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RECOGNITION AND CORRECTION OF FLEXIBLE ERROR USING MULTI-LEVEL REDUNDANT RESIDUE NUMBER SYSTEM IN WIRELESS SENSOR NETWORKS

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ABSTRACT

The application of wireless sensor networks is inevitable in today's life. Here, we can refer to some challenges of designing wireless sensor networks containing: high error rate in sending the information, high throughput, low speed and low security of these networks. In this paper, we used the residue number system in order to solve these problems and improve system performance. Evaluations show that our proposed method has higher speed and lower throughput and it has the capability of recognizing and correcting more errors in comparison with previous proposed systems.

Keywords: *Redundant Residue Number, Chinese Remainder Theorem, Multi-level Redundant Residue Number System*

1. INTRODUCTION

Wireless sensor networks have special limitations due to the restricted and specific features of their nodes, their nature and application. Sending the information in a secure manner and information error tolerance capability is one of the very significant tips in transferring information in wireless sensor networks [1]. Wireless sensor networks have important differences compared with other distributed systems. Lack of resources in wireless sensor networks creates an important challenge for the security of these networks. The nodes of these networks have very low computational power. Encoding the public key is costly and thus it is useless for these kinds of networks [2]. Even a faster and cheaper symmetric key should also be used very carefully. The bandwidth of these networks is also essential. Because transferring each bit in these networks needs an energy equivalent to the execution of 800 to 1000 instructions [3]. The energy and throughput are more important than all of the resources and their value are limited. As a result, it should be noted that the energy issue is a considerable factor in designing any aspect of wireless sensor networks.

Wireless sensor networks are composed of some small sensors in the size of 1 to 2 millimeters, which send information to the central device as the End user. By taking advantage of the secure Residue Number System, we would be able to recognize and correct the flexible errors in wireless sensor networks [4]. Data connection security is achieved by encoding residue data flow in sender and decoding it by special modular numbers in the receiver. Thus, modular numbers behave like an encoding/decoding key and by putting redundant modules to this system, it is also possible to correct errors. Transforming big numbers of small modules is an advantage of residue number systems that optimizes energy consumption [5]. In this paper, we have proposed a method that uses residue number system and redundant modules to correct errors in wireless sensor networks. Also, in our method sensors increase/decrease redundant modules flexibly by considering the amount of noise in the environment. The proposed encoding system is able to recognize and correct more errors [6].

The rest of this paper is organized as follows; In section 2, we illustrate the details of our proposed system. Section 3 proposed method's algorithm step by step. Evaluation of the proposed method set by

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arithmetic calculations is depicted in section 4. Section 5 is about the comparison of our proposed method with previous common encoding methods. Finally, in section 6 we demonstrate the conclusion part.

2. INTRODUCING THE PROPOSED METHOD (RECOGNITION AND CORRECTION OF ERRORS IN WIRELESS SENSOR NETWORKS)

In this algorithm, we used multi-level residue number system encoding method in order to send information in wireless sensor networks and we achieved a big display range. In this proposed method the new set of second-level modules perform separately, since the redundant modules set to the new second-level modules set select frequently, therefore it increases the computation speed. Also, selecting the redundant module set that is prime with respect to the modules of the second level is easier. As it can be seen in figure 1. Each of the modules of the first level are transformed into new sets and r modules are also added to the modules set of the second level as redundant modules which gives the system the capability of recognizing and correcting errors [7,8].

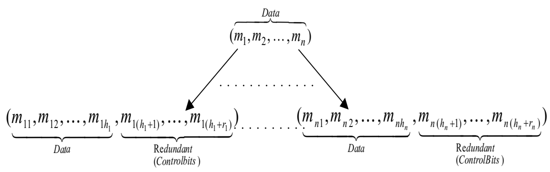

Figure 1. The proposed two-level redundant residue number system

The nodes in the network are composed of a set of sensors which are able to recognize the amount of noise in the environment. Each node increases/decreases the redundant modules by taking into account the amount of noise in the environment and then they recognize and correct the flexible errors. By means of this algorithm, the more the amount of noise in the environment increases, the more the redundant modules are used and if the amount of noise in the environment is low, the less number of redundant modules are used. So, the consumed energy of the sensors reduces optimally. In the proposed method, recognizing and correcting the errors in the second-level modules is done by means of the Chinese Remainder Theorem (CRT) and finally the correct received module set is converted to the binary mode by applying CRT.

