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An Enhanced Vitality Efficient and Reliable Wireless Sensor Networks with CRT-Based Packet Breaking Scheme

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Abstract: Wireless sensor networks (WSNs) consist of a large number of wireless sensor nodes dispersed in an area of interest with one or more base stations mainly used in monitoring our environment and also for physical conditions. It has been established that energy is the most constraining factor on the functionality of such networks because they are powered with limited energy and replacement of power resources might be unfeasible. Duty Cycling and In-Network Aggregation could be used to reduce energy consumption but energy saving is obtained at the expense of an increased node complexity and network latency. However, in order to reduce energy consumption and increase reliability, nodes only need to send small packet to the sink. A secured and energy efficient wireless sensor network using Chinese Remainder Theorem (CRT) based packet splitting algorithm is therefore proposed. This technique involves splitting the messages sent by the source node of a wireless sensor network so that the maximum number of bits per packet that a node has to forward is reduced which decreases the energy consumption of the network. However, it also increases the message security because the remainders of sensed data are sent instead of data itself, the received packet is encrypted and for decrypt the message, need to have the moduli set which serves as the secret key. The results obtained shows the proposed algorithm outperforms traditional approaches in terms of energy saving, reliability, simplicity and fair distribution of energy consumption among all nodes in the network as well as reduction in end-to-end delay.

Keywords: Energy Efficiency, Reliability, Packet Breaking, Chinese Remainder Theorem, Wireless Sensor Networks

1. Background

The availability of smarter, smaller and inexpensive sensors measuring a wider range of environmental parameters has enabled continuous timed monitoring of the environment and real-time applications [1]. The major issues in computer systems are the reliability and availability of computer, communication and storage devices. Many techniques that enhance the reliability and availability of computer and communication systems were developed both in academia and industry. As the complexity of computing and communication devices increases fault-tolerance has gained more importance. Also, the emergence of wireless sensor networks (WSNs) has also increased the importance of fault tolerance [2].

Wireless Sensor Networks (WSNs) consist of interconnected Sensor nodes which are deployed in a very large number and are capable of sensing, gathering, processing and transmitting the data [2]. They usually used to monitor areas, collect data and report to the base station or sink. There are a lot of potential applications that are envisioned for sensor networks. For example, they can be used in a battlefield, where they can detect and spy on the enemies or they can support the positive forces. Also, they can be used in intelligent security systems in buildings and security of critical applications. They can be used for habitat monitoring applications where they can monitor and study the changes in phenomena such as temperature, sound humidity etc. for a long time [4].

Based on received data appropriately, wireless sensor networks are capable of sensing and forwarding the sensed data, and performing different reactions. WSN's consists of sensor nodes and sink nodes which usually have low costs, limited energy supply and limited transmission range; they are responsible for detecting events or sensing environmental data [3]. The base stations are resource-richer nodes with abundant energy sources, higher communication and computation capability, and the ability to perform powerful reactions. When the base station performs some action then theses nodes are called actor nodes. When a sensor node detects some data to be delivered in its monitoring area, it will transmit the event to neighbouring nodes, which in turn will forward the event one hop further.

Figure 1 below shows a Wireless Sensor Networks containing WSN nodes and the sink. A sensor node is a tiny device that includes three components: a *processing unit* used to process local data, *a sensing subsystem* used for data acquisition from its environment, and a *wireless communication* transceiver that transfers the sensing information to the sink. These sensor nodes perform data sensing and processing tasks and also communicate with each other [4].

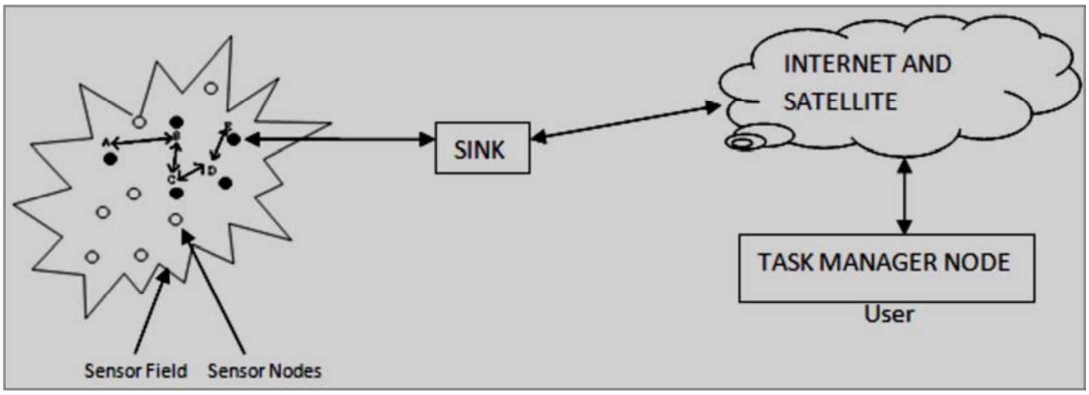

Figure 1. *Wireless Sensor Network [5].*

However, WSNs are usually equipped with limited energy which makes it resource constrained. Thus, the most important aspect is how to minimize the energy depletion of nodes in order to increase the network lifetime significantly. In WSNs once deployed, sensor node batteries cannot be replaced or recharged, hence WSNs application should be designed in an energy efficient manner [5]. Moreover, nodes in WSN are typically mass produced and are often deployed in unattended and hostile environments making them more susceptible to failures than other systems [6]. However, manual inspection of faulty sensor nodes after deployment is typically impractical. Nevertheless, many WSN applications are mission-critical, requiring continuous operation. Thus, in order to meet application requirements, a secured, reliable and energy efficient methodology is required in WSNs [7].

