International Journal of
Sensor Networks and Data Communications

El Dien et al., Sensor Netw Data Commun 2016, 5:1
DOI: 10.4172/2090-4886.1000136

Research Article Open Access

Energy-Aware Cross Layer Framework for Multimedia Transmission over Wireless Sensor Networks

Mohammed Ezz El Dien*, Aliaa AA Youssif and Atef Zaki Ghalwash

Department of Computer Science, University of Helwan, Helwan, Egypt

Abstract

Wireless Multimedia Sensor Networks (WMSNs), is a network of sensors which are limited in terms of computational, memory, bandwidth, and battery capability. Multimedia transmission over WSN requires certain Qos guarantees such as huge amount of bandwidth, strict delay and lower loss ratio, which makes transmitting multimedia content over it, is a challenging problem. Recently adopting cross-layer design in WMSNs proved to be a promising approach, which improves quality of service of WSN under various operational conditions. In this work, an energy aware framework for transmitting multimedia content over WSN (ECWMSN) is presented, where packet and path scheduling were introduced, so that It adaptably selects optimum video encoding parameters at application layer according to current wireless channel state, and schedules packets according to its type to drop less important packets in case of network congestion. Finally, path scheduling is introduced so that different packets types/priority is routed through suitable path with suitable Qos taking into consideration the network lifetime. Simulation results show that ECWMSN optimizes video quality and prolongs network lifetime.

Keywords: Wireless multimedia sensor networks; Cross layer design; WMSNs; GOP structure; Packet scheduling; Queue scheduling; Path scheduling

Introduction

WMSNs is an ad-hoc arrangement of wirelessly interconnected multifunctional sensor nodes that allow retrieving video and audio streams, still images, and scalar sensor data. Sensor nodes can be densely distributed over large even remote areas, and will continue to collaborate their efforts to the benefit of the network; even if a number of nodes malfunction, the network will continue to function.

It is expected that there will be different multimedia applications [1] with different Qos metrics will exist, such as family monitors [2], traffic routing [3], industrial process control [4], surveillance sensor networks [3], and healthcare delivery [5], but there are many challenges for transmitting multimedia over such type of networks [6] due to constrained nodes whether in terms of limited battery lifetime, limited memory and limited throughput. In addition, all of such wireless networks commonly uses wireless channel for communication, which suffers from interference problems, multipath fading, shadowing and high signal attenuation effects, that results in a high bit error rate and fluctuated bandwidth due to link failures and congested packets.

In addition to multimedia Qos guarantees, Network lifetime management and balanced usage of battery power add additional challenges, due to sensors operating using batteries and progress in battery development is limited and replacing such battery is costly or impossible.

Routing protocols plays an important role for increasing throughput and decreasing end-to-end delay. However single path routing protocols are not efficient for Qos requirements for multimedia transmission such as delay and loss. Multipath routing [7] is an alternative approach to handle multimedia transmission, as it increases bandwidth efficiency, reliability, decreases end-to-end delay, and evenly spread power consumption in the network.

Cross-layer design [8-12] shows that it is a promising approach to handle multimedia based transmission over WSN. Traditional OSI layered architecture's networking services are organized and provided by specific layers without sharing or communication between them. Cross-layer approach optimizes the performance of the network through violating the traditional approach in many different ways such as: allowing sharing information across layers, direct communication between layers, creating new intermediate interfaces between layers or merging adjacent layers.

In this work, an adaptive multimedia transmission framework called Energy Aware Framework for multimedia Transmission over Wireless Sensor Networks (ECWMSN) is presented. It is an extension of previously introduced [13], so that current framework includes three main characteristics: adaptive MPEG-4 video encoder, packet and path scheduling.

It is a cross-layer framework that communicates current wireless channel state to application layer, so that application layer can apply proper video encoding parameters according to the current state of the wireless channel. Each video packet has different priority and effect on video transmitted, so for packet effect on video transmitted, Sink node analyzes suitable video encoding parameters and sends it back to source node to use it, while for packet priority it schedules packets into different queues and at time of congestion, it drops less important packets without affecting video quality. Finally framework extended to schedule different packet types on different routes according to packet type and matched path cost considering network lifetime.

So by combining cross layer design with multipath routing, packet and path scheduling in one single framework to transmit multimedia content over WSN shows a promising framework that can optimize bandwidth, multimedia quality and network lifetime.

***Corresponding author:** Mohammed Ezz El Dien, Department of Computer Science, University of Helwan, Helwan, Egypt, Tel: 201118600224; E-mail: mohamed.ezz011@gmail.com

Received February 14, 2016; **Accepted** February 15, 2016; **Published** February 18, 2016

Citation: El Dien ME, Youssif AAA, Ghalwash AZ (2016) Energy-Aware Cross Layer Framework for Multimedia Transmission over Wireless Sensor Networks. Sensor Netw Data Commun 5: 136. doi: 10.4172/2090-4886.1000136

The remainder of the paper is organized as follows: section two presents a survey on cross layer protocols for WMSN. In section three, the newly introduced ECWMSN framework is presented. In section four, an evaluation of the newly introduced framework ECWMSN using extensive simulation scenarios is presented. In section five the paper is concluded.

