Blind Mode/GI Detection and Coarse Symbol Synchronization for DVB-T/H

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Abstract—In a Non-Data-Aided (NDA) broadcasting system such as DVB-T/H, blind transmission mode, guard interval (GI) length detection and coarse symbol synchronization (CSS) play important roles to estimate the transmitted OFDM symbol parameters and start the synchronization processes. In this paper, a single hardware and division-free architecture, modified from Normalized-Maximum-Correlation (NMC) architecture, for DVB-T/H blind mode/GI detection and coarse symbol synchronization (CSS) is proposed. By adopting the proposed twister memory access scheme and sequential blind mode detection scheme, the architecture reduces 33% of memory costs and at most 58.18% mode detection latencies.

I. INTRODUCTION

The digital video broadcasting-terrestrial (DVB-T) standard has been released by ESTI (European Telecommunications Standards Institute) in 1997 [1]. Later, ESTI released digital video broadcasting-handheld (DVB-H) [2] as a new standard for handheld application. DVB-T/H systems use Concatenated-coded orthogonal frequency division multiplexing (ODFM) to provide a high data rate required for video transmission. Fig. 1 shows the proposed DVB-T/H baseband inner receiver. For the purpose to survive from different channel conditions, several parameters of OFDM in DVB-T are flexible. For example, the sub-carriers in an OFDM symbol can be either 2048 (2K) or 8192 (8K) which is determined according to the transmission distance, Doppler-spread and etc. Besides, a 4096 (4K) sub-carriers transmission symbol mode is especially selected for DVB-H. Four kinds of guard interval (GI) lengths (1/32, 1/16, 1/8 and 1/4) are selected to conquer different inter symbol interference (ISI) effect caused by multipath phenomenon in a single frequency network (SFN). Therefore, a blind mode/GI detection process that detects the transmission mode and GI length is necessary for the DVB-T/H receivers. Furthermore, timing synchronization also plays an important role in any OFDM systems. Note that, the coarse symbol synchronization (CSS) process requires the information of transmission mode and GI length, detected by blind mode/GI detection process, to achieve an accurate symbol boundary. For this reason, mode/GI detection process must be done prior to CSS process.

The concept of blind mode/GI detection is similar to CSS (both of them use the cyclic prefix characteristic to find the correlation peak or plateau [4]). As a result of the similar concepts, this paper proposes single hardware architecture for both blind mode/GI detection and CSS processes. A sequential blind mode detection scheme is also developed to detect the transmission mode with less hardware cost than parallel blind mode detection. Besides, a twister memory access scheme is used to reduce the latency of the proposed blind mode detection. Overall, the required memory number compared to parallel mode detection architecture is reduced with a few extra latencies for 4K/8K transmission mode. Moreover, comparing to separated blind mode/GI detection and CSS architectures, the architecture of proposed blind mode/GI detection and CSS hybrid scheme is more efficient in area cost.

The rest of this paper is organized as follows: The adopted blind mode/GI detection and CSS algorithms are discussed in section Ⅱ. Also the twister memory access scheme is presented in section Ⅱ. The proposed blind mode/GI detection and CSS hybrid scheme is described in section Ⅲ. The simulation and design results of the proposed scheme are presented in section Ⅳ. Eventually, a conclusion is made in section Ⅴ.

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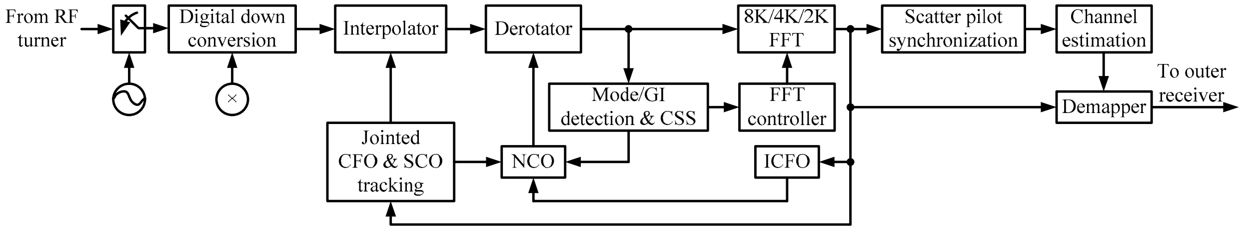


Fig. 1 DVB-T/H baseband inner receiver architecture.

