Energy Aware Adaptive Image Transmission Scheme with Data Authentication in Wireless Sensor Networks

Alice Abraham, Narendra Kumar G

Department of Electronics & Communication
Bangalore University
Bangalore, Karnataka 560001, India

Abstract

Wireless Multimedia Sensor Networks (WMSNs) are gaining research interest due to the availability of low-cost cameras and CMOS image sensors, also due to their broad application opportunities. The energy and resource constrained environment of WMSNs calls for low complexity energy aware image authentication and transmission schemes with minimal overheads. The proposed scheme enhances the data security with stream authentication while minimising the energy utilization for the authentication as well as transmission by adopting a preferential transmission based on the importance of the data packets in the code stream. Inherent correlation among neighbouring pixels in an image and the multi resolution capability of wavelet coding is exploited to propose an adaptive priority based image authentication and transmission scheme. Simulation results show an encouraging and improved energy efficiency without compromising reconstructed visual quality.

Keywords: *DWT; scalable; stream authentication; WMSNs.*

1. Introduction

Wireless sensor networks are maturing as an application area in the real world with advancements in hardware and technology research. The availability of low cost and small sized image sensors have increased the domain of applications of these networks. The application domains of Wireless Multimedia Sensor Networks (WMSNs) [1] are very wide: they range over multimedia surveillance systems, traffic monitoring and control in urban/suburban areas, support to military and/or anti-terrorism operations, tele-medicine, assistance to disabled and/or elderly people, environmental monitoring, secure localization of services and users, industrial process control.

The design of a WMSN has many challenges and needs expertise from a variety of research areas. Multimedia source coding, high bandwidth demand, application specific QoS requirements, energy consumption, coverage resource constraints, variable channel capacity etc[2]. The resources requirements for transmission of multimedia data include higher buffering, bandwidth, battery consumption, and processing, in comparison with WSNs that measure and transmit scalar data.

There are stringent constraints for deployment of sensor nodes : in addition to these sophisticated components, the sensor nodes should be small sized , extremely power-conscious, operate in high density, be autonomous and unattended, and be adaptive to the environment. Of these the main concern is the energy consumption. For most applications, the WSN is inaccessible, or it is not feasible to replace the batteries of the sensor nodes. Energy harnessing from the environment, like using solar cells, are some options but the amount of energy that can be extracted is limited. As the battery powered sensors have limited energy supply, minimizing the energy consumption can extend the lifetime of the network.

Compared with traditional WSNs, multimedia data in wireless image sensor networks require sophisticated processing and transmission techniques to meet the limited energy budget. Wireless image sensor networks also require larger bandwidth for transmitting image data. Minimizing average energy consumption and maintaining a good quality of service (QoS) are contradictory objectives. Mechanisms to efficiently deliver application level QoS and to map these requirements to network layer metrics such as latency and jitter need to be addressed.

The primary application of WMSNs is surveillance and an important requirement of such applications is security. Security is required to protect sensor data against unauthorized access and modification to ensure the availability of network communication and services in spite of malicious activities. In a severely a resource constrained set up like the WMSN, novel methods are required to ensure security and authentication of data while minimizing the computation and transmission overheads.

The design of the sensor network is dependent on various variable factors in real word applications. The transmission media is variable and unreliable in most cases. The sensor data itself may have variable levels of importance with some information requiring guaranteed delivery while others having reasonable tolerance to loss. Again, at different phases of the lifetime of the network, for example during an event, the number of packets that have to be transmitted will vary in density. Adopting adaptive algorithms for the protocols to cater to this variation will lead to an intelligent use of the scarce network resources.

The focus of this paper is on point-to-point image transmission over wireless image sensor networks that minimizes energy consumption given the expected distortion constraint with optimal delay using a priority based transmission of the packets with priority based security based on the variable importance of information in the packets.

The remainder of the paper is organized as follows. Section 2 reviews related work in the area of image transmission in WMSNs and Section 3 gives a brief background to this work. Section 4 describes system model while the algorithm for the proposed scheme is given in Section 5. Section 5 also presents the performance analysis and simulation results and Section 6 concludes the paper.

