Energy Aware and Adaptive Cross Layer Scheme for Video Transmission over Wireless Sensor Networks

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***Abstract*—Wireless Multimedia Sensor Networks (WMSNs), is an ad-hoc network of wirelessly connected sensor nodes that allow retrieving video and audio streams, still images, and scalar sensor data but such sensors are limited in energy, memory, communication and computational power. Multimedia transmission over WSN is a challenging task due to QoS guarantees such as huge amount of bandwidth, strict delay and lower loss ratio. Recently cross-layer approach adopted by WMSNs shows a promising approach that improves quality of multimedia transmitted over WSNs under different wireless conditions. In this work, an energy aware and adaptive cross layer scheme to transmit multimedia content over WSNs is presented. It provides packet, queue and path scheduling, so that it selects optimal video encoding parameters at application layer according to current wireless channel state, and schedules packets according to its type through an adaptive priority video queue so that less important packets are dropped in case of network congestion. Finally, path scheduling is introduced so that different packets types/priority are routed through different paths with different QoS considering network lifetime. Simulation results show that new scheme transmits video over WSNs efficiently and meets QoS requirements and uses energy wisely to prolongs network lifetime.**

Keywords*— GOP Structure Analysis; cross layer design; Wireless multimedia sensor networks; packet scheduling; Queue Scheduling; Path Scheduling; Energy aware routing;

I. INTRODUCTION

Recently the availability of inexpensive hardware such as CMOS cameras and microphones that are able to capture multimedia contents from the environment has stimulated the development of the Wireless multimedia sensor networks (WMSNs). Which is similarly to WSNs, consist of sensor devices wirelessly connected with each other, however the sensor devices have the capability to capture video and audio streams, still images in addition to scalar data.

Sensor nodes in WMSNs can be distributed over large even remote areas in large number of nodes, which will require that network continue to collaborate even some of nodes died.

It is expected that there will be different multimedia applications [34] with different QoS needs will emerge, such as multimedia surveillance sensor networks [26], building automation [51], agriculture [52] , advanced healthcare delivery [24], automated assistance and family monitors [25] and traffic avoidance [26]. Transmitting multimedia over such type of networks [12] is a challengeable task due to limited nodes capabilities whether in terms of processing, battery lifetime, memory and throughput of the network. In addition, it uses wireless channel for communication, which introduces additional challenges such as multipath fading, high signal attenuation effects, shadowing and interference problems, which results in a fluctuated bandwidth due to link failures and congested packets.

In addition to multimedia QoS guarantees, Network lifetime and fair usage of battery power add additional challenges, due to sensors are battery powered, progress in battery technology shows limited advances and replacing such battery is costly or impossible.

The main goal of routing protocols of WMSNs is to increase throughput and to decrease end-to-end delay. Traditionally single path routing protocols used in other type of networks are not efficient for QoS requirements for video transmission over WSNs. Alternatively, multipath routing [13] handles multimedia transmission more efficiently, as it loads balance traffic over more than one path, which increases bandwidth and reliability, in addition it decreases end-to-end delay, and distributes power consumption in the network. Several work [55-56] avoid any type of multipath coupling effect by analyzing carrier sense range effect on multimedia content.

Cross-layer design [11][14][16][18][23][50] is an interesting approach which handles multimedia transmission over WSNs. Traditional communication layered architectures are organized into a specific layers with specific functionality without sharing or communication between them. On the contrary, cross-layer design solves the global optimization of network performance problem through violating the traditional approach in many different ways such as: direct communication between non-adjacent layers, allowing sharing information across layers, merging adjacent layers or creating new interfaces between layers.

In this work, an Energy Aware and Adaptive Cross-Layer Scheme for Video Transmission over Wireless Sensor Networks is presented. It is an extension of previously introduced [47], so that current scheme includes four main characteristics: adaptive MPEG-4 video encoder, packet, queue scheduling and the main contribution of this work is the proposed path scheduling component.

It is a cross-layer scheme where Application, Network, Data Link and Physical layers communicate to optimize multimedia transmission over WSNs. It shares current wireless channel state with the application layer, so that application layer can use suitable video encoding parameters according to the current state of the wireless channel. Each video packet has different priority so it has different loss effect on video transmitted. For packet loss effect on video transmitted, sink node evaluates and analyzes suitable video encoding parameters to be sent to source node to apply it in different wireless channel states, while for packet priority it schedules packets so that in case of congestion, it replaces already existing and less important packets without affecting video quality. Finally, the new scheme extended to schedule different packet types on different paths according to packet type and suitable path's evaluated score considering network lifetime.

The paper is organized as follows: section two presents a recent survey about cross layer approaches of WMSNs. In section three, the new scheme is presented. In section four, an evaluation of the newly introduced scheme using different simulation scenarios is presented. In section five the paper is concluded.

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II. RELATED WORK

Path scheduling aims to establish path between source and destination node not only using optimal hop count as employed by traditional routing protocols but also using other application QoS metrics such as delay, bandwidth, loss and energy requirements, which depends on application of the WSNs.

Path scheduling in a limited networks such as WSNs depends on various routing metrics [35] where paths are ranked based on congestion, hop count and interference. In [32] a single routing metric (hop count, congestion level, bottleneck of node leisure level and the number of congested nodes) is used, in addition it assigns videos frames according to path congestion status whether to single or multipath. While in this work [15] it selects path suitable for each packet type, where, delay-sensitive packets are routed through fastest path, while error-sensitive packets are routed through the most reliable links, and finally non-constrained packets through least energy paths.