Related Work

Path scheduling finds suitable path between source and destination node not only using optimal hop count as used by traditional routing protocols but also using other user defined QoS metrics such as delay, bandwidth, loss and energy requirements, which depends on the application nature of the WSN.

Path scheduling in a constrained networks such as WSN depends on various routing metrics [14] for example; in this work [15] it selects path based on packet type, so that delay sensitive packets to be routed through fastest path, while error sensitive packets are routed through the most reliable links, and non-constrained packets through least energy routes. While In this work [16] paths ranked considering interference, congestion and hop count through an integrated routing metric (bottleneck of node congestion level, hop count, bottleneck of node leisure level and the number of congested nodes), in addition videos frames are assigned to single or multipath depending on congestion level of each path.

In this work [17] a video transmission scheme which schedules different video packet types over different paths, so that critical packets are transmitted through highly rated paths. Source nodes send control messages periodically to sink node with updated state each path, and Sink node receive path status and score each path using (energy level, buffer status, hop count and path reliability) and sends back to source node the new path cost, so that source nodes later schedules packets according to its type through suitable path, While in this work [18] Ants-based multi-Qos routing algorithm that schedules paths using (loss ratio, available memory, queuing delay and remaining energy), Other work [19] uses 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 index of each path using fuzzy logic. While this work [20] uses signal strength, remaining energy and available memory to score each path, while in [21] uses drain rate and delay for scoring path, other cross layer protocol [22] uses energy level and free buffer space.

In [23] CLAR's NWK layer chooses optimal route based on Ad-hoc routing's DSR protocol which selects a route that has an optimal value of PHY layer parameter CQI (channel quality indicator) that asses link reliability and stability. It is estimated from SNIR (signal to noise interference ratio) of the received signal and maintained for each neighbor node by [24] DRMACSN MAC layer protocol. Moreover; CLAR checks network status (number of ongoing transmissions parameter which maintained for each neighbor node by DRMACSN MAC layer protocol) before exchanging routing control packets to further minimize energy consumption in case channel is bad or current simultaneous transmissions are above a threshold value.

In this work [25] a new architecture is presented for video transmission over WSN, which is called energy efficient and high quality video transmission architecture (EQV-Architecture). This architecture affects three layers of communication protocol stack. It considers wireless video sensor nodes constraints like limited process and energy resources in addition to preserving video quality at the sink. Application, transport, and network layers are the layers in which the compression protocol (Modified MPEG), transport protocol, routing and dropping scheme are proposed respectively.

The dropping scheme presented in this work decides 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 [26] the author believes that it is resource efficient to have single scheme which aggregates common protocol layers into a single cross layer protocol XLM for resource constrained sensor nodes. XLM objectives are to provide, high reliable communication with minimal energy consumption, adaptive communication and local congestion control. XLM is based on an initiative determination concept, which allows each node to decide to participate in a communication based on four conditions that must be satisfied before a node decides to start communication. First condition ensures reliable links for communication, while second condition limits the traffic a node can relay to prevent congestion, the third condition ensures no buffer overflow could occur at this node to prevent congestion and the last condition guarantees even distribution of energy consumption by keeping remaining energy level at this node above minimum value.

While previous work focus on multimedia Qos, there are several work [27,28] aim to maximize network lifetime of each node and use battery wisely to prolong network lifetime before network get partitioned, it transmits data at the minimum power level to maintain links or adaptly choose transmit range of each node to minimize energy consumption. While other work [29,30] distribute energy usage of all mobile nodes by selecting under-utilized route instead of shortest path. Other work [31] chooses inactive communication to minimize energy consumption where some nodes are put to sleep to keep minimum number of nodes waken for transmission while others get reduce energy consumption energy consumed while nodes is inactive.

In this work [32] a secure routing protocol is presented which is based on cross layer design and energy-harvesting mechanism. It uses a distributed cluster-based security mechanism. It is a Duty-Cycled WSN, where nodes are initially in active state, where nodes actively participate in WSN operations. However, as long as the energy value of sensor node decreases, it switches to semi-active state. In semi-active state, nodes are in wake and sleep conditions. In wake position, nodes take part in network operations, while in sleep position, nodes only harvest environmental energy. In idle state, nodes only harvest energy until it switches back either to active or semi-active states. Routing in this work is based on energy level, which is exchanged between PHY and NWK layer to ensure efficient use of energy. Energy harvesting system which is based on photovoltaic cells are used to convert sun light energy into electric energy to extract and store energy, which is used to take decisions for the node state and thus for the routing issues.

Proposed ECWMSN Energy Aware Cross Layer Framework for Multimedia Transmission over WSN

It consists of four components (Adaptive Video Encoder, Packet Scheduling, Queue Scheduling, Path Scheduling) as will be explained in next subsections, to solve multimedia transmission problems like limited bandwidth, wireless link failures, congested packets and limited battery resources.