2. Related Work

As sensor nodes are mainly characterized by their limited energy, computation, bandwidth, storage resources of sensor nodes, coupled with the high complexity of multimedia compression/elaboration algorithms and security handling techniques poses new challenging research issues, which are vital for a wide spread application of WMSNs

WMSNs are generally used for surveillance applications, intrusion detection, environmental and building monitoring, etc. These applications imposes additional challenges such as energy-efficient in-data processing both within node and in-network, bandwidth and rate adaptation to overcome the variations in networking conditions, Quality of Service (QoS) delivery to meet application specific requirements and routing and selecting appropriate paths for continual delivery of multimedia streams. Due to the distributed and dynamic nature of these types of networks, the design of a critical information infrastructure based on a WMSN raises many other challenges such as ensuring confidentiality and the integrity of the data stream, providing the means for node

The peculiarity of multimedia imposes challenges for

energy efficiency through the MAC protocols. The main cause of packet loss in sensor networks is through packet collisions and subsequent retransmissions, overhearing packets destined for other nodes, idle listening where the transceiver is in an active state without having to participate in data transfer. Many contention-based protocols have been developed for WSNs with the primary aim of reducing the energy consumption but at the cost of latency and through put degradation. However any design for energy efficiency in WMSNs will have to maintain strict bounds for throughput degradation or latency. This calls for a need to provides variable output rates that depend on the data content. The MAC layer provides many capabilities for efficient communication in WMSNs. TDMA based schemes [3], multi channel protocols [4,5,6,7] etc. However, a potential challenge in multi-channel design is the requirement of a distributed channel assignment protocol and the delays in switching to different channels.

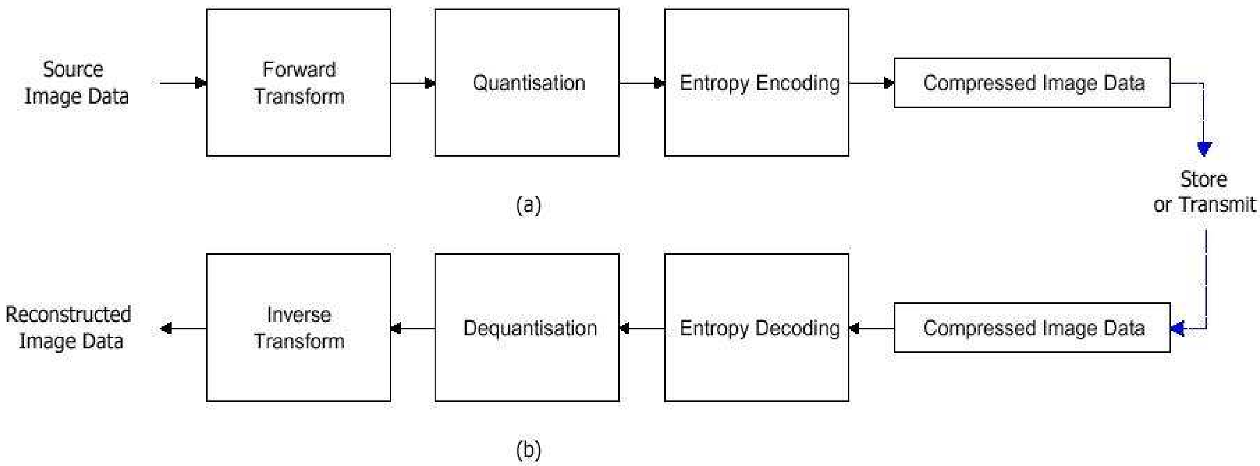

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Fig 1: Block diagram of the JPEG2000 (a) encoder and (b) decoder protocols in WSN is given in [8]. A large number of research works exists to enable energy efficient routing in WSN. The concerns of routing in WSNs differ from the requirements in WMSNs. The latency requirement and the upper bounds on delays in data delivery in a multimedia streaming application call for accurate considerations of network conditions and the traffic classes of the data. In higher layers of the communication protocols stack, performances evaluations of routing protocols for WMSNs have led to multipath routing approach to maximize the throughput of streaming multimedia traffic. This is to utilize diverse paths to route packet streams towards the destinations in order to avoid draining the energy of nodes along a specific route. In [9] the authors propose a multipath routing protocol based on the well known routing protocol Directed Diffusion [10] that reinforces multiple routes to ensure high quality in the links with low latency. In [11] the authors focused on selecting and fixing the multiple paths in multipath routing in WMSNs. The authors then propose a multipath routing mechanism in order to provide a reliable transmission environment with low energy consumption by utilizing the energy levels and signal strength of the received packets to identify multiple routes to the destination.

