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Improving Quality of Service (QoS) in Wireless Multimedia Sensor Networks using Epsilon Greedy Strategy

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Abstract: Wireless Multimedia Sensor Networks (WMSNs) are networks consisting of sensors that have limitations in terms of memory, computational power, bandwidth and battery life. Multimedia transmission using Wireless Sensor Network (WSN) is a difficult task because certain Quality of Service (QoS) guarantees are required. These guarantees include a large quantity of bandwidth, rigorous latency requirements, improved packet delivery and lower loss ratio. The main area of research would be to investigate the process of greedy techniques that could be modified to guarantee QoS provisioning for multimedia traffic in WSNs. This could include optimization of routing decisions, dynamic allocation of resources and effective congestion management. This study introduces a framework called Epsilon Greedy Strategy based Routing Protocol (EGS-RP) for multimedia content transmission over WSN. The framework focuses on energy efficiency and QoS by using reinforcement learning to optimize rewards. These incentives are determined by a number of variables, including node residual energy, communication energy and the effectiveness of sensor type-dependent data collection. Experimental analysis was conducted to evaluate the effectiveness of the proposed routing strategy and compare it with the performance of standard energy-aware routing algorithms. The proposed EGS-RP achieves a throughput of 217 kbps, a bandwidth of 985 bps, a packet delivery ratio of 94.45% and an energy consumption of 32%.

Keywords: Wireless Multimedia Sensor Networks (WMSNs), video transmission, bandwidth, packet transmission, energy efficiency, Quality of Service (QoS).

1. Introduction

Wireless Sensor Networks (WSNs) consist of a large number of linked sensor nodes capable of detecting environmental variables such as pressure, light, temperature, sound, humidity and location. They collaborate using wireless transmission means to exchange data and monitor their environment [1]. To improve the accuracy of this task, it is essential to have multimedia system support to provide more effective information gathering and environmental monitoring. WSNs have led to a significant paradigm shift resulting in the emergence of Wireless Multimedia Sensor Networks (WMSNs). This is due to recent technological advancements that have led to the development of portable and affordable devices for capturing, transmitting and storing multimedia content. These devices include digital video cameras, microphones, inexpensive smartphones, image sensors, memory cards and hard disks [2]. These technologies can be easily integrated into a node, allowing for the collection of information and monitoring of the environment in a more convenient and cost-effective way. Remote multimedia access is possible with wireless embedded device networks [3]. They are used in surveillance, environmental monitoring, traffic monitoring, target tracking, intrusion detection, advanced telemedicine and many more. To increase the data rate in next-generation hospitals, Iqbal et al. [4] improved power allocation and Power-Weighted Hashing (PWH) placement. The strategy considers cognitive radio interference and aims to support paramedics in smart hospitals using multimedia. It is efficient and has low complexity. Routing techniques often improve network performance while reducing end-to-end latency. Traditional single-route routing methods may not be efficient enough to meet the Quality of Service (QoS) requirements of video transmission, especially in terms of minimizing latency and loss. Multipath routing [5] is an ideal strategy that increases bandwidth and reliability, reduces latency and evenly distributes energy consumption across the network.

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2. Related works

In this section, a comprehensive and innovative overview of most of the current state-of-the-art QoS WMSNs routing protocols is presented. The Efficient Weighted Communication Protocol (EWHCP) model is proposed in [6] to improve QoS by selecting the ideal route and transmitting data with a lower end-to-end latency. The EWHCP approach aims to optimize the resource utilization for data transmission by using energy-aware admission control between sensor nodes.

In [7], an energy-aware optimal routing model using novel Prioritized Double Deep Q-Learning (PDDQL) is presented. Evaluation of a proposed routing protocol using metrics such as packet delivery ratio, average residual energy, number of active nodes, and average end-to-end latency resulted in values of 198.33 milliseconds, 2.05 joules, 100, and 0.85, respectively.

A very efficient and intelligent algorithm is presented in [8]. A benchmark comparison between the most advanced method and the proposed approach shows that the time required to identify the best recovery route is significantly reduced, resulting in an estimated reduction of a few milliseconds. The approach significantly shortens the route selection duration by up to 96.3%, resulting in higher end-user satisfaction.