Wireless Sensor Network is applicable in various fields such as data acquisition in hazardous environment, monitoring of critical infrastructures and military operations. The hostile environment affects the monitoring the infrastructures of wireless sensor networks (WSNs). Since sensor nodes are expected to operate autonomously in unattended and possibly hostile environments, they are vulnerable to faults where faults are likely to occur frequently and unexpectedly [6]. WSNs are failure prone due to any of the reasons like malicious attack, energy depletion, hardware failure, communication errors and so on.

It is general believed that nothing is perfect in this universe; faults are also unavoidable in the sensor network and it is very necessary to distinguish between faulty and working nodes [8]. In order to maintain the network quality of service, it is compulsory for WSN to be able to detect the faults and take appropriate actions to handle them. When designing an error control scheme for WSNs, energy efficiency is most important aspect. The use of a specific fault tolerant technique depends on the requirements of the application and the constraints of the WSN. Hence it is very challenging to choose an optimum error correcting code for a WSN where both, the performance and energy consumption are taken into account [9].

Finally, in this paper, an energy efficient and secured WSNs based on Chinese Remainder Theorem (CRT) packet splitting forwarding technique was proposed. This method involved breaking the sensed messages into several packets (depending on number of nodes in the next-hop) such that each node in the network will forward only small sub-packets to the sink. When the sink receives all sub-packets correctly, will reconstructing the original message. The major reason for this approach is to break the messages sent by each source node so as to reduce number of bit transmitted by each forwarding node in the network thereby power consumption is reduced. The proposed algorithm outperforms traditional approaches in terms of security, energy consumption, reliability, simplicity, and reduction in end-to-end delay.

2. Review of Related Works

There have been several studies on minimizing energy consumption in wireless networks and especially in Wireless Sensor Networks (WSNs). Also several energy conservation schemes have been proposed aimed at minimizing the energy consumption of the radio interface. This is because radio unit account for largest power consumption during data communication. Duty cycling (sleep/wakeup scheme) and In-Network data aggregation [10, 11] are the most popular approaches. The first approach involves putting the radio transceiver in the sleep mode whenever communications are not needed and awaken when received a packet from a neighbouring nodes. But energy saving is obtained at the expense of an increased node complexity and network latency. The second approach is intended to merge routing and data aggregation techniques aimed at reducing the number of transmissions. In this scheme, multipath routing algorithms are usually employed. However, multiple paths could remarkably consume more energy than the shortest path because several copies of the same packet could reach the destination. Authors in [12] observed that redundant residue number systems (RRNSs) are appropriate for use in real time wireless sensor networks applications, because it enhances real time operations, strong error control capability, energy saving, and security. The RNS has been used as a tool to reduce transmission energy and increase reliability in wireless sensor networks.

However, authors in [9] proposed an approach that relies on a packet-splitting algorithm based CRT characterized by a simple modular division between integers. Kalman filter was used to reduce the noise and find the shortest path to reach the receiving end. RSA uses the CRT to associate the authenticating procedure of the authentication key and the Message Authentication Code of broadcast messages together. The system has low overhead in computation, communication and storage, immune to DoS attack. Authors in [13] investigated a trade-off between energy efficiency and reliability of the CRT forwarding scheme when duty-cycling techniques are considered. This was achieved with a moderate increase in the overall complexity and with very low overhead. Researchers in [14] observed that the limited energy consumption requirements and the low complexity in the sensor hardware necessitate energy efficient error control and prevent high complexity codes to be deployed. Redundant moduli that play no role in determining the dynamic range was introduced. This was used in WSNs to decrease renewed data sending via occur error in data packets which was focused on low complexity error detection technique which was implemented with low data redundancy and efficient energy consuming in wireless sensor node using residue number systems.

It is therefore is necessary to develop efficient and secured WSNs while still conserving the limited energy of the network as well as end-to-end delay.

3. Concepts of Chinese Remainder Theorem (CRT)

The Chinese remainder theorem is a theorem of number theory, which states that, if one knows the remainders of the division of an integer *n* by several integers, then one can determine uniquely the remainder of the division of *n* by the product of these integers, under the condition that the divisors are pairwise coprime [15]. The Chinese remainder theorem is a result about congruence's in number theory and its generalizations in abstract algebra [9]. In its basic form, the Chinese remainder theorem will determine a number *n* that when divided by some given divisors leave given remainders [17].

Let $n_1,..., n_k$ be integers greater than 1, which are often called *moduli* or *divisors*. Let N denotes the product of the n_i. The Chinese remainder theorem asserts that if the n_i are pairwise coprime, and if $a_1,..., a_k$ are integers such that $0 \leq a_i < n_i$ for every i, then there is one and only one integer x, such that $0 \leq x < N$ and the remainder of the Euclidean division of x by n_i is a_i for every i.

This may be restated as follows in term of congruences: If the n_i are pairwise coprime, and if $a_1,..., a_k$ are any integers, then there exists an integer x such that and any two such x are congruent modulo N.

$$x \equiv a_1 \pmod{n_1}$$

$$x \equiv a_2 \pmod{n_2}$$

$$.$$

$$.$$

$$x \equiv a_k \pmod{n_k}$$

However, all solutions' x of this system is congruent modulo the product, $N = n_1, n_2 \ldots n_k$. Therefore, $x \equiv y \pmod{n_i}$ for all $i \leq i < k$ if and only if $x \equiv y \pmod{N}$. The traditional CRT is defined as follows. For a moduli set $\{m_1, m_2, m_3,.. m_k\}$ with the dynamic range $M = \prod_{i=1}^{k} mi$, the residue number $(x_1, x_2, x_3, \ldots, x_k)$ can be converted into the decimal number X, as follows:

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

where $M = \prod_{i=1}^{k} mi$, $M_i = \frac{M}{m_i}$, and M_i^{-1} is the multiplicative inverse of M_i with respect to m_i. The main drawback of CRT emerges from the required modulo-M operation which, given that M is a rather large number, this operation can be time consuming and rather expensive in terms of area end energy consumption. The CRT is also useful in reverse conversion as well as several other operations [17].

