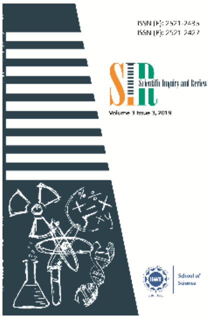

Scientific Inquiry and Review (SIR)
Volume 5 Issue 2, June 2021
ISSN (P): 2521-2427, ISSN (E): 2521-2435
Journal DOI: https://doi.org/10.32350/sir
Issue DOI: https://doi.org/10.32350/sir/52
Homepage: https://journals.umt.edu.pk/index.php/SIR/Home

Journal QR Code:

Article: **Designing an Effective Error Control Scheme for Real Time Wireless Sensor Networks (WSNs)**

Indexing

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Article DOI: https://doi.org/10.32350/sir/52.02

QR Code:

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Citation: Raji KA, Aremu IA, Asaju-Gbolagade AW, Gbolagade KA. Designing an Effective error control scheme for real time Wireless Sensor Networks (WSNs). *Sci Inquiry Rev.* 2021;5(2):16–32.

Estd. 1990

A publication of the
School of Science, University of Management and Technology
Lahore, Pakistan

Designing an Effective Error Control Scheme for Real Time Wireless Sensor Networks (WSNs)

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Abstract

Wireless Sensor Networks (WSNs) subsist on a network of a huge number of hubs distributed in unfavourable environments. They are used for habitat monitoring and to observe changes in them. These hubs are susceptible to faults such as energy exhaustion, hardware glitches, communication link errors, and malicious attacks, which may cause errors during message delivery. Typically, these systems are utilized to send and receive vital information in remote places. Thus, efficient error identification and correction is required in order to maintain the accuracy of the received messages. The aim of this study was to design a high speed reverse converter to devise effective error control codes. It used the Redundant Residue Number System (RRNS) to enhance the accuracy of messages delivered through real time WSNs. In order to attain a greater error correction ability, a reverse converter, based on Mixed Radix Conversion (MRC), was designed for the moduli set $\{2^{n+1}-1, 2^n, 2^n-1\}$. *In addition to this moduli set, an extra redundant moduli set* $\{2^{n+1}+3, 2^{2n} - 3\}$ *was also formulated for better error correction. For correction and identification of corrupted values in the original data, Maximum Likelihood Estimation (MLE) was used. The results revealed that the suggested moduli set offers low energy utilization and consistency of the received messages through real time WSNs.*

Keywords: error control, moduli set, real-time, Redundant Residue Number System (RRNS), reliability, Wireless Sensor Networks (WSNs)

Introduction

Wireless Sensor Networks (WSNs) comprise a network of an enormous number of randomly arrayed minute devices called nodes. These networks have inbuilt storage with computational and communication capabilities. They function in an unattended mode and collect required data from their coverage area [1, 2, 3].

WSNs are capable of sensing data, forwarding the collected data, and processing the collected data to generate suitable reactions depending on the nature of the received data. It consists of two nodes; one is known as a sensor node that senses data, and the other is known as a sink node where information is transferred. Sensor nodes are commonly cheap. Their energy supply is restricted and transmission range is also low. Its transmission ranges can only be used for event detection or sensing data from the environment. Conversely, sink nodes are resource rich nodes that have abundant energy sources, higher communication and computation capability, and the ability to perform powerful reactions [4].

A sensor hub is a gadget that is made up of three components. One of its components is known as a processing unit, which processes information from the surroundings. Its second component is a sensor subsystem, which obtains information from its surroundings. The third component is a wireless communication transceiver, which exchanges the detected data to the sink. These sensor hubs detect information and communicate with each other [5]. In order to maintain message reliability, the WSNs must be capable of detecting errors and taking appropriate measures to correct them [2, 6]. Residue Number System (RNS) is utilized as a tool to reduce communication energy and increase the reliability of WSNs [7]. Some studies also observed that for numerous reasons, Redundant Residue Number Systems (RRNSs) are more suitable for real time application of WSN. These systems improve the real time operations and are fault tolerant. The ability of WSNs to control error detection and correction is also improved. It also provides security and consumes less energy [8, 9].

