DTV TRANSMITTER IDENTIFICATION USING EMBEDDED PSEUDO RANDOM SEQUENCES

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ABSTRACT

A transmitter identification system using embedded spread spectrum sequence is proposed. Code generators are developed to study the auto-correlation and cross-correlation properties of the truncated Gold and Kasami sequences. To reduce the computation complexity, the embedded Kasami sequence is time-synchronized with the DTV frame structure. Therefore, the Kasami sequence length has to be truncated to fit into an ATSC DTV signal field. In this paper, the impact of the truncation noise and in-band DTV interference to the transmitter identification process is investigated. It is shown that the auto-correlation and cross-correlation properties are only slightly affected due to the truncation noises. However, the dominant interference to the transmitter identification is the in-band DTV signal. The signal to truncation noise ratio and signal to DTV interference ratio in the correlator output are derived and verified by computer simulation. The in-band DTV interference can only by mitigated by increasing the code length or by averaging technique to smooth out the in-band interference.

INTRODUCTION

Transmitter identification (TxID, or transmitter fingerprinting) is an important tool for the radio spectrum authority, as well as operators, to identify the source of interference. This is of particular interest with the introduction of Digital TV (DTV) single frequency network (SFN) operation. The neighboring transmitters in the SFN generate unwanted co-channel interference which behaves like multipath distortion. This multipath effect may cause serious convergence problems for ATSC DTV equalizer, for example, when strong pre-echo exists. This problem can be reduced by adjusting the timing of the transmitted signal a using transmitter identification system.

In this paper, a transmitter identification system is proposed. It is based on the embedded spread spectrum technology, i.e., the identification code is deeply buried under the DTV signal. Different spread sequences will be assigned to different transmitters for identification purpose. The injection level of the embedded sequences is very low so that it has virtually no impact on the DTV signal reception. One important property of the selected sequences is their "orthogonality". Transmitter identification is realised by calculating the correlation function between the received signal and the possible spread spectrum sequences. The transmitter identification system can also be used for interference identification, channel estimation, robust low speed data transmission, and location finding.

PRINCIPLE OF TRANSMITTER IDENTIFICATION

In the proposed transmitter identification system, a low level spread spectrum sequence is injected into the DTV signal. The magnitude of the spread spectrum sequence is carefully selected such that the impact on the DTV reception is negligible. Denote the DTV signals for the *i*-th transmitter before and after the injection of the spread spectrum sequence $x_i(n)$ as $d_i(n)$ and $d_i'(n)$, respectively. The injected process is:

$$d_i'(n) = d_i(n) + \rho \; x_i(n) \tag{1}$$

where ρ is a gain coefficient to control the injection level of the identification sequence, which could be different for each transmitter. However, it will be convenient for the identification process, if the gain coefficient is the same for all the transmitters.

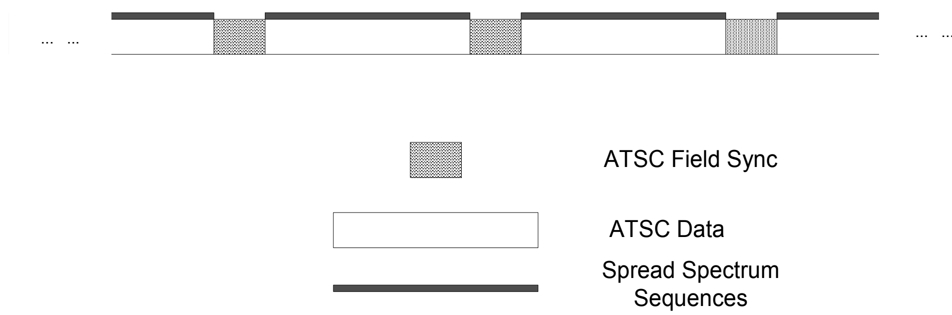


Figure 1. Illustration of the DTV signal with embedded spread spectrum sequences.
(to avoid interference into DTV, the spread spectrum sequence should be injected 30 dB below the DTV signal)