However, the absence of carry propagation between the arithmetic blocks results in high speed processing, RNS is high speed. This feature is beneficial for wireless sensor networks that need to run-time applications. RNS also has parallel operations that reduce power consumption and delay simultaneously [12, 15]. Authors in [20] also observed that CRT can be used to solve problems in computing coding. In computing it can compete with shorter numbers instead of large numbers and this will make the computing-process faster and easier. In coding it can be used for error-searching and error-regulating. The algorithm allows reconstructing a large integer from its remainders modulo, a set of moduli. When all the moduli are co-prime, CRT has a simple single formula, which is well-known not robust, i.e., small errors from any remainders may cause a large reconstruction error.

4. Concepts of Packet Breaking Schemes

The ability to provide differentiated services to users with widely varying requirements is becoming increasingly important, and Internet Service Providers would like to provide these differentiated services using the same shared network infrastructure. In a computer network, packet forwarding technique is the relaying of packets from one network segment to another by nodes [19]. The simplest forwarding model uni-casting involves a packet being relayed from link to link along a chain leading from the packet's source to its destination. Another forwarding model is broadcasting which requires a packet to be duplicated and copies sent on multiple links with the goal of delivering a copy to every device on the network. However, the redundancy adopted is that multiple copies of the same packet that travel to the destination along multiple paths. Multiple paths could remarkably consume more energy than the single shortest path because several copies of the same packet have to be sent.

4.1. Packet Processing

Packet Processing refers to the wide variety of algorithms that apply to a packet of data or information as it moves through the various network elements of a communications network [19]. Usually, there are two broad classes of packet processing algorithms that align with the standardized network subdivision of control plane and data plane. The algorithms are applied to either; control information contained in a packet and these are used to transfer the packet safely and efficiently from origin to destination. The data content (frequently called the payload) of the packet and are used to provide some content-specific transformation or take a content-driven action.

4.2. Packet Splitting

Packet Splitting involves the breaking the original packets into various sub-packets and transmit packets towards the nodes [19]. The original messages are split into several packets such that each node in the network will forward only small sub packets and reconstruct them back. The splitting procedure is achieved applying the packet splitting algorithm as seen in Figure 2.

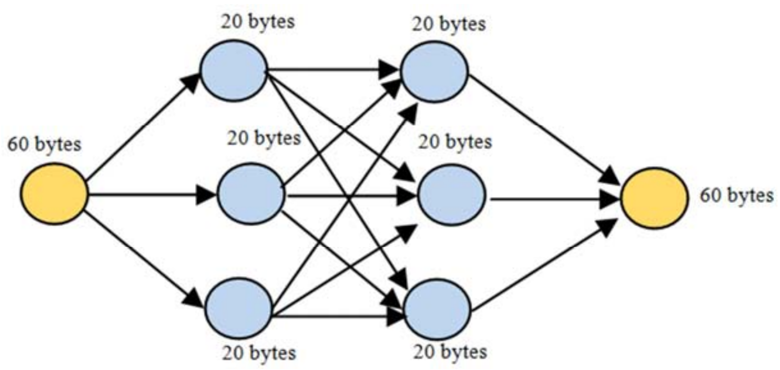

Figure 2. *Packet splitting [19].*

Once all sub packets are received correctly by the sink node, it will recombine them, thus reconstructing the original message. The splitting procedure is especially helpful for those forwarding nodes that are more solicited than others due to their position inside the network. The original messages into several packets such that each node in the network will forward only small sub packets. The splitting procedure is achieved applying the packet splitting algorithm. Hence, this provides a thorough analytical model that allows us to derive some accurate results regarding energy consumption and complexity [11].

5. Methodology

5.1. CRT-Based Transmitting Scheme

Packet splitting forwarding technique is the basic method for sharing information across systems on a network. Packets are transmitted between a sender interface and a receiver interface, usually on two different nodes. The CRT for data packet involves a node starts at a random position, then applying prime numbers to the data packets for some security purpose. For these purpose intruders will not identify the data packet order because the original message is not sent but the prime numbers. CRT-based splitting is more efficient than a simple splitting [18]. The major reason for forwarding technique is to split the messages sent by the source node of a wireless sensor network so that the maximum number of bits per packet that a node has to forward is reduced, increasing in this way the network lifetime [18]. CRT can be formulated simply as follow [3, 13, 18]:

Given N primes $p_i > 1$, with $i \in \{1 \ldots N\}$, by considering their product $M = \Pi_i\ p_i$, then for any set of given integers $\{m_1, m_2, \ldots, m_N\}$ there exists a unique integer $m < M$ that solves the system of simultaneous congruences m = m_i (mod p_i), and it can be gotten by m = $(\sum_{i=1}^{N} c_i m_i)(\bmod M)$. The coefficients c_i are given by $c_i = Q_i q_i$, where $Q_i = M/p_i$, and q_i is its modular inverse, that is, q_i solves $q_i Q_i = 1(\bmod p_i)$. For illustration purpose, let us consider the moduli-set {3, 5, 7} with residue representation (1, 2, 3), thus:

m = 1 (mod 3)

m = 2 (mod 5)

m = 3 (mod 7)

Then by CRT, m = 52 (decimal value). However, it is worth mentioning here that in the above example 7 bits are needed to represent m, while no more than 3 bits are needed to represent each m_i. Therefore, if instead of m, m_i numbers, with m_i = m (mod a_i), are forwarded in a wireless sensor network, the maximum energy consumed by each node for the transmission can be substantially reduced. Consider the Figure 3 below:

