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Error Detection and Correction in Wireless Sensor Networks Using Enhanced Reverse Conversion Algorithm in Healthcare Delivery System

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Abstract: Wireless Sensor Network (WSN) is a group of sensors connected within a geographical area to communicate with each other through wireless media. Although WSN is very important in data collection in the world today, error may occur at any stage of data processing and transmission within WSNs due to its architecture. This study presents error detection and correction in WSNs using a proposed 'pair wise' Residue Number System (RNS) reverse converter in a health care delivery system. The proposed RNS reverse converter required $(10n + 3)_{FA}$ bit hardware resources for its implementation making it suitable for sensors. The proposed scheme outperformed Weighted Function and Base Extension algorithms and Field Programmable Analog Arrays using Kalman-filter algorithm schemes in terms of its hardware requirements.

Index Terms: Wireless Sensor Network, Residue Number System, Healthcare, Error detection, correction

1. Introduction

Demand for real-time data for decision making by many organizations in the world today has brought about the development of Wireless Sensor Networks (WSNs). WSN is a group of sensor nodes connected within a geographical area to communicate with each other through wireless media. WSN is normally established to monitor and track information from the environment in which they are deployed. WSNs are applied in the fields such like life sciences, medicine, military/security and areas where measure of physical quantity is needed [1]**.** A sensor comprises a battery, a microprocessor, a communication module and actuators. Due to the architecture of WSN, error may occur at any stage of data processing and during transmission of data. Hence, there is the need to make sure that data generated and transmitted by these sensors are accurate for decision making.

Although WSN is very good for real-time data collection, it is also faced with some problems that affect its performance in data communication. Some of these problems include faulty sensors, error in data generated, complex algorithms on sensors and availability of reliable energy. Error detection and correction has been very difficult task in the development of WSN in recent times.

Error detection in WSN is the process of checking whether bits of data received at the sink node or base station are the same as the one generated by sensors within a WSN. If there is any change in the bits of data received, it means error has occurred in the data transmitted from sensors to the sink node or the base station. Therefore, error correction needs to be performed to make sure that data received is accurate for decision making by the end users. This means that, data received at the sink node will be accurate if error detection is performed and those errors are corrected successfully [2].

WSNs are very good for healthcare delivery in rural or inaccessible communities in developing countries like Ghana since patients can be monitored remotely by healthcare professionals and communicate any first aid treatment to them in order to manage emergency situations before they are brought to the health facility for intensive treatment. The WSN can also help solve the problem of patient-to-healthcare professional ratio. Thus, since one healthcare professional can be monitoring more than ten patients with non-critical conditions at the same time, the rest of the workers will have time for patients with critical conditions in the health facilities. WSNs can also be used to solve problem of inadequate beds at health facilities. This is because patients whose conditions are stable a bit are allowed to go home whilst the healthcare professionals continue to monitor their conditions remotely from the health facilities. Though WSN can resolve the problem of inaccessibility, high patient-to-healthcare professional ratio and the problem of inadequate beds or lack of beds at health facilities, it is important that any data generated for decision making by healthcare professionals is secured and received as it has been generated by the sensor.

Erroneous data and data theft in WSNs usually occurs during data transmission from the sensors (sensor nodes) to sink nodes (base stations). The introduction of Residue Number System (RNS) in sensors has reduced these problems associated with performance of WSNs due to the complex and fault tolerant nature of RNS. Also, due to small representation of large integer values by breakdown decimal figure into residue values, transmission data is fast; hence, enhancing performance of the system. Due to the architecture of WSN, error may occur at any stage of data processing and transmission. Therefore, the receiver needs to be sure that whatever data he/she received within the WSN is accurate.

To make erroneous data detection and correction easier in WSN, this study presents error detection and correction method which requires less hardware complexity; in data transmitted to the sink node within WSN by using a proposed RNS Reverse Converter. The study also focuses on determining a suitable encoding and decoding theorem to enhance security during data transmission in WSN and to easily recognize moduli set with their corresponding residue values at the sink node within WSN. Therefore, the study demonstrates how the proposed reverse converter can be used to detect error in medical data generated by sensors attached to bodies of patients within the WSN, correct those errors in the data received at the sink node before transmitting the data finally to healthcare professionals about their patients for accurate decision to be taken on them. Therefore, the proposed scheme will help the healthcare professionals to make an informed and accurate decision on patients within a WSN. The scheme will also help technicians to detect faulty sensor nodes within the networks. Since healthcare professionals are always sure that data received from the sensors are well checked and are free of any form of error, they are sure that whatever treatment they are giving to the patient; based on the data received, is a precise decision.