It has been established that energy, speed, and reliability are the major challenges affecting many WSNs applications. These challenges arise mainly because WSNs possess limited energy and are used to collect vital information from the environment. Thus, WSNs need to be energy efficient, fast, and reliable [2, 10]. Substantial efforts have been made by researchers to focus on the development of techniques that can offer high speed and reliability in WSNs. It was observed that none of the researches have offered extensive reliability support for WSNs. Hence, this article introduced an energy efficient reverse converter with error detection and error correction ability. It makes use of RRNS to improve the reliability of a received message in real time WSNs. The scheme of this study employed the moduli set $\{2^{n+1}-1, 2^n, 2^n-1\}$ to design the Mixed Radix Conversion (MRC) based reverse converter. It also employed the Chinese Remainder Theorem (CRT) based error control scheme with supplementary redundant moduli set $\{2^{n+1}+3, 2^{2n} - 3\}$ to attain enhanced error controllability. The results indicated that the recommended scheme is energy efficient and maintains consistency in the received message in real time WSNs.

2. Literature Review

Secure, effective, and reliable information and communication has become need of the hour in the last few decades. [11].

It is important to choose a perfect fault correcting mechanism so that the vitality and execution of a network function properly [12].

It is necessary to find a novel solution that has low latency and at the same time, provides high reliability for real time WSN applications. Hamamreh et al. presented a new energy aware algorithm. This algorithm is known as Minimum Residual Hop Capacity (MRHC) [3]. This algorithm is incorporated into the frequently adopted protocol commonly identified as Low Energy Adaptive Cluster Hierarchical (LEACH) within the broadcast procedure in the clusters. This algorithm reduces energy utilization during its transmission process, extends network durability, and improves the amount of data delivered to the base station. Usually, nodes communicate within the cluster through multi-hop communications and data is sent via other nodes in the cluster till it reaches the cluster head (CH). As a result, multiple copies of the same packet could be sent to the CH. Hence, there is a need for data aggregation which usually results in communication suspension between the CH and the sink [3]. Additionally, other studies also reported that the simplicity in the design of the sensor hardware and its energy efficiency and error control makes it necessary to prevent deployment of high complexity codes, [6, 13, 7]. Moreover, WSNs are naturally vulnerable to numerous sources of unpredictability such as errors generated by hardware noise, transmission errors, and errors in hubs, which is why, WSNs require the need for reliability measures [6, 3]. In this regard, when a message is corrupted, the errors not only need to be recognised, but they also need to be corrected so that the message can return to its original form [14, 15].

An upgraded moduli set $\{2^n-1, 2^n+1, 2^{pn}-1\}$ reverse converter was proposed by Habibi and Salehnamadi (2016), it was based on CRT algorithm. The recommended moduli set improved the complexity of the circuit and reduced energy consumption, but there is still a need to reduce hardware requirements and improve the speed so it applies to WSNs [16]. Additionally, Bankas and Gbolagade (2014) recommended a novel effective reverse converter for the 4-moduli set $\{2^n, 2^n+1, 2^n-1, 2^{2n+1}-1\}$, it was built on an improved CRT and MRC. The area for the cost of reverse converter is $(12n + 2)$ Fas, $(5n + 1)$ HAs with an impeded $(9n + 6)$ $tFA + tMUX$. This converter was identified to be faster than the state of the art reverse converter. However, the former requires more hardware assets than the latter. Barati et al (2014) presented a new scheme with improved vitality and rapid error control, it relied on the RRNS in real time WSNs. The theoretical outcome implemented by the simulation outperforms the renowned error control methods for WSNs with respect to vitality, productivity, error controllability, and reduction of end-to-end delay with minimum hardware requirement [14]. Therefore, it is necessary to provide an efficient, rapid, and reliable error correction scheme for real time WSN while still preserving the vitality of the network.