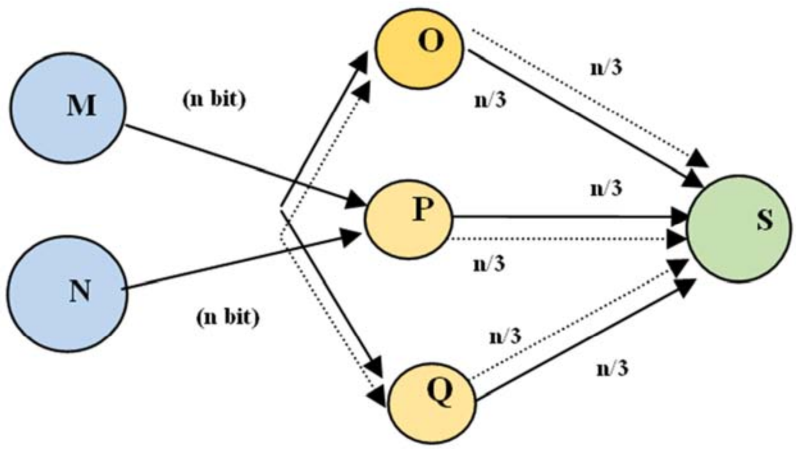

Figure 3. *Example of forwarding after splitting [12, 13, 19, 20].*

If nodes M and N have to forward a packet to the sink *S.* if there are *n* bits for each packet, the maximum number of bits transmitted by a node belonging to the set *{O*, P, Q*}* is n/3bits. In particular, when O, P, and Q receive a packet, they split it and send to the sink only a part (e.g. *n/*3 bits each) In this case, O, P and Q, have to transmit at most 2/3 *nbits* each. It can be concluded that this method reduces the maximum number of bits transmitted by a node belonging to the set *{*O *P*, *Q}* if compared with other forwarding techniques (like normal forwarding with different next-hop or normal forwarding with the same next-hop). However, using splitting algorithm, it certain that maximum number of transmitted bits per node is reduced, and therefore the energy that a node consumes for the transmission is decreased. The splitting procedure is achieved by applying the Chinese Remainder Theorem (CRT) which represents a low complexity approach requiring only a modular division between integers and consequently it can be performed by very simple devices as sensor nodes without taken network reliability for granted. From Figure 4 below:

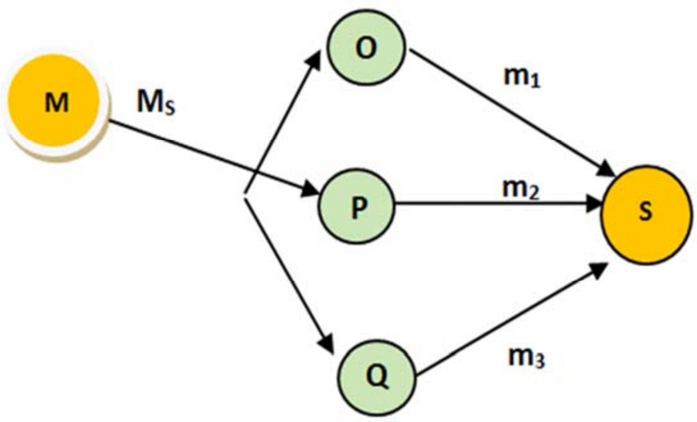

Figure 4. *Forwarding splitting procedure.*

Moreover, from the Figure 4, if nodes *O, P*, and *Q* receive a message M_s broadcast from node M, each of them, applying the procedure shown above, can transmit a message m_i, with $i \in \{1, 2, 3\}$ (called CRT components), to the sink instead of M_s. Furthermore, the sink, knowing a_i, with $i \in \{1, 2, 3\}$, and using the CRT approach, will be able to reconstruct M_s. However, according to the CRT, the number m can be alternatively identified with the set of numbers m_i provided that a_i are known (Figure 5).

For shake of clarity, let assume that N = 11 messages of n= 90 bit are sent. It is obvious that without splitting, at least one of the nodes O, P and Q will forward four messages (i.e. 90*4 = 360 bit). In the same manner, while using a splitting technique, each message can be split into three components of 30 bits each, so that 30*11=330 bits are forwarded. Consequently, when using splitting, the maximum number of transmitted bits per node is reduced by about 8% (30/360 * 100). Moreover, the reduction increases if the ratio "message length over number of components" decreases (i.e., if the number of available next-hop nodes are increases).

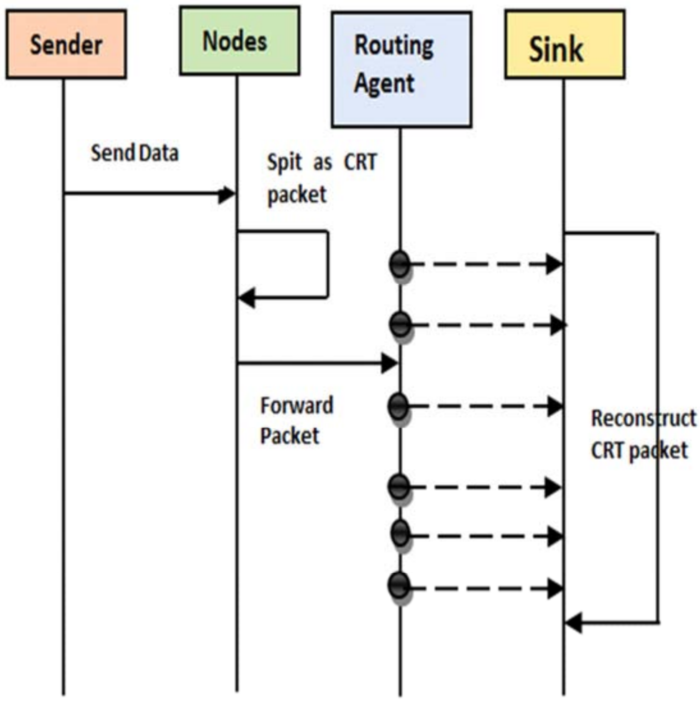

Figure 5. *CRT-based Forwarding Technique [20].*

5.2. Vitality Utilization Factor

Energy is the critical resource in wireless sensor networks, even when it is possible to harvest energy from the external environment so that the network lifetime can be improved to reasonable times. Energy consumption in WSN nodes occurs due to computational processing and communication. It can be minimized by designing an efficient multi-hop routing algorithm [12]. Communication energy can be conserved by limiting the packet sizes and the number of packets routed through the network. Computational energy can also be conserved by limiting the number of tasks that the node has to perform. Considering the fact that the energy consumption is proportional to the number of bits transmitted then, assuming n the number of bits in the original message M_s, and $nCRT_{max}$ (the maximum number of bits of a CRT component), that is [12, 13, 15, 18];

