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Performance Comparison of Resource Allocation without Feedback in Wireless Body Area Networks by Various Pseudo Orthogonal Sequences

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***Abstract*—**Wireless Body Area Network (WBAN) is a short-range wireless communication around human body for various applications such as wearable devices, entertainment, military, and especially medical devices. WBAN attracts the attention of continuous health monitoring system including diagnostic procedure, early detection of abnormal conditions, and prevention of emergency situations. Compared to cellular network, WBAN system is more difficult to control inter- and inner-cell interference due to the limited power, limited calculation capability, mobility of patient, and non-cooperation among WBANs.

In this paper, we compare the performance of resource allocation scheme based on several Pseudo Orthogonal Codewords (POCs) to mitigate inter-WBAN interference. Previously, the POCs are widely exploited for a protocol sequence and optical orthogonal code. Each POCs have different properties of auto- and cross-correlation and spectral efficiency according to its construction of POCs. To identify different WBANs, several different pseudo orthogonal patterns based on POCs exploits for resource allocation of WBANs. By simulating these pseudo orthogonal resource allocations of WBANs on MATLAB, we obtain the performance of WBANs according to different POCs and can analyze and evaluate the suitability of POCs for the resource allocation in the WBANs system.

***Keywords*—**Wireless body area network, body sensor network, resource allocation without feedback, interference mitigation, pseudo orthogonal pattern.

I. Introduction

THE invigoration of wireless networks and the miniaturization of portable devices has expedited the development of Wireless Body Area Networks (WBANs). WBANs are a short-range wireless sensor communication which is within, on, and in the immediate proximity of a human body in order to use for various proposes such as military, entertainment and medical devices [1], [2]. The benefit of wireless sensor networks can provide innovative and practical applications to improve the medical and health care area for monitoring vital body signals such as heart-rate, temperature, blood pressure, electrocardiography (ECG), electroencephalogram (EEG) and pH level of patients [3].

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Therefore, by using WBANs, the continuous health monitoring system with the real-time updates of health records through the wireless sensors network as a diagnostic procedure, early detection of abnormal conditions, and prevention of emergency situations is implemented and the patients experience less restrictions of physical activity compared with the hospitalization.

The main problems of WBANs are induced from the characteristics of the WBANs networks and the physical mobility and convenience of patients. In contrast with cellular networks, the WBANs are a type of distributed systems which are composed of independent and parallel sensors without a central controller. Therefore, the WBANs have the advantages of being a simply network organization and preventing all the sensors failing simultaneously. Because there is no central controller, each WBAN doesn't operate cooperatively so that the WBANs automatically generate interferences with each other, called inter-WBAN interference [4]. Furthermore, due to the limitations of the space and battery of sensors, WBAN may not use interference mitigation schemes based on multiple antennas and channel sensing schemes to mitigate inter-WBAN interference.

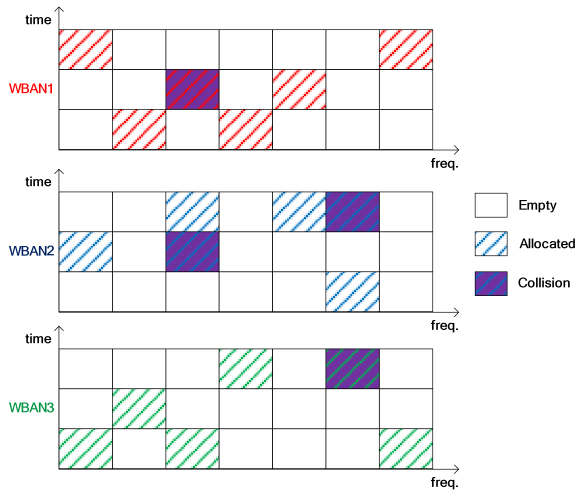


Fig. 1 Schematic diagram of pseudo-orthogonal resource pattern in the wireless body area network

In this paper, to mitigate inter-WBAN interference, we propose new resource allocation scheme based on pseudo orthogonal code in WBANs system. Due to no central controller and no cooperation among WBANs, WBANs allocate their data into two dimensional plane consisted of frequency and time domain without the cooperation of WBANs. As each WBAN operates independently, the inter-WBAN interference is a significant problem. To alleviate this problem, we consider that each of WBANs has the specific pseudo-orthogonal pattern for their resource allocation according to pseudo orthogonal code in the same frequency dimension. The pseudo orthogonal code is binary sequences with the high-quality of auto- and cross-correlation [5]. Therefore, using pseudo orthogonal code for resource allocation in the WBANs, the number of collision which more than two WBANs allocate their data to the same resource slot can be decreased. Fig.1 shows the proposed scheme that configure the resources into slots on the two dimensional plane with time and frequency domain respectively, and each slot is assigned to sensor nodes for data transmission. Three WBANs share the same two-dimensional plane, where the occupied slots by the resource allocation of one WBAN have the diagonal line pattern and the shaded slots denote collisions. Thus, as the number of the shaded slots is increased, system throughput is decreased due to the inter-WBANs interference. Afterward, by using computer simulation on MATLAB, the performance comparison of different pseudo orthogonal resource allocation patterns according to different pseudo orthogonal code is conducted.

