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# A survey and analysis of multipath routing protocols in wireless multimedia sensor networks

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**Abstract** The main objective of this research is to conduct a performance analysis of various multipath routing protocols in wireless multimedia sensor networks for the efficient transmission of the image, audio and video data. To provide efficient routing for the large sized multimedia content, various multipath routing protocols such as energy-aware routing, QoS based routing and geographical routing methods are analyzed. In this analysis, the efficient routing techniques including geographical routing techniques such as GPSR, DGR, PW-DGR presented for wireless multimedia sensor networks are studied and the performance of each technique is evaluated to determine the efficient multipath routing technique. Comparisons are made for evaluated protocols and it is proved that the PW-DGR provides better routing performance for the multimedia data. The findings of the research also show that the PW-DGR method efficiently overcomes the routing problems such as energy bottleneck problem, energy-hole, reduced network lifetime and high delay in packet transmission.

**Keywords** Wireless multimedia sensor networks · Wireless sensor networks GPSR · DGR · PW-DGR

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## 1 Introduction

Wireless multimedia sensor networks (WMSN) [1] are networks of wirelessly interconnected devices that are able to ubiquitously retrieve multimedia content such as video and audio streams, still images, and also scalar sensor data from the environment using suitable multimedia sensors. In order to know about WMSN, WSN data aggregation has to be understood. Data aggregation in WSN takes place in different formats and different processes. Compressed data can be aggregated in an energy efficient manner which is called as compressed sensing [2]. Data can also be aggregated in a predicted way by using a combination of grey model and Kalman Filter [3]. An energy-Efficient, Delay-Aware, and Lifetime-Balancing Data Collection Protocol has been proposed in [4] by integrating it with compressed sensing to improve energy consumption. Compressive sensing can be used for hierarchical data aggregation [5] by setting multiple compression thresholds adaptively based on cluster sizes to optimize the amount of data transmitted such that the compression ratio is high. Energy efficiency in data aggregation of WSN requires support layers. In [6], DSR protocol with a cross layer support has been proposed to provide energy efficient routing. Similarly throughput, in multi-hop networks can be improved by utilizing spatial reusability-aware routing [7]. Likewise many of the techniques which have been utilized in WSN for efficient data aggregation can be extended for multimedia sensor networks by slight modifications.

WMSN, because of the availability of low cost CMOS cameras and microphones can enhance the usage of high quality multimedia content. The high bandwidth requirement, multimedia coding and processing techniques pave the way for the implementation of the WMSN which utilizes the high utility sensor nodes such as video sensors to aggregate the multimedia data and transmit them to the base stations. Video and audio sensors are utilized in the surveillance systems to detect crime activities. Large scale networks of video sensors are employed in the monitoring of public areas, specified private areas and highly secured military reserved areas. The multimedia data like imaging, temperature, pressure monitoring, etc. can be integrated with the machine vision systems for simplified but efficient visual inspections and automated actions that require high-speed, high-magnification, and continuous operation [8]. The main objective of the WMSN is to transmit multimedia content with a particular level of quality of service (QoS). The QoS has to be satisfied along with the reduction in energy consumption in the sensor networks in order to provide efficient applications. But the challenge in WMSN is providing efficient routing of the multimedia content which is normally large in size.

The multimedia content is different from the normal data especially in the size of the data. Thus the routing in WMSN requires special attention because the larger data size reduces the efficiency of the data transmissions. The problem with the larger size of the general sensor networks can be resolved by multi path routing in which the load is balanced among the available paths. But the same approach cannot be directly implemented in WMSN as the data, especially video data, cannot be transmitted in a balanced way as the quality of the data degrades considerably. Hence a unique routing technique has to be utilized in the WMSN which reduces the energy consumption and also reduces the delay in transmission but ubiquitously retrieves the quality of the data. For determining the efficient routing technique, multipath routing techniques have been studied in this paper and their performance has been compared in terms of different simulation parameters.