II. Blind Mode/GI Detection and Coarse Symbol Synchronization Algorithms

A. Blind Mode/GI Detection

Like most blind mode detection algorithms, the adapted blind mode/GI detection uses the cyclic prefix (CP) based correlation algorithm to detect the transmission mode [4]. Equation (1) represents the maximum correlation (MC) based blind mode detection scheme mathematically.

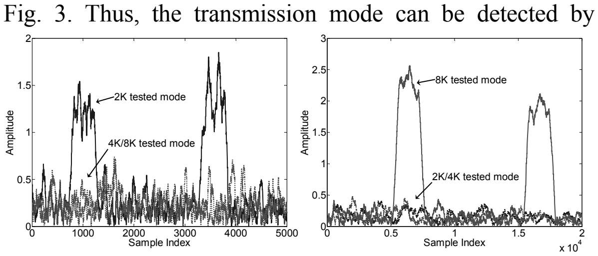
$$x(n) = \left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \times r(n-i-Nsc) \right| \tag{1}$$

where *r(n)* is the received signal, *Nsc* is the sub-carrier number of the tested symbol mode and *Nsc*/32 is the shortest guard interval length of *Nsc*. The successive correlation results will form a peak or plateau area when the tested mode is the same with the transmission mode.

As shown in Fig. 2 (2K/8K transmission symbols surviving from Rayleigh channel with 1/4 GI, 12dB SNR, 50Hz Doppler spread and 23.33 sub-carriers carrier frequency offset), the 2K and 8K correlation results of MC based blind mode detection have different peaks/plateaus threshold and uneven plateaus, especially in 2K transmission mode. Therefore, the normalized maximum correlation (NMC) based blind mode detection algorithm as shown in (2) is used to have normalized peaks/plateaus and flat plateaus.

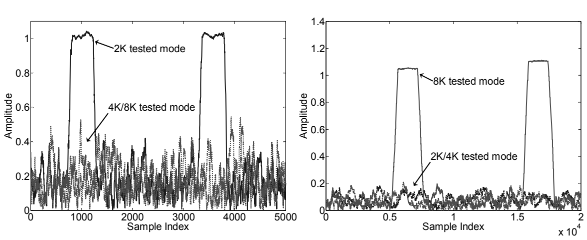
$$x(n) = \frac{\left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \times r(n-i-Nsc) \right|}{\left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \times r(n-i) \right|} \tag{2}$$

where the denominator is the power term integration of signal *r(n)~r(n-Nsc/32)*, which is adopted to get normalized to "1" flat plateaus and a fixed plateau threshold as shown in Fig. 3. Thus, the transmission mode can be detected by observing whether the *x(n)* is bigger than the determined threshold or not.



(a) (b)

Fig. 2. MC correlation of (a) 2K, (b) 8K transmission modes.



(a) (b)

Fig. 3. NMC correlation of (a) 2K, (b) 8K transmission modes.

After the first detected plateau, the transmission mode is known and the GI length is detected by computing the plateau length instead of calculating the period between two successive maximum peaks. As a result of the transmission mode and GI length are detected at the same peak/plateau, at least a symbol time is saved while detecting GI length.

B. Division-Free NMC Based Blind Mode/GI Detection Algorithm

According to the simulation results, peak/plateau threshold is around 0.7. To reduce the computation overhead, 0.707 is selected so will become very clean in (3). The mode detection depends on the existence of peak/plateau and the GI length depends on the length of the peak/plateau. Therefore, the NMC based blind mode/GI detection equation can be modified as the derivation shown in (3).

