A novel soft-demapping algorithm for 16-APSK, for systems employing uncoded modulation

Conference Paper · April 2014

2 authors:

Chatzikontantinou Christos
Aristotle University of Thessaloniki

Xenofon Spafaridis
Aristotle University of Thessaloniki

A novel soft-demapping algorithm for 16-APSK, for systems employing uncoded modulation

Chatzikontantinou Christos and Spafaridis Xenofon
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
Thessaloniki, Greece
email:{chatzikc, xenofons}@auth.gr

Abstract— **In this paper we propose a novel low complexity soft decision demapping algorithm for 16-APSK, which can be used in systems employing uncoded modulation. Calculation of each bit's value is based on decision regions for each bit. The proposed algorithm has a very low complexity, while its performance is comparable to the performance of the most used soft decision demapping algorithms in the literature**

Keywords— ***soft-demapping; uncoded modulation; APSK-16; DVB-S2; demapping;***

I. INTRODUCTION

Amplitude and phase-shift keying (APSK) is an attractive modulation scheme for digital transmission over nonlinear satellite channels due to its power and spectral efficiency combined with its inherent robustness against nonlinear distortion. It was first proposed in the 1970's [2]. APSK is a digital modulation scheme used in Second Generation Standard of Digital Video Broadcast (DVB-S2). DVB-S2 is the second generation DVB specification for broadband satellite applications, developed on the success of the first generation specifications, DVB-S and DVB-DSNG, benefitting from the technological achievements of the last decade [1].

Soft-decision techniques presented below are based on the calculation of the probability that each bit of the received symbol on 16-APSK can be either 0 or 1. So 16 probabilities are calculated, divided in two sets: probabilities that the bit has the value 0 and probabilities that the bit has the value 1, "0 probabilities" and "1 probabilities". The result is calculated either by dividing or by subtracting two sets of probabilities and it presents an estimation of the average probability for a bit to be 0 rather than 1.

One of the most used soft decision techniques is the Log Likelihood Ratio (LLR). It is defined as the common logarithm of the ratio of two sets of possibilities: "0 probabilities" divided by "1 probabilities". LLR algorithm is the optimal solution in terms of performance.

Another soft decision method is the MAX method. MAX function reduces the amount of operations in the conventional LLR method but has small performance degradation. Reduction of the operations is achieved by using the following method: the biggest exhibitor for both probability sets is found, which allows the erasure of the logarithm and the erasure of the result just as a subtraction of two exhibitors

Another method is the Euclidean Method. In this method the Euclidean distance of the received symbol and the constellation symbols is calculated. Hereupon the smallest price for each probability set is calculated and subtracted. Due to the calculation of the Euclidean distance, this method has higher complexity than the MAX method but it is still simpler than LLR method. It also has lower performance than both LLR and MAX method.

In [4], a method of a simplified LLR is proposed where the LLR of each bit is approximately calculated by a few multiplications, based on the decision regions of four bits. Some approximations are made in order to achieve lower computational complexity which leads to a small degradation of the performance. The algorithm is further analyzed in section 3.

In this paper we propose a novel low complexity soft decision demapping algorithm for 16-APSK, which can be used in systems employing uncoded modulation. It has very low complexity and a performance similar to the simplified LLR algorithm presented above. Two less significant bits are calculated in the same way as in the simplified LLR. Two more significant bits are calculated based on the decision regions of constellation points. More information on the proposed algorithm and simulation results are in following sections.

II. SYSTEM MODEL

The diagram of 16-APSK with imperfect Gray coding shown in Fig 1, consists of two concentric rings, the inner of radius R_1 and the outer of radius R_2. Ratio R_2/R_1 defines the coefficient γ. The symbols are placed uniformly, 4 over the inner ring and 8 over the outer ring. Each symbol consists of four bits $b_3b_2b_1$ and b_0, with b_3 being the most significant bit and b_0 the least significant bit

The baseband representation of transmitted signal Y is given as: Y = I + jQ, where I is the in-phase component, Q is the quadrature component and $j = \sqrt{-1}$.

We assume that the prior probabilities are the same for every constellation symbol

Our purpose is to find a low complexity demapping algorithm without significant degradation of BER performance related to soft-decision algorithms referred in section 1.