Previously, researches have provided complete analysis of the multipath routing schemes especially for the WMSN. The major issue with most of the multipath routing survey papers is the unclear evaluation of the routing schemes that results in unexpected performance variations. The multipath routing schemes are of different features and limitations which means that a particular routing scheme may not be efficient for multimedia transmission while may provide efficient performance for other data transmissions. This causes unfair comparison results. For example, the multipath routing schemes such as QoSNET [9] and BP-CMPR [10] provide efficient routing performance for the transmission of general data while they cannot be efficient in multimedia transmission. Likewise the geographical routing schemes such as GPSR [11] and DGR [12] are most suited for multimedia transmission in WMSN. But in most of the previous researches, all these routing schemes have been evaluated and compared with each other which do not provide fair comparison. In our research, the classification of the routing schemes is done to categorize them and the comparison is done separately.

The major contribution of this paper is the analysis of the various efficient multipath routing techniques for the transmission of multimedia content in WMSN. The routing techniques are studied and classified into energy aware routing and QoS aware routing and geographical routing techniques. The performance of the routing techniques is compared by the literature results. The geographical routing techniques namely GPSR, DGR and PW-DGR are intensively studied and the evaluation of the techniques is done by using Network Simulator-2 (NS-2). The experiments are conducted and the performance of the routing techniques is compared in terms of end-to-end delay, PSNR, Lifetime, Hop count and energy per packet. The comparison results show that the PW-DGR has better routing performance than GPSR and DGR.

The rest of the paper is organized as follows: Sects. 2 and 3 presents the analysis of the research methodologies discussed in this paper. Section 4 presents the comparison of the methodologies in literature. Section 5 presents the experimental results of the geographical routing protocols GPSR, DGR and PW-DGR. Section 6 concludes the research.

## 2 Analysis of QoS aware and energy aware routing protocols

Various multipath routing schemes are studied in this research work and are categorized under two groups: QoS aware routing, Energy aware routing protocols, and Geographical routing protocols. The QoS aware routing and Energy aware routing protocols are discussed first in this section. The geographical routing protocols are discussed separately. The timeline of the QoS aware routing & Energy aware routing protocols is given in Fig. 1 The timeline helps in knowing the introduction time of a routing protocol and understanding the range of research and modifications performed in the specific protocol.

He et al. [13] presented a real time communication protocol called SPEED. SPEED is a stateless, localized algorithm with minimal control overhead so that the data delivery can be performed effectively. End-to-end soft real-time communication is achieved by maintaining a desired delivery speed across the sensor network through a novel combination of feedback control and non-deterministic geographic forwarding. SPEED provides efficient routing even where the resources of each node are scarce. The problem with this approach is that SPEED uses more control packets and hence the energy consumption is high due to reduced packet speed.

Multi-Path and Multi-SPEED Routing Protocol (MMSPEED) for probabilistic QoS guarantee in wireless

