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Energy Saving in Wireless Sensor Networks using CRT-Based-Packet-Forwarding Solution

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***Abstract*—Routing in wireless sensor networks is a self-centered task. This has led to a number of routing protocols which efficiently utilize the limited resources available at the sensor nodes. Consumption of the minimum energy path is the distinctiveness of such routing protocols. By using the minimum energy path deprives the nodes energy quickly and the time taken to determine an alternate path increases. Instead of routing all the traffic along a single path, multipath routing schemes distribute traffic among multiple paths. Two criteria that arise in multipath routing are how many paths are needed and how to select these paths. Obviously, the number and the quality of the paths selected dictate the performance of a multipath routing scheme. We recommend an energy proficient adaptive multipath routing technique which exploits multiple paths between source and the sink. Because of low routing overhead, they are adaptive.**

We also made innovative approach that splits the original messages into several packets such that each node in the network will forward only small sub-packets and implementing the CRT Technique (Chinese reminder theorem) for assigning the id for the data packets. And also aims to increase the number of possible next hops that a node can use as forwarders by upgrading the initialization procedure.

***Index Terms*— Wireless Sensor Networks, Chinese Remainder Theorem, Energy efficiency, Packet splitting.**

I. INTRODUCTION

A Wireless Sensor Network (WSN) is a wireless network consists of autonomous devices which are distributed spatially and use sensors to monitor the physical or environmental conditions. These autonomous devices are the nodes. Nodes combine with routers and gateways to form a typical WSN system. A sensor node is capable of gathering, processing, storing and transmission of data which is acquired from its environment. The limitations of sensor nodes such as less memory, slow processing speed and increased energy consumption will affect the lifetime of the network. In order to reduce the energy consumption on nodes, divides the original messages into small sub packets and the network will forward only small packets. For doing so we are using Chinese Remainder Theorem (CRT) algorithm which is [14] the simple modular division between integers. When the sink nodes received the sub packets they will recombine them and thus obtain the original message. The splitting procedure is more useful for the forwarding nodes. To reduce the complexity of the method almost all nodes will work with classical forwarding algorithm while the sink node with some low complex arithmetic operations.

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II. RELATED WORKS

In WSNs the most important things that we have to consider is energy saving, reliability, and complexity. With regards energy saving, two main approaches are: duty cycling and in-network aggregation; see [2] and [10] respectively. In the first method put the radio transceiver in the sleep mode or in power saving mode when there is no communication. Although it is the most effective way to reduce the energy consumption, a sleep/wakeup scheduling algorithm is needed which results in expense of an increased node complexity and network latency. The second approach aimed to merge routing and data aggregation techniques and targeted to reduce the number of transactions. In order to improve sturdiness, multipath routing algorithms are commonly used. Multi paths could consume more energy than the shortest path since the copies of the same packet could reach the destination [4]. The use of a multipath approach together with eradication codes to increase the reliability of a WSN has been described in [9].In that work, the authors suggested the use of disjoint paths. When compared to our proposed forwarding technique, using disjoint paths has two main drawbacks. First, a route discovery mechanism is needed. Second, as the number of disjoint paths is limited, the number of splits (and therefore the achievable energy reduction factor) is limited as well. Furthermore, in [9], the authors considered general Forward Error Correction techniques without investigating their specific complexities and/or their impact on energy consumption. In [7], the authors have proposed a protocol called ReInForM (Reliable Information Forwarding using Multiple paths in sensor networks). The idea in this paper is the introduction of redundancy in data to increase the probability of data delivery. It is achieved by sending multiple copies of same message through different path to the destination. In [12] we can see that, multiple paths could remarkably consume more energy than the single shortest path because several copies of the same packet have to be sent. Moreover, in all the papers discussed, the authors do not consider the splitting procedure as a method for reducing energy consumption. A detailed study regarding packet splitting procedure by maintaining the reliability and minimizing the energy consumption has been made in [8]. As in [9], the authors use distinct paths and erasure codes to provide reliability in the network. However, the algorithm proposed is a centralized one based on convex programming and is not suitable for WSNs. This paper shows that with a by moderate increase in the overall complexity and with very low overhead by using CRT as compared to the commonly used forwarding techniques, both reliability and energy saving can be achieved.