In [12], the author addresses the problem of interfering paths in a WMSN and considers both intra-session as well as inter-session interferences. The paper proposes an incremental path creation mechanism where additional paths are set up only when required (typically in case of congestion or bandwidth shortage).

Security issues in WMSNs are briefly surveyed in [13] and the paper suggests that denial of service (DoS) is the main challenge that WMSN security will require to address. The research in the area of security in WMSNs is limited. scalability of image data during compression/processing and transmission is an important area of research. A quality driven energy efficient dynamic resource allocation scheme with stream authentication is proposed in [14] that uses the unequal importance of image data in a code stream to allocate quality levels to the data and allocate the network resources. This work follows the scheme proposed by Wang et al., by keeping energy efficiency as the top priority while proposing a more simplistic, low complexity network transmission that enhances the lifetime of the network and minimizes potential draining of energy at the intermediate nodes through a priority-based forwarding of packets.

Czarlinska and Kundur [15] proposed a novel paradigm for securing privacy and confidentiality in a distributed manner thereby achieving a low complexity processing and communication. In [16], Mulugeta et al. propose a secure routing protocol that builds on the TGPF protocol for sensor networks.

3. Background

Most images have an inherent correlation among neighbouring pixels and therefore contain redundant information. Image compression aims to remove the spatial and spectral redundancies in an effort to minimize the data-size. J-PEG 2000 is a preferred standard for still image compression. It uses discrete wavelet based coding that has proved to be highly robust during transmission with negligible decoding errors, and most importantly, facilitates progressive image transmission.

An image can be partitioned into γ resolution levels by applying the DWT (γ-1) times. Packets containing the image header and the lowest resolution are the most important to reconstruct the image and is assigned the highest priority. They have to be reliably received by the receiver in order to be able to rebuild a version of the captured image. Because of their inherent multi-resolution ability wavelet coding schemes are chosen for applications where scalability and tolerable degradation are preferred.

A. J-PEG 2000 Image Coding: An overview

This work considers J-PEG 2000 [17], a variable rate image compression scheme that uses DWT encoding and allows both lossy and lossless compression. The compression ratio can be controlled by the decomposition level and the quantization level. J-PEG 2000 uses DWT to transform an image into resolutions and sub-bands, followed by quantization. The quantized coefficients are arranged in code-blocks.

The quantized coefficients are coded in two tiers. In tier-1 coding, each code-block is encoded independently. The coefficients are encoded in bit-planes beginning with the most significant bit-plane all the way to the least significant bit-plane to generate an embedded bit-stream. Leaving the most significant bit-plane, all other bit-planes are split into three coding passes where the information that results in the maximum distortion reduction will be encoded first. Tier-2 coding introduces additional structural elements. A brief description of the concepts and terminology related to JPEG2000 codestream [18-20] is provided below to impart an understanding of the scalable quality adopted in this paper without dwelling too much into the details. A JPEG2000 image codestream is organized hierarchically the following structural elements - tiles, components, tile-components, resolution levels, precincts, layers, and packets

Tiles: JPEG2000 allows an image to be divided into smaller rectangular non overlapping regions known as tiles ,that can be compressed independently as if each is a small independent image. Tiles are used to partition the image data into spatial regions. TO keep things simple, without loosing generality, only single tile codestreams are considered in this work.

Components: An image can consist of more than one component. For example the RGB image has three component in the color space, such as R, G, B, representing the red, green and blue color planes.