$$nCRT_{max} = \max([\log_2(pi)]),$$

we can consider a theoretical maximum energy reduction factor (MERF) given by [12, 13, 18, 19]

$$MERF = \frac{n - nCRT_{\max}}{n}$$

Consider the previous example; it could be deducted that certain percentage of energy could be saved using this CRT-based forwarding technique. We can as well roughly state that CRT-based splitting is more efficient than a simple splitting (i.e. packet chunking) or other FEC-based splitting techniques where redundancy have to be added to the original packet by increasing the total number of bits.

5.3. Choice of Moduli set and Prime Numbers

The best moduli are probably prime numbers-at least from a purely mathematical perspective. The set of the moduli chosen for RNS affects both the representational efficiency and the complexity of arithmetic algorithms [21]. A particularly useful property of such moduli is that of "generation" [17]. For computer applications, it is important to have moduli-sets that facilitate both efficient representation and balance, where the latter means that the differences between the moduli should be as small as possible. However, It is crucial to observe that the set of prime numbers p_i> 1, with i ∈ {1...N}, can be arbitrarily chosen provided that m < M, therefore, the number of bits needed to represent m_i can be reduced by choosing the prime numbers as small as possible [3, 12, 20]. As a consequence of this choice, the MERF is maximized [3]. For example, if the size of original data is 40 bits and the number of split segment is 7, the minimum prime set becomes {43, 47, 53, 59, 61, 67, 71}. When the primes set are chosen as above, the message can be reconstructed if and only if all the CRT components are correctly received by the sink.

5.4. Proposed Packet Breaking Scheme

Considering the network shown in Figure 6 below, the clusters are obtained according to the initialization procedure. Initialization organized the network in clusters and also minimizes the number of hops needed to reach the sink. During initialization, it is assumed that the sink knows the prime numbers pi in order to reconstruct the original packet and also different pi are chosen by each next-hop of the source. However, initialization is realized through an exchange of Initialization Messages (IMs) starting from the sink that is supposed to belong to the cluster 1, i.e., CLID = 1, where CLID identifies the cluster number. Each node that receives an IM from its neighbours with a sequence number SN = h, will belong to cluster h and will retransmit the IM with an increased SN together with its own address and the list of the nodes that will be used as forwarders (that it knows on the basis of the source addresses specified in the received IMs). On the basis of the received IMs, at the end of the procedure each node in the network will know its own next-hops, which other nodes will use it as a next-hop, and into how many parts the received packets can be split. However, initialization is usually activated only once. The initialization phase algorithm is given below:

```
Initialize SN=1 //Reserved to reset an already initialized
        While message IM arrives at a node_i
        do //IM is initialization message
If CL_ID = 1 //assumed that Sink is the only node in CL_ID = 1

Then transmit IM with SN=2 to the next CL_ID at startup
        Increase SN=SN+1
    Else
        Transmit IM to the next CL_ID
        Increase SN=SN+1
    All nodes that receives the IM with SN=i assume to
                belong to CL_ID=j
```

And the packet splitting forwarding rule is given as follow:

```
Initialize SN=1    /Reserved to reset an already
initialized
        While message IM arrives at a node_i
        do //IM is initialization message
If CL_ID ≠ 1 //assumed that Sink is the only node in CL_ID = 1

Then transmit IM with SN=2 to the next CL_ID at startup
        Increase SN=SN+1
    Else
        Transmit IM to the next CL_ID
        Increase SN=SN+1
All nodes that receives the IM with SN=i assume to belong
                to CL_ID=j
```

6. Results Discussion and Findings

Consider the Figure 6 below, messages sent by each node when the source node K sends a message *m* to the sink *S*. According to the initialization procedure, node *L* knows that it is the only next-hop of node K and therefore it must forward the packet without performing a splitting procedure. However, it is not necessary for K to specify the list of the destination addresses *{M, N, O, P}* in the packet. In the initialization phase, nodes *{M, N, O, P}* have already received the IM message IM: [SN = 5, L, *{M, N, O, P}*], and therefore they know that node L has 4 next-hops and that all of them have to split into $node_L$ = 4 parts the messages received from L. Therefore, when *M, N, O, P* receive the packet, they proceed as follows:

a. According to the packet size, *n*, and the number of next-hops, $node_L$, they independently obtain the set of prime numbers;
b. They select one of the prime numbers, each of them on the basis of their position in the list of addresses *{M, N, O, P}* specified in the previously mentioned IM;
c. Then they send the components $m_i = m \pmod{p_i}$ one each, together with a proper mask, to one of the possible next-hops (*Q* or *R*). It is obvious that only node Q is in the coverage range of nodes *M* and *N* and only node *R* is in the coverage range of nodes *O* and *P*. Nodes *Q* and *R* simply forward the received CRT components to the sink because they knew that the received messages were already split.
d. Finally, when the sink S receives a component m_i, it identifies the number of expected components on the basis of the mask, and therefore it calculates the set of prime numbers, and the coefficients c_i needed to reconstruct the original message.