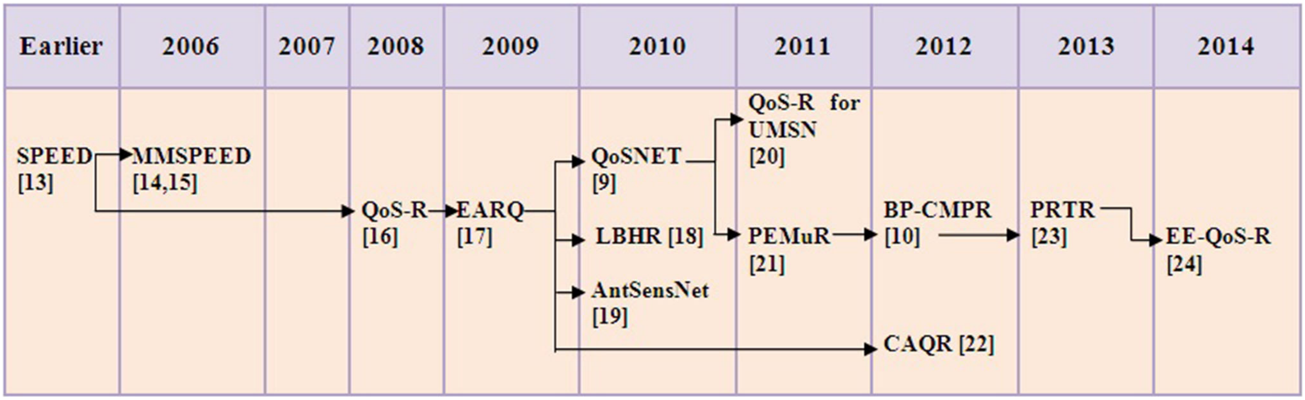


**Fig. 1** QoS aware and energy aware routing protocols

sensor networks has been proposed by Felemban et al. [14]. The QoS parameters-timeliness and reliability are considered for the effective routing of multimedia data. QoS can be satisfied by guaranteeing multiple packet delivery speed options and probabilistic multipath forwarding for timeliness and reliability. This routing approach enables global geographic routing packets by dynamic compensation method. The drawback with this approach is sub-optimal compatibility of the video data which also causes high power consumption for data delivery. The problem of compatibility can be overcome in MMSPEED aware with the embedded information of the multimedia packets as presented by Darabi et al. [15] for effective resource utilization. But still high energy consumption problem has not been resolved. The problem of energy delay tradeoff is also a serious concern.

QoS aware routing techniques are mostly preferred for multimedia content delivery as the QoS parameters normally include delay and energy efficiency which are the two most important factors in determining the routing approach. Hamid et al. [16] presented QoS-aware routing (QoS-R) protocol to support high data rate for wireless multimedia sensor networks. The proposed protocol is employed in the multi-channel multi-path foundation and hence the routing decision is made according to the dynamic adjustment of the required bandwidth and path-length-based proportional delay differentiation for real-time data. The QoS aware protocol ensures the bandwidth and the delay requirements for real-time data in a distributed manner. The throughput of the routing path is also improved by adjusting the service rate of real-time and non-real-time data. The drawback is that the approach requires frequent switching for selection of routes to reduce the switching delay.

The problem of reliable packet delivery has been resolved by using the EARQ [17] energy aware routing protocol for real time large data transmission in sensor networks. In EARQ, a node determines the energy cost, delay, and reliability of a path to the sink node, based only on information from neighboring nodes. Using the calculated information, the probability of selecting a path is estimated. Thus the effective routing can be achieved with less energy and cost but when more types of networks such as WLAN, Bluetooth, etc. are utilized with EARQ, the video data becomes less compatible due to inefficient load balancing. The problem can be resolved by using Load Balanced Hierarchical routing (LBHR) [18] algorithm. The WMSN having the characteristics such as limited resources, variable channel capacity, dynamic links, and high data redundancy reduces the overall QoS. The utilization of the LBHR improves the QoS of routing by using the clustering techniques with minimum spanning tree and improved ant colony optimization algorithm to find a primary path and some backup paths for large data routing. The major challenge is to maintain the success rate of transmission at all situations.

In order to maintain the success rate of transmission with QoS requirements, ant-based multi-QoS routing (AntSensNet) has been presented by Cobo et al. [19]. The approach builds hierarchical network for selecting the suitable paths. The advantage with the approach is that it also uses an efficient multi-path video packet scheduling in order to get minimum video distortion transmission. Another approach to ensure QoS in routing is the QoS NET proposed by Houngbadji et al. [9]. In QoS NET, a promising multipath QoS routing protocol based on a separation of the nodes into two sub-networks in which the first sub-network has specific nodes that are occasionally involved in routing decisions, while the second sub-network includes other nodes which fully take part in routing decisions. Thus efficient routing can be achieved with enhanced network lifetime.

Sarisaray-Boluk et al. [20] also presented a QoS aware routing approach for underwater multimedia sensor network (QoS-R for UMSN) using different combinations of multipath transport, watermarking-based error concealment (EC), forward error correction (FEC), and adaptive retransmission mechanisms. This approach reduces the underwater channel impairments and mitigates packet losses due to node failures and intrinsic underwater acoustic channel characteristics. Though the approach is efficient, energy efficiency is not considered in this approach. Kandris et al. [21] proposed a routing technique that is based on the QoS and also energy efficiency. The authors proposed PEMuR, a routing approach which includes the energy aware hierarchical routing protocol with an intelligent video packet scheduling algorithm. PEMuR enables the selection of the most energy efficient routing paths and manages the network load according to the energy remaining in the nodes. This reduces the useless data transmissions and hence the energy efficiency is improved. But the approach can be further improved by including bandwidth parameter.

