New Identification Sequence Analysis for Multiple Transmitters Subject to Arbitrary Topologies

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Abstract—ENG is a broadcasting industry acronym which stands for electronic news gathering in digital terrestrial television systems. It usually means that a television crew take an ENG truck on location to do a live report for a newcast. The ENG transmitter identification becomes important in digital video broadcasting nowadays. However, the transmitter identification could be quite difficult in a distributed transmission network. A pseudo-random sequence was proposed to be embedded into the digital television (DTV) signal prior to transmission. Thus, the transmitter identification can be realized by invoking the cross-correlation functions between the received signal and the possible candidates of the pseudo random sequences. Kasami sequences are commonly used as the transmitter ID (Tx-ID) sequences as they provide a large family of nearly-orthogonal codes. In order to investigate the sensitivity of the transmitter identification performance to the arbitrary topologies and the Kasami sequence lengths, we present the new analysis here for Tx-ID over random geometric layouts. In our analysis, the lowest received co-channel signal-to-interference ratio is considered as the crucial factor for the multiple-transmitter identification. Moreover, the transmitter location uncertainties are also considered in this paper. The effect of such uncertainties on the minimum required Kasami sequence lengths is investigated. It turns out to be that the larger the Kasami sequence length, the larger the received signal-to-interference ratio. Our new analysis can be used to determine the required Kasami sequence length for an arbitrary ENG-transmitter topology.

Index Terms—Electronic news gathering (ENG), multiple-transmitter identification, Kasami sequence, random topology.

I. INTRODUCTION

The transmitter identification for the digital television (DTV) systems becomes crucial nowadays. Hence, the transmitter identification techniques are in demand for modern DTV systems. Transmitter identification (Tx-ID, or transmitter fingerprinting) technique is used to detect, diagnose and classify the operating status of any radio transmitter of interest [1]. In the ENG (electronic news gathering) network, the transmitter identification refers to the identification of the different ENG signals returned to the (static or mobile) station. Due to an ever-increasing number of transmitters, the need for identification of ENG crews becomes very important and necessary for live televised programs [2]. As a result, transmitter identification has been recognized as an important feature in the ATSC Synchronization Standard for Distributed Transmission [3].

The RF (radio frequency) watermark technology has been employed in the DTV transmitter identification [3]. The RF watermarking transmitter-identification system uses a digital binary sequence as a unique code assigned to each transmitter for Tx-ID [4]. The receiver can therefore decode each binary sequence to identify the associated transmitter. The optimal watermark sequences for Tx-ID should be subject to the number of transmitters. The larger the transmitter number, the longer the Tx-ID sequences are required. Therefore, pseudo-random sequences were proposed to be embedded into the DTV signals before transmission for Tx-ID [1]. Thus, the transmitter identification can be realized by invoking the cross-correlation functions between the received signal and the possible candidates of the pseudo-random sequences. In this method, an essential property of the pseudo random sequences for the transmitter identification is that they are nearly orthogonal to each other. Another important property is that the pseudo-random sequences are embedded into the DTV signals in a low-power level so that the subject DTV signals would be impaired only slightly.

Some well-known sequences, such as \( m \)-sequences, have a very good cross-correlational property. Nevertheless, the number of available \( m \)-sequences for Tx-ID is not sufficiently large. Gold sequences in [5], [6] and Kasami sequences in [7], [8] are two excellent families of candidates for the Tx-ID sequences as they provide a fairly large population of nearly-orthogonal sequences. There are two classes of Kasami sequences, namely the small set and the large set, while the former is a subset of the latter. Kasami sequences from the large set are employed as the most desirable pseudo-random sequences for the Tx-ID of DTV signals. ENG is the term for collecting TV news and employing point-to-point terrestrial microwave signals to deliver videos back to the TV station. Typically, the transmitting equipment is mounted on a van or a truck, and ENG vehicles have a pump-up mast that extends from 10 to 17 meters with an antenna on top [9]. While several ENG trucks are working together in an area, the expected received signal-to-interference ratios at the TV station subject to a random transmitter topology must be concerned. Given a minimum required received signal-to-interference ratio at the base (TV) station, the appropriate Tx-ID sequence lengths are in question. In this paper, we provide a new geometric Tx-ID sequence analysis to study this aforementioned problem.