In [9], across-layer energy-aware packet scheduling technique is described to reduce the congestion ratio and improve the connection quality between routing nodes. The Semi-Markov technique is used to evaluate the quality of links between nodes. In [10], a distributed Cross-interface network Partitioning and Scheduling (CPS) protocol is proposed. A series of comprehensive field tests are carried out in a multi-hop network consisting of 24 prototype nodes capable of transmitting actual multimedia data such as photographs and videos.

3. Proposed methodology

Fig. 1 shows that a WMSN consists of many multimedia sensors that communicate with sinks by exchanging sensed data over a wireless channel.

The scheduler guarantees that the allocation of resources for real-time traffic is not affected by the presence of best-effort traffic. This protocol uses a multipath method that employs an epsilon greedy strategy based routing protocol to identify a set of lowest cost pathways and selects the path that fulfills the specified requirement.

A. Network model

The sensor nodes V, E are vertices and edges, respectively, in an undirected graph *G (V, E)*. Each vertex is identified by a unique index $i \in \{1,2,\ldots N\}$. The link between the nodes i and j is defined as e_{ij}. Use an adjacency matrix to represent the graph. The adjacency matrix *A* of the graph *G* with *N* nodes is $N \times N$. The diagonal element a_{ij} denotes the number of loops at node *i*, while the non-diagonal item reflects the number of edges from node *i* to node *j*. The Spectral Graph Partitioning method is used to cluster the WMSNs. Each node transmits a short message to the sink containing the information about the position of the node. Based on this information, the sink generates the adjacency matrix and the degree matrix and then creates the Laplacian matrix. The Fiedler Vector, which corresponds to the second lowest eigenvalue, is used to divide the WMSNs. The position of each node can be determined using GPS or another localization method.

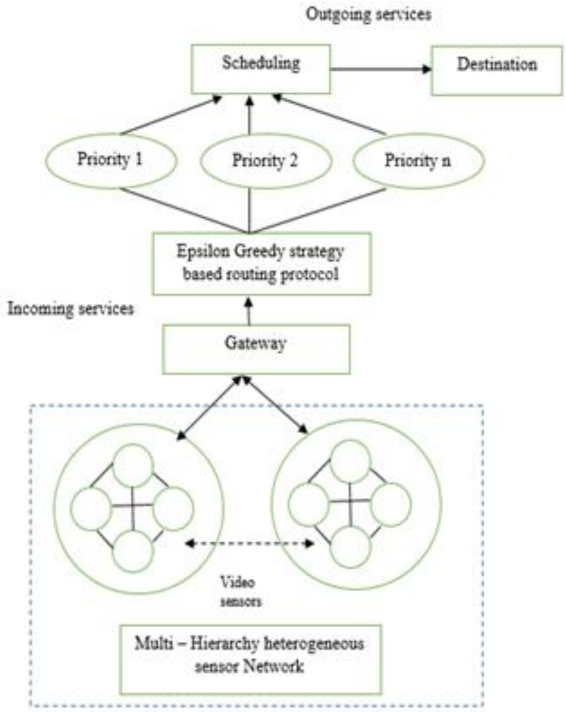

Fig. 1. Network model of the proposed WMSN.

The procedure for clustering is outlined as follows:

1. Create a graph *G* that represents the provided sensor network.
2. Create the normalized Laplacian matrix according to the following formula:

$$\gamma(i,j) = \begin{cases} 1 & if\ i = j\ and\ deg_j \neq 0 \\ -\dfrac{1}{\sqrt{deg_i deg_j}} & if\ i\ and\ j\ are\ adjacent \\ 0 & otherwise \end{cases}$$

   where, deg_i stands for the degree of node *i*.
3. Calculate the eigenvalues and eigenvectors of the Laplacian matrix γ of the graph.
4. Select the second lowest eigenvalue τ_1 of the Laplacian matrix γ.
5. Select the eigenvector value that corresponds to the eigenvalue τ_2.