In this work [36] a video transmission scheme which is content aware that schedules different video packets over different paths, so that high priority packets are transmitted through high quality paths. Source nodes send control messages periodically to sink node to exchange state of each routing path, and Sink node collects path status and ranks each path using (energy level, buffer status, hop count and path reliability) and reply back to source node with new path rank, so that source nodes later route packets according to its type through suitable path. Similarly [37] uses Ants-based multi-QoS routing algorithm which ranks paths using (loss ratio, available memory, queueing delay and remaining energy). Other work [38] apply AI technique for scoring paths, it uses link expiration time, probabilistic link reliable time, link packet error rate, link received signal strength and residual battery power to calculate score of each path using fuzzy logic. While this work [39] uses signal strength , remaining energy and available memory to score each path, while in [40] uses drain rate and delay for scoring path, other cross layer protocol [41] uses energy level and free buffer space.

In this work [21] a new communication cross layer architecture is presented for video transmission over WSNs. It is called energy efficient and high quality video transmission architecture (EQV-Architecture). It influences Application, Transport and Network layers of communication protocol stack by introducing new protocol for layer (Modified MPEG for Application layer, new Transport, new Routing and finally dropping scheme). Moreover, it considers sensor nodes constraints like limited energy and processing capabilities without losing video quality at the receiver side. The dropping scheme presented in this work decided to discard packets based on energy level of each node and priority information that had been provided by video compression layer inside the received packets.

In this work [10] a new protocol called CLAR is introduced where its network layer selects optimal route based on Ad-hoc routing DSR protocol. It favors a path, which has a better value of CQI (channel quality indicator) that asses link reliability and stability in physical layer. It uses SNIR (signal to noise interference ratio) of the received signal to estimate CQI and maintains it for each neighbor node using [22] DRMACSN MAC layer protocol. This protocol checks the of number of ongoing transmissions which maintained for each neighbor node before exchanging routing control packets to minimize energy consumption in case bad channel or simultaneous transmissions which exceeded a threshold value.

In [48] a distortion minimization technique is introduced which used a strict energy budget through UEP (unequal error protection) approach by assigning different priority levels according to image-pixel position or value information. It is a position oriented resource allocation scheme across PHY, MAC, APP layers for image transmission over WMSNs. It assumes that communication loss in p-data (position information) which contains structure and position information has significant effect on the overall quality of the received image than v-data (value information) which contains image pixel value information. It depends on wavelets to compress image data at APP layer as it can easily separate position and value information via coding pass partition, it is noted by this work that correct decoding of p-data depends only on correct decoding of previous p-data segment while correct decoding of v-data depends on successful decoding of previous p-data and v-data. Cross layer approach was employed to maximize total distortion reduction and minimize energy consumption using optimization function which considered BER (Bit error rate), ARQ (Automatic repeat request) and data transmission rate as resources for allocation which used for transmitting each p-data and v-data segments.

While previous work focus on multimedia QoS, there are several work [42-43] aim to maximize network lifetime of each node and use battery fairly to prolong time before network partitioned, it recommends to transmit data at the minimum power level to maintain links or dynamically choose transmit range of each node to minimize energy consumption. While other work [44-45] balance energy usage of all mobile nodes by selecting under-utilized route other than shortest path. Other work[46] chooses inactive communication to minimize energy consumption where some nodes are scheduled to sleep to keep minimum number of nodes awaken for transmission while others get sleep to minimize energy consumed while nodes is inactive.

In this work [49] LESOP (Low Energy Self-Organizing Protocol) for target tracking applications in large scale wireless sensor networks deployment is presented, it employs a cross layer approach where both Application and MAC layers cooperate directly while Transport and Network layers are excluded to simplify protocol design. It introduces a new localization algorithm that considers tradeoff between energy consumption and tracking error. It is a connectionless networking protocol, which advocates consolidation of OSI layers headers and improvement of energy efficiency by excluding initial link acquisition and shared routing information. It implemented a new architecture called EWI (Embedded Wireless Interconnect) where only two layers exists, bottom wireless link layer that provides wireless transmission module to the upper system layer which exploits tradeoff between QoS and energy consumption.

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III. Proposed Energy Aware and Adaptive Cross Layer Scheme for Video Transmission over WSN

It consists of three components (Adaptive Video Encoder, Adaptive Priority Queue and Path Scheduling) as will be explained in next subsections. The three components work and communicate together in a cross-layer way to transmit multimedia over WSNs, while overcoming transmission problems like congested packets, fluctuation and failure of wireless link, and limited battery power.

It uses cross-layer communication where Application, Network, Datalink and Physical layer are influenced as shown in Figure.1. At application layer MPEG-4 encoder configures multimedia application encoder using adaptive encoding parameters according to current wireless channel status, which is communicated from physical layer, in addition, to feedback from sink node [47]. Moreover, it apply path scheduling to route packets through different paths according to packet type and suitable path's QoS guarantees. Finally, it uses adaptive priority queue which buffers each packet according to its type which is communicated from application layer, in different priority queues, such priority queues save the higher priority packets in case of congestion and drop less important packets with less effect on video quality.