2. Literature Review

2.1 Residue Number System

Residue Number System (RNS) is a complex number system which is difficult to understand, therefore, making it difficult for most people who may tap the information transmitted by the sensor in WSN to understand the data; hence, providing some level of security during data transmission in WSN [3]. RNS base sensors in a WSN are types of sensors by which data generated in decimal digits are converted into residue representation based on a given moduli set before they are transmitted to the sink node for users' consumption [4]. Residue Number System (RNS) is introduced into sensors (RNS base sensors) within WSN to enhance security of data and data transmission rate to the sink node [5]. RNS also makes the transmission of data in WSN faster since the data generated by sensors are divided into smaller bits before they are transmitted to the sink node for consumption by the end user (healthcare professional). Since many people including healthcare professionals cannot understand the RNS information digits transmitted to them by sensors in the WSN; there is the need to convert the RNS digits back into decimal digits for healthcare professionals before any decision is taken on the patients.

RNS is a unique, non-weighted, carry-free number system that provides parallel, high speed and fault tolerant arithmetic operations. This makes it a tough candidate for high-performance, low power, fault tolerant and secure Digital Signal Processing (DSP) application. The RNS is a number system that comprises of set of positive pairwise prime numbers $\{m_1, m_2, ..., m_n)$ known as moduli set, residue representation $(x_1, x_2, ..., x_n)$ and the dynamic range M which is the product of the moduli set. In this number system, a decimal number X is represented in an ordered set of residues $(x_1, x_2, ..., x_n)$ in respect of each modulus in the moduli set. This means that the weighted number X is converted to a non-weighted number. Each residue x_i is represented by:

$$x_i = X \bmod m_i = |X| m_i \tag{1}$$

From (1), x_i is computed by performing the modulo operations on the decimal number in respect of each modulus in a given moduli set where $i = 1, 2, ..., n$. The value of x_i is less than its corresponding m_i, thus $0 \le x_i \le m_i$

RNS is also a strong candidate against error occurrence in WSNs because change in one residue value does not affect the rest of the residue values due to the parallel nature of RNS; however, it will have an effect on its reverse conversion [6]. To add more security to the data during transmission, the study uses Redundant Residue Number System (RRNS) QC encoder/decoder to make it more difficult for attackers to understand the data being transmitted by sensors in WSN. The RRNS QC encoder/decoder makes the transmitted data more complex for attackers to understand, since it transmits both the residue information and their corresponding moduli through different channels within a transmission media [7].

In general, sensors are small devices which has very small memory and processor, hence, running an algorithm that require large hardware resources on sensors in WSNs will make the system run slowly and inefficient. To make erroneous data detection and correction easier and efficient in WSN, the study presents error detection and correction method in data transmitted within WSN by using a proposed 'pair wise' Residue Number System Reverse Converter other than the traditional Chinese Reminder Theorem (CRT) and Mixed-Radix Conversion (MRC) approach. This is because the CRT method of detecting error in data transmitted in WSN involves a large integer *M* (dynamic range) which results in large hardware complexity [8, 9].

2.2 Related Works

Some studies have proposed various error detection and correction and faulty sensors in the past. [3] proposed a method to detect and correct error in data generated by a sensor within Wireless Sensor Networks (WSNs). Weighted Function was used to reduce the "effect" of defective sensors rather than reprogramming the circuit to detect and correct any error that may occur in the data transmitted within a WSN. This study used RNS to reduce traffic and enhance security in WSNs. Chinese Remainder Theorem (CRT) was used to convert the RNS values generated RNS-based sensors to decimal digits for error detection and correction. To perform the error detection and correction, redundant modulus (RRNS) was introduced in the residue number system. Thus, additional moduli set that has no effect on the dynamic range is added to the chosen RNS moduli set. RNS have improved the achievements of WSNs through the reduction in traffic congestion during data transmission in the network. Therefore, enhancing Energy-Efficiency of the sensor nodes. Their scheme also has good flexibility and scalability abilities. Thus, new sensors can be added to the network without a need to change the scheme for existing sensors. Although the study by [3] shows some level of security in the communication channel, it is not suitable for sensor nodes since CRT's computational operations required large integer value *M* (dynamic range) which results in a complexity of $O(n^3)$ and its parallel means of computation limits this approach; hence, this makes it difficult for anyone to perform the CRT reverse conversion method in order to detect error in the system.