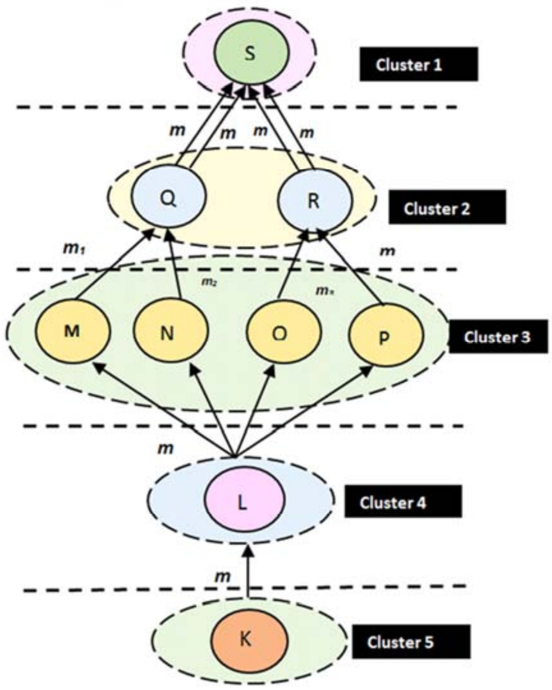

Figure 6. *Example of Packet Splitting Forwarding Technique.*

Moreover, when the sink receives the components of the original message, it can reconstruct the message by $m = \sum_i c_i m_i \pmod{M}$ where M is the product of the prime numbers related to the received components. Note that nodes $\{M, N, O, P\}$ can easily obtain the set of prime numbers by considering the smallest consecutive primes that satisfy $M > 2^n$.

7. Performance Evaluation and Simulation of Results

WSN performances are evaluated by using following matrices:

$$Packet\ Delivery\ Ration = \frac{Number\ of\ Received\ Packets}{Number\ of\ Transmitted\ Packets}$$

$$End - to - End\ Delay = \frac{\sum(Arrive\ time - Send\ time)}{\sum(Number\ of\ Connection)}$$

Packet Lost = Number of Packets send – Number of Packets Received

Throughput: It is defined as the total number of packets delivered over the total simulation time.

Throughput= N/1000

Where N is the number of bits received successfully by all destinations.

Energy Vitality: It is defined as the total unused energy level of nodes in the network. Node Energy consumption is defined as the communication (transmitting and receiving) energy the network consumes; the idle energy is not counted.

A set of simulations are used to evaluate the performance of the nodes. The simulations are all performed using *prowler (Probabilistic Wireless Network Simulator)* running under MATLAB. Different numbers of sensor nodes were deployed randomly starting from 10 to 50 in a sensing field of 150 x 150 square meters. All the sensor nodes are identified with unique id and assumed each sensor node is stationary after deployment. The simulations are run on random networks model, where the nodes placements are changed randomly in uniformly square area. Each node has limited battery energy, whereas the available energy at the sink may be relatively unlimited. At Initial stage, 10 Joules of energy was assigned to every node and then inject the network with 500 randomly generated message packets. The simulations results are shown in figures below.

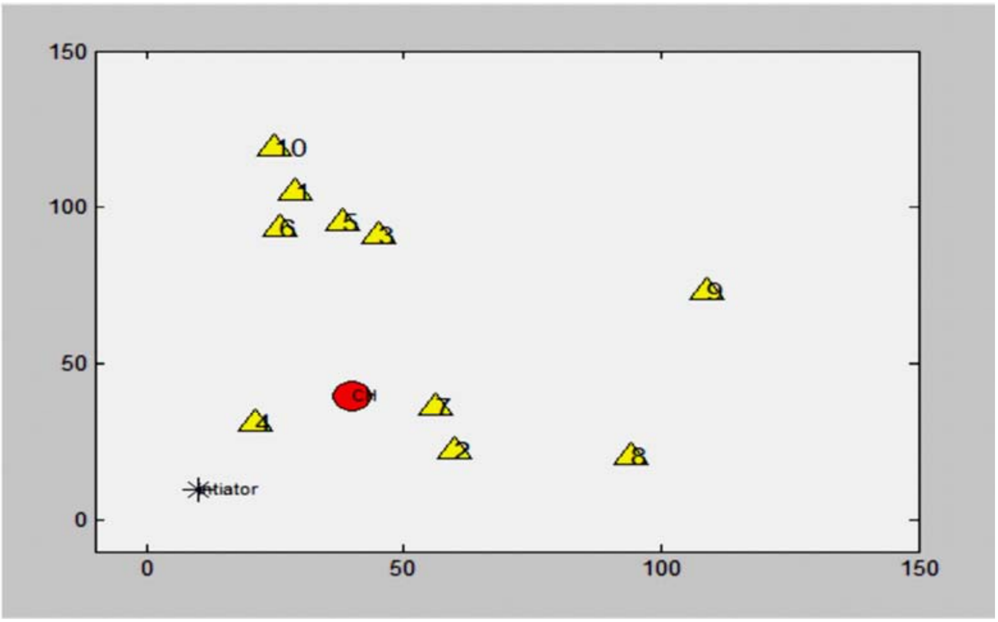

Figure 7. *Sensor nodes deployed.*

Figure 7 shows 10 sensor nodes that are uniformly distributed over a 150m×150m area. Packet delivery ratios were calculated based on the number packet sent and packet received. The message splitting is performed only one time by the nodes that are the closest to the source, whereas the other sensor nodes in the network will just forward the sub packets. Moreover, only the sink node will reconstruct the original message.

Table 1. *Number of Sensor Nodes Deployed vs PDR.*

No of Node/PDR	10	15	20	25	30	35	40	45	50
CRT	0.73	0.735	0.739	0.75	0.76	0.78	0.79	0.80	0.82
Shortest Path	0.76	0.765	0.761	0.78	0.795	0.80	0.81	0.82	0.85
Normal Forwarding	0.80	0.81	0.84	0.85	0.88	0.885	0.90	0.91	0.92

Table 1 shows the packet delivery ratios with respect to numbers of nodes.