In the following, each component will be explained as follows:

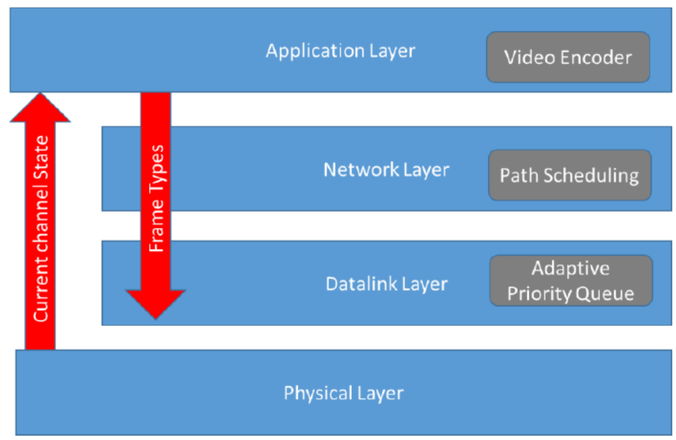

Fig. 1. Energy-Aware and Adaptive Cross Layer Scheme for Video Transmission over WSN Packet Scheduling Component

A. Adaptive Video Encoder Component

Group of Picture (GOP) affects video transmitted over wireless sensor network [7-8], where N and M, which controls the sequence of I, P and B frames. Parameter N controls the I-frame interval while parameter M determines I-Frame or P-Frame interval. I-Frame loss causes distortion to $N + M - 1$ frames; while P-Frame will cause distortion to $\frac{2M+N-2}{2}$ and finally B-Frame contains temporal information and is not used as a reference, their loss only causes motion artifacts and it does not spread errors. As stated in [1, 9] there is a trade-off between the video quality and video file size, where the higher frequency of I-Frame will decrease the error propagation but on the other hand, it will reduce compression ratio of the video that will result in a large video file.

The adaptive video encoder component of the new proposed scheme is based on the analysis found in [47], where sink node periodically sends recommended video encoding parameters, which, are GOP total length (GL) and number of B-Frames (Bf) to source nodes after analyzing video received during previous period in different wireless channel states as explained in [47]. So that different parameters settings can be used by each source node according to the status of wireless channel that can be low to high error loss ratio. It is found in [47] that in case of error free environment or environment with moderate error rate, it is recommended to use larger GL = 5:20 with Bf = 1:2 to obtain better video quality. Whereas in lossy wireless channels with higher error rates it is recommended to use smaller GL = 2:5 and

B = 0 to minimize effect of lost I-Frames which would affect all dependent P/B Frames.

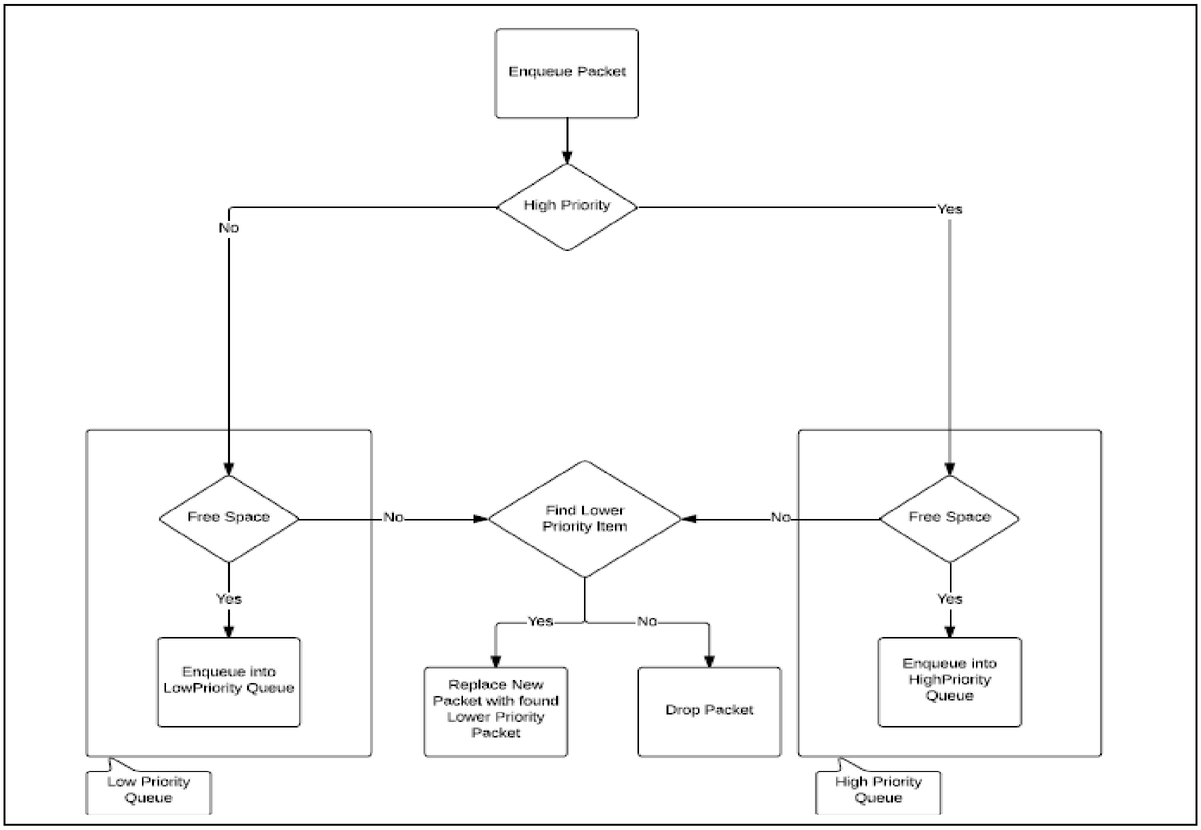

Fig. 2. Adaptive Priority Queue

TABLE 1. ADAPTIVE PRIORITY QUEUE EXAMPLE

EMPTY BUFFER SCENARIO

Q1	Q2	
	Before	**After**
I-Frame1		B-Frame1
		B-Frame2
		P-Frame1
		B-Frame3
		B-Frame4
		Data-Frame1

PARTIALLY FILLED BUFFER SCENARIO

Q1	Q2	
	Before	**After**
I-Framex	I-Framex	
I-Framex	Data-Framex	I-Frame1
I-Framex		B-Frame1
I-Framex		B-Frame2
I-Framex		P-Frame1
I-Framex		B-Frame3

FULL BUFFER SCENARIO

Q1	Q2	
	Before	**After**
I-Framex	I-Framex	
I-Framex	Data-Framex	I-Frame1
I-Framex	B-Framex	P-Frame1
I-Framex	P-Framex	
I-Framex	B-Framex	
I-Framex	Data-Framex	B-Frame1

B. *Adaptive Prority Queue Component*

The new scheme schedules packets according to its priority using a simple adaptive priority queue algorithm [47] as shown in Fig.2. It classifies data packets as less important than video packets, in addition, video packets are further priotorized according to packet type. It consists of only two main queues, one for higher priority packets which are I-Frames in case of video applications and lower priority queue which holds less important packets such as P then B then data packets.