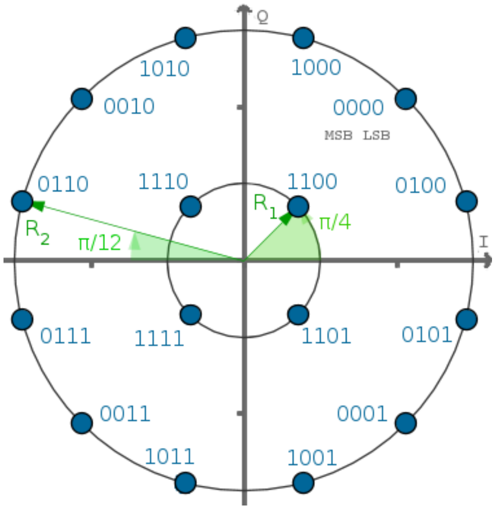

Figure 1. 16-APSK Constellation

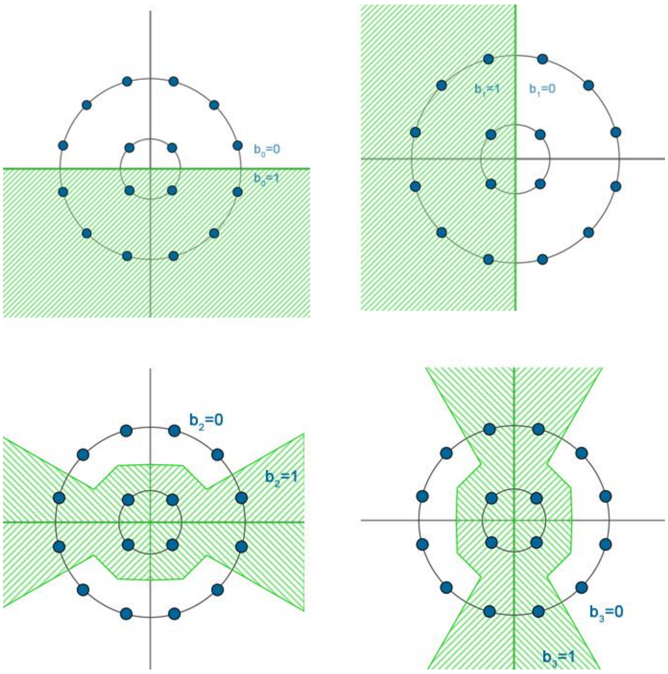

Figure 2. Decision region for four bits

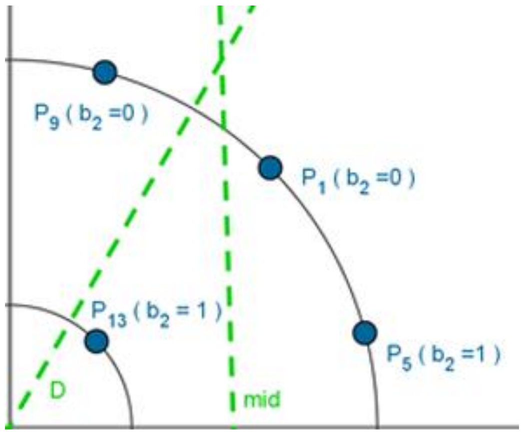

Figure 3. The first quadrant of b_2 bit

III. ALGORITHM DETAILS

Motivated by the algorithm proposed in [4], we propose a new method for soft demapping, which is very efficient, both in terms of performance and computational complexity for 16-APSK. We begin this section presenting the algorithm proposed in [4].

Figure 2 shows the decision regions of all four bits. The values for LLR (b_0) and LLR (b_1) are calculated as follows

$$LLR(b_0) = \frac{a_1 \times Amp \times Q}{N_o} \quad (1)$$

$$LLR(b_1) = \frac{a_2 \times Amp \times I}{N_o} \quad (2)$$

Where N_0 is the power spectral density of Gaussian noise, Amp is the average amplitude of the constellation, a_1=1.6185 and a_2=1.2703 are weight factors.

LLR (b_2) is calculated as

$$LLR(b_2) = \frac{\|Y - P_1'\|^2 - \|Y - P_0'\|^2}{2\sigma^2} \quad (3)$$

P_0 and P_1 are coordinates of two symbols, calculated as follows:

$$P_0' = \begin{cases} P_9 & when \quad \sqrt{3} \times I \le Q \\ P_1 & when \quad \sqrt{3} \times I > Q \end{cases} \quad (4)$$

$$P_1' = \begin{cases} P_{13} & when \quad I \le mid \\ P_5 & when \quad I > mid \end{cases} \quad (5)$$

Where P_9, P_1, P_{13} and P_5 are the coordinates of the symbol in the first quadrant and

$$mid = \frac{1}{2} \times (R_1 \times \cos(\frac{\pi}{4}) + R_2 \times \cos(\frac{\pi}{12})) \quad (6)$$

The decision region of b_3 is symmetric with the decision region of bit b_2. The signal Y=I+jQ is mapped to Y=Q+jI and the same procedure is followed.