After passing through channel h_i, the received signal from the *i*-th transmitter r_i can be formulated as:

$$r_i(n) = d_i'(n) \otimes h_i + n_i(n) \tag{2}$$

where $n_i(n)$ is the equivalent noise for the *i*-th channel. The overall received signal $r(n)$, from M transmitters, can be formulated as:

$$r(n) = \sum_{i=1}^{M} \left[d_i'(n) \otimes h_i + n_i(n) \right] \tag{3}$$

The existence of the particular transmitter is unknown without any further identification process. Details of existence and strength of each specific transmitter at the reception site can be achieved by calculating the correlation function. For example, the correlation between $r(n)$ and $x_j(n)$ can provide the information, e.g., the existence and signal strength, of the *j*-th transmitter:

$$
\begin{aligned}
R_{rx_j}(m) &= \sum_{l=0}^{N-1} r(n)x_j(n-m) = \sum_{l=0}^{N-1}\left\{\sum_{i=1}^{M} d_i{}'(n)\otimes h_i + n_i(n)\right\}x_j(n-m) \\
&= \sum_{l=0}^{N-1}\left\{\sum_{i=1}^{M}\left[\left(d_i(n)+\rho x_i(n)\right)\otimes h_i + n_i(n)\right]\right\}x_j(n-m) \\
&= \rho R_{x_j x_j}\otimes h_j + \sum_{i=1, i\neq j}^{M}\rho R_{x_i x_j}\otimes h_i + \sum_{l=0}^{N-1}\sum_{i=1}^{M}\left[d_i(n)+n_i(n)\right]x_j(n-m)
\end{aligned}
\tag{4}
$$

With the orthogonal property of the selected spread spectrum sequences, $R_{x_j x_j}$, the correlation functions of the spreading codes, can be approximated as a delta function. The second term in the above equation is close to zero. The third terms are only noise like sequences from the in-band DTV signals of all the transmitters. Therefore, the received channel response h_j from the *j*-th transmitter can be approximated by $R_{rx_j} \approx \rho \ \ h_j$.

CODE SELECTION

As we mentioned, one essential property of the spread spectrum codes for transmitter identification is the code orthogonality. The importance of this property can be clearly seen from equation (4). Different transmitters can only be identified when orthogonal identification codes are used. Another requirement for TxID sequence is the number of the available orthogonal codes, because each code, or sequence, can only be assigned to one transmitter by a regulating body on a national-wide or region-wide base. Gold and Kasami sequences are two good candidates as they can provide a large family of orthogonal sequences.

A. *Gold Sequence*[1][2]

The Gold sequences are defined using a specified pair of sequences *u* and *v*, of period $N = 2^n - 1$, called a preferred pair, defined as:

- N is not divisible by 4,
- $v = u[q]$, where q is odd with $q = 2^k + 1$ or $q = 2^{2k} - 2^k + 1$. This indicates that v can be obtained by sampling every q-th symbols of *u*.

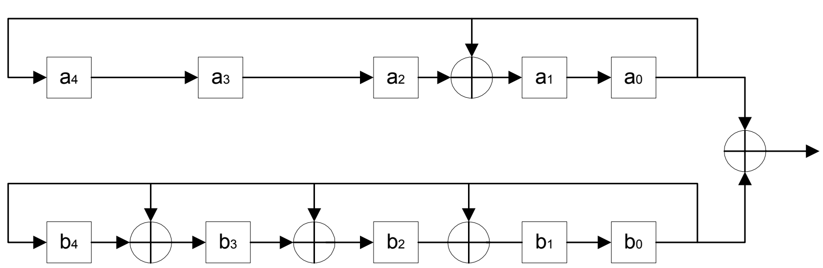


Figure 2. Typical Gold Code Generator.

The set $G(u, v)$ of Gold sequences is defined by

$$G(u,v) = \{u, v, u \oplus v,\ u \oplus Tv, u \oplus T^2 v,\ \dots ,\ u \oplus T^{N-1} v\} \tag{5}$$

where T represents the operator that shifts vectors cyclically to the left by one place, and $\oplus$ represents modulo 2 addition. Note that $G(u,v)$ contains $N + 2$ sequences of period N, which have good orthogonality, and may be used for transmitter identification. Having found a preferred pair, the actual Gold codes can be generated using two shift registers, as shown in Figure 2. Note that, to generate a nonzero Gold sequence, at least one element of the initial states vectors must be a nonzero value, i.e., at least one of the registers' initial state must be nonzero.

The Gold Sequence Generator outputs one of the sequences according to the block's parameters. Denote the auto-correlation function and cross-correlation function as R_{xx} and R_{xy}, respectively. From the gold code properties, we have [3]:

$$R_{xx}(k) \in \begin{cases} 1 & k = 0 \\ \left\{ -\frac{t(N)}{M}, -\frac{1}{M}, \frac{t(N)+2}{M} \right\} & k \neq 0 \end{cases} \tag{6}$$

$$R_{xx}(k) \in \left\{ -\frac{t(N)}{M}, -\frac{1}{M}, \frac{t(N)+2}{M} \right\} \tag{7}$$

where

$$t(N) = \begin{cases} 1 + 2^{0.5(N+1)} & N\ odd \\ 1 + 2^{0.5(N+2)} & N\ even \end{cases}$$