It uses cross-layer communication between Application, Network, Data link and Physical layer as shown in Figure 1. At application layer MPEG-4 encoder adjusts encoding parameters according to current wireless channel status, which is communicated from physical layer

Citation: El Dien ME, Youssif AAA, Ghalwash AZ (2016) Energy-Aware Cross Layer Framework for Multimedia Transmission over Wireless Sensor Networks. Sensor Netw Data Commun 5: 136. doi: 10.4172/2090-4886.1000136

and recommendation from Sink node [13]. Moreover, it apply path scheduling to routes packets through different paths according to packet type and path's Qos guarantees; finally it apply queue scheduling so that it can drop less important packets in case of network congestion without affecting video quality.

There is continuous feedback messages sent from Sink node to source nodes, to propagate back both recommended video encoding parameters and path cost. Received video will be analyzed at sink node [13] and could be assessed using PLSR (Partial Least Squares Regression) [33] or other video quality assessment techniques (such as VQM, MS-SSIM,…) [34,35], so that, the optimum MPEG-4 encoding parameters suitable for current wireless channel state is sent back to source nodes. Source node will configure MPEG-4 encoder using new video encoding parameters sent from sink, in addition source node will select suitable path at time of sending new video packet according to current packet type and communicated path cost from sink node.

Packet scheduling component

MPEG (Moving Pictures Experts Group) employed today by most of the video compression systems; it is inter-frame video compression algorithm which exploits temporal correlation between frames to achieve high level of compression by independently coding reference frames. It is found [36] that the number of distorted frames due to loss of I, P or B depends on the type and position of the lost frame. I-Frame will cause distortion to (N + M-1) frames; while P-Frame will cause distortion to (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. So each packet type will need to be scheduled differently according to its type [37], where I-Frames will need more protection than P-Frame and B-Frames to reduce its loss effect of video quality. Queue and path scheduling will uses packet type information communicated from application layer so that higher priority packets such as I-Frame will be queued and routed in way better than lower priority packets as will be explained in next sub sections.

Adaptive video encoder component

Group of Picture (GOP) structure affects video transmission over lossy wireless sensor network [38,39], it is determined by parameters N and M, which defines the sequence of I, P and B frames. Parameter N specifies the I-frame interval and parameter M determines I or P frame interval. The higher frequency of I-Frame [36,40] will reduce error propagation and causes better video quality but on the other hand it will reduce compression ratio of the video which will produces large sized video file. Based on results found in [13], the sink node periodically sends recommended video encoding parameters GOP total length (G_L) and number of B-Frames (B_f)to source node after analyzing video received during previous period. It recommends optimum parameters according to current wireless channel status (Packet Loss Ratio, BER …).

Queue scheduling component

ECWMSN framework differentiates between two types of packets, data and video packets, data packets are less important than video packets. Video packets are further prioritized according to its frame type, so that I-Frame packets are the highest priority followed by P-Frame and B-Frame and finally data packets. After identifying priority of packets, each intermediate node can schedule incoming packets as shown in Figure 2 as follows, buffer space is divided into high and low priority queues, and the priority of each packet determines whether such packet will be queued or dropped according to priority of packet and current status of the buffer.

In case of the incoming packet has high priority it will be queued in high priority queue if there is a room for it. Otherwise it will search low priority queue for lowest priority packet to replace it. Low priority packets is queued into low priority queue in case there is a room for it; otherwise it can replace lower priority packet in lower priority queue or to be dropped, and at time of dequeue, it will dequeue higher priority packet then lower priority.

Path scheduling component

ECWMSN is a cross layer framework where different layers interact with each other, so after recognizing packet type at Application layer, it communicates it with Network layer so that path is scheduled according to each packet type, where higher priority packet will be scheduled through path with higher Qos measures, while lower priority packets will be routed through lower Qos guarantee path.

It is based on AOMDV [41] multipath routing protocol which route packets using optimal number of hops for routing packets; while ECWMSN routing protocol which is a modified version of [36] that uses path cost function to rank each path based on network energy status, available buffer, number of hops, lost packet. the new framework preserve power consumed in network by choosing paths with less power consumption until network reach energy threshold value, then it favor paths with better energy reserve regardless power consumed.