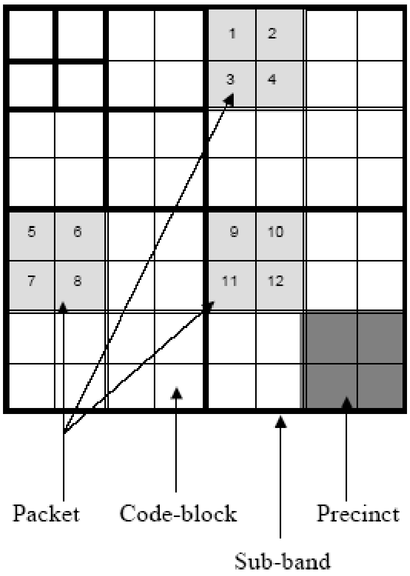

Fig 2: JPEG 2000 code blocks and partitions in JPEG 2000.

Resolution : Given a tile-component, a multiple-level dyadic wavelet transform is performed. The first wavelet transform decomposes a tile-component into four sub-bands *LL1;LH1;HL1;HH1* where *LL1* is the lowest frequency subband. The second wavelet transform decomposes *LL1* into another four sub-bands *LL2;LH2;HL2;HH2*. Applying the wavelet transform continuously on each *LL* sub-band generates a series of sub-bands belonging to different transform levels. A $(n_r\ -1)$level wavelet transform generates nr sets of sub-bands, denoted as *R0 = {LLnr-1}, R1 = {LHnr-1;HLnr-1;HHnr-1 ..Rnr-1 = {LH1;HL1;HH1}. Ri* is the resolution level i.

Resolutions: The sub-image constructed from R0 is a small "thumbnail" of the original image. The sub-image constructed from R0 and R1 together is a bigger "thumbnail" of the original image. The sub-image constructed by R0, R1 and R2 is an even bigger "thumbnail" of the original image. Continue like this, it is possible to get a series of "thumbnails" and the last "thumbnail" is the original image, which is constructed from R0, R1... Rnr¡1.

Layers: Following wavelet decomposition, wavelet coefficients are quantized and each quantized subband is partitioned into smaller rectangular blocks, known as code blocks. Each code block is independently entropy encoded to create4 a bit stream, distributed across n_l quality layers. Layers determine the quality or SNR of the reconstructed image. To put it in simple terms, a higher quality image requires more bits for each pixel representation than a lower quality image. If L_0 represents the codestream data required to form a layer 0 image, and L_l represents the addition code stream data required to form the layer l image, where L_0, L_1 L_{l-1} , $l= 0,1,2\ldots n_{l-1}$. That is, a layer L image is formed from $\{L_0, L_1, \ldots L_l\}$, where image of layer , n_{l-1} is the original image.

Precincts: Each resolution of a tile-component is partitioned into several rectangle regions, called precincts. Precincts are used to make it easier to access the wavelet coefficients corresponding to a particular spatial region of the image. If a resolution level is partitioned into n_p precincts, then these np precincts are denoted as $P_0, \ldots, P_{n-1}$.

Packets: Packets are the fundamental building blocks in a JPEG codestream, It comprises the compresses bitstream from codeblocks belonging to a specific component, resolution, layer and precinct. The original image is first decomposed into components . Then a dyadic wavelet transform is applied to each component. The figure 1 shows the steps involved in a wavelet transform and compression. The wavelet transform produces the subbands corresponding to various resolutions. Each subband is quantized and decided into codeblocks. Spatially contiguous code-blocks in subbands of a resolution form a precinct. Each code-block is encodes separately into compresses bit streams that may be distributed into quality layer increments. Finally , the compressed bits from the same component, resolution, precinct and layer are encapsulated.