3. THE PROPOSED METHOD'S ALGORITHM

a. A wireless network with n nodes is presumed.
b. Each node is composed of some sensors which calculate the amount of noise in the environment.
c. The node i is selected as the initial node.
d. The information achieved for the environment is collected and stored in each node.
e. The stored information is transformed into RNS values.

- ✓ The residue number system is defined by a set of modular numbers like $(m_1, m_2, ..., m_{L-1}, m_L)$
- ✓ Some extra modules are added to the original modules to recognize and correct the errors.
- ✓ If the real number X is located in the display range of our selected set of modular numbers, it has a unique display in residue number system and it is displayed by means of remainder set $(x_1, x_2, x_3, ..., x_{L-1}, x_L)$ where:

$$x_i = X \mod m_i \quad , i = 1, 2, ..., L$$

- ✓ The node i sends the information
- ✓ The information are reached to the j-the node (middle nodes).
- ✓ By paying attention to the amount of noise in the environment, the node j works as follows:
  - If the amount of noise is of type N3 which shows the high level of noise in the environment, CRT($m_1, m_2, m_{r+1}, m_{r+2}, m_{r+3}$) is used for error recognition.
  - If the amount of noise is of type N2 which shows the high level of noise in the environment, CRT($m_1, m_2, m_{r+1}, m_{r+2}$) is used for error recognition.
  - If the amount of noise is of type N1 which shows the high level of noise in the environment, CRT(m_1, m_2, m_{r+1}) is used for error recognition.

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- ✓ If the sensors could not recognize any noise in the environment, the data are sent to the next node without error recognition and correction.

f. Finally, the information is reached to the sink node.

g. The set of true received modules is transformed into the binary mode by using Chinese Remainder Theorem.

4. EVALUATION OF THE PROPOSED METHOD

We analyzed and proved the proposed protocol on our new multi-level module set by arithmetic calculations. In this module set modules $(2^{2n}-2^{n}-1, 2^{2n}-2^{n})$ are located in the first level, which are transformed into the module $\{(2^{n}-1, 2^{n}), (2^{n}-1, 2^{n})\}$. The modules $2^{n}+1, 2^{n}+3, 2^{n}+5$ are considered as the redundant modules for the purpose of error recognition and correction. Finally, from the module set $\{(2^{n}-1, 2^{n}, 2^{n}+1, 2^{n}+3, 2^{n}+5), (2^{n}-1, 2^{n}, 2^{n}+1, 2^{n}+3, 2^{n}+5)\}$, 3 bits are used for error recognition and 1 bit is considered for error correction.

Suppose we have *n=3*, in this case the modules (55,56) will be existed in the first level and they will be transformed into the modules set {(7,8,9,11,13), (7,8,9,11,13)} in the second level.

For the evaluation of the proposed method, we created a wireless sensor network and investigated the way of preventing our method from error occurrences in the received information of each node by applying different undesired conditions in sending and receiving the information. To do so, our wireless sensor network was created with 11 nodes, which used straight propagation of routing. The node *A* was used to collect the information from the environment and it carried them to the desired module set as illustrated in the table1.

Table 1. Transforming the data into the selected module set

Data	$(m_{11}, m_{12}, m_{1(h+1)}, m_{1(h+2)}, m_{1(h+3)})$
	$(m_{21}, m_{22}, m_{2(h+1)}, m_{2(h+2)}, m_{2(h+3)})$
76	(0,5,3,10,8)
	(6,4,2,9,7)
1042	(3,4,7,8,0)
	(6,0,3,4,9)
2357	(5,7,2,3,8)
	(5,5,5,5,5)

As it can be seen in the figure 2 the act of sending the information begins from the node *A* toward the sink.

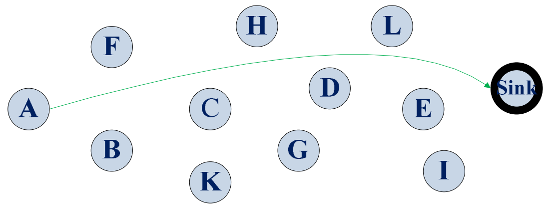

Figure 2. Sending the information from the node A toward the sink

By taking advantage of the straight propagation protocol for sending the information from the node *A* toward the sink, each packet was traversed the path A-B-C-D-E-Sink.