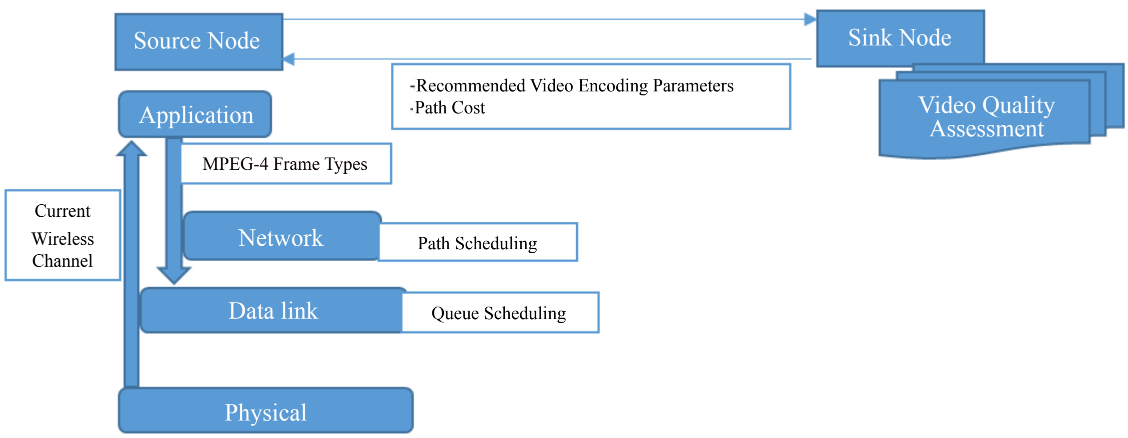

Figure 1: Energy-aware adaptive cross layer framework for video transmission over WSN.

Citation: El Dien ME, Youssif AAA, Ghalwash AZ (2016) Energy-Aware Cross Layer Framework for Multimedia Transmission over Wireless Sensor Networks. Sensor Netw Data Commun 5: 136. doi: 10.4172/2090-4886.1000136

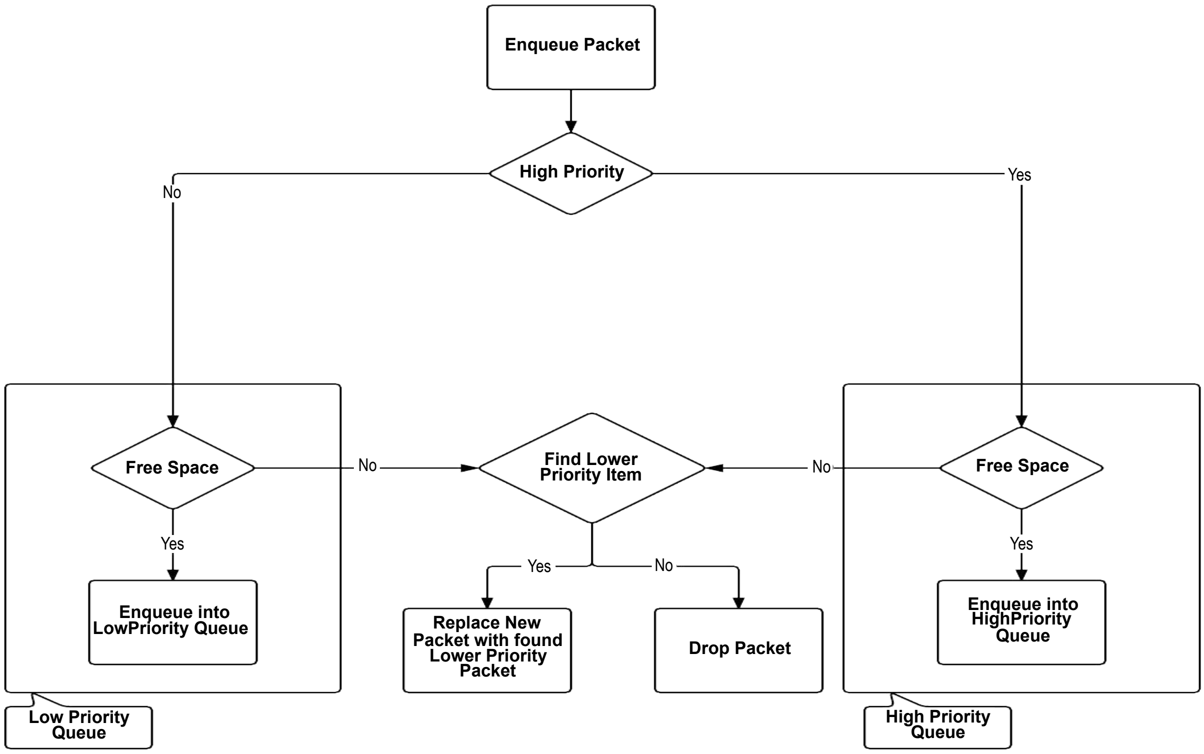

Figure 2: Adaptive priority queue.

ECWMSN introduces new messages "Metric-Update" to AOMDV protocol, which sent periodically from source node to sink node as "Forward-Metric-Update" message, which collects status of each node along different paths toward sink node. Sink node will evaluate each received message from different paths and generates "Backward-Metric-Update" message to be sent back through path which it came from, with calculated cost of such path.

Upon receiving "Forward-Metric-Update" message at intermediate nodes along path, it will update such message with its current energy level if it is less than minimum energy stored within message, otherwise no updates as shown in Equation1, where *re* is remaining energy of node *S* along path *P*.

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

Intermediate nodes which received "Forward-Metric-Update" will updates message with its current free buffer count if it is less than minimum free buffer count within message, otherwise no updates as shown in Equation 2, where, *bf* is free buffer at node *S* along path *P*.