Xu et al. [10] presented bandwidth-power aware multipath routing which considers QoS, bandwidth and energy efficiency for selecting the routing paths. The approach defines bandwidth-power aware cooperative multi-path routing (BP-CMPR) problem and considers it as NP-hard which can be solved by a polynomial-time heuristic algorithm CMPR. Suurballe's method is employed in the approach to find k minimal-weight node-disjoint paths from source to destination on a weighted graph. Then, dynamic programming is used to implement relay assignment and power allocation. The approach also includes a distributed CMPR (DCMPR) for the effective power allocation and hence the BP-CMPR provides better routing than PEMuR.

Dai et al. [22] proposed a correlation-aware QoS routing algorithm (CAQR) to efficiently deliver visual information under QoS constraints by exploiting the correlation of visual information observed by different camera sensors. The approach provides better load balancing along with reduced network congestion based on the correlation of the data so that the need for retransmissions can be reduced with reduced sensors energy consumption. The use of optimization QoS routing framework further reduces the energy consumption under delay and reliability constraints. The problem with the approach is that the correlation of the visual informations requires efficient compression techniques for efficient video data routing.

To satisfy the QoS, the parameters like delay, reliability and energy efficiency have to be considered. Potential-based Real-Time Routing (PRTR) protocol is proposed by Xu et al. [23] for efficient routing with reduced delay and reduced congestion. PRTR provides better routing without choosing point to point communication and thus improves the maintenance of the selected routes. Sung-Lee et al. [24] presented an energy efficient QoS aware routing (EE-QoS-R) technique for the transmission of multimedia content. The approach is sensitive to the changes in delay and reliability even at the stages of the resource deficiency. The technique reduces the control messages and instead utilizes the broadcast message from the sink for reducing energy consumption during routing.

## 3 Analysis of geographical routing protocols

The timeline of the geographical routing protocols is shown in Fig. 2. Geographical routing schemes are more effective for the transmission of multimedia content than the energy aware and QoS aware multipath routing techniques.

The Greedy Perimeter State Routing (GPSR) [11] approach uses the locations of the nodes to provide routing in a greedy manner. GPSR uses the geographical locations of the nodes discovered using the positioning systems like GPS or Galileo. Using the location of the destination node, the GPSR forms the route for data delivery in a greedy manner by selecting the nearest node in the route to the destination. When there is no available node for greedy forwarding or presence of voids, the perimeter formation uses the right hand rule to forward the data packets. Though GPSR approach provides better routing, the approach suffers from the inability to eliminate the edge without obstacles. GPSR takes other nodes into

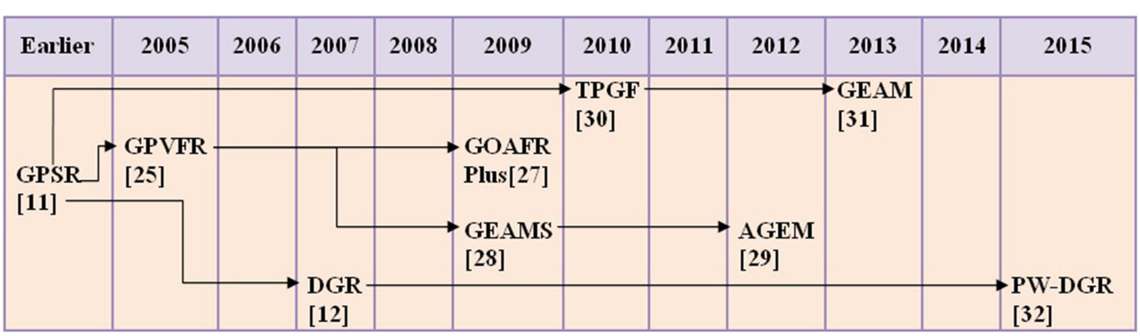


Fig. 2 Geographical routing protocols

consideration only when the energy of the nearest neighbor nodes is used up and it forms energy hole. This problem reduces the ability to forward packets especially multimedia content.