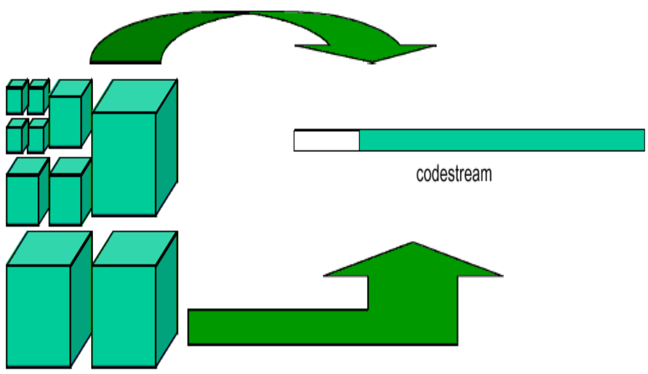

Fig 3: Different modes of scalability can be realized by way in which the information is written onto the code stream.

Table 1: The pseudo code for ordering of packets under the progression order LRCP.

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for each l = 0, ... , nl - 1 // nl is the number of layers
    for each r = 0, ... , nr - 1 //nr is the number of resolution levels
        for each c = 0, ... , nc - 1 //nc is the number of components
            for each p = 0, ... , np - 1 //np is the number of precincts
                arrange the packet for component c, resolution r, precinct p, layer l
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To summarize, the layers enable quality scalability, and each layer includes a number of consecutive coding passes contributed by the individual code-blocks. The precincts are a collection of spatially contiguous code-blocks from all subbands at a particular resolution. All coding passes that belong to a particular precinct and a particular layer

JPEG2000 supports progression in four dimensions, : quality layer, resolution, spatial location and component. A packet in a given tile is uniquely identified by four parameters: C (component), R (resolution level), P (precinct) and L (layer). The packets of an image code stream are sorted with respect to these four parameters in some orders, called progression orders. JPEG2000 allows five orders of progression - LRCP, RLCP, RPCL, PCRL and CPRL. For example, a tile with progression order of LRCP can be constructed by writing the packets using four nested loops as shown in Table 1.

As this work is interested in layer progression, the other types of progression provided by JPEG 200 is not discussed here. In quality layer progression, the image quality is improved when more layer increments are receives at the receiver end. For example, image with the lowest quality is reconstructed from decoding L_0 . Image of the next quality ia obtained by decoding L_0 and L_1. Improving quality is then a simple matter of decoding more bits.

B. Scalable Stream-based Authentication

Due to high redundancy in multimedia data, minor modifications to a code stream may still be considered as authentic in multimedia authentication. Dropping of less important data blocks of a scalable code stream without significant reduction of the resulting perceptual quality is usually acceptable in multimedia authentication. In the context of resource-starved WMSNs, an acceptable authenticated image at the receiver can be that which is decoded exclusively from authenticated packets. The authentication scheme detailed in [7] is adopted in this work and is briefly recounted below.

After the original image is encoded, the sender signs the resultant code stream by constructing an authentication graph. Each J-PEG-2000 packet has at least one path destined at the signature packet. Considering a subset of packets in the code stream, one of the packets P_{sig} is denoted the signature packet and it is signed with a public key algorithm such as RSA.

The authentication scheme is a directed graph without loops and n packets. We denote a directed edge starting at node i and ending at node j, by $\vec{e}(i, j)$. If $\vec{e}(i, j)$ is present in the graph, then the relationship between packets P_i and P_j can be described as follows: if both the contents and source of P_j can be authenticated, then the receiver is capable of verifying the source and content of P_i. Packet P_i can be authenticated if it has a path to the signature packet. The redundancy degree of the packet Pi is the number of edges coming out of Pi. In particular the redundancy degree of the signature packet is zero. The authentication probability of a packet is directly proportional to the redundancy degree of the packet. The authentication probability is also proportional to the overheads incurred for each redundancy exercise It was mentioned in the previous section that there is a variation in importance of packets in the code stream generated after DWT. The overheads incurred for authentication of the image can be minimized by having a scalable authentication of the packets based on this difference in importance levels.

The image packets can be differentiated into two priority levels based on the importance level of the packets. This is besides the signature packet which is allocated the top priority. In the proposed scheme it is critical and assumed that the signature packet is always be received. Therefore the authentication probability of the signature packet is 1.