$$\begin{aligned}
& x(n) \in \text{plateau} \quad \text{if} \quad \frac{\left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i-Nsc) \right|}{\left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i) \right|} \geq 0.707 \\
& \Rightarrow \left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i-N) \right| \geq 0.707 \times \left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i) \right| \\
& \Rightarrow \sqrt{\left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i-N) \right|^2} \geq \sqrt{0.707^2 \times \left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i) \right|^2} \\
& \Rightarrow \left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i-N) \right|^2 - 0.5 \times \left| \sum_{i=0}^{\frac{Nsc}{32}-1} r^*(n-i) \cdot r(n-i) \right|^2 \geq 0
\end{aligned} \tag{3}$$

By moving the denominator to the right side and using the determined threshold, the division operation is replaced by a bit shitting and subtraction operation. Then, using the square operation to replace the absolute operation reduces large hardware complexity and area cost of doing radical operation. Thus, no approximation is done and a divider is saved without performance loss.

C. Coarse Symbol Synchronization Algorithm

Since the division operation is reduced, this paper adopts the maximum correlation (MC) scheme [3] as CSS scheme. The function structure of MC, as shown in (4), is almost the same with the numerator of the NMC based blind mode/GI detection function, as shown in (2), but with different integration length.

$$K_{est} = \arg \max_n \left| \sum_{i=0}^{N_g-1} r^*(n-i) \times r(n-i-Nsc) \right| \tag{4}$$

where, *Ng* is the GI length. Due to the correlation expression is similar to the numerator of (2), the CSS process is able to be realized by using the hardware of NMC based blind mode/GI detection process after blind mode/GI detection process is done.

D. Twister Memory Access Scheme

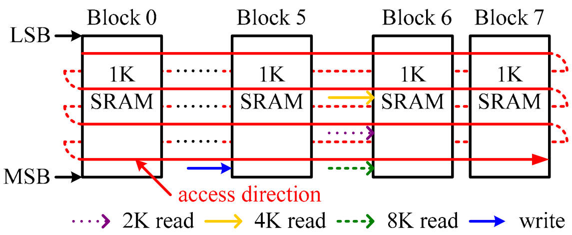


Fig. 4. R/W operation of twister memory access scheme.

Equation (2) and (4) contains at least two delay-lines, delay for Nsc and delay for Nsc/32 or Ng (also called moving sum delay-line), as [5] shows. The longest delay for Nsc delay-line is 8K (due to the 8K mode) and the longest delay for MS delay-line is 2K (due to 8K/4). By interleaving the read/write accesses, the delay-lines are able to be implemented by single port SRAM blocks instead of shift registers or dual port SRAM blocks. For the purpose to share the storage elements with channel estimation after the blind mode/GI detection and CSS processes, the delay-lines are composed of several 1K indexes single port SRAM blocks.

The twister memory access scheme for Nsc delay-line is presented in Fig. 4. The writing operation has only one writing mode; and it is to access the whole 8K memory as the access direction indicates. There are three reading modes for reading operation, 2K-1, 4K-1 and 8K-1 later than writing operation. Therefore, by changing the reading mode, the delay-line is able to be changed as a 2K, 4K or 8K delay-line to realize r(n-Nsc). Furthermore, the delay-line is able to store 8K samples data because of the single writing mode. That means there will need no refilling or replenishing the delay-line while the application is changed from 2K/4K to 8K. TABLE I. summarizes the area of three Nsc delay-line realization ways. Because of using the single port SRAM blocks to realize the Nsc delay-line, at least 33.3% area is saved comparing to 8K dual port SRAM block.

TABLE I. AREA OF THREE DELAY-LINE REALIZATION METHODS

	Shift Register (W/O wire)	**8K dual-port SRAM (TSMC018)**	***8*1K single-port SRAM (TSMC018)***
Area	5.56 mm^2	1.56mm^2	***1.04mm^2***

III. PROPOSED BLIND MODE/GI DETECTION AND COARSE SYMBOL SYNCHRONIZATION SCHEME

A. Blind Mode/GI Detection and Coarse Symbol Synchronization Hybrid Scheme

Due to the hardware of blind mode/GI detection and CSS are similar to each other and the operation time are different, a single hardware for modified NMC based blind mode/GI detection and CSS hybrid scheme, called sub-based NMC (Sub-NMC), is proposed; and the state diagrams of the proposed scheme are shown in Fig. 5 (where the Nsc Filling state is to fill Nsc delay-line with 2K samples and the MS filling state is to fill the MS delay-line with mode/32 samples). The procedure listed below represents the action of the proposed scheme in detail.