3. Residue Number System

Residue Number System (RNS) is characterized as a non-weighted numeral system that was introduced by Garner in 1959. It delivers a high speed, carry free, parallel secure arithmetic operation which is fault-tolerant [14, 17]. In RNS, instead of the original number being represented by itself, the remainders of the original number with reference to the moduli set are commonly used for representation. Hence, the remainder of the original number will be fragmented into smaller independent numbers. Thus, operations can be accomplished on them separately. This makes the computation much simpler and swift [16, 18]. RNS is very useful for detecting and correcting errors because no other digit is corrupted by the error in one digit. Furthermore, RNS is also founded on the congruence relation, which is described in terms of relatively prime moduli set *{m_1, m_2, ... m_n}* that is the greatest common divisor gcd(m_i, m_j) = 1 for *($i \neq j$)*. Therefore, the weighted number X can be given as follows:

$$X = (x_1, x_2 \ldots x_n), \text{ where:}$$

$$x_i = X \bmod m_i = \left| x \right|_{p_i},\ 0 \le x_i < p_i$$

This depiction applies for any integer X which is in the range [0, M) when M = ($m_1 m_2 \ldots m_n$) and is referred to as dynamic range of the moduli set {m_1, m_2,…m_n}. Conversely, RRNS is the kind of RNS which detects and corrects the errors by adding redundant modules to the original modules. RRNS is indicated by moduli set {m_1, m_2, m_3, …m_n, m_{n+1}, m_{n+2}, … m_{n+r}} and $m_i > m_{i-1}$ for i=2,3,..,n+r. Given that all the moduli set are pairwise prime, the Dynamic Range (DR) of the system is given by

$$[0,\ M = \prod_{i=1}^{n+r} m_i)$$

Finally, the traditional CRT is characterized per given formula as: for a moduli set {m_1, m_2, m_3,..m_k} having the dynamic range M = $\prod_{i=1}^{k} mi$, the residue number (x_1, x_2, x_3, …, x_k) can be altered to the decimal number X using:

$$X = \left| \sum_{i=1}^{k} Mi \left| M_i^{-1} x_i \right|_{mi} \right|_M$$

Given that when M = $\prod_{i=1}^{k} mi$, $M_i = \frac{M}{m_i}$, and M_i^{-1} is representing the multiplicative inverse of M_i in reference to m_i.

4. Methodology

In order to realize the proposed scheme, the moduli set {2^{n+1}-1, 2^n, 2^n-1} was used to design MRC based reverse converter and CRT based error control scheme by utilizing supplementary redundant moduli set {2^{n+1}+3, 2^{2n} - 3}. As shown in Figure 1, a node sent a residue of the sensed message to the cluster head (CH). The CH, in turn, forwarded the gathered residues in its cluster to the sink node which then converted the received residues into their binary equivalent. Lastly, the sink checked, located, corrected the errors, and then recovered the sink from error to have an error free message.