[10] proposed a scheme which aims at eliminating many errors in data by using the MRC and Base Extension (BEX) decoding schemes with lower complexity compared to the higher order of complexity of CRT which performs error detection and correction using more consistent check. BEX offers a reduction in the latency and hardware resources. According to [10], MRC is used to perform error detection by comparing Multiple Residue Digit Error Detection and Correction Algorithms to determine whether error has occurred in a transmission path. Their scheme used base extension and MRC to detect and correct errors in data by removing table look up. Although the study has proven that the base extension and MRC approach for error detection and correction performs better, as compared to CRT, it still requires some level of hardware implementation complexity of *O(n).* Due to the involvement of the moduli set in the MRC computation, it is difficult to compute the base extension and MRC as the moduli set becomes large. Therefore, it will require more hardware complexity for its implementation.

[8, 11, 12] also proposed algorithms to convert residue digits back into decimal digits. Their proposed reverse conversion algorithms were based on CRT and MRC which made them to require larger hardware resources for their implementation; hence, making their proposed schemes unfit for devices like wireless sensors.

A summary of RNS Reverse Converters and Error Detection and Correction Methods is presented in Table 1 below.

Table 1. Summary of RNS Reverse Converters and Error Detection and Correction Methods.

S/No	Paper	Problem	Method	Strength	Weakness	Matrix
1	[13]	Detection of faulty sensor in WSNs	Comparing Field Programmable Analog Arrays (FPAA) using a Kalman- filter estimate of the output	Good for several different failure modes detection	Cannot recover from all sensor failure	Error detection rate
2	[14]	RNS reverse conversion based on the moduli set	Simplifying the traditional CRT	Demonstrated reduction the hardware complexity	Cannot consider large range of RNS arithmetic operations due to limited dynamic range	Delay and Area

3	[15]	Residue number to binary conversion for two 4-moduli set	CRT-2 and CRT-1	Reduction in the processing complexity	Requires large hardware resources for its implementation	Delay and Area
4	[3]	Error Detection and Correction Algorithm in WSNs	Weighted function, RNS and CRT	Security is enhanced in the communication channel	Processing complexity of	Not applicable
5	[16]	Faulty sensor and patient anomaly detection in WSNs in healthcare delivery	Decision tree J48 algorithm and linear regression algorithm	Low false alarm rate with a high detection accuracy	No mechanism in place to check the accuracy of the data received at sink node No security mechanism is provided during data transmission	Not applicable
6	[9]	RNS reverse conversion based on on the moduli set	CRT-1 and CRT-2	Delay has large dynamic range	No reduction the processing complexity Require more bit wide and large hardware resources for implementation	Delay and Area
7	[12]	RNS reverse conversion based on the moduli set	Sub- grouping and MRC	Reduction in the processing complexity	Cannot consider large range of decimal figures for RNS arithmetic operations Requires more bit wide and large hardware resources for implementation	Delay and Area
8	[17]	Faulty sensor detection in WSNs	Centralized Naïve Bayes Detector (CNBD)	Capable of handling reliable fault detection task for sensor network of 100 nodes. Less false alarm rate	Was unable to determine erroneous data in the WSNs	Transmission rate Sensor node capacity.
9	[10]	Error detection and correction in WSNs	Radix Conversion (MRC) and Base Extension (BEX) decoding schemes	Memory less based scheme as compared to CRT	Hardware implementation complexity of O(n)	Hardware complexity
10	[8]	Reverse conversion for the three- moduli set	CRT	Has larger dynamic range	Requires more bit wide and large hardware resources for implementation.	Delay and Area

3. Methodology

This study presents an error detection and correction method in Wireless Sensor Networks (WSNs) using Residue Number System (RNS) reverse conversion algorithm. The proposed reverse conversion algorithm used by the study is based on the moduli set $\{2^{2n+1}-1, 2^{2n}-1, 2^{2n+1}\}$ and the residue number $e_i = \{e_1, e_2, e_3\}$. The reverse converter is referred to as "Pair-Wise" RNS reverse converter. The RNS reverse converter is used for error detection and correction in wireless sensor networks.