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And also to increase the number of possible next hops that a node can use as forwarder.

III. BACKGROUND DETAILS

Consider a wireless sensor network in which the sensor nodes periodically send messages to a sink node through a multi hop transmission. Our basic aim is to split the messages sent by the source nodes for reducing the number of bits transmitted by each forwarder node.

For the better understanding, let us consider the example in Fig. 1. Nodes A and B have to forward a packet to the sink S and can do it through nodes X, Y, and Z, which are all in the coverage range of A and B.

Two cases can be considered in normal forwarding .Either A and B select different next-hops nodes with probability 2/3 [Fig 1(a)] or same next-hop node with probability 1/3[Fib 1(b)].If the number of bits in a packet is *w* then the maximum number of bits transmitted by the nodes is *w* in the first case and 2*w* in the second case. Let us now assume that each node in the set {X,Y,Z} knows that A and B have three possible next-hops and that a different forwarding scheme is adopted, as shown in Fig. 1(c).When X, Y, and Z receive a packet, they split it and send to the sink only a part with *w*/3 bits each. Here X, Y, Z has to transmit at most 2/3*w* bits each. So the reduction factor is 1-2/3 = 1/3 by first case and (2-2/3). ½ = 2/3 in the second case. So an average reduction factor of 4/9 is obtained.

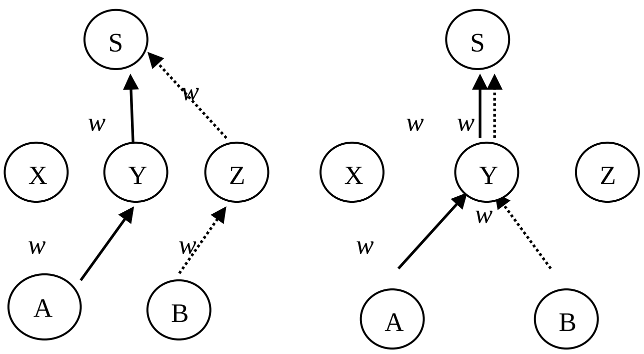
From this example we are able to understand that the total amount of transmitted bits does not change by splitting the packet. By splitting we can decrease the maximum number of transmitted bits per node and the energy for each transmission. Life time of the sensor network gets increased as the energy consumption is distributed among nodes.

IV. CRT-BASED FORWARDING TECHNIQUE

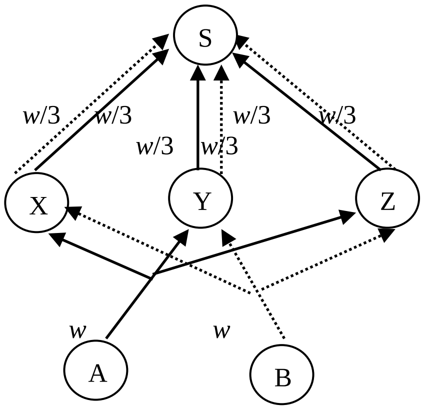
In this section, we briefly outline the CRT and show how to use it to implement a new forwarding technique that is both reliable and energy-efficient.

A. Chinese Remainder Theorem

Basically, in its simpler form, the CRT can be formulated as follows [14]: *Given N primes pi > 1, with i € {1...N}, by assuming M their product, i.e.* $M = \prod_i p_i$ *then for any set of given integers* $\{m_1, m_2, ..., m_N\}$*, there exists a unique integer m< M that solves the system of simultaneous congruence* $m = m_i \ (mod\ p_i)$ *and it can be obtained by* $m = (\sum_{i=1}^{N} c_i \cdot m_i) \ (mod\ M)$*.*



(a) **(b)**



(c)

Fig. 1. Forwarding examples: (a) normal forwarding with different next-hops; (b) normal forwarding with the same next-hop; (c) forwarding after splitting.