B. Epsilon Greedy Strategy based Routing Protocol (EGS-RP)

The proposed Q-learning system for WMSN routing considers the agent as a network-wide data flow. The typical single-agent paradigm uses a centralized network controller to monitor network conditions and manage packet delivery at sensor nodes. The use of this central agent strategy comes at a significant additional cost and leads to problems in obtaining real-time knowledge about the state of the entire network. The EGS-RP being developed is based on the principles of Q-learning. The next nearby node to send type t collection data must be selected when the waiting time of sensor node i ends. Here, s_i represents the current state. Neighboring nodes represent current activities. Type t data is transmitted to s_j, the following state. Definitions of states and actions:

$$S = \{s_1, s_2, \dots s_N\} \tag{1}$$

$$A = \{A_1, A_2, \dots A_N\} \quad A_i = \{a_j = s_j \in N_{s_i}\} \tag{2}$$

where N represents the total number of sensor nodes, while N_{s_i} denotes the collection of neighboring nodes for a given node s_i. Assume that the agent in state *s* chooses action a, receives a reward *R*, and then transitions to a new state *s'*. Next, the Q-value function, $Q\ (s, a)$, is modified in the following way:

$$Q\ (s, a) = (1-\propto)Q(s, a) + \alpha\{R + \gamma . Q(s', a)\} \tag{3}$$

where the symbol $\propto$ represents the learning rate, while γ represents the discount factor for future rewards. To strike a compromise between utilizing known information and exploring new possibilities, the epsilon-greedy approach is often used to choose the optimal action (a^*) in a given state (s), as described in (4).

The Epsilon Greedy approach focuses primarily on exhausting the best option, with a modest possibility to explore other alternatives.

$$(a_*|s) = \begin{cases} argmax\ Q(s, a) & with\ probablity\ 1-\in \\ any\ action\ a & with\ probablity\ \in \end{cases} \tag{4}$$

Assuming we are in state s_i, and the waiting time for type t_1 expires, the data in the queue $Q_i^{t1}(n)$ is summarized to $AD_i^{t1}(n)$. The agent selects the action with the highest action value from the current Q-table for type t_1. The optimal course of action for the specified condition may vary depending on the data type t. The action value of *a* in state *s* is denoted as a vector as shown in (5) to reflect the predicted rewards for each action, which depend on the type of sensor data.

$$Q(s, a) = [Q^{t1}(s, a), \dots Q^{tk}(s, a)] \tag{5}$$

where *K* is the quantity of sensor categories. The optimum procedure for transmitting type *t* data in states is:

$$(a_*|s) = argmax\ Q^t(s, a) \tag{6}$$

We have specified the energy status reward, which does not depend on the type. The energy status reward R_E is:

$$R_E = \frac{E_{s'}^r(n)}{E_{s'}^r(o)} - \left(\frac{d_{s-s'}}{d_{max}}\right)^{\beta} \tag{7}$$

where $E_{s'}^r(n)$ and $E_{s'}^r(o)$ is are the residual energies of the next node s' at in the n^{th} and o^{th} time step and $d_{s-s'}$ is the estimated distance between the nodes s and s', d_{max} is the maximum transmission range of the sensor nodes and β is the route loss exponent.

The reward must be smaller than the largest Q-value of the parent hop count node to send data to the sink. However, the fixed reward for all network nodes is more likely to encourage nodes further away from the sink to send data in the opposite direction. To prevent backwarding, add a discount factor to the node rewards. Finally, the reward *R* for action *a* in state *s* is calculated:

$$R = \begin{cases} \varphi^{H_s} \times (R_{DA} + R_E \times 1) & if\ s'is\ not\ a\ sink \\ R_s \times 1 & else \end{cases} \tag{8}$$

where H_s is the number of hops from node *s*, 1 is a vector with all elements equal to 1 in *K* dimensions, R_s is the reward received by the sink node and φ is the discount factor for the payment, which ranges from 0 to 1. When the intermediate nodes receive the "Forward-Metric-Update" message, they update the message with the average total power consumption per node along the path, denoted as $path_w$. This update occurs either at the time of sending or receiving the message, as shown in (9), where t_x represents is the average power consumed by node *S* when transmitting along route *P* and t_r represents is the average power consumed by node *S* when receiving along route *P*.

$$pw(p) = \textstyle\sum_{s \in p} t_x(s) + \sum_{s \in p} t_r(s) \tag{9}$$

The cost of each route at the sink node is determined by evaluating each received message using (9). The weight factors $\propto + \beta + \gamma + \delta = 1$, are adjusted by the user based on the current usage of the network.

$$cost(p) \ = \ \omega \cdot \alpha + min.buffer(p) \cdot \beta + \\ + \left(\frac{1 + maxHC - HC(p)}{maxHC}\right) \cdot \gamma + 1 - \frac{number\ of\ delayed\ packets}{total\ packets} \cdot \delta \tag{10}$$

4. RESULTS AND DISCUSSION

The simulation factors used for the implementation of the proposed EGS-RP and the benchmarked approaches EWHCP [6], PDDQL [7] are analyzed below.