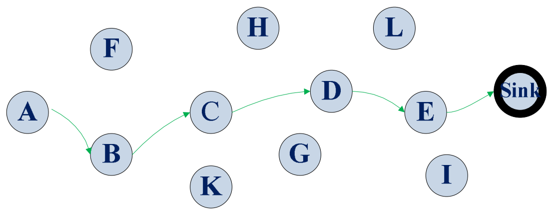

Figure 3. The path of sending the information from the node A toward the sink

In the first level the information was sent from the node *A* to the node *B*. As it can be observed the amount of noise in the node B is presumed of type N3.

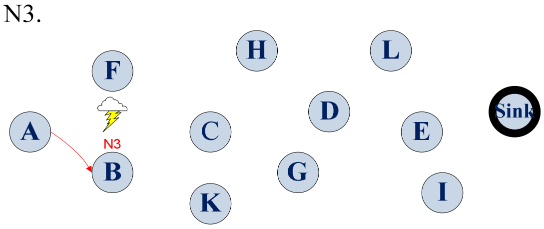

Figure 4. Sending the information from A to B

As shown in the table 2, the information is transferred to the node *B*.

Table 2. Receiving the information in the node B

Data	$(m_{11}, m_{12}, m_{1(h+1)}, m_{1(h+2)}, m_{1(h+3)})$	
	$(m_{21}, m_{22}, m_{2(h+1)}, m_{2(h+2)}, m_{2(h+3)})$	
76	(0,3,3,10,8)	--
	(6,4,2,9,7)	Ok
1042	(3,4,7,8,0)	Ok
	(6,0,3,4,9)	Ok
2357	(5,7,2,3,8)	Ok
	(5,5,3,3,5)	--

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As shown in figure 2. The information was received by the high error rate, because of the high amount of noise in the environment and the number 1042 was received correctly. The whole redundant module is used to correct the errors caused by the existing high amount of noise in the environment. In the following, we have explained about the error tolerance in the data 76 as an example.

CRT(x_1, x_2, x_3, x_4, x_5):

$$\left\langle \begin{array}{l} \langle 6x_1\rangle_7 *10296 \\ +\langle x_2\rangle_8 *9009 \\ +\langle 4x_3\rangle_9 *8008 \\ +\langle 8x_4\rangle_{11} *6552 \\ \langle 11x_5\rangle_{13} *5544 \end{array} \right\rangle_{72072} = \left\langle \begin{array}{l} \langle 6*0\rangle_7 *10296 \\ +\langle 3\rangle_8 *\ 9009 \\ +\langle 4*3\rangle_9 *8008 \\ +\langle 8*10\rangle_{11} *6552 \\ \langle 11*8\rangle_{13} *5544 \end{array} \right\rangle_{72072} = 62073$$

CRT(x_1,x_3,x_4,x_5) : 21 -----------Yes
CRT(x_1,x_2,x_4,x_5) : 1498---------No
CRT(x_1,x_2,x_3,x_5) : 1289--------No
CRT(x_2,x_3, x_4,x_5): 1342--------No
CRT(x_2,x_3,x_4) : 910-----------No
CRT(x_1,x_2,x_5) : 774------------No
CRT(x_1,x_3,x_5) : 21-------------Yes
CRT(x_1,x_3,x_4) : 21------------Yes

The following results are achieved by observing the above equations:

1. Since the results of the equations CRT are not identical, the node *B* discovers the error occurrences.
2. Since the results of the CRTs: CRT (x_1, x_3, x_4, x_5), CRT (x_1, x_3, x_5) and CRT (x_1, x_3, x_4) are identical, the node *B* recognizes the correct data which is equal to 21and carries it to the first level.
3. By comparing the equations CRT (x_1, x_2, x_4, x_5), CRT (x_2, x_3, x_4, x_5), CRT (x_2, x_3, x_4) and CRT (x_1, x_2, x_5), the node *B* found out that the only false residue data through all these 5 results is x_2. So, the destructed residue is x_2.

It should be mentioned that there is no need to achieve all of the CRTs in order to recognize the errors and correct them. As soon as an achieved data is equivalent to one of the obtained results, that number will be considered as the corrected one and the module which is not joint in both of the results, the data is incorrect.