To detect error using proposed RNS reverse converter, redundant moduli set was introduced to the RNS moduli set at the sensor node to help check for error in the data received at the sink node. The received residue information digits are converted to a decimal number. Redundant moduli set is used to convert the converted decimal number to redundant residue values and compare them with the initial redundant residues received. If the new redundant residues are the same as the initial ones with respect to the redundant moduli set, then error has not occurred in the data during transmission. The proposed error detection and correction method developed by the study is a centralized approach.

The general architecture of wireless sensor networks with an RNS base sensor is shown in Fig. 1 below:

Thus, the algorithm is implemented at sink node which has stable power supply. The study also proposes that before RRNS can be applied to an RNS base sensors, the choice of redundant moduli set should satisfy the following conditions:

1. Should be greater than residue moduli set.
2. Should be equal to the residue moduli set.
3. Should be co-prime numbers.

Hence, the RRNS moduli set becomes $(g_1, g_2, g_3, g_4, g_5, g_6)$ with their corresponding residue values $(e_1, e_2, e_3, e_4, e_5, e_6)$

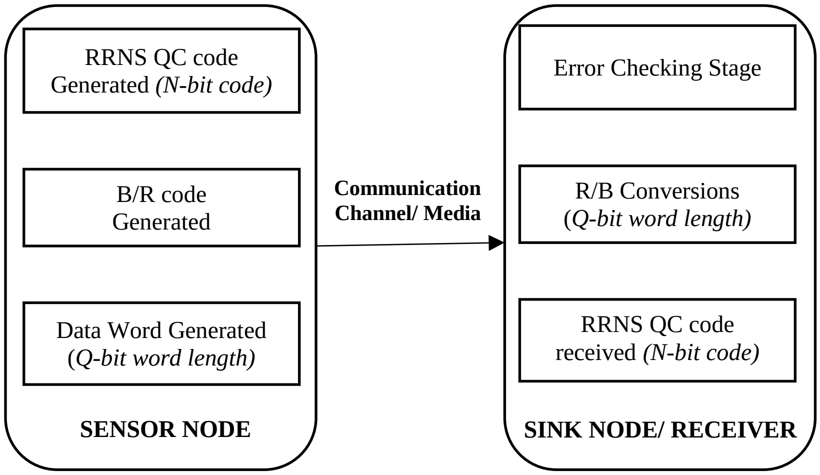

Fig. 1. General Architecture of the RNS base Wireless Sensor Networks with Error Detection

a. Sensor Node

Data is generated from the environment in which the sensor is being deployed. Therefore, given the information moduli set (g_1, g_2, g_3) and redundant moduli sets (g_4, g_5, g_6) respectively, the data generated is converted into the information residue digits and redundant residue digits based on both information and redundant moduli sets. Thus, given that the data generated at the sensor node is *E*, then, its RRNS representation is: $E = \{e_1, e_2, e_3, e_4, e_5, e_6\}$ where (e_1, e_2, e_3) are the information residues and (e_4, e_5, e_6) are the redundant residues. Information residue digits and redundant residue digits were encoded using RRNS QC encoder/decoder technique.

The RRNS QC encoder/decoder encoded residue information digits, and redundant residue digits together with their corresponding moduli were transmitted through the transmission media to the sink node. At this stage, the residue digits were transmitted through different channels from that of their corresponding moduli. This will make it difficult for any attacker to get the information during transmission and understand.

b. Sink Node or Base Station

At the base station or receiver, RRNS QC encoder/decoder encoded residue information values and redundant residue values were received. The received information residue values and redundant residue values were decoded and converted into binary number using the proposed RNS reverse conversion algorithm. After converting the residue values to decimal number, error checking was performed using redundant moduli set and their corresponding redundant residue digits. If error was detected, reverse conversion was performed using the redundant information digits. After converting the redundant information digits into weighted value, the weighted value was converted back into residue digits to determine which of the residue information digits contained the error.

3.1 Error Detection and Correction Algorithm (EDCA)

EDCA in WSN is as follows:
Error Detection and Correction

1. Start
2. Input: $e_1, e_2, e_3, e_4, e_5, e_6$ // received residue information digits and redundant information digits
3. Input: $g_1, g_2, g_3, g_4, g_5, g_6$ //received RRNS moduli set.
4. $G \leftarrow g_1 \times g_2 \times g_3$
   // G is the dynamic range
   //Re-group g_1, g_2, g_3 into two subset (e.g. P_{12}, P_{23})
   i. If $g_1 \bmod g_2 = 1$ and $g_2 \bmod g_2 = 1$ then,
   $P_{12} = \{g_1, g_2\}$ and $P_{23} = \{g_2, g_3\}$