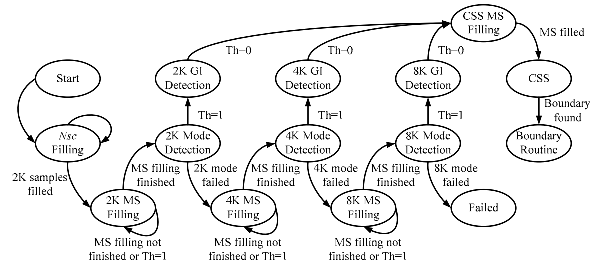


Fig. 5. Finite state machine of the proposed blind mode/GI detection and coarse symbol synchronization scheme.

1. *Set the tested mode TM as 2K and fill the Nsc delay-line with 2K samples.*
2. *Set the moving sum (MS) delay-line length as TM/32 and fill it with TM/32 samples.*
3. *Doing the mode detection process for a period of (1+1/32)*TM. If a peak or plateau occurs, jump to Step 4. If the peak and plateau doesn't exists, set the TM as TM*2 and jump to Step 2.*
4. *Compute the plateau length, set MS delay-line length as detected GI length.*
5. *Fill the MS delay-line then find the maximum correlation result as coarse symbol boundary.*

The proposed blind mode/GI and CSS scheme divides the mode detection, GI length detection and boundary detection processes separately, and executes the processes one by one. By using the twister memory access scheme and doing the mode detection form 2K to 8K, the system needs only the first 2K latency to have the r(n-NSC) signal in the Nsc delay-line. While the tested mode changes from 2K to 4K, the delay-line doesn't need an additional 4K/2K samples to fill/replenish the Nsc delay-line because of the r(n-4K) signal is saved while doing 2K mode detection by twister memory access scheme. So does the 8K mode detection.

B. Timing Analysis and Hardware Cost

Fig. 6 illustrates the detection timing of parallel, sequential and proposed blind mode detection schemes. As shown in Fig. 6 (f), for the 4K/8K mode detection, the r(n-4K)/r(n-8K) signal is already stored by twister memory access scheme while doing 2K/4K mode detection process. Therefore, the proposed mode detection scheme needn't to refill or replenish the Nsc delay-line. Due to the moving sum and detection period, the proposed scheme is 3.03/4.55 percent (128/384 samples) slower than parallel 4K/8K mode detection scheme. In summary, TABLE II. lists the latency requirement of the proposed blind mode detection scheme comparing to parallel and sequential mode detection

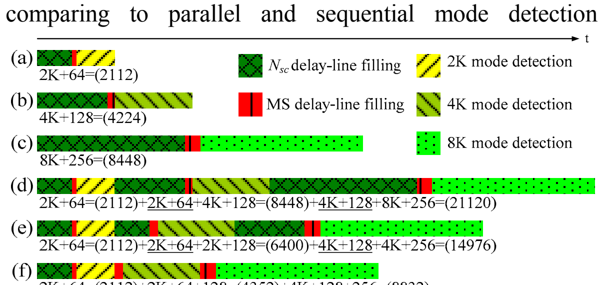


Fig. 6. Timing of parallel (a) 2K, (b) 4K, (c) 8K, sequential (d) refill, (e) replenishment and (f) proposed mode detection schemes.

schemes. At most 58.18% (12288 samples) is saved comparing to sequential (refill) mode detection scheme.

TABLE II. LATENCY TO MODE DETECTION

Transmission mode	2K	4K	8K
Parallel	2112	4224	8448
Sequential (refill)	2112	8448	21120
Sequential (replenishment)	2112	6400	14976
Proposed Sub-NMC	***2112***	***4352***	***8832***

The hardware cost summary is listed in TABLE III. below. The parallel blind mode/GI detection and CSS scheme requires three times of computation hardware than the proposed scheme exception the power term complex multiplier. The NSC delay-line is supposed to use one 8K samples delay-line to realize 2K/4K/8K delay at the same time. The parallel scheme requires 64, 128 and 256 samples long MS delay-lines and a 2K MS delay-line for CSS. If the 2K samples MS delay-line is able to be shared with the 256 samples delay-line, the total MS delay-line requirement is 2K+192 samples long.