After the error correction of the data in the node *B*, the data are sent toward the neighbor node. If the sender node sends the information of table 1. To the node C as shown in figure 5, according to the proposed method the information is sent without any control due to the lack of noise in the environment.

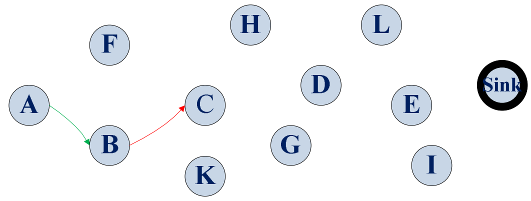

Figure 5. Sending the information from the node B to the node C

Now, according to the figure 6, the node *C* sends the information of table 1 to the node *D* and due to the existence of noise of type N_2 in the environment, the act of error control is performed by means of 2 redundant modules.

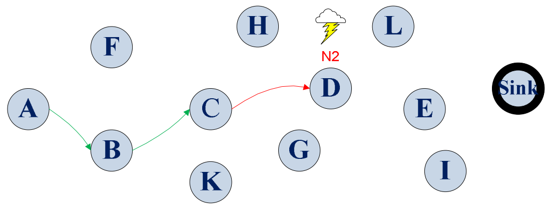

Figure 6. Sending the information from the node C to the node D

According to the table 3, the information is transferred to the node *D*.

Table 3. Receiving the information in the node D

Data	$(m_{11}, m_{12}, m_{1(h+1)}, m_{1(h+2)}, m_{1(h+3)})$	
	$(m_{21}, m_{22}, m_{2(h+1)}, m_{2(h+2)}, m_{2(h+3)})$	
76	(0,5,3,10,8)	Ok
	(6,4,2,9,7)	Ok
1042	(3,1,7,2,0)	--
	(6,0,3,4,9)	Ok
2357	(5,7,2,3,8)	Ok
	(5,5,5,5,5)	Ok

As it can be seen, the node *D* receives the data 1042 with two errors. Thus, it just has the ability to recognize the errors. Now, we continue inspecting the results of the CRT.

CRT(x_1,x_2,x_3,x_4) : 2764 -------------No
CRT(x_1,x_2,x_3) : 1394 ----------------No
CRT(x_1,x_2,x_4) : 1732 ----------------No
CRT(x_1,x_3,x_4) : 986 ------------------No
CRT(x_2,x_3,x_4) : 1126 ----------------No
CRT(x_1,x_2) : 84 ----------------------No
CRT(x_1,x_3) : 52----------------------Yes
CRT(x_1,x_4) : 66-----------------------No
CRT(x_2,x_3) : 36-----------------------No
CRT(x_2,x_4) : 60-----------------------No
CRT(x_3,x_4) : 93-----------------------No

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By paying attention to the equations above, the node *D* detects the error occurrence since none of the results of the CRT equations are the same and this node cannot correct the error.

After receiving the data in the node *D*, the data are sent toward the neighboring node. If the node *D* finds the node *E* as a neighbor, it sends the data toward the node *E*.

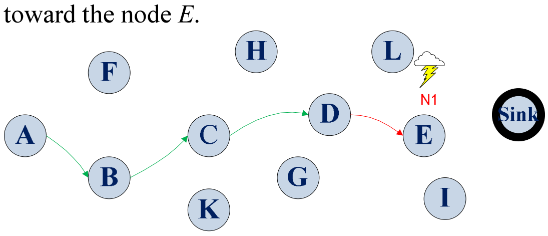

Figure 7. sending the information from the node D to the node E

Corresponding to the table 2, the data are reached to the node *E*. Due to the noise existence of the type N_1 around the node *E*, controlling the error is performed with the redundancy equal to 1.

Table 4. receiving the information in the node E

Data	$(m_{11}, m_{12}, m_{1(h+1)}, m_{1(h+2)}, m_{1(h+3)})$ $(m_{21}, m_{22}, m_{2(h+1)}, m_{2(h+2)}, m_{2(h+3)})$	
76	(0,5,3,10,8)	Ok
	(6,4,2,9,7)	Ok
1042	(3,4,7,8,0)	Ok
	(6,0,3,4,9)	Ok
2357	(3,7,2,3,8)	--
	(5,5,5,5,5)	Ok

As it can be seen in the table 4, the node E has received the data 2357 in error. Now, we continue analyzing the results of the CRT.