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, i.e.* q_i *solves* $q_i Q_i = 1 \ (mod\ p_i)$*.*

For instance, let us consider the system: m = 1 (mod 3); m = 4 (mod 5); m = 1 (mod 7). It is simple to prove that solves the system and that it can be obtained through the above equations (in fact, we have *M* =105; c_1=70, c_2=21, c_3=15, and m=64).

B. Metrics for Energy Efficiency

According to the CRT, if p_i is known and m_i is the set of numbers, then the number m can be identified. In our example which is shown above, *m* can be represented using 7 bits and for m_i , not more than 3 bits. So instead of *m*, m_i numbers with $m_i = m (\text{mod } p_i)$, forwarded and thus the energy consumption in each node is tremendously reduced.

Consider Fig 2 .If node A sends a message *m* to sink s, then the *m* is splitting to m_i where I € {1, 2, 3} and send to sink node. The sink will reconstruct the original message, m by knowing p_i and through CRT approach. Consider that the energy consumption is proportional to the maximum number of bits transmitted .Assume the number of bits transmitted by *m* is *w and* $w_{CRT\ max}$ is the maximum number of bits of the CRT component.

$$W_{CRT\ max} = \max(\lceil \log_2(p_i) \rceil) \quad (1)$$

Theoretical maximum energy reduction factor (MERF)

$$MERF = (w - w_{CRT\ max}) / w \quad (2)$$

In the previous example, MERF = 7-3 / 7 ≈ 0.57.This shows that energy can be saved about 57 % by using the proposed forwarding scheme.

When the CRT components, m_i are forwarded by different nodes, the previous energy reduction factor is obtained. But in real situation the CRT components are not always forwarded through dissimilar paths. Maximum Energy Reduction Factor is rarely obtained and the Expected Energy Reduction Factor is obtained by taking the actual number of bits forwarded by a traditional forwarding algorithm and our proposed CRT-based forwarding algorithm.

We are using Shortest Path algorithm (SP) with Load Balancing for comparison purposes. This is same as that of probabilistic routing.

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The number of hops is minimised by selecting neighbour node towards the sink. Load balancing also helps to retain the network life time. We consider that an SP packet is composed by K words of bits each and that the CRT-based splitting procedure can be applied to each word by considering that the same prime number is used for all the words of the same packet.

C. On the Choice of the Prime Numbers

It is important 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. As a result, the MERF is maximized. And the overhead due to the MAC layer overhead also discussed. All the words in the i th packet generated by the splitting procedure are represented with the same number of bits (i.e. $\lceil \log_2(p_i) \rceil$), and therefore their length can be obtained from the prime number used to split the packet.

Using this hypothesis, by considering the mean energy consumed by a node the expected energy reduction factor can be calculated. By CRT and SP forwarding technique:

$$E_{CRT} = n_c\, k\, w_{CRT} \,.\, €b \text{ and } E_{SP} = n_p\, k\, w \,.€b \qquad (3)$$

Where n_c and n_p are mean number of forwarded packets. w_{CRT} is the mean number of bits and €b is energy needed to represent CRT component.