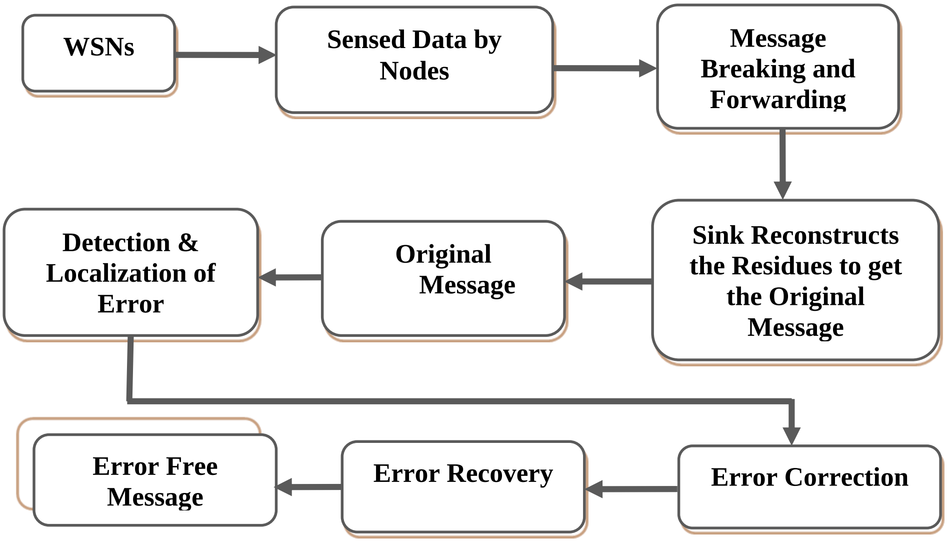

Figure 1. Proposed error detection and correction process

4.1. Design of the High Speed Reverse Converter

To design a reverse converter that will convert the received residues to its original message, it is required that the moduli set $\{2^{n+1}-1, 2^n, 2^n-1\}$ be somewhat prime numbers. This can be done using Euclidean algorithm:

$$gcd\ (a, b) = gcd\ (b, \left|a\right|_b), \quad a > b$$

Where the gcd represents greatest common divisor:

$$\text{gcd}\ (2^{n+1}-1, 2^n) = \text{gcd}\ (2^n, \left|2^{n+1}-1\right|_{2^n}) = \text{gcd}\ (2^n, 1) = 1$$
$$\text{gcd}\ (2^{n+1}-1, 2^n-1) = \text{gcd}\ (2^n-1, \left|2^{n+1}-1\right|_{2^n-1}) = \text{gcd}\ (2^{n-1}-1, 2) = 1$$
$$\text{gcd}\ (2^n, 2^n-1) = \text{gcd}\ (2^n-1, \left|2^n\right|_{2^n-1}) = \text{gcd}\ (2^n-1, 1) = 1$$

Thus, all the greatest common divisors (gcd) are equal to 1, this indicates that the moduli set $\{2^{n+1}-1, 2^n, 2^n-1\}$ are somewhat prime. Then, let us calculate the multiplicative inverse based on MRC algorithm and then in the conversion algorithm, substitute those values with the modulus set.

First, the multiplicative inverse of $(2^{n+1}-1)$ with respect to (2^n) is K_1**.**

$$\left|m_1^{-1}\right|_{m_2} = \left|(2^{n+1}-1)^{-1}\right|_{2^n} = \left|(-1\times 2^{n+1}-1)\right|_{2^n} = 1$$

Therefore, $K_1 = -1$

Also, multiplicative inverse of $(2^{n+1}-1)$ analogous to (2^n-1) is $K_2 = 1$

$$\left|m_1^{-1}\right|_{m_3} = \left|(2^{n+1}-1)^{-1}\right|_{2^n-1} = \left|(1\times 2^{n+1}-1)\right|_{2^n-1} = 1$$

Therefore, $K_2 = 1$

And lastly the multiplicative inverse of (2^n) analogous to (2^n-1) is K_3.

$$\left|m_2^{-1}\right|_{m_3} = \left|(2^n)^{-1}\right|_{2^n-1} = \left|(1.2^n)\right|_{2^n-1} = 1$$

Therefore, $K_3 = 1$

MRC is generally given by:

$$X = a_1 + a_2 m_1 + a_3 m_1 m_2 \quad (1)$$

where

$$a_1 = x_1 \quad (2)$$

$$a_2 = \left|(x_2 - a_1)\left|m_1^{-1}\right|_{m_2}\right|_{m_2} \quad (3)$$

and

$$a_3 = \left|((x_3 - a_1)\left|m_1^{-1}\right|_{m_3} - a_2)\left|m_2^{-1}\right|_{m_3}\right|_{m_3} \quad (4)$$

Next, a_2 values are substituted in equation (3) and simplified to decrease the hardware requirements:

$$a_2 = \left|(x_2 - a_1)\left|m_1^{-1}\right|_{m_2}\right|_{m_2} = \left|-x_2\right|_{2^n} + \left|a_1)\right|_{2^n}$$

$$= \left|-x_2\right|_{2^n} + \left|x_1\right|_{2^n} = a_{21} + a_{22}$$

Hence, the binary representation of the residues is:

$$a_{21} = \left|-x_2\right|_{2^n} = \underbrace{\overline{x}_{2,n-1}\,\overline{x}_{2,n-2}\ldots\overline{x}_{2,1}\,\overline{x}_{2,0}}_{nbit} \quad (5)$$

$$a_{22} = \left|x_1\right|_{2^n} = \underbrace{x_{1,n-1}\,x_{1,n-2}\ldots x_{1,1}\,x_{1,0}}_{nbit} \quad (6)$$