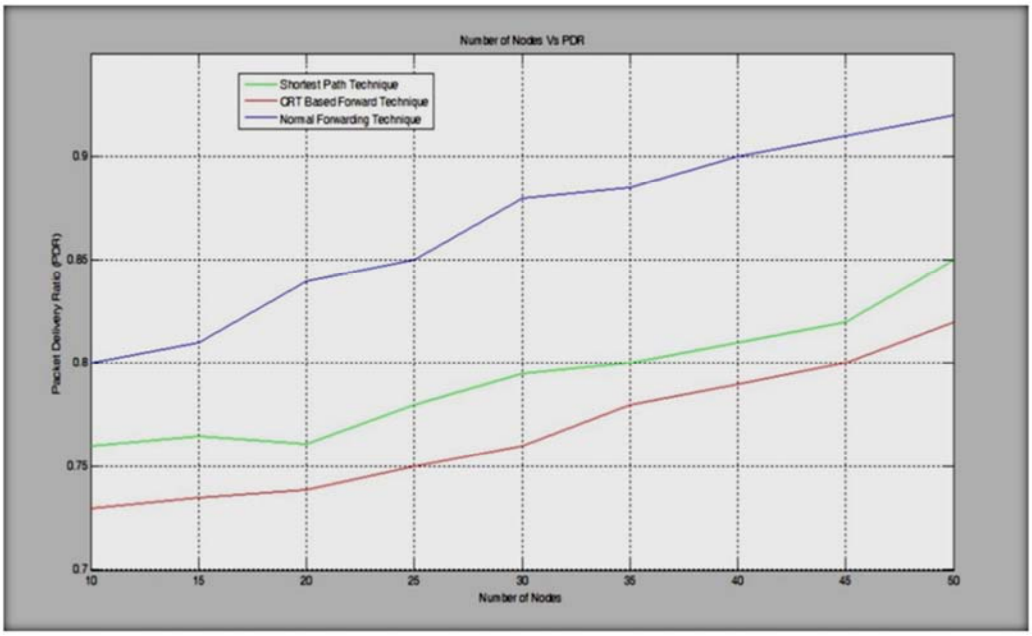

Figure 8. *Number of Sensor Nodes Deployed vs PDR.*

The Figure 8 shows packet delivery ratio for three different approaches. The proposed CRT-based forwarding techniques approach achieves a high packets delivery ratio compared to the existing approach (shortest path and Normal forwarding technique).

Table 2. *End-to end Delay.*

Traffic Data (kb)/Delay (ms)	50	100	150	200	250	300	450	400	450	500
CRT	3.1	3.6	3.8	3.6	3.81	3.9	4.5	4.6	5.1	5.7
Shortest Path	4.2	4.7	5.0	5.2	5.4	5.5	5.7	6.3	6.5	7.2
Normal Forwarding	4.0	4.55	4.8	5.0	5.25	5.35	5.5	6.1	6.3	7.0

Table 2 shows end-to-end delay when different numbers of nodes were deployed using different techniques. Figure 9 shows the end to end delay when message packets were sent from source to sink. The CRT-based forwarding technique reduced the delay in packet forwarding compared with the existing approach increase the delay in packet forwarding.

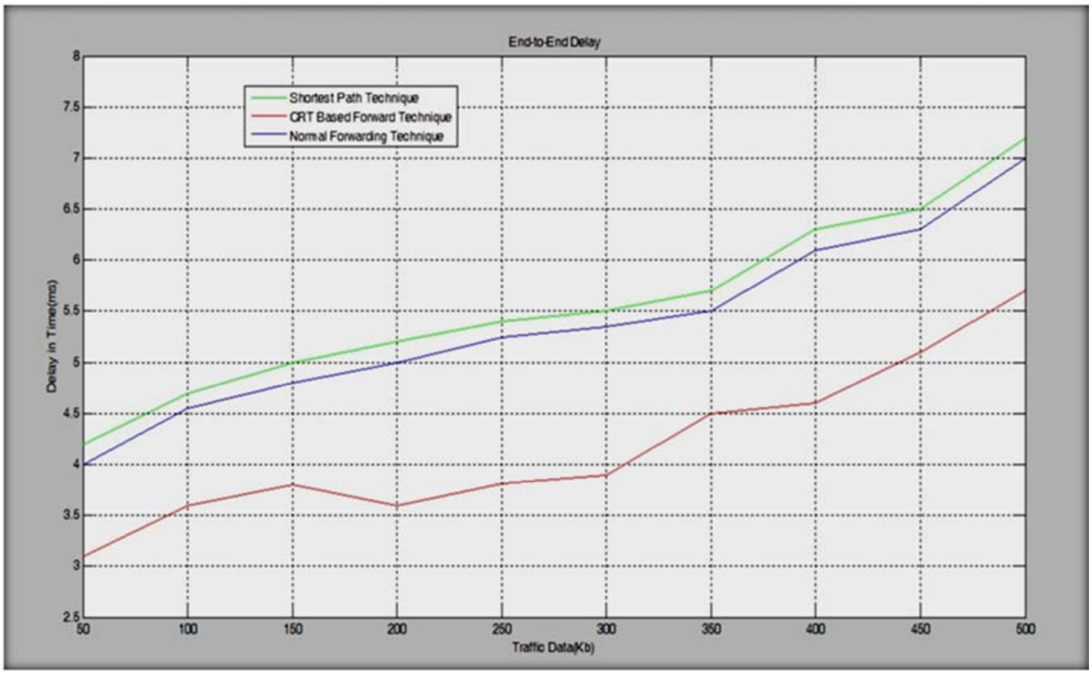

Figure 9. *End-to end Delay.*

Table 3 displays the percentage packet lost calculated for different numbers of nodes. Figure 10 gives the percentage packet lost when packets were sent over different approach. Existing approach achieves more packet loss but the CRT-based approach avoids this much of packet loss.