ii. $g_{12} \leftarrow g_1 \times g_2$

iii. $g_{23} \leftarrow g_2 \times g_3$

iv. $\delta_{12} \leftarrow [(e_2 - e_1) \times (g_1^{-1}) \bmod g_2] \bmod g_2$

// g_1^{-1} is the multiplicative inverse of g_1

v. $\delta_{23} \leftarrow [(e_3 - e_2) \times (g_2^{-1}) \bmod g_3] \bmod g_3$

// g_2^{-1} is the multiplicative inverse of g_2

vi. $E_{12} \leftarrow e_1 + \delta_{12} \times g_1$

vii. $E_{23} \leftarrow e_2 + \delta_{23} \times g_2$

viii. $\mu \leftarrow [(E_{12} - E_{23}) \bmod g_{23} \times (g_{12}^{-1}) \bmod g_{23}] \bmod g_{23}$

ix. $E_c \leftarrow X_{12} + (\mu \times g_{12}) \bmod G$

// Error checking after the reverse conversion.

5. Convert E_c to redundant digits; $E_c \leftarrow e_{41}, e_{51}, e_{61}$
6. If $e_4 = e_{41}$, $e_5 = e_{51}$ and $e_6 = e_{61}$ then error has not occurred
7. Else, there is an Error in the message
   //Perform error correction using redundant information digits
8. let $e_1 = e_{41}, e_2 = e_{51}, e_3 = e_{61}$, $g_1 = g_4, g_2 = g_5, g_3 = g_6$ and ***go to* 4**
9. End.

3.2 Area Cost and Delay Comparison of the Proposed RNS Reverse Converter

The performance of the proposed RNS reverse conversion method for error detection and correction in WSN is compared to other state of the art methods by [8, 9, 12] in respect of conversion time and area of hardware resources required in Full Adder. The delay and area cost comparison are shown in the Table 2 below:

Table 2. Delay and Area Cost Comparison

Converter	Dynamic Range (DR)(bits)	Delay	Area
[12]	$4n+1$	$(11.5n + 2\log 2n + 2.5)_{FA}$	$(2n^2 + 11n + 3)_{FA}$
[9]	$6n+2$	$(4n+6)_{FA}$	$(8n+2)_{FA}$ and $(4n-2)_{HA}$
[8]	$8n$	$(8n+2)_{FA}$ (CE) $(4n+2)_{FA}$ (SE)	$(8n+2)_{FA}$ (CE) and $(12n+2)_{FA}$ (SE)
Proposed Scheme	$6n+2$	$(6n+3)_{FA}$	$(10n+3)_{FA}$

4. Experiments and Results

In using wireless sensor networks in healthcare delivery, sensors are fixed on the skin or body of each patient within the network. The sensors in the network are connected to a base or sink node usually a smartphone or a stationary computer for data consumption by the end user (healthcare professional). The sensors monitor the conditions of the patient, generate data in decimal digits, convert them into both residue information digits and redundant information digits and then send them to the base station or sink node via the wireless transmission media. Before any healthcare professional takes a decision on the health conditions of any patient based on the data collected using WSNs, they need to be sure that the data received at the base or sink node of the system is devoid of any form of error. Therefore, the study used the proposed error detection and correction algorithm to make sure that any bit errors that may occur in the data during transmission are corrected before the information is given to the healthcare professionals.

Some of the attributes on which data can be collected on patients using WSNs include Heart Rate (HR), PAPmean, Peripheral Arterial Pressure Systolic (PAPsys), Peripheral Arterial Pressure Diastolic (PAPdias), PULSE, Respiration

(RESP), Standard Pressure of Oxygen (SpO2), Temperature (T^0), ABPmean, ABPsys, and ABPdias. Data based on these attributes can help healthcare officials to monitor the conditions of their patients in real-time.

This study focuses on PAPsys to demonstrate how to detect and correct error in medical data using the proposed scheme in WSNs for healthcare delivery. PAPsys is a blood pressure condition which ranges from 100mmHg to 140mmHg (heart beats per minute) for a normal person. This means that any value outside the normal range either above the maximum value or the minimum value is considered as an emergency situation. For instance, if a sensor generates PAPsys value of 135mmHg from a patient, the sensor in the proposed RNS based WSN architecture will convert the data into both residue information and redundant information digits using RRNS QC encoder/decoder before sending the data to the sink node or base station. At the sink node, the residue information digits are converted to decimal numbers for the healthcare professional to read and understand and take a decision on them to determine whether the health condition of the patient is a normal or an emergency condition.