To implement a_3 by simplifying equation (4) as follows:

$$a_3 = \left|(1(x_3 - a_1) - a_2)(1)\right|_{m_3} = \left|(x_3 - x_1) - a_2\right|_{2^n - 1}$$

$$= \left|x_3\right|_{2^n - 1} + \left|-x_1\right|_{2^n - 1} + \left|-a_2\right|_{2^n - 1} = a_{31} + a_{32} + a_{33},$$

Where the binary representation of the residues is:

$$a_{31} = \left|x_3\right|_{2^n - 1} = \underbrace{x_{3,n-1}\, x_{3,n-2} \ldots x_{3,1}\, x_{3,0}}_{(n)bit} \tag{7}$$

$$a_{32} = \left|-x_1\right|_{2^n - 1} = \underbrace{\overline{x}_{1,n-1}\, \overline{x}_{1,n-2} \ldots \overline{x}_{1,1}\, \overline{x}_{1,0}}_{(n)bit} \tag{8}$$

$$a_{33} = \left|-a_2\right|_{2^n - 1} = \underbrace{\overline{a}_{2,n-1}\, \overline{a}_{2,n-2} \ldots \overline{a}_{2,1}\, \overline{a}_{2,0}}_{(n)bits} \tag{9}$$

To obtain X based on the equation (1),

$$X = a_1 + a_2 m_1 + a_3 m_1 m_2 = x_1 + m_1(a_2 + a_3 m_2)$$

$$= x_1 + (2^{n+1} - 1)\underbrace{(a_2 + (2^n)a_3)}_{C} = x_1 + (2^{n+1} - 1)C \text{ where } C = a_2 + (2^n)a_3$$

$$\left\{\begin{array}{l} C = \underbrace{a_{3,n-1} \ldots a_{3,0}}_{(n-1)bits}\ \underbrace{a_{2,n-1} a_{2,n-2} \ldots a_{2,n}}_{1bit}\ \underbrace{\overline{a}_{3,n-1} \ldots \overline{a}_{3,0}}_{(n)bits} \\ +\underbrace{1 \ldots 1 \ldots 1 \ldots 1 \ldots 1 \ldots 1 \ldots 1}_{(n)bits} \ldots \underbrace{a_{2,n-1} \ldots a_{2,0}}_{(n)bits} \end{array}\right\} \tag{10}$$

$X = x_1 + (2^{n+1} - 1)C =$ Concatenation of (x_1, C)

$$\left\{\begin{array}{l} X = \underbrace{C_{3n} \ldots C_n}_{(n+1)bits}\ \underbrace{C_{n-1} \ldots C_0}_{(n)bit}\ \underbrace{\overline{C}_{n+1} \ldots \overline{C}_0}_{(n+1)bits} + \\ \underbrace{1 \ldots 1 \ldots 1 \ldots 1 \ldots 1 \ldots 1}_{(n+1)bits} \ldots \underbrace{\overline{C}_{3n} \ldots \overline{C}_{n+1}}_{(n)bits} \times \underbrace{x_{1,n+1} \ldots x_{1,0}}_{n+1} \end{array}\right\} \tag{11}$$

Therefore, the implementation of X based on equation (10) and (11) is given in Figure 2.