As shown in Fig.2, each incoming packet is classified by application layer then packet type is communicated in a cross layer way to queue component which checks the type of packet and accordingly will enqueue it in higher priority queue or lower priority queue, while at the time of dequeue, it will dequeue higher priority packet then lower priority one. Queue Scheduling Component handles network congestion by keeping higher priority packets and drops less important packets, in addition it may replace already queued packet with incoming higher priority packet as will be explained next.

For example, in case of incoming sequence of packets were I-B1-B2-P1-B3-B4-D1. As shown in Table.1, in case buffers are empty, so normal enqueue order is applied where I-Frame only enqueued into Q1, while other packet types are inserted into Q2. In case of partially filled buffer, while enqueing I-Frame1 found no available space in Q1, so it switches to Q2 and replaced the least priority packet which is Data-Framex then followed by normal order of insertion of reset of incoming packets , while dropping B-Frame4 and Data-Frame1. In last scenario where the buffer is full, Incoming I-Frame1 switched to Q2 as there are no spaces in Q1, then it searched for least priority packet which is Data-Framex to replace it, then incoming B-Frame1 search Q2 for lower priority packet to replace and found Data-Framex. For B-Frame2 it did not find any lower priority packet in Q2 to replace so it is dropped. Next is P-Frame1 which found lower priority packet to replace which is B-Framex. Finally rest of packets did not find lower priority packets to replace so they are dropped (B-Frame3,B-Frame4 and Data-Frame1).

C. *Path Scheduling Component*

The new scheme is a cross layer scheme, where different layers interact with each other, so after identifying packet type at application layer, it communicates it with network layer so that path is scheduled according to packet type. Where higher priority packet will be routed through path with higher QoS guarantees, while lower priority packets will be routed through lower QoS guarantee path.

Path scheduling component is based on AOMDV [28] multipath routing protocol, which routes packets regardless its type, as it uses only optimal number of hops for routing packets; while the new scheme routing protocol which is a modified version of the work presented in [36], which uses path score function (Eq.4) to score each path based on network energy status, available buffer, number of hops and number of lost packets. The new scheme design goal not only considered previous QoS parameters as introduced earlier in [36] to select paths, but also considered power consumed in network as shown in Fig.3, so that it selects paths with least power consumption by default as will be explained in (Eq.4.1) until network energy reserve reaches a predefined energy threshold value, then it switches its decision automatically to select paths with higher energy reserve regardless power consumed. In the following only the modifications done to AOMDV protocol are explained, otherwise the path discovery and maintenance of AOMDV is applied without modification.

1) *Path Score Calculation Phase*

The new scheme introduces new message "Metric-Collection" to AOMDV protocol, which sent periodically from source node and propagated to sink node through different paths as "Forward-Metric-Collection" message, which collects local QoS status of each node and virtual unique id for such node while traversing network through different paths toward sink node. Sink node will evaluate each received message from different paths and generates "Backward-Metric-Collection" message to be sent back through the path which it came from, with a generated unique Id for such path and the calculated global score of such path, so that only source nodes of such path will update its routing table with such additional information to be used later in decision of the routing.

Upon receiving "Forward-Metric-Collection" message at intermediate nodes, each node will update such message with its current energy level if it is less than the minimum energy stored within the message, otherwise no updates as shown in Eq.1, where re is remaining energy of node s along path p.

$$\text{Min.Energy(p)} = \min_{s \in p} re(s) \tag{1}$$

Intermediate nodes, which received "Forward-Metric-Collection" message, will update the message with its current free buffer count if it is less than the minimum free buffer count stored within message, otherwise no updates as shown in Eq.2. Where bf is free buffer at node s along path p.

$$\text{Min.Buffer(p)} = \min_{s \in p} bf(s) \tag{2}$$

Upon receiving "Forward-Metric-Collection" message at intermediate nodes, It accumulates Pw value within the message, where Pw is the total average power consumed during sending and receiving operations of such node as shown in Eq.3. Where Tx is the average power consumed at sending time at node s along path p, and Tr is the average power consumed at receiving time at node s along path p.

$$\text{Pw(p)} = \sum_{s \in p} Tx(s) + \sum_{s \in p} Tr(s) \tag{3}$$

Each message received along different paths at Sink node will be evaluated to calculate score of each path as shown in Eq.4, where $\alpha + \beta + \gamma + \delta = 1$ are the weight factors that represent

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importance of each term (such values should be pre-configured according to each application requirements).