$$R_{xx}(k) = \frac{1}{M} \sum_{n=0}^{M-1} x(k)x(n+k) \tag{8}$$

and

$$R_{xy}(k) = \frac{1}{M} \sum_{n=0}^{M-1} x(k)y(n+k) \tag{9}$$

B. Kasami Sequence[3]

Gold sequence is a special case of the Kasami sequence. There are two classes of Kasami sequences: the small set and the large set Kasami sequences. The large set contains all the sequences in the small set. The large set size of the Kasami sequence makes it more desirable than the Gold code for transmitter identification purpose as it contains more sequences. However, only the small set is optimal in the sense of matching Welch's lower bound for correlation functions. The generation of the Kasami sequences is similar to the Gold code generator as shown in Figure 3. The difference is that a third sequence generator is needed in a Kasami sequence generator. For a 16-bit Kasami sequence generator, it has 24 shift registers, which can have $2^{24} - 1$ (about 16 millions) initial states, and generate 16 millions different sequences. The Kasami sequence correlation functions have five values

$$\{-t(n),\ -s(n),\ -1,\ s(n)-2,\ t(n)-2\} \tag{10}$$

where

$$t(n) = 1 + 2^{\frac{n+2}{2}} \tag{11}$$

and

$$s(n) = \frac{1}{2}\left[t(n) + 1\right] \tag{12}$$

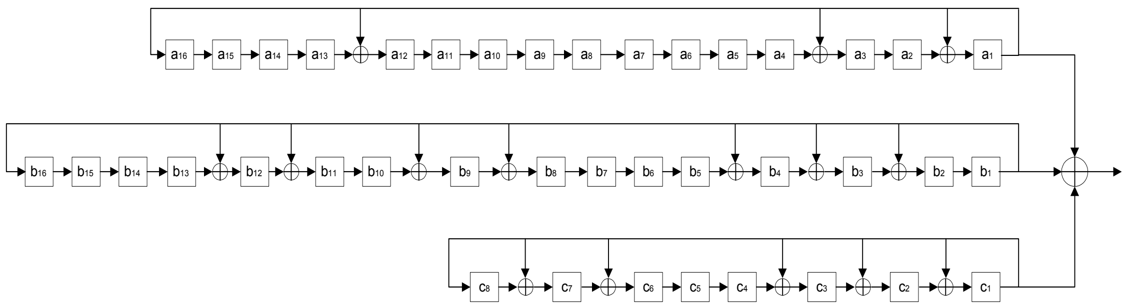


Figure 3. Example of the 16-bit Kasami Sequence Generator.

NUMERICAL SIMULATIONS & DISCUSSIONS

Auto-correlation and cross-correlation functions of a 19-bit Gold sequence are illustrated in Figure 4 and 5, respectively. Correlation functions with truncated sequence are also simulated as shown in Figure 6 and 7. As expected, the truncation noise of 5119 to the 19-bit gold sequence is very small. Compared to the DTV interference, the sequence truncation noise is negligible, as the Signal to Truncation-noise Ratio (STR) is roughly 45dB (Figure 6 and 7).

The dominant interference for transmitter identification is the in-band DTV signal as indicated in Figure 8, where channel identification sequence is injected 30 dB below the DTV signal. It can be estimated that the Signal to DTV interference Ratio (SDR) for $2^{19} - 1 - 5119$ sequence is 10log($2^{19} - 1 - 5119$) – 30 = 27dB. However, this 27dB dynamic range is relative to the variance of the in-band DTV interference. The in-band DTV signal, which can be modeled as a Gaussian process, typically has a peak to average power ratio of about 9 to 10 dB. The instantaneous magnitude of the DTV interference plays an important role in transmitter identification. Therefore, the dynamic range for the transmitter identification scheme is around 27 dB – 9 dB = 18dB, see Figure 8, without post processing of the impulse response.