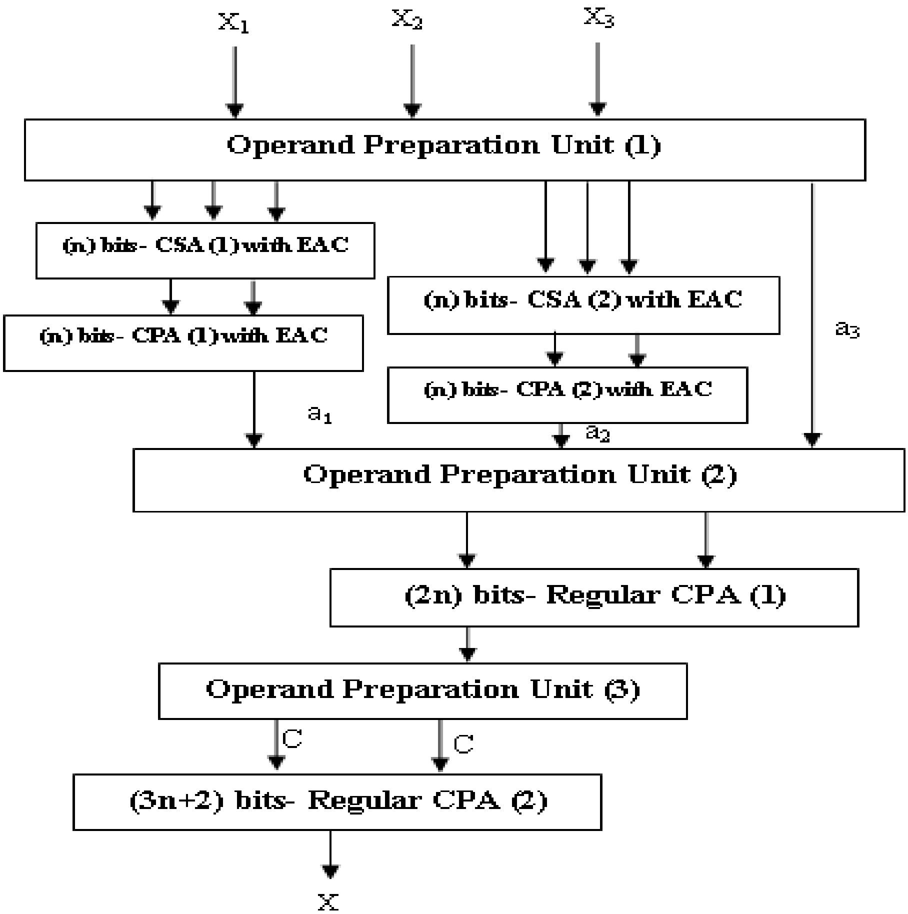

Figure 2. Implementation of X based on equations 10 and 11

In order to implement X, consider equations 10 and 11, it needs ($2n$) bits and ($3n$+2) bits Regular Carry Propagate Adder (CPA). The Operand Preparation Unit 2 (OPU-2) and OPU (3) is needed to prepare the 1's complements respectively. However, (n) bits and (n+1) bits are 1 in equations 10 and 11, respectively. Therefore (n) and (n+1) Full Adders (FAs) can be substituted with (n) and (n+1) pairs of OR/XNOR gates respectively.

4.2. RRNS Error Control Scheme

When the base station receives the collected residues from the CH, it reconstructs the original information using the information moduli as well as their residues. The remainders of the calculated number are divided by the redundant moduli. Additionally, when the remainders collected for those redundant moduli are unequal, an error is discovered, which will, in turn, initiate a process for error correction. Three residues out of the five can be utilized by the base station to restructure the original data. Thus, RRNS codes which has a redundant modulus can identify *n* errors and correct *n-1*given that the condition $m_1<m_2<\ldots<m_k<m_{k+1}$ is met. However, to detect and correct, errors, the complete moduli set will now contain {2^{n+1}-1, 2^n, 2^n-1, 2^{n+1}+3, 2^{2n} - 3}, where {2^{n+1}-1, 2^n, 2^n-1} are an information moduli, while {2^{n+1}+3, 2^{2n} - 3} are redundant moduli. The actual number can be represented by just the residues obtained using the main moduli. The legitimate range is defined by the product of the information moduli, whereas, the illegitimate range is characterized by product of the entire moduli set.