The rest of this paper is organized as follows. The fun-
fundamental mathematical properties of Kasami sequences and how to employ Kasami sequences for Tx-ID are introduced in Section II. The Kasami Tx-ID sequence studies for arbitrary deployed ENG topologies are manifested in Section III. The simulation results and conclusion will be presented in Sections IV and V, respectively.

II. MATHEMATICAL PROPERTIES AND Tx-ID APPLICATION OF KASAMI SEQUENCES

Any Kasami sequence should have a code period \( N = 2^n - 1 \), where \( n \) is a positive even integer. The large set of Kasami sequences have a much larger population than that of the small set of Kasami sequences and hence the former can serve for many more users. For an arbitrary pair of sequences \( a_i(m) \) and \( a_j(m) \) drawn from the large set of Kasami sequences, the cross-correlation over a code period can be characterized as the following five-valued function:

\[
\rho_{ij}(\tau) = \begin{cases} 
-t(n), & \text{if } \tau = 0 \\
-s(n), & \text{if } \tau = 1 \\
-1, & \text{if } \tau = \pm(2^{n+1} - 1) \\
-s(n) - 2, & \text{if } \tau = -2 \\
t(n) - 2, & \text{if } \tau = 2 
\end{cases}
\]

where 
\[
t(n) \equiv 1 + 2^{(n+2)/2}
\]

and 
\[
s(n) \equiv \frac{t(n) + 1}{2}.
\]

For example, there exist about 32000 different Kasami sequences for \( n = 10 \) and their cross-correlation values can only be either -65, -33, -1, 31, or 63 according to Eq. (1). The family of Kasami sequences can be generated simply by employment of shift-registers. With the different preloading codes, different Kasami identification sequences can be generated and assigned to different ENG transmitters. In order to minimize their negative impact on the subject DTV signal reception, the signal power of the Kasami Tx-ID sequence injected into a DTV signal should be designed carefully. Denote the subject signal power of the Kasami Tx-ID sequence injected into a different ENG transmitters. In order to minimize their interference and noise need to be considered at the receiver thereby. For example, several ENG broadcasting vehicles for live news reports are working in the same area. Different DTV signals sent by different vehicles should be identified by the television station (base station) in order to pinpoint the desired subject ENG signal. In this paper, we assume that the omnidirectional antenna is used at the television station to sense the ENG crews who share the same RF band in the worst scenario.

A. Tx-ID Sequence-Length Determination for Arbitrary Known Transmitter Topologies

In general, the periodic cross-correlation function \( R_{\tau, j}(\tau) \) of the two Kasami sequences \( a_i(m) \) and \( a_j(m) \) both with period \( 2^n - 1 \) is defined as

\[
R_{\tau, j}(\tau) = \sum_{m=0}^{2^n-1} (-1)^{a_i(m) - a_j(m + \tau)}.
\]

We assume that the total number of the ENG trucks for newscasting in the same area is \( L \) as shown in Figure 2. Consider that the subject ENG transmitter (indexed by \( k_1 \)) delivers its transmitter ID sequence \( a_{k_1}(m) \) back to the base station. It will be interfered by the DTV signal \( a_{k_2}(m) \) sent by another ENG transmitter (indexed by \( k_2 \)) if \( l \neq 1 \). This can be considered as a near-far problem. Hence, \( d_{k_1} \) indicates the distance from the transmitter to the base station, where \( l \) ranges from 1 to \( L \). Thus, for each ENG truck, the received signal-to-interference ratio (SIR) \( \eta \) at the base station can be defined as

\[
\eta \overset{\text{def}}{=} \frac{\frac{1}{d_{k_1}^2} \frac{1}{d_{k_2}^2} R_{k_1,k_2}(0)}{\sum_{l=2}^{L} \frac{1}{d_{k_1}^2} \frac{1}{d_{k_l}^2} R_{k_1,k_l}(\tau_{1,l})},
\]