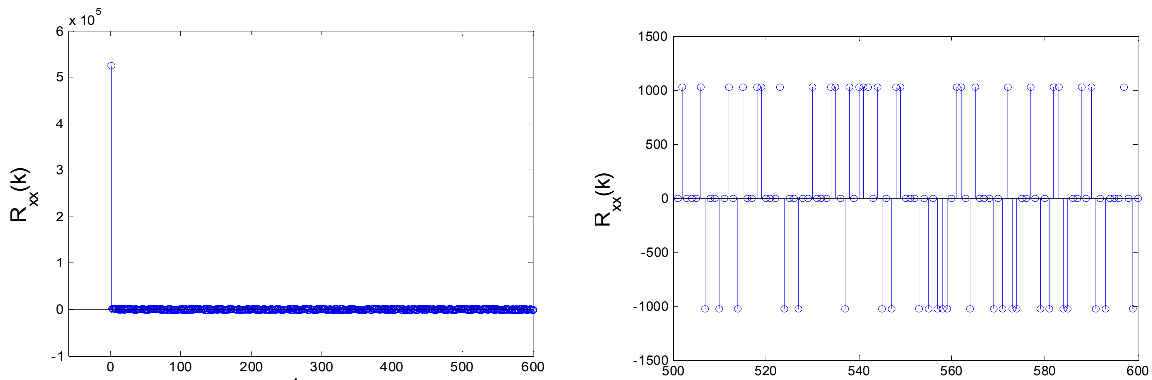
Simulation of the transmitter identification using embedded Kasami sequence with a period of $2^{18} - 1$ is shown in Figure 10. For comparisons with the previous Gold Code simulation, the Kasami sequence is also buried 30dB below the DTV signal. A 6 dB and a 10 dB echoes are injected. It is observed that the dynamic range used for transmitter identification with $2^{18} - 1$Kasami sequence is around 15 dB (18 dB for the 19-bit Kasami sequence) without any post-processing, as indicated in Figure 10. Time averaging of the correlation functions can be used to improve the dynamic range. The improvement is $10\log_{10}\left(\frac{1}{L}\right)dB$, where L is the number of averaging times.

CONCLUSIONS

A transmitter identification system using embedded or buried spread spectrum sequence is presented. Computer simulations are conducted to study the auto-correlation and cross-correlation properties of the Gold and Kasami sequences. The impact of the truncation noise and in-band DTV interference on the transmitter identification is analyzed. It is verified by simulation that the auto-correlation and cross-correlation properties are only slightly affected due to the truncation process. The dominant interference to the transmitter identification is the in-band DTV signal. It is further recognized that in-band DTV interference can only by mitigated by increasing the code length or by using averaging technique to smooth out the in-band interference. Although this channel ID system is developed for the ATSC DTV. It can also be applied to other DTV systems.

REFERENCE

1. W. W. Peterson, E. J. Weldon, "*Error-Correction Codes* (2nd Edition)", MIT press, 1972.
2. R.E. Ziemer and R.L. Peterson, "*Digital Communications and Spread Spectrum Systems*", Macmillan, 1985.
3. D.V. Sarwate and M.B. Pursley, "Crosscorrelation Properties of Pseudorandom and Related Sequences", *IEEE Proceeding*, vol.68, no.5, pp.593-619.



(a) **(b)**

Figure 4. (a) Auto-correlation of a Gold code with period of $2^{19}-1$; (b) A zoom in of Figure 4 (a).

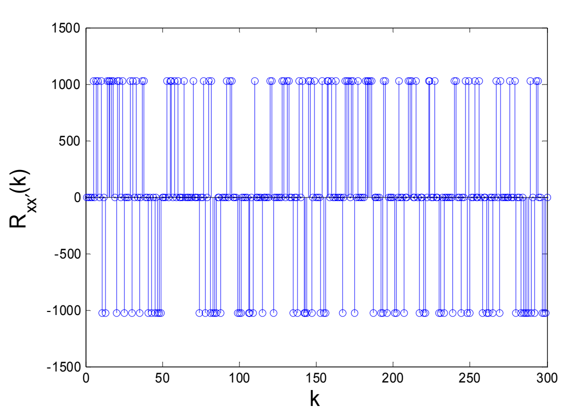


Figure 5. Cross-Correlation functions of the two Gold codes with period of $2^{19}-1$.

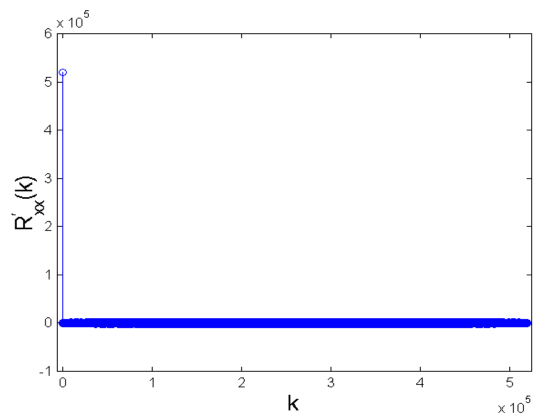


Figure 6. Auto-correlation of a truncated Gold code with period of $2^{19}-1-5119$.