$CRT(x_1,x_2,x_3)$: 1394----------------No
$CRT(x_1,x_2)$: 84----------------------No
$CRT(x_1,x_3)$: 52----------------------Yes
$CRT(x_1,x_4)$: 66----------------------No
$CRT(x_2,x_3)$: 45----------------------No

By observing these equations, the node E discovers the error occurrence due to the inequality of the results of the CRT equations. So, it cannot correct the error because of the usage of 1 redundancy. Finally, the information is sent to the sink as shown in figure 8.

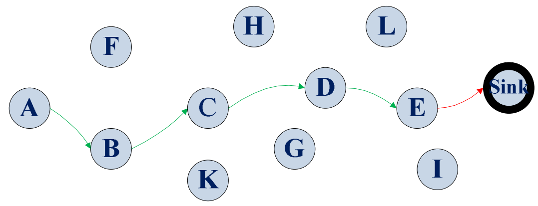

Figure 4. Sending the information from the node E to the sink

The node sink returns the correct received data to the binary mode by using Chinese Remainder Theorem.

5. COMPARISON

In this part, we have analyzed the speed of the original data extraction from the encoded data in the receiver part and also the ability to recognize and correct the errors in our proposed method in comparison with previous common encoding methods.

5.1. Comparison Of The Original Data Retrieving Speed In The Complicated Encodings

In all of the encoding methods to retrieve the main data within the encoded data in the receiver part, we should first receive all of the sent data containing the main data and the encoded data and then we must encode this data based on their special relationships and extract the main data. But in our proposed method, as soon as receiving *m* modules from *m+r* sent data modules whether from the data related to the main modules or the data related to the redundant modules, the main data can be built by means of an inverse transformer. This feature increases the speed of the original data retrieval a lot more.

5.2. The Comparison Of The Ability To Recognize And Correct The Errors In The Sophisticated Encodings

In this section, the sophisticated encoding mechanisms are compared based on 3 parameters:

1- The ability to recognize and correct the errors.
2- The ability to recognize the continuity errors.
3- The ability to recognize and correct the redundancy errors.

As it can be seen in the table 5, the multi-level redundant residue number system encoding is compared with the *m* to *n* encoding, Checksum encoding, Burger encoding, Hamming encoding, Alternative redundancy check encoding and Parity check encoding. None of these error control mechanisms are able to separate the sent packet

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into smaller parts (segments). One of the main advantages of the multi-level redundant residue number system is to recognize the continuous error.

Error control mechanism	Ability	Recognize the continuity error	Detection and error correction redundancy
m to *n* Encoding	Error recognition	No	Only recognition
Checksum Encoding	Error recognition	Yes (Honeywell)	Only recognition
Burger Encoding	Error recognition	No	Only recognition
Parity check Encoding	Error recognition	No	Only recognition
Cyclic redundancy check (CRC)	Error recognition	Yes	Only recognition
Hamming Encoding	Error recognition and correction	No	Error recognition and correction
multi-level redundant residue number system (MLRRNS)	Error recognition and correction	Yes	Error recognition and correction

The continuity error recognition mechanism is performed at the module level.

Table 5. Comparison of the error control mechanisms

6. CONCLUSION AND FUTURE WORK

In this paper, we have introduced a strong mechanism for error recognition and correction called "multi-level redundant residue number system "in order to have a secure connection with error tolerance capability for data transferring in wireless sensor networks. An important and discriminating feature of this system is breaking big numbers into small numbers which increases the processing speed in modules. The redundant data are increased or decreased on the basis of the amount of noise in the environment of sensor nodes. This optimizes the amount of energy in the nodes. In this algorithm for each of the *r* redundant modules, there is recognizing ability *r* and error correction [*r*/2]. Another discriminating advantage of this system is its great speed in retrieving the original data from the encoded data which are sent in the receiving part. The data are broken into smaller modules and some extra modules are added to it as redundant data. The data are transferred distributed to the neighbor nodes by considering the amount of their energy. Usage amount of the middle nodes is dependant on their amount of energy. Also, the speed of the original data retrieval from the encoded, sent data in receiver part increases. In this paper, we have used multi-level redundant residue number system based on read-only memories in order to improve processing speed. Experimental results show that our proposed method outperforms previously proposed systems in terms of higher speed and lower throughput. Our implementation can be mentioned, reduces the risk of errors and debugging easier and thus increase the efficiency of wireless sensor networks.

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