II. Background

A. Related Works

In order to accommodate the expected growth in wireless sensor networks, ad-hoc networks and Radio-Frequency Identification (RFID), the simple and efficient multiple-access algorithms for these systems are necessitated. Randomness is widely exploited to design the multiple-access schemes. For example, when collisions are occurred in ALOHA system [6], transmitters should wait for random time independently before trying to send their data again. To implement the random access schemes in practice, pseudo random numbers are usually used for random parameters. However, there are complexity problems to generate high-quality pseudo random numbers, because computing power and battery is limited in wireless sensor networks. To address this problem, there are several different methods to conduct random multiple-access algorithms and randomness.

The deterministic coding sequences defined by random access protocol without feedback can commence with the seminal research of Massey and Mathys [7]. The protocol sequence is binary sequences which can successfully transmit at least one packet in the predetermined length of time slots. The zero error sum-capacity is characterized by e^{-1} in the collision channel without feedback, which is defined for all non-empty subsets of users, not just for pairs of users. Protocol sequences with high-quality auto- and cross-correlation properties are called shift-invariant sequences [7]–[9]. The advantage of the shift-invariant protocol sequences is less fluctuation of system throughput according to the delay offsets, and hence the shift invariant protocol sequences have the significant degradation of system throughput. Nevertheless, as the number of users increases in the system, the period of the shift-invariant protocol sequences exponentially increases [8]. Long period length has the disadvantage that individual or system throughput is invariant only if it is averaged over a long period. The increment of the period may indicate that individual users undergo low system throughput, because the throughput of the shift-invariant protocol sequences is averaged over a long period.

Afterward more constructions of protocol sequences are researched, such as cyclically permutable constant-weight codes, or optical orthogonal codes [10]–[12]. Optical Orthogonal Code (OOC) is also a collection of binary sequences with the high-quality of correlation to apply code division multiple-access scheme in the optical networks [5], [12]. According to the auto- and cross-correlation, the constructions of OOC are different. As both auto- and cross-correlation are equal to 1, wavelength/time multiple-pulses-per-row (W/T MPR) codes can provide the good auto- and cross-correlation properties, good cardinality and high spectral efficiency [5]. They described an expression for the upper bound on the cardinality of W/T MPR codes. However, the construction method of OOC wasn't described in [5]. In case of unequal auto- and cross-correlation, the construction method of OOC with the auto-correlation of 2 and cross-correlation of 1 was derived by exploiting Galois field [13].

In order to achieve short period length and small variance of Hamming cross-correlation, another class of protocol sequences, called Chinese Remainder Theorem (CRT) code, is considered in [14]. CRT code is basically similar to the OOC in terms of the construction of the protocol sequences. The only difference is that CRT sequences may be very large Hamming auto- or/and cross-correlation compared with OOC.

B. Basic Principles of Pseudo Orthogonal Resource Allocation

In this section, the basic principles of a pseudo-orthogonal code are introduced as a slotted asynchronous environment, and auto- and cross-correlation, which are related to the resource allocation and the performance analysis of WBANs.

In this paper, we assume that WBANs system is a slotted asynchronous environment without considering a control channel in the reverse direction due to the limitation of the sensor nodes such as the limited battery capacity and no additional receiver antenna of sensor nodes. The slotted asynchronization denotes that each WBAN has a different delay offset and sends a packet within the boundaries of a time slot. In other words, all WBANs start to send their packet with random integer time offset at the boundary of time slots. Therefore, in the slotted asynchronization, the resource patterns of WBANs in the direction of time domain may have different starting points and time offsets of each resource patterns in the WBANs system. Successful transmissions denote that only one WBAN sends a packet in one resource slot as adjacent WBANs can't transmit any other packets at this resource slot. If two or more WBANs transmit in the same resource slot, collision is occurred.