where both \( R_{k_1,k_1}(0) \) and \( R_{k_1,k_l}(\tau_{1,l}) \) are given by Eq. (3) and \( \tau_{1,l} \) specifies the arrival time difference at the receiver between the 1st and the \( l \)th Tx-ID signals. For the worst situation, we set \( R_{k_1,k_l}(\tau_{1,l}) \) as its maximum absolute value \( |t(n)| = 1 + 2^{(n+2)/2} \) and let \( R_{k_1,k_1}(0) \) be equal to \( 2^n - 1 \) for the \( n \)-bit-length Kasami sequences. Consequently, we achieve the lower bound for the received SIR \( \eta \) as

\[
\eta \geq \frac{1}{d_{k_1}^2} \frac{1}{d_{k_2}^2} \frac{1}{(2^n - 1)} \sum_{l=2}^{L} \frac{1}{d_{k_1}^2} \frac{1}{d_{k_l}^2} (1 + 2^{(n+2)/2}) \frac{1}{(2^n - 1)} \sum_{l=2}^{L} \frac{1}{d_{k_l}^2} (1 + 2^{(n+2)/2}).
\]
ENG transmitter to the receiving station as well as the Kasami sequence bit-length \( (n) \). Such a lower bound of the received SIR can be utilized to determine the minimum Kasami sequence length required for reliable Tx-ID transmission from an ENG vehicle to the base station. Furthermore, the larger distance between an ENG transmitter and the base station, the lower the received SIR may be expected for Tx-ID. Thus, the received SIR associated with the farthest ENG transmitter to the base station is crucial for the base station to deal with all transmitters in the same area (topology). Therefore, we denote the farthest ENG transmitter (to the base station) by a particular index \( k_f \). In order to carry out the new geometric study about the relationship between the required received SIR and the embedded Kasami sequence length, \( \lambda \) is defined as the parameter to indicate the transmitter distribution within an area of interest, which is

\[
\lambda \overset{\text{def}}{=} \frac{d_{k_f}^2}{\sum_{l \neq f} L \frac{d_{k_l}^2}{d_{k_l}}}, \quad (6)
\]

According to Eqs. (5) and (6), the Kasami sequence bit-length \( n \) can be bounded as

\[
n \geq \left[ 2 \log_2 \left( \frac{2 \lambda \eta + \sqrt{(2 \lambda \eta)^2 + 4(\lambda \eta - 1)}}{2} \right) \right]^2, \quad (7)
\]

where \( \lceil \cdot \rceil_2 \) is the \textit{radix-2 rounding-up operator} such that it approximates \( \xi \) as its closest positive even integer \( \lceil \xi \rceil_2 = \iota \) and \( \iota \geq \xi \). For any given received SIR \( \eta \) in an arbitrary ENG topology, the minimum required Kasami sequence bit-length can be determined according to Eq. (7) thereby.

\section*{B. Tx-ID Sequence-Length Determination for Arbitrary Transmitter Topologies with Uncertainties}

In Section III-A, we assume that \( d_{k_1}, d_{k_2}, \ldots, d_{k_L} \) are known exactly (ENG transmitters can be precisely localized). However, it is impossible in reality. Interference studies on the random sensor network topologies have been presented in [12], [13]. In this subsection, we also take the uncertainties (transmitter location imprecisions) into consideration. Denote the transmitter location error by \( \Delta d \) for each ENG truck. The aforementioned \( \lambda \) in Eq. (6), which represents the ENG transmitter distribution, can thus be reformulated as

\[
\lambda' \overset{\text{def}}{=} \frac{(d_{k_f} \pm \Delta d_{k_f})^2 \sum_{l \neq f} L \frac{1}{(d_{k_l} \pm \Delta d_{k_l})^2}}{P}, \quad (8)
\]

where

\[
\Delta d_{k_f} \overset{\text{def}}{=} \frac{d_{k_f}}{P} \quad \text{(9)}
\]

and

\[
\Delta d_{k_l} \overset{\text{def}}{=} \frac{d_{k_l}}{P}, \quad l = 1, 2, \ldots, L. \quad (10)
\]

