(i)}\}$ for user k, where we have $c_{\hat{x}_v^{(i)}+a_{v,l},l}^{(i)} = 1$, and zero otherwise. Using this matrix, we proceed by assuming that if the (q, l)th element of the interference matrix, namely $\mathbf{C}_k^{(i)}$, is not 0, then this particular element of the received signal matrix, $\mathbf{R}^{(i)}$, will be corrupted by the MUI with a high probability. Thus, we propose that the (q, l)th, and only the (q, l)th element of $\mathbf{R}^{(i)}$ be updated using the following relationship:

$$r_{q,l}^{(i+1)} = \rho \cdot r_{q,l}^{(i)} \tag{2}$$

where ρ is a positive real-valued constant constrained to the range of $0 < \rho < 1$. Intuitively, a small value of ρ may necessitate the employment of a high number of detection stages, but has the benefit of ensuring that low signal contributions are not inadvertently cancelled. By contrast, a high value of ρ may result in cancelling the desired signal. It is worth noting that in the MUD of [3] $r_{q,l}^{(i+1)} = 0$ was used, when the condition of $|c_{\hat{x}_v^{(i)}+a_{v,l},l}^{(i)} - r_{\hat{x}_v^{(i)}+a_{v,l},l}^{(i)}| < \varepsilon_v$ was satisfied, where $c_{\hat{x}_v^{(i)}+a_{v,l},l}^{(i)} = E_v \cdot E_v$ as well as ε_v, respectively, were defined as the received signal power and the detection threshold related to user v, $1 \le v \le K$, $v \ne k$.

The next detection stage invokes again the same procedure, as described above. When we curtail this iterative detection at the $(i+1)$th stage, the received signal hosted by $\mathbf{R}^{(i)}$ is decoded again. The final detection step is constituted by finding the specific row of $\mathbf{R}^{(i)}$, which exhibits the maximum decoded power that is expressed as:

$$x_k^{\prime(i+1)} = \max_n \left\{ \sum_{l=1}^{L} r_{(n-a_{k,l}),l}^{(i+1)} \right\} \tag{3}$$

Without proof we note that this detection scheme is not optimum for interference-contaminated channels [4]. This issue constitutes the subject of our future research.

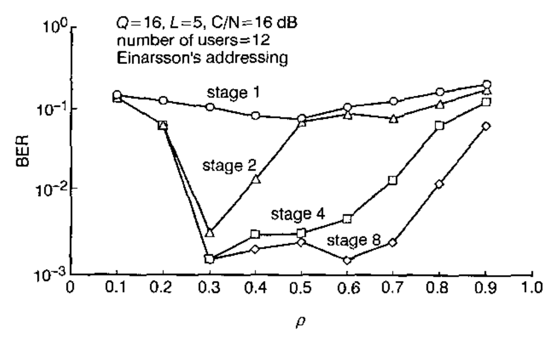

Fig. 2 *ρ against BER of fast-FH/MFSK system using Einarsson's addressing scheme [4] invoked in proposed MUD for transmission over AWGN channel at C/N = 16 dB and number of users = 12*

Results and discussions: Since the proposed procedure involves a nonlinear process, it is rather impervious to theoretical analysis. Hence we evaluated its BER performance using computer simulation. This Section characterises the BER performance of the fast-FH/

MFSK system employing the proposed MUD, as well as a single-user detector (SUD) and the MS-MUD of [3] as benchmark schemes, where the SUD simply finds the row of $\mathbf{D}_k$ containing the highest number of nonzero elements.

Fig. 2 shows the ρ against BER results, where $Q=16$, $L=5$ and number of users = 12. Einarsson's multi-user addressing scheme [5] was used for the sake of minimising the chip collisions. An AWGN channel was used, we had $C/N=16$ dB. δ was defined in the same manner as in [3], where the false alarm threshold introduced for detecting the presence of noise rather than a useful signal was set to 0.01. The power of the desired signal and that of each interfering signal was the same. In these environments, we can see that when we set ρ to 0.3 the achievable BER is lower, despite using a lower number of stages.

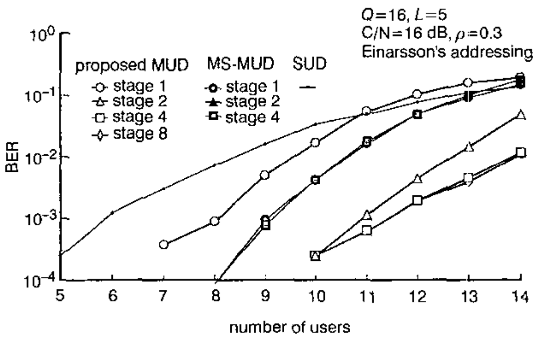

Fig. 3 *BER of fast-FH/MFSK system using Einarsson's addressing scheme [4] invoked in proposed MUD, as well as in SUD, and MS-MUD of [3] for transmission over AWGN channel at $C/N=16$ dB*