We consider three different pseudo-orthogonal codes for the resource allocation of WBANs to analyze the system performance of WBANs without feedback channel. By using the properties of pseudo-orthogonal codes, the effect of inter-WBAN interference and correlation properties on the resource allocation in the WBANs system without feedback channel can be analyzed. In Section II.B, the basic concept and properties of the pseudo-orthogonal codes are explained, which is a collection of binary sequences, called codewords, with high quality auto- and cross-correlation properties. There are several different types of the construction methods of the pseudo orthogonal code under specific environments.

The Pseudo Orthogonal Codeword (POC) can be characterized by $\Phi(L, \omega, \lambda_a, \lambda_c)$, where L is the length of pseudo orthogonal codeword, ω is the Hamming weight, λ_a is the auto-correlation, and λ_c is the cross-correlation [5]. The number of POCs in the collection, Hamming weight and correlation are determined to the length of POC, the length of POC is directly related to the efficiency of resource allocation in the WBANs system. Thus, to evaluate the performance of POC, an auto- and a cross-correlation are necessary to represent the quantity and quality of the orthogonal properties of POCs. The auto-correlation of a POC $s_1[n]$ with a minimum length L is given in [5]:

$$Z_{s_1 s_1}[k] := \sum_{k=0}^{L-1} s_1[n] s_1[n-k] \qquad (1)$$

where n is time offset, and $n-k$ is the difference in modulo-L arithmetic. $Z_{s_1 s_1}[k]$ satisfies:

$$Z_{s_1 s_1}[k] \begin{cases} = \omega, & if\ k = 0 \\ \le \lambda_a, & otherwise \end{cases} \qquad (2)$$

where λ_a denotes the peak out of phase autocorrelation. The cross-correlation ($Z_{s_1 s_2}[k]$) between two periodic POCs $s_1[n]$ and $s_2[n]$ with length L is represented as:

$$Z_{s_1 s_2}[k] := \sum_{k=0}^{L-1} s_1[n] s_2[n-k] \qquad (3)$$

$Z_{s_1 s_2}[k]$ satisfies:

$$Z_{s_1 s_2}[k] \le \lambda_c, \quad if\ 0 \le k \le L-1 \qquad (4)$$

where λ_c denotes the peak out of phase cross-correlation.

The duty factor [7] of binary sequence $s[n]$ is defined by:

$$f_s := \frac{1}{L} \sum_{n=0}^{L-1} s[n]. \qquad (5)$$

WBAN1 (frequency →, time ↓)

$$\begin{bmatrix} 1 & 2 & 13 \\ 1 & 5 & 10 \\ 1 & 4 & 11 \end{bmatrix} \text{ represents } \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

WBAN2 $\begin{bmatrix} 8 & 9 & 10 \\ 4 & 8 & 12 \\ 2 & 9 & 12 \end{bmatrix}$ WBAN3 $\begin{bmatrix} 5 & 6 & 7 \\ 3 & 7 & 11 \\ 3 & 6 & 13 \end{bmatrix}$

Fig. 2 Example of resource allocation pattern based on the pseudo-orthogonal code. Corresponding to Fig. 1, the allocated resource slots are mapped with the corresponding elements of matrix

The system performance of WBAN is related to the number of overlapped slots among different WBANs. The outage probability of WBANs is dependent upon the maximum number of overlapped slots among WBANs in the system, which is decided by the maximum value of correlation as λ_a and λ_c. Therefore, the pseudo-orthogonal pattern of WBANs which is generated by POCs can reduce the maximum number of the overlapped slots at the two dimensional time-frequency plane according to correlation properties. Therefore, by using computer simulation, we evaluate the performance of pseudo orthogonal patterns based on different POCs in WBANs system.

III. Pseudo Orthogonal Resource Allocation without Feedback in WBANs

In this paper, we consider three different types of POCs construction as the resource allocation of WBANs; 1) OOC with both auto- and cross-correlation of 1 [5], 2) OOC with auto-correlation of 2 and cross-correlation of 1 [13], and 3) CRT code [14]. According to the different properties of auto- and cross-correlation, the system performance of WBANs is also changed. By exploiting computer simulation, the performance comparison of the different POCs construction is conducted in Section IV.

Corresponds to Fig. 1, Fig. 2 shows that pseudo-orthogonal code is represented by the chip positions of 1s in each row, where the row of matrix denotes the frequency dimension and the column of matrix is the time dimension in the two dimensional plane. For example, as the first row of WBAN1 is $[1 \quad 2 \quad 13]$, this means that the first, second, and thirteen resource slots are occupied in the frequency dimension.