The above algorithm is used mainly for systems employing coded modulation, where the LLR values are used also in decoding. In this work, this algorithm is modified in order to be used as a demapping algorithm for systems employing uncoded modulation. We can see this algorithm below. Considering that in [4] there is no version for systems employing uncoded modulation, we modified it in the way we thought it was the best. The procedure, until the part we define P_0 and P_1 for bits b_2 and b_3 is the same as in [4] ($P_{0,2}$ and $P_{1,2}$ are P_0 and P_1 respectively for b_2, $P_{0,3}$, $P_{1,3}$ for b_3 likewise). As a result, for each one of the two bits mentioned above (the "current bit") we have two possible symbols: one symbol where the current bit has the value 0 and one symbol where the current bit has the value 1. Comparing the coordinates of the received symbol with the line bisector of the two symbols we have concluded to, we find the value of the current bit.

We define line bisector of P_{13} and P_1 as

$$line\_bisector = \frac{R_1 + R_2}{\sqrt{2}} \quad (7)$$

procedure modified(I, Q)
  $b_3 \leftarrow b_2 \leftarrow b_1 \leftarrow b_0 \leftarrow 0$

  if $Q < 0$ **then** $b_0 \leftarrow 1$
  end if

  if $I < 0$ **then** $b_1 \leftarrow 1$
  end if

  $I \leftarrow |I|$
  $Q \leftarrow |Q|$

  if $I \times \sqrt{3} < Q$ **then** $P_{0,2} \leftarrow P_9$
  else $P_{0,2} \leftarrow P_1$
  end if

  if $Q \times \sqrt{3} < I$ **then** $P_{0,3} \leftarrow P_5$
  else $P_{0,3} \leftarrow P_1$
  end if

  if $I <$ mid **then** $P_{1,3} \leftarrow P_{13}$
  else $P_{1,3} \leftarrow P_5$
  end if

  if $Y <$ mid **then** $P_{1,2} \leftarrow P_{13}$
  else $P_{1,2} \leftarrow P_5$
  end if

  if $P_{0,2} = P_9$ **and** $P_{1,2} = P_{13}$ **then**
    if $Q <$ mid **then** $b_2 \leftarrow 1$
    end if

  else if $P_{0,2} = P_1$ **and** $P_{1,2} = P_{13}$ **then**
    if $I + Q <$ line_bisector **then** $b_2 \leftarrow 1$
    end if

  else if $P_{0,2} = P_1$ **and** $P_{1,2} = P_5$ **then**
    if $I > Q \times \sqrt{3}$ **then** $b_2 \leftarrow 1$
    end if
  end if

  if $P_{0,3} = P_5$ **and** $P_{1,3} = P_{13}$ **then**
    if $I <$ mid **then** $b_3 \leftarrow 1$
    end if

  else if $P_{0,3} = P_1$ **and** $P_{1,3} = P_{13}$ **then**
    if $I + Q <$ line_bisector **then** $b_3 \leftarrow 1$
    end if

  else if $P_{0,3} = P_1$ **and** $P_{1,3} = P_9$ **then**
    if $Q > I \times \sqrt{3}$ **then** $b_3 \leftarrow 1$
    end if
  end if
  return [b_3 b_2 b_1 b_0]
end procedure

Algorithm 1.Modified algorithm

In the proposed algorithm, the computation of b_0, b_1 is the same as in [4]. We also calculate P_0, P_1 for both b_2 and b_3. Finally according to the values of P_0 and P_1 and using line bisectors for each pair of symbols the value of b_2 and b_3 is calculated.