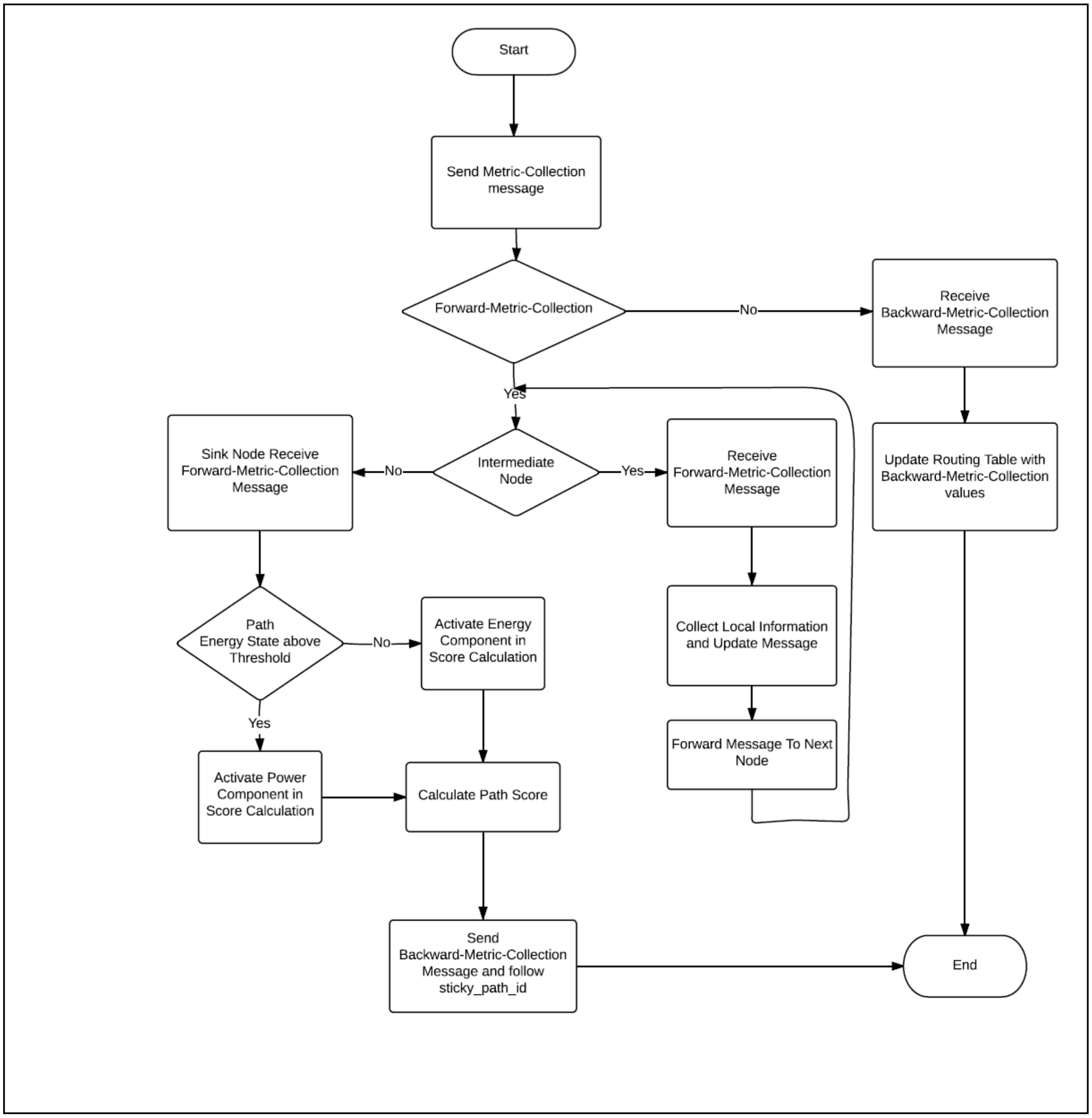

Fig. 3. Path Scheduling Component

$$\text{Score (p)} = \omega \,.\, \alpha + min.buffer(p).\beta + \left(\frac{1+Max\ HC - HC(p)}{Max\ HC}\right).\gamma + 1 - \left(\frac{no.\,DelayedPkts}{totalPktsRecv}\right).\delta \qquad (4)$$

the first component ω is the network lifetime term, which is designed in this equation to favor paths with minimum power consumed in routing process up to a critical point in network lifetime then it switches to favor only paths with higher energy reserve regardless power consumed in routing along such path. As shown in Eq.4.1. Ω is energy threshold value and it should be pre-configured (default value used in this simulation is 20% of the initial energy value). If the minimum energy value along path p, is greater than the energy threshold value Ω, then it uses power consumption term $pw(p)$ (Eq.3) which is the total average power consumed along path p, otherwise it uses remaining energy term which is the minimum remaining energy calculated along path p.

$$\omega = \begin{cases} \dfrac{min.energy(p)}{initla\ energy}\ , & min.energy(p) < \Omega \\ \dfrac{1}{pw(p)} & min\,.energy(p) \geq \Omega \end{cases} \qquad (4.1)$$

The second component $min.buffer$ represents minimum buffer found along path p . While third component ($\frac{1+Max\ HC - HC(p)}{Max\ HC}$ which measures hop count for this path. Max HC is the maximum hop count in the network which defaults to number of hops to reach farthest node in the network, while $HC(p)$ is the hop count of current evaluated path.

Finally , the fourth component $1 - \frac{no.DelayedPkts}{totalPktsRecv}$ measures path reliability as it measures ratio of packets delivered to the sink node, which are delayed than a predefined threshold value to the total packets received.

2) Data Sending Phase

During data and video sending phase in AOMDV version of the protocol, the normal routing decisions are applied which routes each packet based on the optimal number of hops regardless its importance. While in the new scheme, source node will look up its routing table to select the path toward sink node with score suitable to packet type. So that higher priority packets such as I-Frame will be routed through the paths with higher score value, while lower priority packets such as P/B/Data frames will be routed through path with lower score value in descending order. Source node intelligently favors paths calculated using power component than energy component as they have more energy reserve in addition they consume lower power for packet transmission and reception. In addition source node will append the selected path id to the packet being forwarded. For each intermediate nodes, sticky_path_routing is applied, so that the global optimal path score value determined only by source node will be also selected by each intermediate node toward sink using path_id attached to each packet. Such path_id contains set of nodes_id captured during path score calculation phase. In this way no local path score is calculated at each intermediate node which may not be the optimal value and it only uses the global one.