Table I shows an example of pseudo orthogonal resource allocation patterns WBANs where there are three WBANs in the system and the resource allocation pattern of each WBAN is determined by different POCs. Without cooperation and feedback channel among WBANs, each WBAN don't know the resource allocation of the other WBANs.

Thus, each WBAN generates independently own resource allocation pattern based on POCs. In (a) and (b), each row of matrix is composed by POCs and the red colored additional numbers denote time offset which affects cyclic shift in the direction of frequency domain. Thus, each row has different starting point according to the time offset. Whether two WBANs have different pseudo orthogonal resource allocation pattern or different time offset, several resource slots can be transmitted successfully. As a result, the auto- and cross-correlation of POCs can be represented by the collisions of resource slots. As the number of overlapped slots is associated with the performance of WBAN, the correlation function can evaluate the performance of WBANs system.

TABLE I
EXAMPLES OF PSEUDO ORTHOGONAL PATTERNS ACCORDING TO DIFFERENT GENERATION OF PSEUDO ORTHOGONAL SEQUENCES

A. OOC $\Phi(37,4,1,1)$ WITH BOTH AUTO- AND CROSS-CORRELATION OF 1

	Pseudo orthogonal resource allocation pattern
WBAN1	$\begin{bmatrix} 1 & 2 & 4 & 25 \\ 1 & 5 & 10 & 16 \\ 1 & 8 & 18 & 26 \end{bmatrix}$
WBAN2	$\begin{bmatrix} 1 & 5 & 10 & 16 \\ 1+5 & 2+5 & 4+5 & 25+5 \\ 1+2 & 8+2 & 18+2 & 26+2 \end{bmatrix}$
WBAN3	$\begin{bmatrix} 1 & 8 & 18 & 26 \\ 1+11 & 2+11 & 4+11 & 25+11 \\ 1+7 & 5+7 & 10+7 & 16+7 \end{bmatrix}$

B. OOC $\Phi(25,4,2,1)$ WITH AUTO-CORR. OF 2 AND CROSS-CORR. OF 1

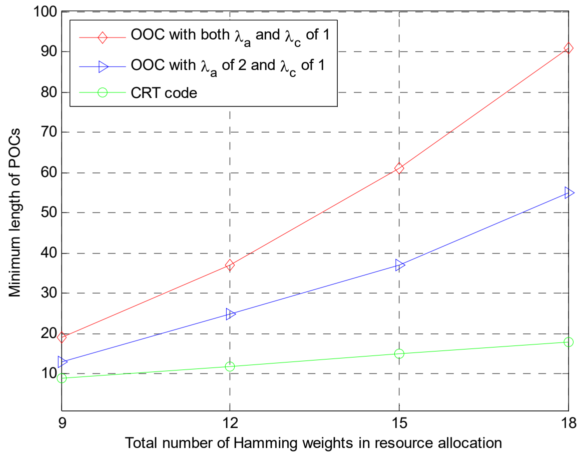
	Pseudo orthogonal resource allocation pattern
WBAN1	$\begin{bmatrix} 1 & 8 & 12 & 14 \\ 4 & 6 & 7 & 23 \\ 3 & 16 & 17 & 24 \end{bmatrix}$
WBAN2	$\begin{bmatrix} 4 & 6 & 7 & 23 \\ 3+1 & 16+1 & 17+1 & 24+1 \\ 1+4 & 8+4 & 12+4 & 14+4 \end{bmatrix}$
WBAN3	$\begin{bmatrix} 1 & 8 & 12 & 14 \\ 3+3 & 16+3 & 17+3 & 24+3 \\ 4+10 & 6+10 & 7+10 & 23+10 \end{bmatrix}$

C. CRT CODE AS 3 BY 12 MATRIX

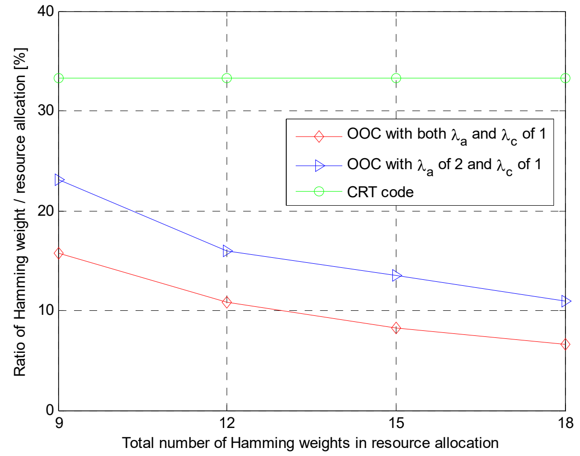
	Pseudo orthogonal resource allocation pattern
WBAN1	$\begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 \\ - & - & - & - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & - & - & - & - \end{bmatrix}$
WBAN2	$\begin{bmatrix} 1 & 4 & 7 & 10 \\ 2 & 5 & 8 & 11 \\ 3 & 6 & 9 & 12 \end{bmatrix}$
WBAN3	$\begin{bmatrix} 1 & 4 & 7 & 10 \\ 3 & 6 & 9 & 12 \\ 2 & 5 & 8 & 11 \end{bmatrix}$