Consider Eq. (7); the larger is the value of \( \lambda \), the larger the Kasami sequence bit-length \( n \) will be required. Therefore, the maximum value of \( \lambda' \), denoted by \( \lambda'_{\max} \), is crucial to determine the Kasami sequence bit-length. According to Eq. (8), \( \lambda'_{\max} \) can be expressed as

\[
\lambda'_{\max} \overset{\text{def}}{=} \frac{(d_{k_f} + \Delta d_{k_f})^2 + (d_{k_f} - \Delta d_{k_f})^2}{P} = \frac{[(P + 1)d_{k_f}]^2 \sum_{l \neq f} L \frac{1}{(P - 1)d_{k_l}}}{P^2}, \quad (11)
\]

where \( \Delta d_{k_f} \) and \( \Delta d_{k_l} \) are defined by Eqs. (9) and (10), respectively. According to Eqs. (7) and (11), the Kasami sequence bit-length \( n \) for Tx-ID subject to transmitter location uncertainties can be bounded as

\[
n \geq \left[ 2 \log_2 \left( \frac{2 \lambda'_{\max} \eta + \sqrt{(2 \lambda'_{\max} \eta)^2 + 4(\lambda'_{\max} \eta - 1)}}{2} \right) \right]^2, \quad (12)
\]

\section*{IV. SIMULATION}

The ENG transmitters which surround the TV station are assumed to be located arbitrarily in a given area. We use MATLAB to randomly generate the ENG locations and no ENG vehicle is allowed to be very close to the base station since such a situation can hardly happen. Figure 3 depicts an example consisting of eight ENG vehicles where the red node at the center of the plane indicates the TV station location and blue nodes indicate the ENG transmitters.

In our assumption, the ENG trucks will not be deployed within the circular area with the radius \( r_g \) because hardly any ENG vehicle would be located in the close vicinity of the base (TV) station. The eight ENG trucks are deployed in the \( 10 \times 10 \) square area as depicted in Figure 3. We set \( r_g = 2 \). In this simulation, the \textit{minimum allowable received SIR} \( \eta_{\min} \) is 6 dB or 8 dB. We randomly generate the ENG locations for twenty different trials. We set \( P = 10 \) to quantify uncertainties. The minimum required Kasami sequence bit-lengths according to Eqs. (7) and (10) are thus determined for comparison.

In the ATSC standard [2], the RF watermark is injected at 10 to 20 dB below the desired signal-to-noise-ratio threshold level and the required signal-to-interference-and-noise ratio by the data return link (DRL) system is 7 dB. Consequently, we choose \( \eta_{\min} = 6 \) dB and 8 dB for investigation. The minimum Kasami sequence bit-lengths \( n \) are delineated versus the trial order in Figure 4 for \( \eta_{\min} = 6 \) dB and in Figure 5 for \( \eta_{\min} = 8 \) dB, respectively. According to Figures 4 and 5, the Kasami sequence bit-lengths do not vary significantly with \( \pm 10\% \) uncertainty in ENG locations.

\section*{V. CONCLUSION}

The multiple-transmitter identification for ENG deployment applications has been studied in this paper. According to the ATSC standard, the Kasami sequences are adopted as the injected Tx-ID sequences due to their excellent correlational properties compared to other pseudo-random sequences. We introduce the crucial mathematical properties of the Kasami
sequences and determine the lower bound of the received signal-to-interference ratio for the Tx-ID. On the other hand, we derive the minimum required Kasami sequence bit-length for a given minimum allowable received signal-to-interference ratio. The uncertainties of transmitter locations have also been considered to quantify such an effect on the variations of the minimum required Kasami sequence lengths. Our Monte Carlo simulation results demonstrate that the minimum required Kasami sequence bit-lengths do not vary much when a ±10% location imprecision is considered.

REFERENCES


Fig. 4. The minimum required Kasami sequence bit-length $n$ over 20 different trials ($\eta_{\text{min}}=6$ dB). Each trial consists of a randomly generated ENG deployment topology.

Fig. 5. The minimum required Kasami sequence bit-length $n$ over 20 different trials ($\eta_{\text{min}}=8$ dB). Each trial consists of a randomly generated ENG deployment topology.