The first packet in the stream (signature packet and the packets in the higher priority are placed in level L_0 and the packets in the lower priority level are placed in L_2. The edges of packets in level L_1 always terminate in the signature packet. Since it is assumed that the signature packets are always received, the authentication probability of received higher priority packet is also 1. Packets in the lower level always terminate only in packets in level L_1 which means that the hashes of the lower level packets are placed into the higher level packets. The loss of any L_0 packets will lead to the failure in verifying some L_1 packets but it will not be particularly detrimental to the visual perception of the image since these are packets allocated a lower priority.

C. Energy Aware Priority based Transmission

Once raw data of the captured image is encoded, stream authenticated and packetized into different priorities, the packets are ready to be sent. The sender transmits the packets starting with those of the higher priority and then continues to the next priority and so on. Since it is not mandatory to receive all the priority levels at the base station except the basic level zero , in order to recover the image, packets of the subsequent priority are forwarded by the intermediate nodes only if the energy of the path is above a given threshold. This concept of semi-reliable image transmission through priority based packet discarding by intermediate nodes based on their battery-state-of-charge has been proposed in [22].

While the hop-by-hop transmission is handled as reliable, i.e., the data packet is always acknowledged and retransmitted if lost, the end-to-end transmission is semi-reliable,i.e., the intermediate node decides to forward or discard a packet according to the battery state-of-charge and the packet priority. This is carried out using a threshold based drop scheme where each of the *p* priority levels is associated to an energy level q_1, q_2 ..., q_{p-1} subject to $q_l \in [0, 1[$. By governing the energy threshold for the different priority levels, the network can choose to promote energy saving orfavour image quality. Values for *q* closer to zero will allow the intermediate node to forward more packets.

When a packet is forwarded by the sender, the packet header will have two additional two pieces of information: the priority level of the packet and the total number of priority levels. The intermediate node takes a decision to forward or discard the packet based on this information in addition to the information it has about its energy level as well as the energy levels of the next nodes relative to the energy thresholds. This information is gradually built up from received acknowledgement packets. Thus the intermediate node is able to anticipate the decisions of the next nodes and discard packets itself, if they are likely to be discarded down the path by a node with insufficient energy.

4. System Model

Considering a multi-hop wireless sensor network with cam era sensors nodes and a base station, it is assumed that all sensor nodes have the same initial energy and processing and communication capability. The available energy in a node is assumed to remain the same during the transmission of a complete image. The base station is not limited by energy and has the highest ability of communication and computation. A node responds to a query by generating a fixed size raw image (eg: a snapshot of its sensing area), compressing and encoding the raw data using the image compression and authentication algorithm to be transmitted to the base station. When sending the query, the base station specifies the desired PSNR (distortion level) based on the network conditions. A sensor generates *k* bytes of raw image data after receiving a query from the base station. The sensor compresses this image at wavelet transform level *L* to achieve compression ratio βL.

The code stream is divided into different priority levels based on the importance of the information in the packets that are transmitted after assigning them a digital signature and hash edges based on the assigned priority levels.The communication energy is evaluated in terms of the energy consumed for transmission between nodes similar to the way suggested in [22].

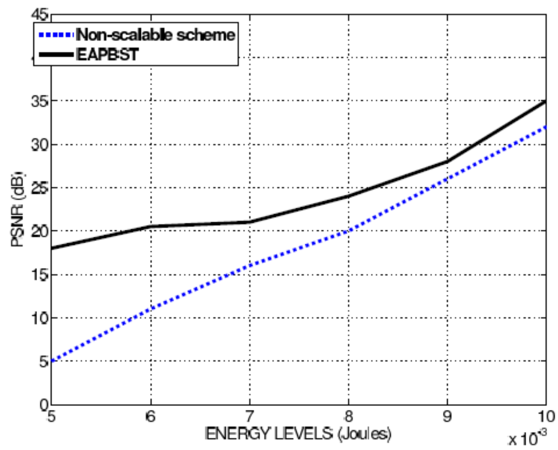

Fig. 4. Graph showing the distortion response in relation to energy budgets

5. Simulation and Performance Analysis

The proposed scheme was simulated in MATLAB to compare the algorithm with a non scalable authentication and transmission algorithm based on the performance metric of energy consumption. The algorithm of the proposed scheme is given in Table 2. A 256x256 pixel Lena image is used to evaluate the the algorithm. Three image quality layers are embedded in the coded stream and the progression order

LRCP in J-PEG 2000 is adopted. Crypto-hash function SHA is used for hash links and the digital signature is of 128 bytes. MAC header is 11 bytes and payload is 36 bytes. The receiver power is fixed to 0.20mW and the symbol rate is 1000 KHz. The energy consumption in relation to the distortion levels in the proposed scheme is compared to a non-scalable authentication scheme for the same compression ratios in Figure 4.