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

Upon receiving "Forward-Metric-Update" message at intermediate nodes along path, it updates message with *Pw* total average power consumed per each node along path whether at time of sending or receiving as shown in Equation 3. Where *Tx* is average power consumed at sending time at node *S* along path *P*, and *Tr* is average power consumed at receiving time at node *S* along path *P*.

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

Each message received along different paths at Sink node will be evaluated to calculate cost of each path as shown in Equation 4, where $\alpha + \beta + \gamma + \delta = 1$ are weight factors for each term, so that it is configured by user according to current application of the network.

$$Cost(p) = \omega.\alpha + \min.buffer(p).\beta + \left(\frac{1 + max\ \text{HC-HC(p)}}{\max HC}\right).\gamma + 1 - \frac{no.DelayedPkts}{totalPkets\,\mathrm{Recv}}.\delta \quad (4)$$

The first component ω is the network lifetime term, which is evaluated as shown in Equation 4.1, where Ω is energy threshold, so that if minimum energy value along path p, is greater than energy threshold value Ω, it uses power consumption term *pw(p)* (Equation 3) which is total average power consumed along path p, otherwise it uses *Min. Energy(p)* (Equation 1) term which is the minimum remaining energy found along path p.

$$\omega = \begin{cases} \dfrac{\min.energy(p)}{inital\ energy} & \text{min.energy(p)} < \Omega \\ \dfrac{1}{pw(p)} & \text{min .enrgy (p)} \geq \Omega \end{cases} \quad (4.1)$$

For the second component it represents minimum buffer found along path p, while third component it measures hop count for this path where Max HC is maximum hop count in the network, while HC(p) is hop count of current evaluated path. Finally fourth component it measures path reliability as it measures ratio of packets delivered to sink node without delay to total packets received.

Sink node will evaluate each path's cost after receiving "Forward-Metric-Update" message using Equation 4, then it sends back along such path a new corresponding message "Backward-Metric-Update", which it came from, so that each intermediate node update its routing table with new cost for such evaluated path.

During data and video sending phase, source node will select path toward sink node according to type of packet and suitable path cost; so that higher priority packets will be routed through paths with higher cost value. Each packet is modified to carry path id that identify hops of the selected path, so that intermediate node will selects next hop according to path selected previously by source node.

Simulation and Results

In this section ECWMSN framework will be compared to non-adaptive QPS, QPS+ [17], which uses static encoding parameters G_L = 7 and B_f = 2 regardless wireless channel state, while ECWMSN framework adaptively uses suitable G_L and B_f parameters [13] depending on wireless channel condition; in addition it apply packet, queue and path scheduling as explained in previous section. QPS-Scheme [17] applies packet, path and queue scheduling techniques, where queue priority scheduling is used at data link layer that uses 4 different queues to prioritize packets in round robin way. Finally it uses path scheduling that route packets according to its type but without considering fair usage of battery through network. QPS+ is QPS scheme but it uses Equation 4.1, which considers energy at scheduling time similar to ECWMSN.

The results in this work obtained using NS2 network simulator [42] to simulate packet transmission over the wireless network. The three schemes use similar settings as shown in Table 1. There are 150 nodes 2 of them are video nodes which sends video packets to sink node and every other node sends data packets of 255 bps to sink node. All nodes work as intermediate routing nodes, which are uniformly distributed in rectangular field of dimension 1000m x 1000m.

Evalvid framework [43-46] used to generate MPEG-4 video traffic using ffmpeg [47] to transmit Paris video with 1065 frame. Our used performance metrics are PSNR, End-to-End Delay, Loss, Network Lifetime and energy usage among nodes.

PSNR

Figure 3 shows that ECWMSN gives better video quality of 30.40 dB than other schemes as it depends on communicated packet type that allow 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. While other Schemes QPS, QPS+ show similar PSNR of 28 dB, where their queue scheduling does not keep high priority packets in case of congestion, in addition ECWMSN reduces energy usage of the network so that more packets can be transmitted.

End - to - end delay

Figure 4 show that ECWMSN scheme recorded an average of 24 milliseconds while other schemes recorded average 27 milliseconds. E-ACWSN, QPS and QPS+ schemes use path scheduling that depends on an overhead of Metric-Update messages to propagate network status and path cost to nodes, such overhead causes delay or loss of packets flow in the network.

Lost frames

Figure 5 shows that ECWMSN scheme recorded average loss ratio of 5.5, as ECWMSN in congestion time keeps higher priority packets by replacing lower priority packets in adaptive priority queue; while QPS schemes just drop packets even they are high priority in case of overflow.

In addition ECWMSN uses energy wisely among nodes to keep network lifetime long so that more packets can be transmitted without loss.

Network energy

ECWMSN 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 Figure 6 that ECWMSN and QPS+ schemes recorded better energy usage value 24.02 and 23.77 joules through simulation time, while QPS scheme is 23.72 joules as it only seeks to select paths which have better reserve of energy. while ECWMSN and QPS+ select paths with low cost of power consumption as explained earlier, in addition selecting paths with better reserve of energy in case network reach critical threshold energy value.