Thus, before the final decimal value is given to the healthcare professional, the system performs error detection activities on the received data at the sink node and correct them if any error has occurred to make sure that whatever is given to the healthcare professional is accurate. The tables 3 and 4 below shows some an assumed PAPsys data that could be generated from patients in RRNS residue (information residues and redundant residues) representations for the RRNS moduli set (32,31,15,68,67,33) by RNS based sensors within WSN.

Table 3. PAPsys Data Collected on Patients

1	2	3	4	5	6
Patient ID	Data Generated (mmHg) at a Particular Time	Information Residues (32,31,15)	Redundant Residues (68,67,33)	Received Information Residue Digits with the RNS moduli set (32,31,15)	Received Redundant Residue Digits with redundant moduli set (68,67,33)
P/01/2019	125 (1111101)	29,1,5 (11101, 01, 101)	57,58,26 (111001, 111010, 11010)	{111*01*, *10*, 101} =29,2,5	{111001, 111010, 11010} =57,58,26
P/02/2019	131 (10000111)	3,7,11 (11, 111, 1011)	63,64,32 (111111, 1000000, 100000)	{11, 111, 1011} =3,7,11	{111111, 1000000, 100000} = 63,64,32
P/03/2019	95 (1011111)	31,2,5 (11111, 10, 101)	27,28,29 (11011, 11100, 11101)	{11111, 10, 101} =31,2,5	{11011, 11100, 11101} =27,28,29
P/04/2019	139 (10001011)	11,15,4 (1011, 1111, 100)	3,5,7 (11, 101, 111)	{1011, *0*11*0*, 101} =11,7,5	{11, 101, 111} =3,5,7
P/05/2019	155 (10011011)	27,0,5 (11011, 00, 101)	19,21,23 (10011, 10101, 10111)	{11011, 00, 10*1*} =27,0,5	{10011, 10101, 10111} =19,21,23

From Table 3, after the data is converted into RRNS digits by the RNS based sensor, they are then encoded using QC encoder/decoder. The encoded RRNS bit digits are sent to the sink node. The encoded data is then received; show in column 5 and 6. The received data at the sink node is processed by using the proposed RNS reverse converter to convert the information to decimal digits for consumption by the healthcare professionals. During data transmission, bit error may occur; thus, there may be a change in bits of data transmitted. Therefore, the redundant moduli set is used to check if error exists in the data received at the sink node. Before the received data in column 5 of table 3 are given to the healthcare professional to determine the status of each patient and decide on the kind of treatment to administer to them, the data needs to be converted to decimal numbers so that each healthcare professional can read and understand the data.

The proposed reverse converter was used to perform the residue-to-decimal conversion. It is observed from the tables above that some of the bits have changed before reaching the sink node; error detection and correction are then performed on the bits of data received to make sure that whatever data or information is given to the healthcare professionals is the same as the data generated by the sensors attached to the patients' body. In performing the bit error detection on the data, the reverse converted decimal number is converted to redundant residues with respect to the redundant moduli set received at the sink node. The result is then compared with the redundant residues received from the sensor node. If they are the same, then there is no error in the data received; else, error has occurred in the information residue received at the sink node. If error has occurred, the proposed reverse converter is used to convert the original redundant residue values with respect to their redundant moduli set to decimal numbers to determine the actual decimal values generated by the sensor on the body of the patient.

The tables below show the decimal equivalence of the information residues, and determine whether an error has occurred or not.

Table 4. Error Detection and Correction in Patients' PAPsys Records

1	2	3	4	5	6
Patient ID	Decimal Equivalence of the Information Residues Received	Redundant Residues of the Decimal Equivalence of the Information Residues Received for the Moduli Set (68,67,33)	Received Redundant Residue Digits with Redundant Moduli Set (68,67,33)	Remark	Patients' PAPsys (mmHg) at a Particular Time
P/01/2019	149	{*1101, 1111, 10001*}	{111001, 111010, 11010}	Error occurred	125
P/02/2019	131	{111111, 1000000, 100000}	{111111, 1000000, 100000}	No error occurred	131
P/03/2019	95	{11011, 11100, 11101}	{11011, 11100, 11101}	No error occurred	95
P/04/2019	875	{*111011, 100, 10001*}	{11, 101, 111}	Error occurred	139
P/05/2019	155	{10011, 10101, 10111}	{10011, 10101, 10111}	No error occurred	155