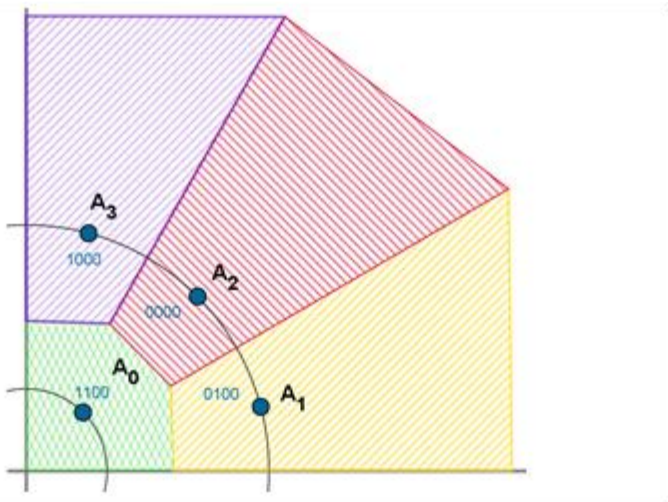

Figure 4. Decision regions at the first quadrant

For the calculation of b_2 and b_3, as mentioned before, 5 borders are used: I=mid, Q=mid, I=1.7×Q, Q=1.7×I and I+Q=line_bisector, which divide each quadrant in four regions: A_0(b_2=1, b_3=1), A_1(b_2=1, b_3=0), A_2(b_2=0, b_3=0), A_3(b_2=1, b_3=0), as shown in Fig 5.

We define A_0 as the inner region for which we have: I<mid and Q<mid and I+Q<line_bisector. If this expression is true, the received symbol belongs to A_0.

If the received symbol belongs to A_1, the following expression is true: I>mid and I>1.7×Q.

If the received symbol belongs to A_2, the following expression is true: I+Q>line_bisector and I<1.7×Q and Q<1.7×I.
Finally, if the received symbol belongs to A_3, the following expression is true: Q>mid and Q>1.7×I.

procedure demap(I, Q)
  $b_3 \leftarrow b_2 \leftarrow b_1 \leftarrow b_0 \leftarrow 0$
  if $Q < 0$ **then** $b_0 \leftarrow 1$
  end if

  if $I < 0$ **then** $b_1 \leftarrow 1$
  end if

  $I \leftarrow |I|$
  $Q \leftarrow |Q|$

  inner← $I <$ mid **and** $Q <$ mid **and** I+Q< line_bisector
  if inner = true **then** $b_2 \leftarrow 1$ $b_3 \leftarrow 1$
  else
    if $I >$ mid **and** $I > Q \times \sqrt{3}$ **then** $b_2 \leftarrow 1$
    end if
    if $Q >$ mid **and** $Q > I \times \sqrt{3}$ **then** $b_3 \leftarrow 1$
    end if
  end if
  return [b_3 b_2 b_1 b_0]
end procedure

Algorithm 2.Proposed algorithm

On the following table Table 1 we can see the average number of additions, multiplications and comparisons for each received symbol, of our proposed algorithm and the modified algorithm of alg.1. For the results we counted total additions, multiplications and comparisons for SNR = {0, 2, 4, ..., 18}, 10000000 symbols for each one of the above SNR and in the end we divided each count with the total number of symbols for all above SNR.

TABLE I. COMPARISSONS OF PROPOSED AND MODIFIED ALGORITH

	Proposed in alg.2	**Algorithm of alg.1**
additions	0.26	0.67
multiplications	0.93	2.92
comparisons	4.24	18.7

We can see that our proposed algorithm requires fewer additions, multiplications and comparisons which mean much lower computational complexity.