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IV. SIMULATION AND RESULTS

In this section, the new scheme is referred as E-ACWSN will be compared to previous work [47] ACWSN, AOMDV and non-adaptive QPS, QPS+ schemes [36]. The non-adaptive schemes (AOMDV,QPS and QPS+) use static encoding parameters GOP Length (GL) =7 and Number of B-Frames (Bf) =2 regardless wireless channel state. While the new scheme and ACWSN adaptively uses suitable GL and Bf parameters [47] according to wireless channel condition. QPS Scheme [36] applies packet, path and queue scheduling techniques. Queue priority scheduling is used at data link layer that uses four different queues to priotorize packets in round robin way, moreover; it apply path scheduling that route packets according to its type, but without considering fair usage of battery through network as the new scheme did and explained in Eq.4.1. QPS+ is the same as QPS scheme but it uses Eq. 4.1, which considers power consumption at scheduling time similar to the new scheme. The schemes (E-ACWSN, ACWSN, QPS , QPS+) use four weight variables used in Eq.4 as follows (α =0.5, β =0.1, γ =0.2, δ =0.2) and “Metric-Collection” is being sent periodically every 20 seconds.

The results in this work obtained using NS2 network simulator [2] to simulate packet transmission over the wireless network. The four schemes use similar settings as shown in Table 2.There are 150 nodes 2 of them are video nodes which send video packets to sink node and every other node sends data packets of 255 bps to sink node. The nodes are uniformly distributed in a rectangular field of dimension 1000m x 1000m.

Evalvid framework [3-5] is used to generate MPEG-4 video traffic using ffmpeg[6] to transmit Paris video with 1065 frames and Foreman video with 400 frames. The performance metrics evaluated in this work are PSNR, VQM, MOS, Frame delivery ratio, End-to-End Delay, Network Lifetime and overhead of “Metric-Collection” messages.

TABLE II.

Parameters	Values
Total Nodes	150
Queue length	50
Network Dimension	1000m x 1000m
Routing Protocol	AOMDV,Modified version of AOMDV
Video	Paris, Foreman
Enoding	MPEG-4
Frame Rate	30 Hz
Format	QCIF 176*144
Bit rate	64000
No. Video Frames	1065 , 400
Initial Energy	1000 joules
Traffic Model	Two videos nodes send video to sink while every other node sends 255 bps data traffic to sink.

A. Peak Signal-To-Noise-Ratio (PSNR)

PSNR is the widely accepted objective metric used to measure the video quality level based on original and processed video sequences. As shown in Fig.4 that E-ACWSN gives better video quality of 30.23 dB as an average value of two videos streams received. It depends on the communicated packet type that allows higher priority frames such as I-Frame to be kept without dropping in case of congestion and routed through more reliable paths in addition adaptively uses suitable encoding parameters according to current wireless channel. QPS+ recorded better value of 30.11 dB than ACWSN as 29.93 and that due to QPS+ apply path scheduling and consumed energy wisely as explained in previous section using Eq.4.1. While other schemes QPS, AOMDV show similar PSNR of 28.86 dB and 29.81 dB where QPS shows better value than AOMDV due to path scheduling applied in QPS while AOMDV only consider optimal number of hops.

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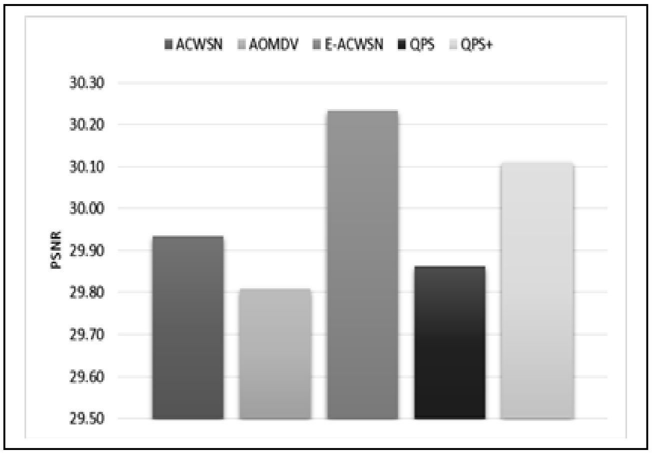

Fig. 4. Peak Signal-To-Noise-Ratio (PSNR)

B. Video Quality Metric (VQM)

PSNR only provides an indication of the difference between the received frame and a reference signal, while as shown in [53][27], VQM takes HVS aspects into consideration during the evaluation process. VQM outputs a value from 0 to 5 (0 is the best possible score) to presents the video quality level based on the human eye perception and subjectivity aspects including blurring, global noise, block distortion and color distortion. In Figure 5, the average value of VQM is calculated for all frames transmitted for (Paris and Foreman) video references.