However, error can be detected if $a_j\neq 0$ with $j\in[k+1, n]$. Even a single error corrupts the i^{th} residue digit which appears in the residue of the received integer *X*. This error could be dealt with by adding the number e_i to the residue when $0 < e_i < m_i$, that is given as:

$$X^{'} \rightarrow [r_1, r_2, r_3 \ldots (r_i + e_i) \ldots, r_{n-1}, r_n]$$

Where altered number is represented by *X'*. Similarly, *X'* can be described as the sum of the altered number *X* and an integer *E* created by the residue e_i,

$$X^{'} \rightarrow X + [0, 0 \ldots e_i \ldots, 0, 0].$$

$$[0, 0 \ldots e_i \ldots, 0, 0] \equiv E (\mathrm{mod}\, m_i).$$

Therefore,

$$E = \sum_{j=1, j\neq 1}^{n} a_j \prod_{i=1}^{j-1} m_i \text{ such that}$$

$$X^{'} = X + \sum_{j=1, j\neq 1}^{n} a_j \prod_{i=1}^{j-1} m_i$$

In view of the fact that the redundant modulus m_{k+1} is greater compared to every information moduli, then E is greater than the legitimate range *M*. The only case decoding the integer isa_j=0, which shows up in the legitimate range, where $j\in[k+1, n]$. Accordingly, $a_j\neq 0$ specifies the residue digit has been corrupted, else no error occurs.

For illustration purposes, let us consider n = 2 for moduli set $\{2^{n+1}-1, 2^n, 2^n-1, 2^{n+1}+3, 2^{2n} - 3\}$. The moduli set will now be (7, 4, 3, 11, 13) where (7, 4, 3) is the information moduli set and (11, 13) is the redundant moduli set. The legitimate Range called Dynamic Range (DR) is 84 and the illegitimate range is 12012.

For example, if the gathered message "X = 52" is to be conveyed from CH to the sink using the moduli set above. The number would then be represented as the residue set (3, 0, 1, 8, 0), where (3, 0, 1) is the non-redundant moduli set and (8, 0) is the redundant moduli set. Such residue representation is needed to manage transmitted data in WSN communication. Accordingly, in order to check if the transmitted data was received correctly by the recipient node in real time WSN, a reverse conversion of the residue is done using CRT to reconstruct the original number from the residue set using:

$$X = \left| \sum_{i=1}^{k} M_i \left| M_i^{-1} x_i \right|_{m_i} \right|_M$$

where

$$M_i = \frac{M}{m_i} = \frac{\prod_{i=1}^{N} m_i}{m_i} .$$

Moreover, in case one of the residues is corrupted by an electrical fault or noise, the proposed scheme has the capacity to identify the error and correct it. For illustration purpose, assuming the residue subset of {3, 0, 1} has been corrupted into the values {3, 3, 1} (x_2 has been altered from the right value of 0 to the incorrect value of 3). The conversion process then gives:

$$X = \left|12*|3*3|_7 + 21*|1*3|_4 + 28*|1*1|_3\right|_{84}$$

$$X = |115|_{84},\ X = 31$$

In order to correct the error, the Maximum Likelihood Estimation (MLE) is utilized to obtain the original data. To achieve this, extra combinations of information and redundant residues are created. Each combination can then be changed by utilizing the CRT. In this case, the value within the legitimate range appearing most often will be the correct value of the original data as indicated in Table 1.

Consider the previous instance where residue x_2 for the decimal number 52 of X = (3, 0, 1, 8, 0) was corrupted into the incorrect value from 0 to 3, now having corresponding residue digits of X = (3, 3, 1, 8, 0). With CRT's approach, the integer X is in the dynamic range [0, 84) and can be recovered by raising any of the three moduli and their equivalent residue numbers given that no errors occurred in the received RNS representation. Then, we filter all similar cases and aim at recovering the number X represented by (3, 3, 1, 8, 0) from moduli set (7, 4, 3, 11, 13). The additional residue mixture can be formed from likely combinations of three residue digits out of five residue digits as shown in Table 1.

