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Applications of Complete Complementary Codes and Propositions for Future Research Areas of These Codes

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Abstract

Complete complementary codes represent special group of codes with unique properties, which were not detected for any other codes. These codes found a wide application in several science areas with the broadest application possibilities in telecommunications. This review paper analyses the applications of these codes proposed so far and aims to propose not sufficiently explored and new areas for further research endeavors.

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1. Introduction

The theory of Complete Complementary Codes (CCC) represents a vivid area of research. These codes attracts interest of many researchers thanks to their unique properties, which are not detected for another code groups so far. These codes possesses ideal cross- and auto-correlation properties that allow concurrent interference free transmission of multiple users and recognition of particular user by the use of matched filter on receiving end in Code Division Multiplex Access (CDMA) systems. These codes have found broad application in several technical areas, however, the broadest application has been proposed in the field of telecommunications.

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In this paper, several application areas of CCCs are summarized. Next, the development of the theory of complete complementary codes is briefly described with a discussion of the impact of each milestone followed by the summarization of the most important construction milestones in field of CDMA systems. Finally, the conclusion discusses the research implications and proposes future areas of research for these codes.

2. Application Fields

Extensive ongoing research of complementary and complete complementary codes contributed to the wide application of theoretical knowledge gained from research and studies in different disciplines. Today it is possible to find the application of these codes in different areas of high-end technologies and diverse disciplines:
- physics - Ising spin model[1-2];
- mathematics: combinatorics - orthogonal model[1-2], Hadamard matrices[3-4];

and the widest application was found in information and communication technology (ICT) including telecommunication digital systems and networks.

Complete complementary codes found their application in following digital processing:
- model surface acoustic waves[5],
- navigation system LORAN C[6],
- radar[7-13],
- optical transmission[14],
- measuring characteristics of the channel measurement and analysis of optical routes (OTDR)[15-17],
- image processing and transmission[18-21],
- watermarking[22-28],
- fingerprinting[29],
- steganography[30-31],
- video transmission and processing[32-33],
- eHealth[34],
- data hiding method to an evacuation guiding system[35],
- disaster prevention broadcasting[36],

The application of these codes in modern telecommunication systems and architecture:
- signal processing[37],
- synchronization[38-39],
- cell interference elimination[40],
- multiterminal source[41],
- network spread coding[42-43],
- body area network[44],
- modern communication wireless architectures such as spread spectrum systems (SSS), orthogonal frequency division multiplexing (OFDM) and CDMA and others.

The ideal autocorrelation property allows the use of a matched filter on the receiving end for optimal and rapid recognition of the respective set. The ideal characteristic of mutual correlation function allows simultaneous transmission of multiple users using different sets of the same CCC without mutual interference (ICI)[45-46] . Full utilization efficiency of spectrum in the Direct Spread Spectrum (DS-CDMA) is possible assuming ideal correlation properties. In the DS-CDMA system using the CCC each user is allocated to at least one unique set, comprising different sequences. Each sequence has to be transferred through separate channel, selected by the matched filter and sequences are re-combined into one set at the receiving end. Individual channels in the case one-dimensional completely complementary codes (1D-CCC) can be distributed in time[47] and the frequency[48] space. Channels can be separated in frequency or with the time. The second case was also analyzed by SM Tseng and MR Bell[49], while in the second case the numerical results can be found in works of C Hsiao-Hwa et al.[50] and T Kojima et al.[51]

The use of CCCs for CDMA systems is currently also studied in Multicarrier Systems (MC-CDMA) and in systems with multiple input and multiple output (MIMO).

In view of the extensive use of the knowledge of the theory of the CCC, a continuous research and continued studies in this field may be assumed.