IV. SIMULATION RESULTS

The system performances of various resource allocation schemes, such as the OOC with different correlation and the CRT code, are verified by using computer simulation. To evaluate the system performance, we consider Monte Carlo method with the random selection of time offsets for cyclic shift and POCs for each frequency dimension and each WBAN. We assume that there are three WBANs in the system to analyze the system performance of WBANs. To maximize the system efficiency of POC, the number of POCs in the collection of pseudo orthogonal code is equal to the number of WBANs, because the length of POCs is a function of the number of POCs in the collection. Thus, in this simulation, we consider the number of time dimension is equal to that of WBANs as 3.



(a) Minimum length of resource allocation



(b) Efficiency of resource allocation

Fig. 3 Quantity and efficiency of resource allocations for WBANs according to different POCs and Hamming weight

Fig. 3 depicts the quantity and efficiency of pseudo orthogonal resource allocations in the WBANs system according to the different POCs and Hamming weight. We consider three different POCs; 1) OOC with both λ_a and λ_c of 1 [5], 2) OOC with λ_a of 2 and λ_c of 1 [13], and 3) CRT code [14]. The efficiency of resource allocation defines that the number of allocated slots is divided by total resource slots. The length of OOC with λ_a of 2 and λ_c of 1 is less than that of OOC with both λ_a and λ_c, because $\lambda_a = 2$ is represented by existing the repetition of some patterns in the code word. As the number of Hamming weight increases, the minimum length of POCs increases rapidly due to the difficulty of unique patterns according to auto- and cross-correlation. However, CRT code has the constant efficiency of resource allocation because CRT only considers less variation of correlation regardless of good auto- and cross-correlation.

TABLE II
PERFORMANCE COMPARISON OF WBANS IN REGARD TO COLLISIONS OF DATA TRANSMISSION WITHOUT FEEDBACK

	Hamming weight	System Efficiency [%]	Outage [%]
OOC($\lambda_a, \lambda_c = 1$)	3	33.94737	0.114444
	4	25.71589	0.01
OOC($\lambda_a = 2, \lambda_c = 1$)	3	40.75368	1.841111
	4	33.82773	0.066667
CRT code	3	44.44444	100
	4	44.44444	100

Table II shows the system performance of WBANs by considering collisions of data transmission without feedback in WBANs system. Outage probability represents that less than 30% of total allocated resource slots are successfully received. Similar to Fig. 3, the increment of Hamming weight affects the performance degradation of resource allocation in WBANs due to the difficulty of maintaining correlation properties. However, as the length of POCs increases, the outage probability decreases. Because the less efficiency of POCs denotes the increment of empty slots so that the number of collision decreases although the correlation is fixed. As CRT code does not consider good correlation, CRT code has poor outage probability conflicted with the resource allocation efficiency of CRT code. Therefore, it is necessary that the usage of POCs for the resource allocation of WBANs is optimized to increase the efficiency and reliability of WBANs system, in terms of auto- and cross-correlation of POCs.

V. CONCLUSION

In this paper, we make a comparison of resource allocation efficiency according to several different POCs. Previous studies exploit POC as a protocol sequence and optical orthogonal code which is a collection of binary sequences with the high-quality of correlation. However, in this paper, we propose the pseudo-orthogonal resource allocation scheme based on POCs to mitigate inter-WBANs interference. According to each frequency dimension and each WBANs, POCs and time offset are randomly selected for resource allocation to mitigate interference. We consider three different types of POCs construction as the resource allocation of WBANs; 1) OOC with both auto- and cross-correlation of 1 [5], 2) OOC with auto-correlation of 2 and cross-correlation of 1 [13], and 3) CRT code [14]. By simulating these pseudo-orthogonal resource allocation schemes based on MATLAB, the performance comparison of WBANs is shown according to different POCs.

Therefore, it remains a future research topic to optimize pseudo resource allocation patterns to increase the efficiency and reliability of WBANs system according to auto- and cross-correlation of POCs.

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