Table 1. Possible Combinations of Residue Digits

Residues	Residues Values	Moduli Set	X_{ijk}	X	DR
$\{x_1, x_2, x_3\}$	(3, 3, 1)	{7, 4, 3}	X_{123}	31	84
$\{x_1, x_2, x_4\}$	(3, 3, 8)	{7, 4, 11}	X_{124}	283	308
$\{x_1, x_2, x_5\}$	(3, 3, 0)	{7, 4, 13}	X_{125}	143	364
$\{x_1, x_3, x_4\}$	(3, 1, 8)	{7, 3, 11}	X_{134}	52	231
$\{x_1, x_3, x_5\}$	(3, 1, 0)	{7, 3, 13}	X_{135}	52	273
$\{x_1, x_4, x_5\}$	(3, 8, 0)	{7, 11, 13}	X_{145}	52	1001
$\{x_2, x_3, x_4\}$	(3, 1, 8)	{4, 3, 11}	X_{234}	19	132
$\{x_2, x_3, x_5\}$	(3, 1, 0)	{4, 3, 13}	X_{235}	91	156
$\{x_2, x_4, x_5\}$	(3, 8, 0)	{4, 11, 13}	X_{245}	195	572
$\{x_3, x_4, x_5\}$	(1, 8, 0)	{3, 11, 13}	X_{345}	52	429

5. Performance Evaluation and Discussion of Results

The reverse converter was compared with the existing advance reverse converters. The results of theoretical analysis depicts that the suggested error correction scheme is efficient with regard to area and delay when compare with Barati et al, 2014 [14] and better in terms of delay as compared to Habibi & Salehnamadi [16] as shown in Table 2.

Table 2. Comparison of Area and Delay

Reverse Converter	Moduli Set	Area (A_{FA})	Delay (t_{FA})
[14]	$\{2^{2n+1}, 2^{2n+1}-1, 2^n-1\}$	7n+3	9n+8
[19]	{2n, 2n + 1, 2n− 1, 22n+1– 1}	12n+2	9n+6
[16]	$\{2^n-1, 2^n+1, 2^{2n}-1\}$	5n + 1	10n + 6
Proposed	$\{2^{n+1}-1, 2^n, 2^n-1\}$	6n +2	9n +2

Additionally, the proposed error control scheme is more effective in terms of speed and energy utilization when compared with Roshanzadeh and Saqaeeyan's study [6].

The suggested converter has an area Full Adders of $(6n+2)A_{FA}$ with low cost hardware requirements and power usage. It also has a delay Full Adder of $(9n+2)t_{FA}$ that provides relatively low conversion delay and high performance for the WSNs in terms of energy usage and improved reliability when compared with other reverse converters. Similarly, conversion using the CRT that yields different values of X was displayed in Table 1. X_{ijk} signifies the yielded result by applying moduli m_i, m_j and m_k and their analogous residue digits x_i, x_j, and x_k. From the Table 1, X_{124}, X_{125}, X_{235}, and X_{245} represents illegitimate numbers which are out of the legitimate range [0, 84). Out of the six cases that remained, the results of four cases (X_{134}, X_{135}, X_{145}, X_{345}) are all the same and are equal to 52. For the above given case, the value within the legitimate range appearing most often will be the correct value of the original data. As 52 appears the greatest number of times, it is known to be the accurate original data. Furthermore, these results were obtained from three moduli excluding x_2. Consequently, it might be concluded that the accurate result is 52 or there might be an error in x_2, which can be amended by calculating:

$$x_2 = 52 \pmod 4 = 0.$$

6. Conclusion

In this study, an effective error control scheme is formulated and showcased for real time WSNs having $\{2^{n+1}-1, 2^n, 2^n-1\}$ as a moduli set and with $\{2^{n+1}+3, 2^{2n}-3\}$ for error detection and correction. MRC based reverse converter was designed to convert the received residues to their original message. The results obtained outperform the existing advance reverse converter in terms of speed, hardware requirements, and energy consumption. Maximum Likelihood Estimation (MLE) was used to find the value appearing most frequently, often within the legitimate range. This value was used to correct the corrupted values to their original state. The proposed moduli set outperforms the existing state of the art error control schemes for real time WSNs.

Conflict of Interest

The authors declare no conflict of interest.

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