Table 3. *Percentage Packet Lost.*

Packet Size/ %Lost	75	150	250	350	450	600	700	800	900	1000
CRT	10.6	7.1	3.2	2.9	2.68	2.5	2.3	2.1	2.0	1.8
Shortest Path	16	12	5.0	4.8	4.4	3.2	3.0	2.6	2.45	2.4
Normal Forwarding	14	10	4.8	4.6	4.2	3.0	2.8	2.4	2.35	2.3

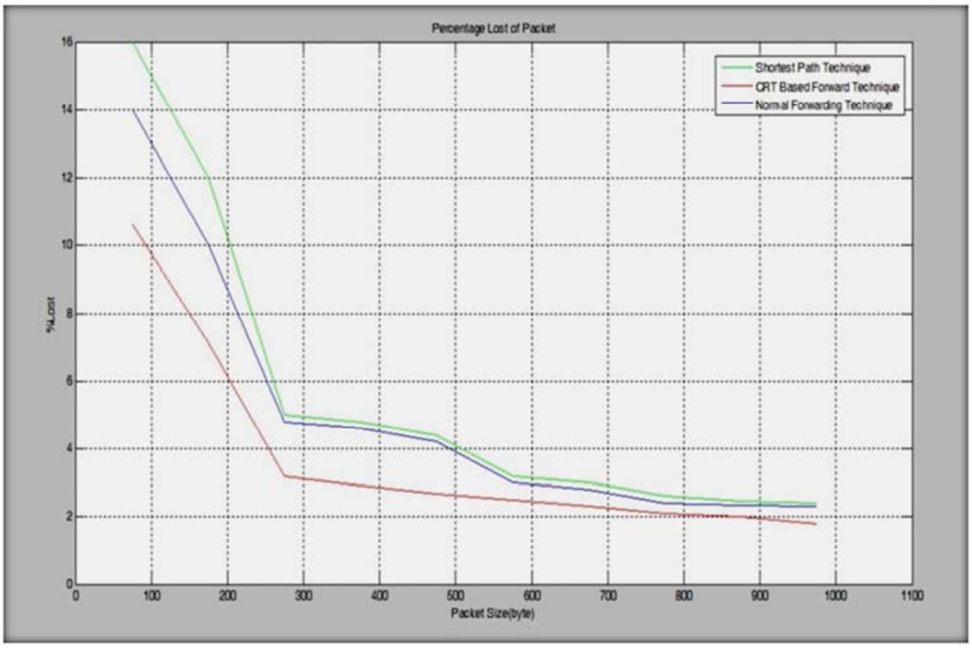

Figure 10. *Percentage Packet Lost.*

Table 4 displays the energy consumption by different numbers of nodes using three different techniques. Figure 11 displays the energy consumption by each node using three different approaches. In proposed CRT-based forwarding technique energy efficiency reach the level of 0.17.

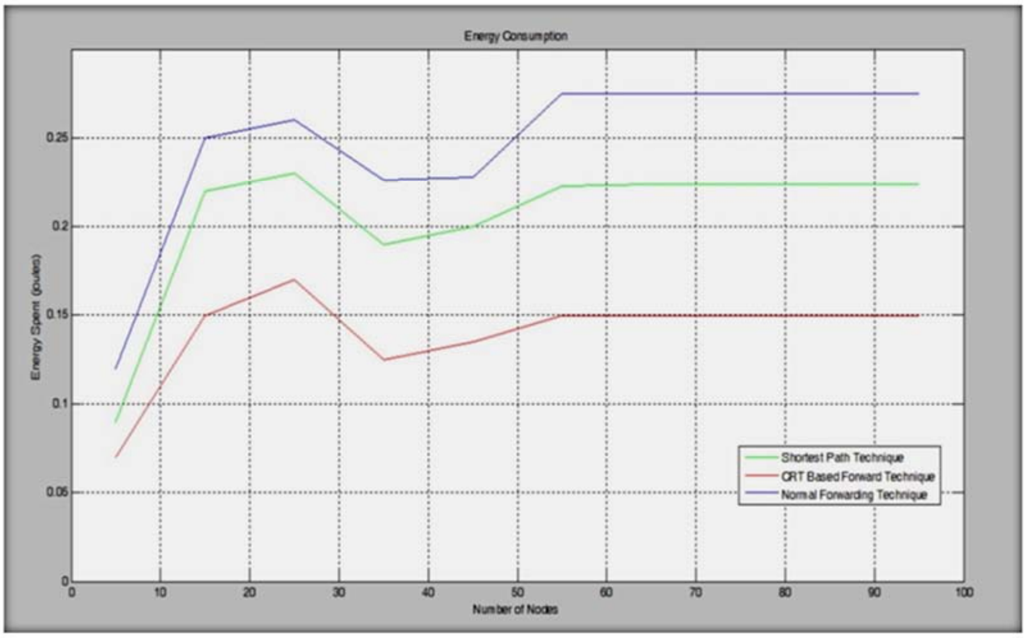

Figure 11. *Energy consumption by each Node.*

Table 4. *Energy consumption by each Node.*

No of Nodes/Energy Spent(joule)	5	20	30	50	60	70	80	90	100
CRT	0.07	0.15	0.17	0.135	0.15	0.15	0.15	0.15	0.15
Shortest Path	0.09	0.22	0.23	0.2	0.223	0.224	0.224	0.224	0.224
Normal Forwarding	0.12	0.25	0.26	0.228	0.275	0.275	0.275	0.275	0.275

9. Conclusion

An enhanced fault tolerant in wireless sensor network using Chinese Remainder Theorem is proposed. The proposed algorithm is compared with other forwarding techniques such normal forwarding technique with different next hop, normal forwarding technique with the same next hop as well as shortest part. The simulated result shows that the proposed CRT-based forwarding techniques outperform other techniques in term of energy consumption and end-to-end delay.

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