Parameters	Value
Total Nodes	150
Queue length	50
Network Dimension	1000 m × 1000 m
Routing Protocol	Modified version of AOMDV
Video	Paris
Encoding	MPEG-4
Frame rate	30 Hz
Format	QCIF, 176 × 144
Bit rate	64000 bps
No. video frames	1065
Initial energy	50 joule
Traffic Model	Two video nodes send video to sink while every other node sends 255 bps data traffic to sink

Table 1: Parameters of simulation scenario.

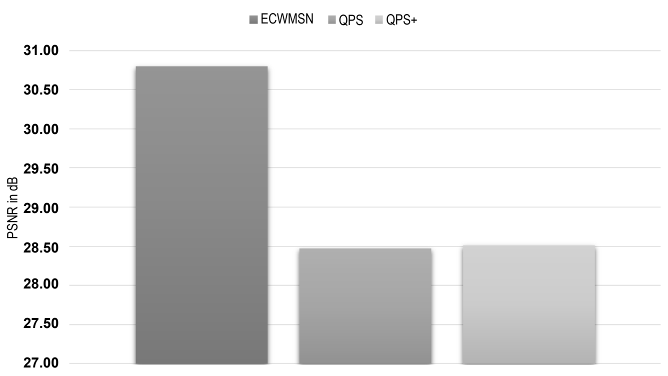

Figure 3: ECWMSN vs. Non-adaptive Video Transmission Scheme.

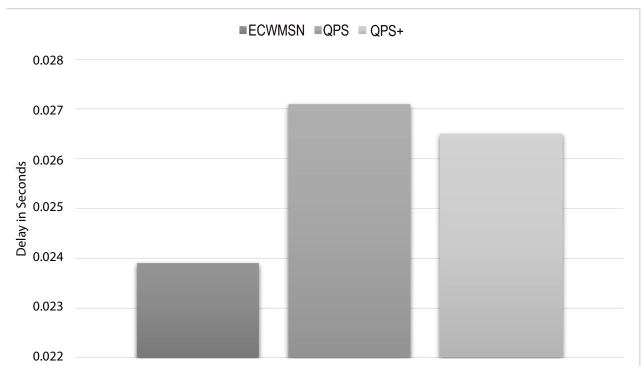

Figure 4: End-to-End delay.

In Figure 7 shows minimum energy recorded through simulations, both ECWMSN and QPS+ tries to save energy usage by using minimum energy cost of routing and that causes to lower their energy till network reach its energy threshold then it starts to switch back to avoid paths with nodes have lower energy values.

Conclusion

Transmitting video over WSN is a challenging problem due to huge amount of bandwidth it requires, so by combining different protocols into a single framework is a promising approach to handle such challenge. In this work ECWMSN is an multimedia transmission framework that uses optimal GOP structure / size suitable to current wireless channel state, an adaptive queue that schedules incoming packets to drop less important packets with affecting overall video quality. Finally, it modified AOMDV multi-path routing protocol to schedule paths according to packet type and balance traffic and energy over multiple paths instead of single path transmission. By comparing ECWMSN to QPS schemes QPS+, it gave better video quality with average PSNR value 30.40 dB. In addition ECWMSN show great energy saving and balanced energy consumption scheme over other schemes, it recorded 24.02 joule as average energy consumed by all nodes through simulation while QPS recorded 23.72 joule.

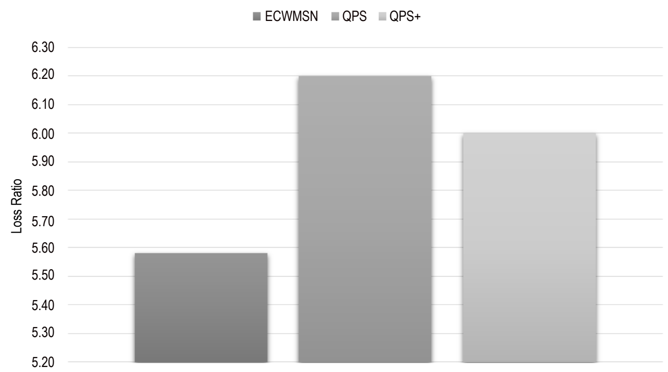

Figure 5: Lost frames.

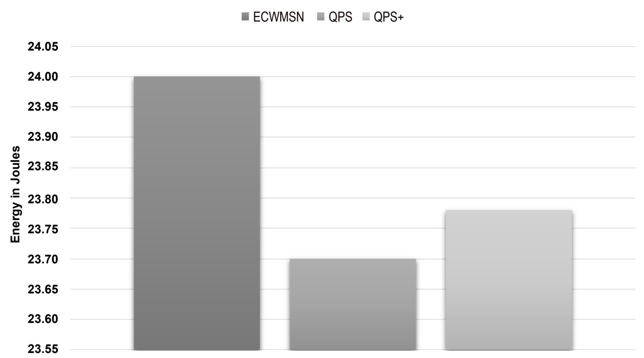

Figure 6: Energy usage of nodes.