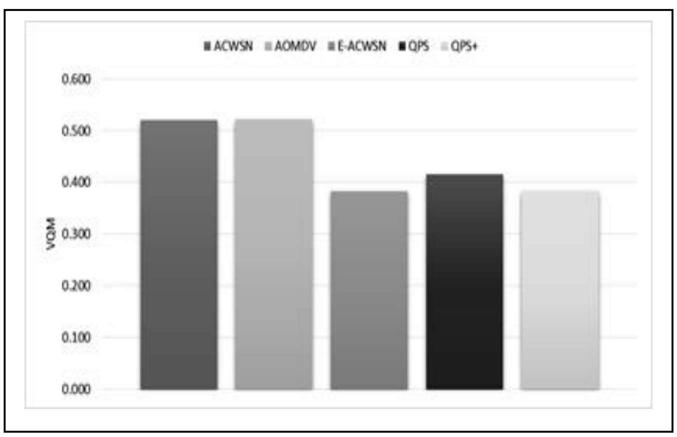

Fig. 5. VQM

Fig.5 shows that E-ACWSN-scheme and QPS+ gives similar VQM values of 0.38. While QPS+ recorded value of 0.41. Finally, both ACWSN & AOMDV recorded similar value of 0.52.

C. Mean Opinion Sscore (MOS)

The traditional subjective metric is named MOS that rates the quality of video sequences on a scale of 1 to 5, where 5 is the best possible score. MOS represents user experience and as shown in Fig.6 that E-ACWN recorded the highest value of 3.81 while other schemes that did not consider path scheduling recorded an average value 3.65 (ACWSN & AOMDV) as they did not consider selecting reliable paths.

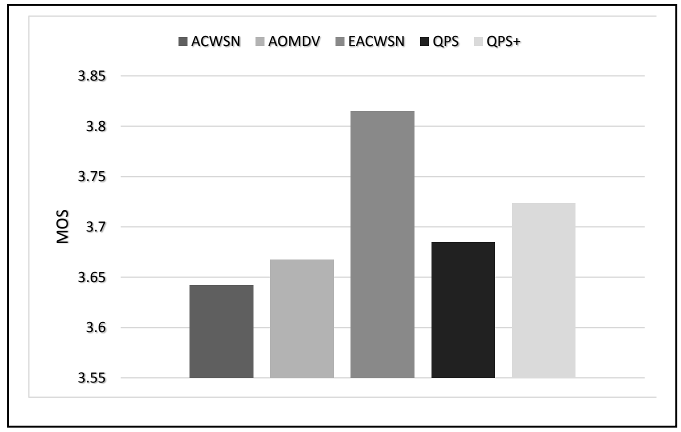

Fig. 6. MOS

D. End to End Delay

Fig.7 shows that E-ACWSN scheme recorded an average of 36 milliseconds while QPS & QPS+ recorded 40 milliseconds. Finally, both ACWSN & AOMDV recorded 45 and 50 milliseconds. Path scheduling based schemes such as E-ACWSN, QPS and QPS+ recorded better values as they route packets using QoS function that selects paths with least delay (as expressed in Eq.4 in terms of the number of hops and available buffer space). In addition to Queue Scheduling component which proposed in both ACWSN & E-ACWSN that queue/dequeue packets according to their priority, that leads to quick delivery of video packets than lower priority packets such as data packets.

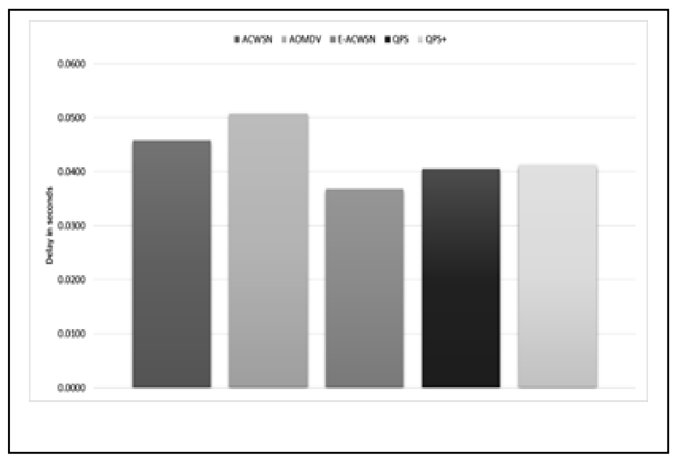

Fig. 7. End to End Delay

E. Delivery Ratio

E-ACWSN Fig.8 shows that path scheduled based schemes such as E-ACWSN, QPS and QPS+ schemes recorded average delivery ratio of 98%, which calculated as $\frac{\textit{Total Video Frames Received}}{\textit{Total Video Frames Sent}}$. While ACWSN & AOMDV recorded a lower delivery ratio of 88% as they did not try to avoid paths with higher loss ratio as path scheduling-based routing schemes. In addition Queue scheduling component which is proposed in ACWSN, EACWSN that keeps high priority packets even in congestion time through replacement as explained earlier while

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QPS, QPS+ even they priotorize packets at time of enqueue and dequeue, but still they may drop packets at time of congestion, even though there are less important packets are queued. Finally, scheduling-based schemes guarantee better network lifetime as will be shown in next subsection, which will give the chance of more packets to be routed in network before nodes begin to die.

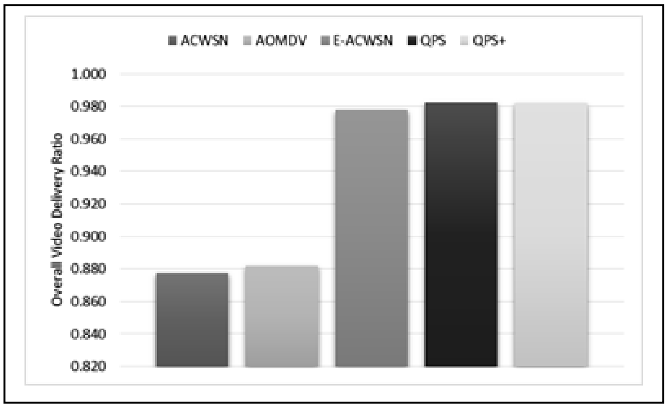

Fig. 8. Delivery Ratio

F. Energy

Both E-ACWSN and QPS+ use Eq.4.1, which, not only maximized network lifetime by choosing paths with higher remaining energy, but also used energy fairly through the network by choosing paths with lower energy consumption. It is shown in Fig.9 that E-ACWSN and QPS+ recorded better energy reserve at different simulation times 42, 26 and 12 joules at 5000, 10000 and 20000 seconds. While QPS scheme recorded 41, 25 and 11 joules which selects paths of better reserve of energy regardless power consumed in the path which will leads