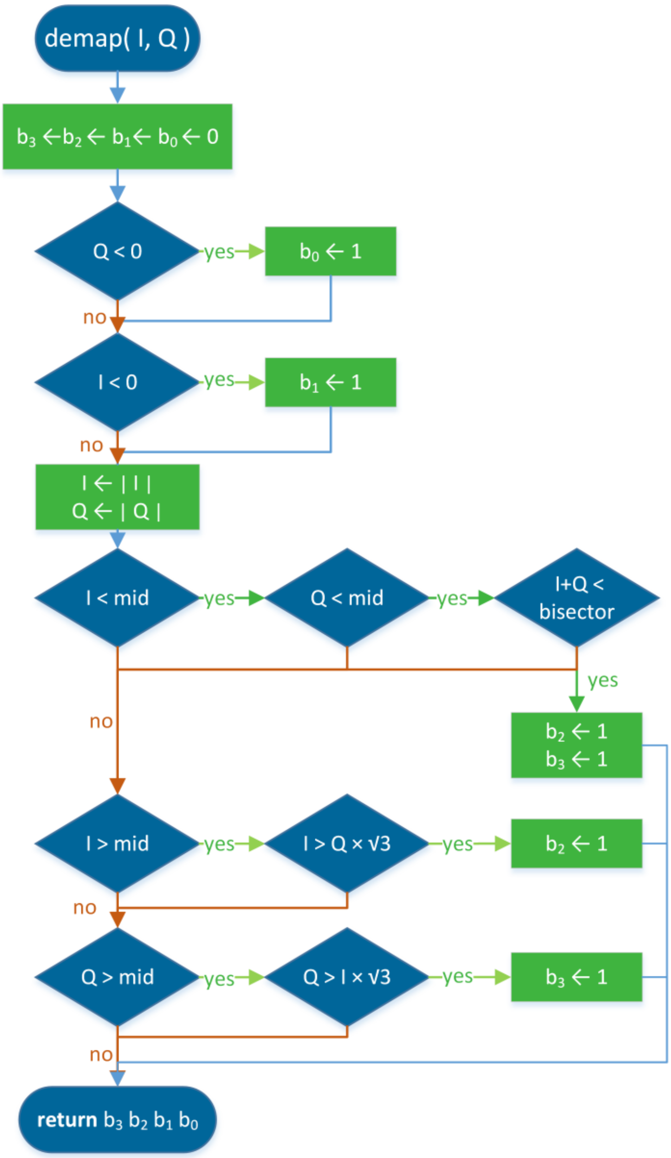

Figure 5. Flow diagram of proposed algorithm

IV. RESULTS

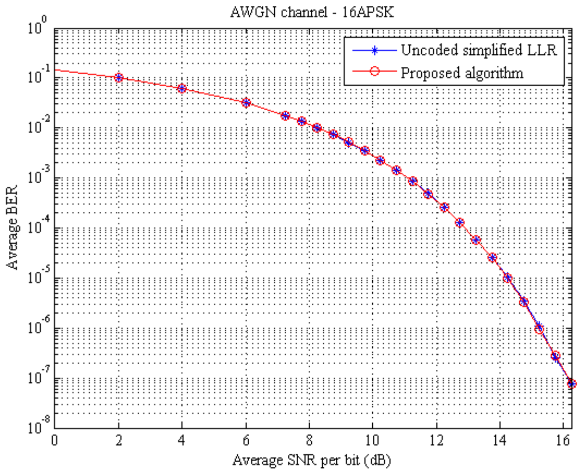

Figure 6. BER performance by simulation.

In this section we present the simulation results of the proposed algorithm and the uncoded version of algorithm proposed in [4]. In figure 6 the BER performance of the two above algorithms is illustrated without using any Error Correcting Code $\gamma = 3$ is assumed.

As shown in [5], when SNR is higher than 9 dB LLR algorithm has slightly better performance than Log-MAX algorithm and much better than Euclidean algorithm. Also as showed in [4] the Simplified LLR algorithm has slightly worse performance than the LLR algorithm.

In figure 6 we can see that our proposed algorithm has the same performance as the Simplified LLR algorithm. However as we showed in Section 3 our algorithm has much lower computational complexity than all the above

V. CONCLUSION

In this paper we proposed a novel low complexity soft decision demapping algorithm for 16-APSK, which is a digital modulation scheme used in Second Generation Standard of Digital Video Broadcast (DVB-S2). Calculation of each bit's value was based on the decision regions of the bits. The proposed algorithm is used for systems employing uncoded modulation but with a few changes it can also calculate LLR which is used for coded modulation. It has very low complexity but its performance is comparable to the performance of the most used soft decision demapping algorithms in the literature. It is possible that proposed algorithm can be extended to 32-APSK demapping, already included in various mobile communication standards.

REFERENCES

[1] ETSI TR 102 376 Digital Video Broadcasting (DVB): "User guidelines for the second generation system for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2)", *ETSI publications*, February 2005.

[2] Konstantinos P. Liolis, Riccardo De Gaudenzi, Nader Alagha, Alfonso Martinez, and Albert Guillén i Fàbregas, "Amplitude Phase Shift Keying Constellation Design and its Applications to Satellite Digital Video Broadcasting, Digital Video, Floriano De Rango" (Ed.), *ISBN: 978-953-7619-70-1*, InTech, DOI: 10.5772/8042, 2010

[3] Jang Woong Park, Myung Hoon Sunwoo , Pan Soo Kim, Dae-Ig Chang, "MULTI-LEVEL MODULATION SOFT-DECISION DEMAPPER FOR DVB-S2", *Signal Processing Systems, IEEE Workshop* on 7-9 Oct. 2009

[4] Enxin Yao, Shuai Yang and Wei Jiang , "A Simplified Soft Decision Demapping Algorithm of 16-APSK Signals in AWGN Channels", *Second International Conference on Networks Security, Wireless Communications and Trusted Computing*, 2010

[5] In Ki Lee, Dae Ig Chang and Deock Gil Oh, Ji Won Jung, Duk Gun Choi, "Multi-level modulation LDPC Decoding Algorithm for New Generation DVB-S2 system",*24th AIAA International Communications Satellite Systems Conference (ICSSC) and 4t*, San Diego, California, 11-14 June 2006