Fig. 3 shows the number of users against BER results. The condition is the same as Fig. 2. ρ was set to 0.3. Whilst the SUD is the simplest detection scheme, its BER is the highest among the detection schemes studied, especially, when the number of users is low. The MS-MUD of [3] performs better than the SUD, because the effects of interference are efficiently cancelled. Moreover, as is seen in Fig. 3, the achievable BER does not tend to improve when increasing the number of detection stages. This is because the MS-MUD has the preponderance to set certain elements of the received signal matrix to zero during the first detection stage and hence the achievable BER does not improve during the successive detection stages. Conversely, although the BER of the proposed MUD is worse than that of the MS-MUD after the first detection stage, its BER is substantially improved upon increasing the number of detection stages involved. This is because certain elements of the received signal matrix become smaller owing to the scaling by the constant factor ρ used in (2) and hence the effects of MUI are gradually reduced. Finally, Fig. 3 also shows the tendency that the achievable BER of the successive detection stages slows down after the fourth stage in the scenario studied.

Conclusion: A multi-stage MUD is proposed for employment in fast-FH/MFSK systems. In the proposed MUD the received signal level is attenuated by a constant scaling factor, when the signal is deemed to be overwhelmed by MUI. In the investigated scenario the achievable BER of the proposed MUD was reduced by as much as an order of magnitude in comparison to the benchmarker scheme of [3]. Alternatively, the number of users supported may be increased by about 30% with the advent of the proposed scheme.

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References

1 FIEBIG, U.: 'Iterative interference cancellation for FFH/MFSK MA systems', *IEE Proc., Commun.*, 1996, **143**, (6), pp. 380–388
2 TIMOR, U.: 'Improved decoding scheme for frequency-hopped multilevel FSK system', *Bell Syst. Tech. J.*, 1980, **59**, (10), pp. 1839–1855
3 HALFORD, K.W., and BRANDT-PEARCE, M.: 'Multi-stage multiuser detection for FHMA', *IEEE Trans. Commun.*, 2000, **48**, (9), pp. 1550–1562
4 YUE, O.: 'Maximum likelihood combining for noncoherent and differentially coherent frequency-hopping multiple-access systems', *IEEE Trans. Inf. Theory*, 1982, **28**, (4), pp. 631–639
5 EINARSSON, G.: 'Address assignment for a time-frequency-coded, spread-spectrum system', *Bell Syst. Tech. J.*, 1980, **59**, (7), pp. 1241–1255

Optimum transmission strategy for power saving in fading channels

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An optimum transmission strategy in a fading channel with known channel side information at the transmitter and receiver is addressed. The Shannon channel capacity is reformulated based on dynamic programming and it is demonstrated how this model can extend the information-theoretic domain for solving the channel capacity when a closed-form solution cannot be found.

Introduction: Traditionally, the perspective and aims of information theory and networking have been dissonant [1]. The information-theoretic approach typically determines the performance of the best possible scheme with simple assumptions for source traffic and with a limited set of constraints. In contrast, the networking approach considers more practical assumptions while mostly analysing the performance of a particular scheme or algorithm.

Let us denote by X and Y the input and output of a communication channel. The ergodic capacity of channels with memory and memoryless channels are obtained using the relations $C=\max_X I(X;Y)$ and $C=\lim_{n\to\infty}\sup_{X^n} I(X^n;Y^n)$, respectively, where n is the number of symbols [2]. However, these two general formulas are useful only when the maximum transmission rate over a long time interval is the parameter of concern. In practical communication systems, where there is a required maximum tolerable delay for each information packet, the optimum transmission strategy is a function of channel variation in the specific time duration in which the packets must be transmitted and of the statistics of the arrival process to the queue.

In general, the optimum transmission strategy in a communication system depends on: (i) the available information on the network, such as knowledge of traffic characteristics or number of packets in the buffer, (ii) system constraints, such as the maximum transmit power or maximum probability of error, and (iii) an objective function defined in order to minimise some system resource, such as the total transmit power. Here, the optimum transmission strategy is defined as the one which satisfies all the constraints while utilising all of the nodes' knowledge of the communication system to optimise an objective function.

We consider the Shannon capacity of a fading channel with channel side information at the transmitter and receiver. We then formulate the problem based on dynamic programming (DP) [3] and compare the result to those obtained from information theory. DP, explored recently in [4], forms the basis of the present method because of its generality and ability to encompass a variety of constraints.

Power-constraint capacity: Consider an AWGN, flat, slowly fading channel and assume that perfect channel state information (CSI) is available to both transmitter and receiver. Now assume that the slowly varying part of the path gain level be modelled by a stationary and ergodic process G. In this case, each channel state can be uniquely identified with a distinct value of G, and for each value of G, the standard Shannon capacity can be used. Let P_n denote the average power of AWGN at the receiver and P_{T_avg} the average transmit signal power. We define $\gamma=G/P_n$ with a known distribution $p(\gamma)$ and set $P_T(\gamma)$ equal to the instantaneous transmit power as a