Experimental setup - The algorithms are coded in the C programming language. It is important to emphasize that all experiments described in this study were conducted with a physical test-bed and an actual implementation. The experimental system comprises seven sensor nodes with Raspberry Pi. Multi-hop communication enables the transmission of all multimedia data from a source node to a sink node. Each Raspberry Pi has a stored stream of pre-recorded video captured in a booth environment. The parameters are listed in Table 1.

Table 1. Simulation parameters.

Parameter	Value
Number of video sensor nodes	50
Number of sink nodes	1
Frames per second [fps]	19
Area [km^2]	50
Bandwidth [Mbps]	11
Power of each node [W]	0.005
Number of video sensor nodes	50
Number of sink nodes	1
Frames per second [fps]	19

A. Throughput

Throughput (kilobits/sec) =

$$\sum \frac{(number\ of\ successful\ packets) * (average\ packet\ size)}{Total\ Time\ sent\ in\ delivering\ that\ amount\ of\ data}$$

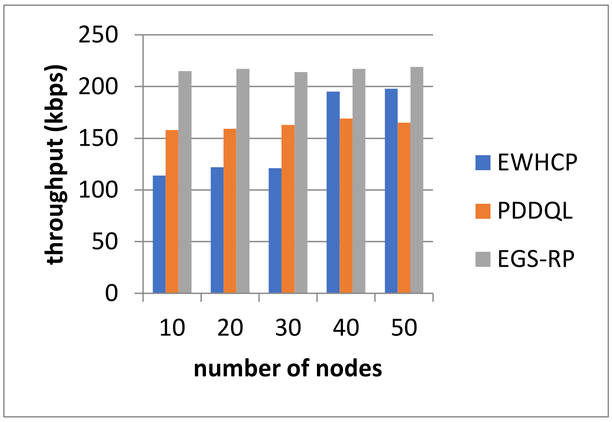

Fig. 2. Performance of throughput analysis.

Fig. 2 shows the comparison of the throughput analysis of the proposed EGS-RP and the existing technique of EWHCP, PDDQL. The proposed EGS-RP has achieved the highest throughput of 200 kbps, while the existing technique EWHCP has achieved 198 kbps and PDDQL has achieved 176 kbps.

B. Bandwidth

In the context of networks, bandwidth often refers to the highest rate at which data can be sent over a network connection, usually measured in bits per second (bps).

$$bandwidth = (2 \times bitrate) \times log2(L)$$

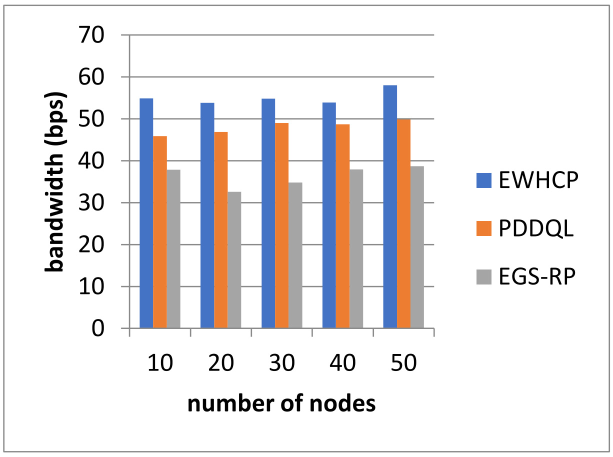

Fig. 3. Performance of bandwidth.

Fig. 3 shows the comparison of the bandwidth analysis of the proposed EGS-RP and the existing technique of EWHCP, PDDQL. The proposed EGS-RP has achieved the highest bandwidth of 38 bps, while the existing technique EWHCP has achieved 58 bps and PDDQL has achieved 48 bps.