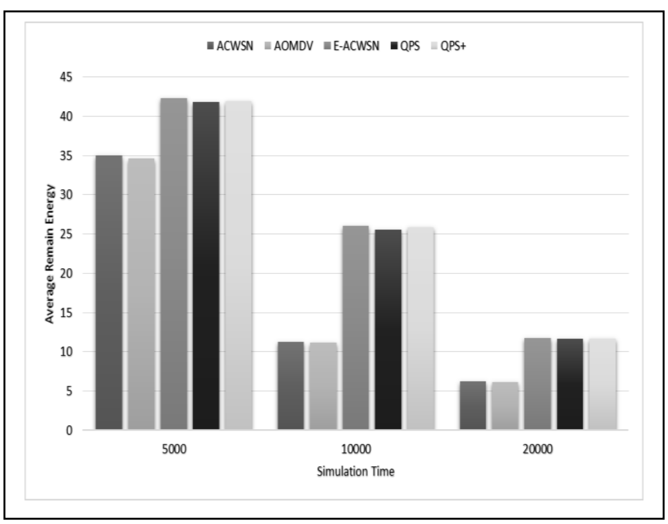

Fig. 9. Remaining Energy

to faster network energy drain. Finally, AOMDV and ACWSN show lower values of 34, 11, and 6 joules as they did not consider energy in routing decisions.

In Fig.10 & 11 the average power consumed due to "Metric-Collection" messages exchange as introduced in E-ACWSN, QPS and QPS+ show that, there is about 8.5 joules are consumed per node to send and receive "Metric-Collection" messages. It is

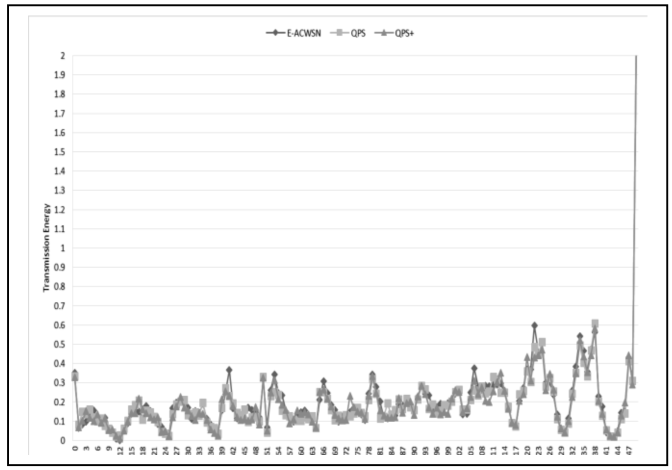

Fig. 10. Energy used per node for transmitting Metric Messages

also shown that neighbor nodes to sink node consume more energy than farthest nodes, nodes with number above 120 consumed about 0.6 joules for transmission, while nodes numbered above 70 consumed about 6.5 joules for receiving "Metric-Collection" messages.

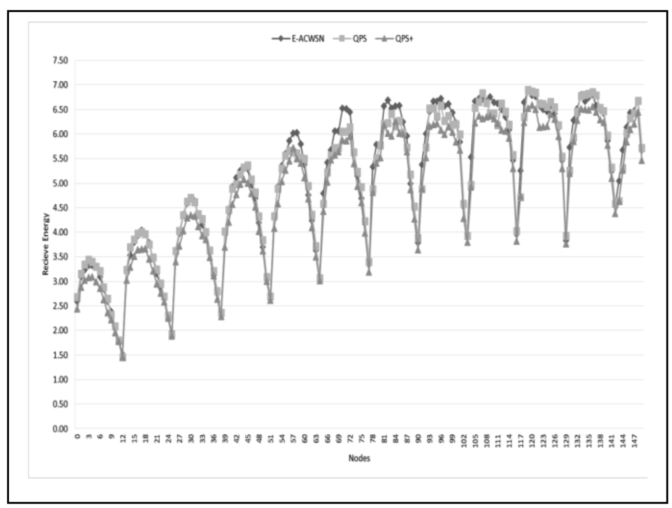

Fig. 11. Energy used per node for Receiving Metric Messages

V. Conclusion

Transmitting video over WSNs is a challenging problem due to limited capabilities of sensor nodes in terms of energy, communication, memory and processing. In this work a new scheme is introduced which is built up on a promising design approach, where cross-layer communication between Application, Network and Physical layers allowed an adaptive and efficient video transmission over WSNs. It uses optimal video encoding parameters, which dynamically specified according to current wireless channel state, an adaptive priority queue, which schedules incoming packets to drop less important packets without affecting video quality. Finally, it modified AOMDV multi-path routing protocol to schedule paths according to an aggregate score value (path length, energy state, loss ratio, congestion level) so that higher priority packets are routed through paths with higher score, while lower priority packets are routed through paths with lower score, which efficiently distributed energy over such multiple paths. The new scheme E-ACWSN shows better video quality over other schemes such as QPS, QPS+, AOMDV and ACWSN, in terms of PSNR, VQM, and Delivery Ratio. In addition, it saves network energy by selecting paths with minimum power consumption that greatly enhanced network lifetime.

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