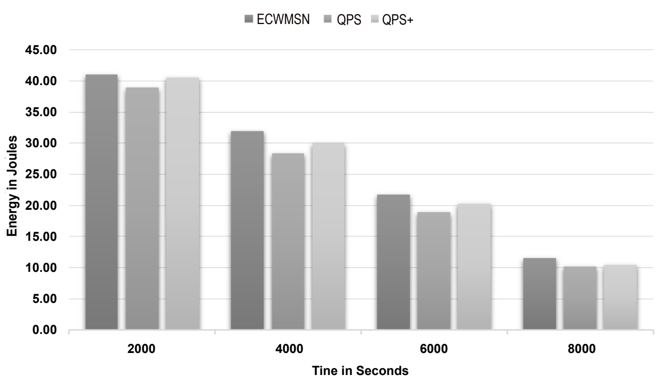

Figure 7: Minimum energy through simulation time.

References

1. Shen Z, Luo J, Zimmermann R, Vasilakos AV (2011) Peer-to-Peer Media Streaming: Insights and New Developments. Proceedings of the IEEE 99: 2089-2109.
2. Eeves AA (2005) Remote Monitoring of patients suffering from early symptoms of Dementia. In International Workshop on Wearable and Implantable Body Sensor Networks, London, UK.
3. Campbell J, Gibbons PB, Nath S, Pillai P, Seshan S, et al. (2005) IrisNet: an Internet-scale architecture for multimedia sensors. In Proceedings of the 13th ACM International conference on Multimedia, Singapore.
4. Guha A, Pavan A, Liu JCL, Roberts BA (1995) Controlling the Process with Distributed Multimedia. IEEE Multimedia 2: 20-29.
5. Hu F, Kumar S (2003) Multimedia query with QoS considerations for wireless sensor networks in telemedicine. Society of Photo-Optical Instrumentation Engineers-International Conference on Internet Multimedia Management Systems, Orlando, Florida, USA.
6. Xiong Z, Fan X, Liu S, Zhong Z (2010) Distributed image coding in wireless multimedia sensor networks: A survey. Third International Workshop on Advanced Computational Intelligence, Jiangsu.
7. Rosário D, Costa R, Santos A, T Braun, Cerqueira E (2013) QoE-aware Multiple Path Video Transmission for Wireless Multimedia Sensor Networks. Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos, Brasil.
8. Farooq MO, Kunz T, St-Hilaire M (2011) Cross layer architecture for supporting multiple applications in Wireless Multimedia Sensor Networks. 7th International Wireless Communications and Mobile Computing Conference, Turkey.
9. Alikhani S, Kunz T, St-Hilaire M, Richard F (2010) A central-networked cross-layer design framework for wireless sensor networks. Proceedings of the 6th International Wireless Communications and Mobile Computing Conference, China.
10. Mendes L, Rodrigues J (2011) A survey on cross-layer solutions for wireless sensor networks. Journal of Network and Computer Applications 34: 523-534.
11. Costa D, Guedes L (2011) A Survey on Multimedia-Based Cross-Layer Optimization in Visual Sensor, Sensors 11: 5439-5468.
12. Gunasekaran R, Qi H (2008) XLRP: Cross Layer Routing Protocol for Wireless Sensor Networks. WCNC. IEEE Wireless Communications Networking Conference, USA.
13. Youssif A, Ghalwash A, Kader MA (2015) ACWSN: an adaptive cross layer framework for video transmission over wireless sensor networks. Wireless Networks 21: 2693-2710.
14. Zara H, Hussain F (2014) QoS in Wireless Multimedia Sensor Networks: A Layered and Cross-Layered Approach. Wireless Personal communication 75: 729-757.
15. Boukerche A, Araujo RB, Villas L, Novel A (2007) QoS Based Routing Protocol for Wireless Actor and Sensor Networks. IEEE Global Telecomm Conference, Washington, DC.
16. Wan Z, Xiong N, Yang LT (2015) Cross-layer video transmission over IEEE 802.11e multihop networks. Multimedia Tools and Applications 74: 5-23.
17. Karimi E, Akbari B (2013) Priority Scheduling for Multipath Video Transmission in WMSNS. International Journal of Computer Networks & communications 5: 167-180.
18. Cobo L, Quintero A, Pierre S (2010) Ant-based routing for wireless multimedia sensor networks using multiple QoS metrics. Computer Networks 54: 2991-3010.
19. Palaniappan S, Chellan K (2015) Energy-efficient stable routing using QoS monitoring agents in MANET. EURSIP Journal on Wireless Communications and Networking 2015: 1-11.

20. Pillai M, Sebastian M, Madhukumar S (2013) Dynamic multipath routing for MANETs -A QoS adaptive approach. 3rd International Conference on Innovative Computing Technology, London, UK.

21. Begum A, Iqbal F, Mohammad A (2015) Quality of service routing for multipath manets. International Conference on Signal Processing and Communication Engineering Systems, Guntur.