C. Packet Delivery Ratio (PDR)

$$PDR = \frac{numberofpacketreceivedsuccesfully}{Totalnumberofpacketsforwarded}$$

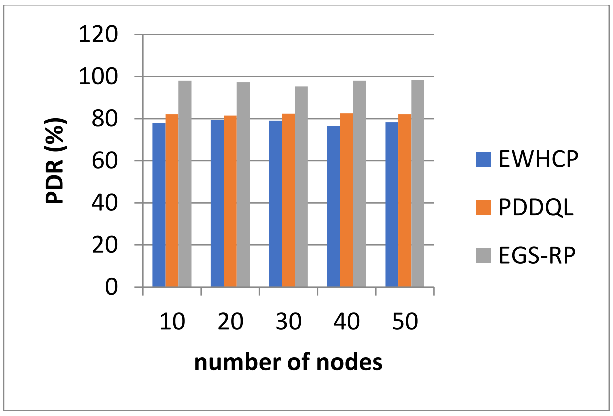

Fig. 4. Performance of packet delivery ratio

Fig. 4 shows the comparison of the packet delivery ratio analysis of the proposed EGS-RP and the existing technique of EWHCP, PDDQL. The proposed EGS-RP has achieved the highest packet delivery ratio of 98.56%, while the existing technique EWHCP has achieved 78% and PDDQL has achieved 82%.

D. Energy consumption

This is quantified as the cumulative energy of all hops and calculated as follows:

$$Energy = \frac{1}{p}\sum_{n}^{p} E_n$$

where in multi-hop routing, p is the number of hops and E_n represents the energy of the n^{th} hop.

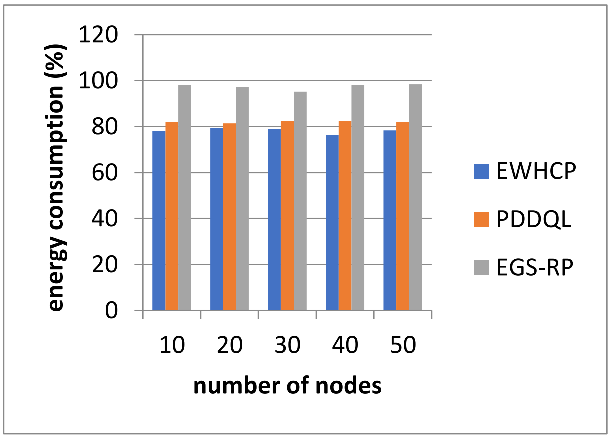

Fig. 5. Performance of energy consumption.

Fig. 5 shows the comparison of the energy consumption of the proposed EGS-RP and the existing technique of EWHCP, PDDQL. The proposed EGS-RP has achieved the highest energy consumption of 98%, while the existing technique EWHCP has achieved 76% and PDDQL has achieved 82%.

In Table 2 overall comparative analysis is given.

Table 2. Comparison of the proposed EGS-RP and the existing technique EWHCP and PDDQL.

Parameter	EWHCP [6]	PDDQL [7]	EGS-RP [proposed]
Throughput [kbps]	123	168	217
Bandwidth [bps]	79	82	98
PDR [%]	68.23	84.60	94.45
Energy consumption [%]	54.80	45.65	32.00

5. Conclusion

In this paper, a routing protocol called Epsilon greedy strategy based routing protocol (EGS-RP) is presented to evaluate our performance in a real transmission system. The experiments show that the developed approach can efficiently reduce the redundant information in videos over a long period of time and improve the user experience in situations with limited network resources. Consequently, this strategy improves the efficiency of network resource utilization in WMSNs. This article has some limitations. The proposed Enhanced Global Shutter Rolling Shutter Pipeline is not suitable for dynamic video sensors, such as those used in unmanned aerial vehicles. Dynamic video sensors exhibit significant fluctuations in the backdrop of the video. The super-resolution performance varies in different video scenarios. Additional quality differences occur between the individual video segments, in which leads to a decrease in the stability of the video playback quality. Another limitation is that the sensor requires a super-resolution model specifically designed for the scene being recorded. The consideration of the energy consumption and performance is an additional concern. Future optimization efforts aim to eliminate the above limitations.

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