Energy Reduction Factor can be defined as

$$ERF = (E_{SP} - E_{CRT}) / E_{SP} = 1 - (n_c\ w_{CRT} / n_p\ w) \qquad (4)$$

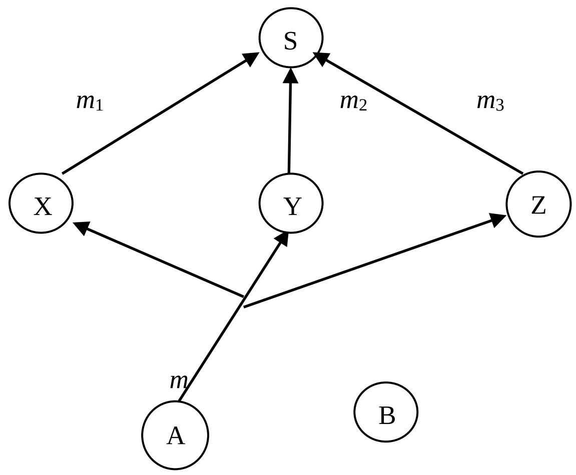

Fig 2 Forwarding after splitting

Minimum Prime Set (MPS) is a set of smallest consecutive primes that satisfy the condition $M \geq 2^w$. If N=4 and m is a 40 bit word then MPS is {1019, 1021, 1031, 1033}. MPS - f is the Minimum Primes Set with admissible failures.

D. Forwarding Algorithm

In a sensor network, sensor nodes periodically send messages to a sink using multi hop transmission. In this paper we split the message send by the source node in order to reduce the number of bits transmitted by the forwarding nodes.

The forwarding algorithm has two temporal phases. The initialization phase and the forwarding phase.

1) Initialization Phase

This phase organizes the network in clusters and has the advantage of minimizing the number of hops needed to reach the sink. The *Initialization phase* has been described in detail in [5], and it is realized through an exchange of initialization messages (IMs) starting from the sink that is supposed to belong to the cluster 1, i.e. CL_{ID} =1 where CL_{ID} is the cluster number. Each node that receives an IM from its neighbours with a sequence number SN= h, will belong to cluster h. It then retransmits the IM with high SN and its own address. At the end of the procedure each network node will know its own next-hops on the basis of the received IM. The computation of MPS-f is shown in Fig 3.

Each node will get the MPS –f after initialization phase and select different prime numbers of MPS –f by taking the order of address specified in the IM. w, f and N are sufficient to obtain MPS-f. Number of next possible hops can be determined on the basis of N. For each source node X, N is different .So it can be represented as N_X. For example see F igure 4

MPS-f for each node, N_X is unique. So there is no need for the sink to receive prime numbers which is used to split the packet. It requires only the number of component i for each m_i to reconstruct the original message. For doing so we assume a field called *mask* in the header of each packet. It is actually the binary representation of the index i followed by number of components ie,(i, N_X). The overhead of *mask* is ignorable. So we consider that a *mask* is of few bits while a packet consists of several words of w bit each.