22. Chen J, Li Z, Liu J, Kuo Y (2011) QoS Multipath Routing Protocol Based on Cross Layer Design for Ad hoc Networks. In Internet Computing and Information Services, Hong Kong.

23. Chabalala SC, Muddenahalli TN, Takawira F (2011) Cross-layer adaptive routing protocol for wireless sensor networks. AFRICON, IEEE, Livingstone.

24. Muddenahalli T, Takawira F (2009) DRMACSN: New mac protocol for wireless sensor networks. SATNAC Conference on Network Planning & General Topics, RSS, Swaziland.

25. Aghdasi H, Abbaspour M, Moghadam M, Samei Y (2008) An Energy-Efficient and High-Quality Video Transmission Architecture in Wireless Video-Based Sensor Networks. Sensors 8: 4529-4559.

26. Vuran M, Akyildiz I (2010) XLP: A Cross-Layer Protocol for Efficient Communication in Wireless Sensor Networks. IEEE Transactions on Mobile Computing 11: 1578-1591.

27. Toh C (2011) Maximum battery life routing to support ubiquitous mobile computing in wireless ad hoc networks. In Communications Magazine IEEE 39: 38-147.

28. Prakash S, Saini J, Gupta S (2010) A review of Energy Efficient Routing Protocols for Mobile Ad Hoc Wireless Networks. International Journal of Computer Information Systems 4: 37-46.

29. Buddhdev B (2013) Energy Enhancement in AOMDV. International Journal of Advanced Research in Computer Engineering and Technology 2: 1924-1929.

30. Gálvez J, Ruiz P, Skarmeta A (2010) A feedback-based adaptive online algorithm for multi-gateway load-balancing in wireless mesh networks. In World of Wireless Mobile and Multimedia Networks IEEE, Canada.

31. Chen B, Jamieson K, Morris R, Balakrishnan H (2001) Span: an energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks. Proceedings of International Conference on Mobile Computing and Networking, Italy.

32. Alrajeh N, Khan S, Lloret J, Loo J (2013) Secure Routing Protocol Using Cross-Layer Design and Energy Harvesting in Wireless Sensor Networks . International Journal of Distributed Sensor Networks 2013: 1-11.

33. Wang Z, Wang W, Xia Y, Wan Z, Lin W (2014) No-reference hybrid video quality assessment based on partial least squares regression. Multimedia Tools and Applications 74: 10277-10290.

34. Chikkerur S, Sundaram V, Reisslein M, Karam LJ (2011) Objective video quality assessment methods: A classification, review, and performance comparison. IEEE Transactions on Broadcasting 57: 165-182.

35. Wang Z, Wang W, Xia Y, Wan Z, Wang J, et al. (2014) Visual Quality Assessment after Network Transmission Incorporating NS2 and Evalvid. The Scientific World Journal 2014: 1-7.

36. Huszak A, Imre S (2010) Analysing GOP Structure and Packet Loss Effects on Error Propagation in MPEG-4 Video Streams. 4th International Symposium on Communications, Control and Signal Processing, Cyprus.

37. Wan Z, Xiong N, Ghani N, Vasilakos AV, Zhou L (2014) Adaptive Unequal Protection for Wireless Video Transmission over IEEE 802.11e Networks. Multimedia Tools and Applications 72: 541-571.

38. Zulpratita S (2013) GOP Length Effect Analysis on H.264/AVC Video Streaming Transmission Quality over LTE Network. 3rd International Conference on Computer Science and Information Technology, Indonesia.

39. Fang T, Chau L (2005) An Error-Resilient GOP Structure for Robust Video Transmission. IEEE Ttransactions On Multimedia 7: 1131-1138.

40. Sousa R, Mota E, Silva EN, Paixão KSP, Faria B, et al. (2010) GOP size influence in high resolution video streaming over wireless mesh network. Computers and Communications, IEEE Symposium, Italy.

41. Marina, Mahesh K, Das SR (2006) Ad hoc on-demand multipath distance vector routing. Wireless Communications and Mobile Computing 6: 969-988.

42. Information Science Institute (2003) NS-2 network simulator, Software Package.

43. Klaue J, Shieh CK, Hwang WS, Ziviani A (2008) An Evaluation Framework for More Realistic Simulations of MPEG Video Transmission. Journal of Information Science and Engineering 24: 425-440.

44. Klaue J, Rathke B, Wolisz A (2003) EvalVid-A Framework for Video Transmission and Quality Evaluation. 13th International Conference on Modelling Techniques and Tools for Computer Performance Evaluation, Urbana, Illinois, USA.

45. NCKU (2015) Integrating EvalVid with NS2.

46. Wang H, Wang W, Wu S, Hua K (2010) A Survey on the Cross-Layer Design for Wireless Multimedia Sensor Networks. 3rd International Conference Mobile Wireless Middleware, operating systems and applications, USA.

47. FFMPEG (2015) MPEG-4 encoder.