TABLE III. HARDWARE COST OF PARALLEL AND SUB-NMC MODE DETECTION SCHEMES

	Parallel	*Proposed Sub-NMC*
Nsc delay-Line	8K	***8K***
MS delay-line	2K+192	***2K***
Complex multiplier	7	***3***
Adder	9	***3***
Subtractor	12	***4***
Multiplier	3	***1***

IV. PERFORMANCE SIMULATION AND DESIGN RESULTS

A. Peak/Plateau Threshold Simulation

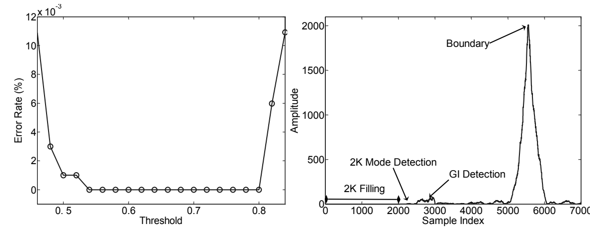
In order to prove the determined threshold 0.707 is able to detect the correct transmission mode and GI length, a threshold vs. mode/GI detection error rate simulation is presented in Fig. 7 (a). After testing 1000 2K transmission mode symbols (with 1/4 GI, 12dB SNR, 23.33 sub-carriers CFO and surviving from Rayleigh channel), the simulation results show the threshold is reliable.

B. Mode/GI Detection and Coarse Symbol Synchronization Simulation

The gate level simulation result of the proposed blind mode/GI detection and CSS scheme is shown in Fig. 7 (b). The environment is 2K transmission mode symbols with 1/4 GI, 12dB SNR, 23.33 sub-carriers CFO and surviving from Rayleigh channel.

C. Design Results

The architecture of the proposed blind mode/GI detection and CSS based on (3) is shown in Fig. 8. Overall, TABLE IV. shows the design result using TSMC 018um technology. The delay-line memory occupies a large partition of the design. Therefore, the design work of delay-line and memory sharing contribute a lot for reducing the whole circuit area.



(a) (b)

Fig. 7. (a) Threshold vs. error rate (b) MC^2 results of the proposed Sub-NMC.

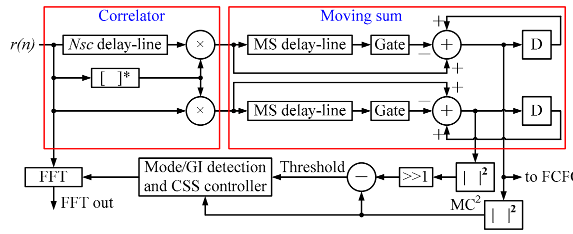


Fig. 8. Architecture of the proposed Sub-NMC.

TABLE IV. DESIGN RESULT

Synthesis result of proposed Sub-NMC (TSMC018)	
Area	1,973,646um2 (≒201,392 Gates)
Power	12.6mW @10MHz
Max delay/freq.	20ns/50MHz
Memory area	1876000um2 (≒95%)

V. CONCLUSION

Due to the fact that the MC based CSS scheme is enough to detect a roughly boundary [3] and the NMC based one has the characteristic of detecting the mode/GI easily, this paper proposed a modified NMC based scheme which has the mode/GI detection advantage without division operation and using the MC part to determine the coarse symbol boundary. This paper also proposes an efficient mode/GI detection and CSS scheme. By detecting transmission mode sequentially, the hardware is reduced to a single hardware. For some blind mode detection schemes, the NSC delay-line is refilled or replenished while the tested mode changes. To overcome the delay penalty during the tested mode changes, a twister memory access scheme is offered to reduce the refilling/replenishing penalty. Furthermore, the twister memory access method also reduces the delay-line refilling/replenishing penalty successfully.

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