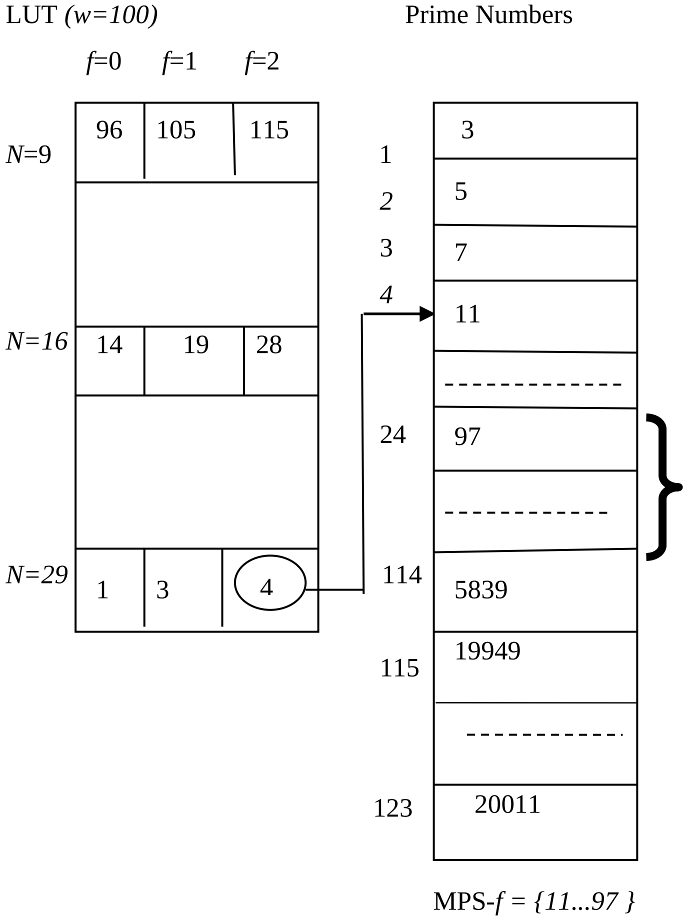

Fig 3: Computation of MPS-f

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In some cases we can further refined the initialization procedure to increase the number of possible next-hops that a node can use as forwarders.

(c)

Fig 4. Initialization procedure (a) Sink sends the first IM. (b) Nodes X, Y, and Z belong to CL_{ID}= 2. (c) Node X knows that A will use X and Y as next-hops and therefore that all packets originated by A can be split in N_A=2parts.

Fig 5. Comparison between (a) the original Initialization procedure and (b) the modified one. The neighbours of the node Y have been increased.

A node will not join to cluster *h* as soon as it receives a very few IMs with SN=h. It waits for IMs with next sequence number h+1 .The modification done can be explained using Fig.5. Consider node Y. In conventional initialization method, Y will receive IM with SN = 3 from node X and belongs to CL_{ID} = 3.[See Fig 5(a)].And now Y have only one next – hop, the X node. The reason is that Y is at the end of coverage range of nodes with CL_{ID} =2.

In our proposed method, then Y receives the IM with SN=3 it does not suddenly joins to CL_{ID} = 3.It waits for some time and receives two new IMs with SN=4 from nodes A and B. Thus belongs to CLID=4 and achieves two possible next-hops. In order to avoid the tremendous increase of the number of hops to reach destination, a threshold value is maintained. It is either specified in IM or stored in the node memory. So the node can receives number of IMs less than that of the threshold value. And it is also possible to use any shortest path approach for sending packets to the sink.

When the network set up is made and network is activated, the initialization procedure is done only one time. There is no need for repeating the procedure when a new node joins the network or a node runs out of energy. When these two conditions occur, few IMs are exchanged between the nodes and neighbors belong to the nearer clusters. This process is described in [5].

Each node can start a new joining procedure when there is a loss of IM packets or the number of neighbors is insufficient. The ultimate aim is to maintain the reliability of the channel.

2) Forwarding Phase

Forwarding phase is applied when the network has been organized. Basically, all nodes follow the same forwarding rule: *If* there is a number of neighbours at least equal to, and the packet has not previously split, *then* split the packet; *else* use conventional shortest path approach.

Consider the network shown in Fig 6. The figure shows a clear idea of transmitting the message *m* from the source node H to the sink node S. Node G knows that it is the only one next-hop of node H by initialization procedure. So it forwards the packet without any split. During initialization phase, nodes {C,D,E,F} have already received the IM message , IM : [SN=5, G,{C, D ,E ,f}] and they are able to know that node G has four next-hops and thus splits the message received from G into N_G=4 parts. After receiving the packet, they deliberately selects the prime numbers and send the component $m_i = m(mod\ pi)$ to the next-hop with proper *mask.* When the sink receives m_i, it examines the *mask* and identifies the expected components. Then calculates MPS-*f* and C_i , the coefficient for reconstructing the original message by $m = \sum_i C_i\, mi(\text{mod } M')$.

V. CONCLUSION

In this paper an analytical model for a proposed algorithm based on Chinese Remainder Theorem has introduced. Because the energy consumption per node is proportional to the amount of bits received and subsequently forwarded, by applying the proposed technique it is possible to reduce significantly the energy consumed for each node and consequently to increase the network lifetime of the wireless sensor network. The number of next – hops is also maintained by refining the initialization procedure.

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