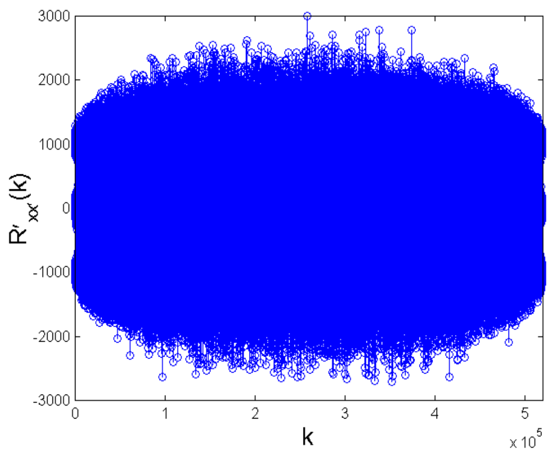


Figure 7. Cross-correlation of two truncated Gold codes with period of $2^{19}-1-5119$.

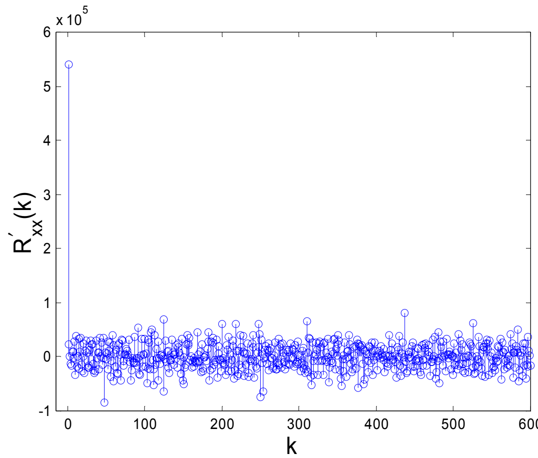


Figure 8. Auto-correlation of a truncated Gold code with 30dB DTV signal injected.

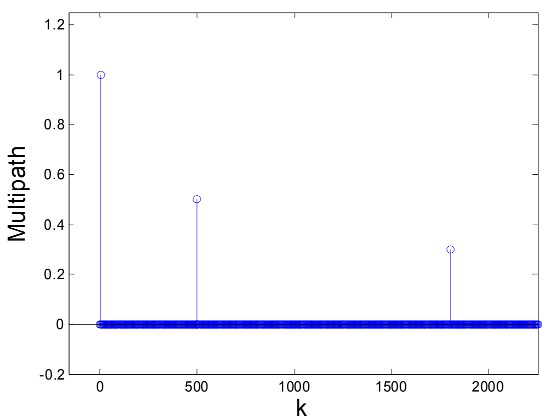


Figure 9. Multipath used in the simulation.

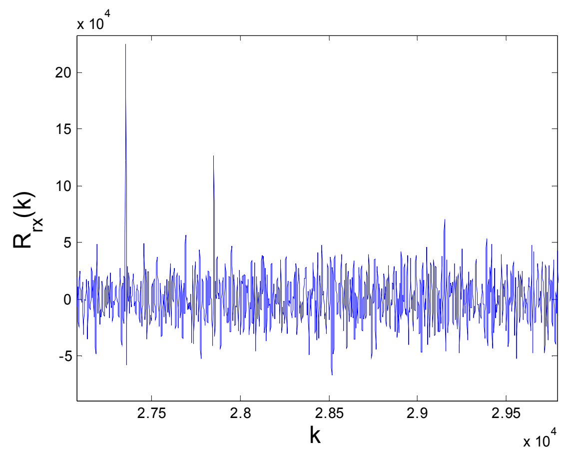


Figure 10. Auto-correlation function of the Kasami sequence with period of $2^{18}-1-2518$ Injucted 30 dB below DTV signal (without post-processing).

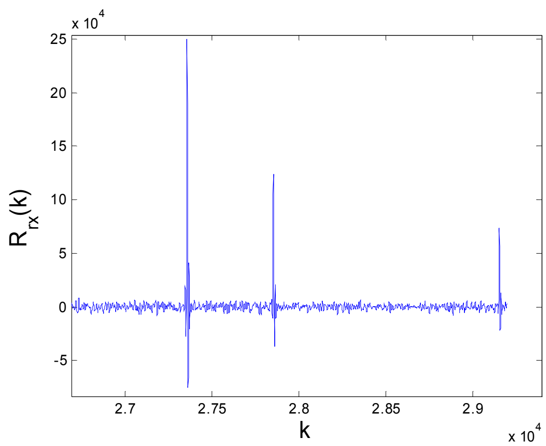


Figure 11. Auto-correlation function of the Kasami sequence with period of $2^{18}-1-2518$ (with 60 times of time domain averaging).