Table 2: EAPBST Algorithm for image transmission and reconstruction at the user end.

At Sender Node

Perform 2D DWT on the image

Partition packets into r-sized priority classes, each of z-packets.

Add image identification number, data offset,

packet priority level, total priority levels to packet header.

For level $i = 0$ (high priority packets) Do

Packet $1, j = 1$, is the signature packet, no edges originate

out of node Si, j

For Packets $j = 2, 3 ..., k_{(0+1)}$ add edge $\vec{e}(s_{i,j}, s_{i,j-1})$

For Packets$j = k_0 + 2$, ..., z, add edge $\vec{e}(s_{i,j}, s_{i,j-1-k_0})$

For level $i = 1, 2 ... r$ (Lower priority packets)do

For Packets $j = 1, 2, 3 ... k_i + 1$ add edge $\vec{e}(s_{i,j}, s_{0,j})$

For Packets $j = k_i + 2$, ...,z, add edge $\vec{e}(s_{i,j}, s_{0,j})$

and edge $\vec{e}(s_{i,j}, s_{i,j-k_0})$

At Intermediate nodes

For node $m = 2, 3 ... n$

For level $i = 0$ Do

For packets $j = 1, 2 ... z$ forward packet, build look up table

on energy levels of nodes in the path

End for

For levels $i = 1, 2 ... r$

For packets $j = 1, 2, ... z$

If $q_{th} \leq min(q_n)$ then FORWARD packet, update table

End for

End for

End for

At destination node

Verify packet and order using the image identification number,

and data offset. For missing packets insert zero. Apply I-DWT.

At lower energy budgets the PSNR is higher by adopting scalable authentication and energy aware aware forwarding of packets in the network for the same distortion levels.The energy savings in the proposed scheme are obtained by avoiding forwarding of packets that may be lost further down the route. The image quality can be governed by fixing Fig. 2. Graph showing the distortion response in relation to energy budgets the expected PSNR value and the energy threshold of the intermediate nodes.

5. Conclusions

This work has examined the energy saving and distortion levels when a priority based image stream authentication and transmission scheme is implemented for a wireless sensor network. It unifies earlier works on JPEG 2000[17], scalable authentication by piggybacking, [21], and scalable semi-reliable transmission [22,23] to propose a low complexity implementation where the bit overhead for the authentication scheme and resources utilisation are minimal, ensuring an all-round saving on the energy expenditure. The simulation results show that the network lifetime is much enhanced when compared to a non-scalable non-priority based WMSN especially with tight energy budgets, without perceptive loss in visual quality of the image.

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Alice Abraham, is a graduate in Electrical Engineering and a post graduate in Power Electronics , both from University Visvesvayraya College of Engineering, Bangalore, India. Currently a research scholar in Bangalore University in the Department of Electronics & Communication, she is actively involved in research in the areas energy efficiency and applications of wireless sensor networks under the guidance of Professor Narendra Kumar G .

Dr. Narendra Kumar G, Obtained Masters Degree in Electrical Communication Engineering, (Computer Science & Communication) from Indian Institute of Science, Bangalore, Karnataka, India in 1987. Was awarded PhD in Electrical Engineering(Computer Network) from Bangalore University, Bangalore, Karnataka, India in 2006. Currently Professor in the Department of Electronics & Communication Engineering, University Visvesvaraya College of Engineering., Bangalore University, Bangalore, held the positions of Associate Professor, Lecturer and Director of Students Welfare. Research interests include Mobile Communication, Wireless Communication, E-Commerce, Robotics and Computer Networks.