From Table 4, it is realized that the new redundant bits for patients numbered P/01/2019, P/04/2019 were not the same as the redundant bits sent to the sink node by the sensors. This means errors have occurred in the records of patients numbered P/01/2019 and P/04/2019 in Table 4. To correct these errors, the system coverts the redundant residues to decimal values using the proposed RNS reverse converter and converts the results back to information residues to determine which of the information residues contains the error. After all error detections and corrections are performed, the final decimal figures are sent to the healthcare professionals for decision making. Column 6 show the final PAPsys data about patients within a WSN after the error detection and correction activities. From column 6 of table 4, the healthcare professionals can clearly determine that the patients numbered P/03/2019 and P/05/2019 need urgent attention, since their PAPsys information fall outside the normal range. The patient numbered P/03/2019 recorded 95mmHg which is below the minimum PAPsys value of 100mmHg for a healthy person whilst the patient numbered P/05/2019 recorded 155mmHg which is also above the maximum PAPsys value of 140mmHg for a healthy person. Since every error detected was corrected before the final information is given to the healthcare professionals, any decisions made by them will be accurate because the data received is the same as the one generated by the sensors attached to the bodies of the patients within the network.

4.1 Performance Evaluation of the Reverse Converter

The performance analysis of the scheme/algorithm was done based on Table 2. Given the values of *n*, the dynamic range (DR), delay and area cost were computed for the proposed converter used in the error detection and correction scheme by the study as compared with other converters. The delay and area cost comparison table is expanded in Table 5 below with different values of *n*:

Table 5.Expanded Delay and Area Cost Comparison

Converter	***n***	**2**	**3**	**4**
[12]	$Delay_{FA}$	27.5	40.2	52.5
	$Area_{FA}$	33	54	79
[9]	$Delay_{FA}$	14	18	22
	$Area_{FA}$	18	26	34
	$Area_{HA}$	6	10	14
[8]	$Delay_{FA}$ (CE)	16	26	34
	$Area_{FA}$ (CE)	16	26	34
	$Delay_{FA}$ (SE)	10	14	18
	$Area_{FA}$ (SE)	26	38	50
Proposed Converter	$Delay_{FA}$	15	21	27
	$Area_{FA}$	23	33	43

From Table 5 above, when *n* is 2, the scheme by [12] has an area cost of 33 bits full adder (FA) and delay 27.5 time full adder (FA) against area cost of 23 bit FA and delay of $15t_{FA}$ for the designed scheme. This shows that the proposed scheme performs better than the one proposed by [12]. The scheme by [9] has delay of $14t_{FA}$ and requires hardware resources of 18_{FA} and 6_{HA}. This implies that the proposed method is more effective than this scheme in terms of area cost. The scheme by [8] has a total of 16_{FA}bit hardware area cost and delay of $16t_{FA}$ for the Cost-Efficiency (CE). Their scheme also has 26_{FA} bit hardware area cost and delay of $10t_{FA}$ for the Speed-Efficiency (SE) architecture.

This makes the proposed scheme which has 23 bit FA and delay of $15t_{FA}$ a stronger candidate than the SE scheme proposed by [8]. It is observed that the proposed algorithm used to detect and correct errors in data generated by sensors conversion within WSNs require lesser hardware resources and conversion time as compared to [8, 9, 12]. Therefore, making the error detection and correction algorithm a preferred choice for sensors.

5. Conclusion

The study uses redundant moduli set to detect and correct erroneous information residue digits received at the sink node or base station. The proposed method performs better as compared to those reviewed in literature in respect of memory required for their algorithm implementation. The proposed method also serves as a basis for schemes that are based on data received from the sensor nodes in the network. Therefore, before any of such schemes could be implemented effectively, there is the need for accurate data; hence, the error detection and correction scheme developed by the study. The error detection and correction scheme designed by the study is implemented at the sink node and it is capable of handling any number of sensor nodes in a WSN.

The proposed scheme ensures that data given to the healthcare professionals for decision making and treatment of patients are accurate and devoid of any form of error. Therefore, whatever treatment is given to a patient by healthcare professionals; based on the data received, is a precise decision. The propose scheme can also be implemented in any form of data encryption and decryption system as well as in the field of acoustic data collection.

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