To overcome the problem of faces in the position connectivity graph, Leong et al. [25] presented protocols called Path Vector Exchange Protocol (PVEX) and Oblivious Path Vector Face Routing (OPVFR) for effective local face detection. Using the face detection, Greedy Path Vector Face Routing (GPVFR) is proposed to provide better routing performance in terms of both path stretch and hop stretch by determining available local face information even without identifying the face informations or limited routing state. The only problem with this approach is that the energy consumption is high because of the mapping of face locations.

To overcome the problems in GPSR and GPVFR, the Directional Geographical Routing (DGR) [12] has been introduced. DGR constructs number of multiple disjointed paths for a video sensor node to transmit parallel FEC-protected real time video streams in multiple paths so that the video streams can be forwarded efficiently. DGR reduces the route coupling problems and has many advantages such as less delay, longer network lifetime, and better received video quality. DGR can also be extended for the green vehicular networks for environmental friendly data aggregation [26]. But the drawback is that the approach does not support multiple active video sources due to the limited bandwidth which is a result of high received video quality. Similarly, DGR suffers from the energy bottleneck problem due to the multi-path forwarding.

GOAFR plus [27] is an efficient geographical routing technique to overcome the detection of local face problems. The approach has been currently utilized extensively in MANETs which can be extended to sensor networks with effective selection of the boundary circle the adaptive boundary circle selection without any local information of the face neighbors. Thus the routing can be improved without unnecessary expansion of the boundary circle and hence reduces the calculation cost. Though the forwarding cost is less, the drawback in the approach is the inability to adapt to the multiple active video sources.

Geographic Energy-Aware Multipath Stream-based (GEAMS) routing protocol is presented by Medjiah et al. [28] for the effective forwarding of the multimedia content without global knowledge to reduce the high energy consumption problem. GEAMS routing decisions are made online, at each forwarding node without requiring the global topology knowledge and maintenance. GEAMS uses smart greedy forwarding and walking back forwarding for efficient routing. The problem of the approach is that it cannot offer adaptive path selection for the next hop node selection which may reduce the routing efficiency. Medjiah et al. in another paper [29] proposed an online multipath routing protocol to be used along with geographical routing to overcome the problem of GEAMS in WMSNs. The proposed technique is called as Adaptive Greedy-compass Energy-aware Multipath (AGEM) routing which considers both node energy constraints and QoS needs of audio and video streams for the selection of paths. The greedy forwarding of GPSR is utilized with forwarding decision approach considering the factors such as the residual energy at node, the number of hops visited by the packet before it arrives at this node, the distance between the node and its neighbors, and the history of the packets forwarded belonging to the same stream. But still AGEM depends on beacon exchange for neighborhood state maintenance which reduces the overall efficiency.

Shu et al. [30] presented the Two-Phase geographic Greedy Forwarding (TPGF) routing algorithm for reducing the energy consumption. TPGF performs two phases for finding one shortest path per execution and can be executed repeatedly to find more on-demand shortest node-disjoint routing paths. In the first phase, the possible paths are selected while in the second phase, the optimization of paths is performed for finding the routing path with the least number of hops. TPGF supports hole-bypassing, the shortest path transmission, and multipath transmission and at the same time improves the energy efficiency. But the approach has a minor drawback in geographical forwarding phase which is not good as in previous research techniques.

Geographic Energy-Aware non-interfering Multipath (GEAM) has been proposed by Li et al. [31] for effective multipath routing of multimedia transmission in WSN. GEAM divides the whole network topology into many districts and forwards data through these districts without interfering with each other resulting in interference-free transmissions. The approach adaptively manages the load in each district based on the remaining energy status of the nodes and hence maintains the performance of the routing even when the topology changes rapidly. To send a packet, GEAM will assign the packet with district boundary and send it through the district by the greedy algorithm to the sink. The use of district adjustment for selection of paths with fewer hops will also reduce the energy-hole problem. But the use of many source-sink pairs may reduce the overall efficiency.

Pair-wise directional geographical routing (PWDGR) strategy is proposed by Wang et al. [32] to solve the problems present in the existing scenarios like GPSR, GOAFR, DGR, TPGF and GEAM. In PWDGR, first the source node can send the data to the pair-wise node around the sink node in accordance with certain algorithm and then it will send the data to the sink node. These pair-wise nodes are equally selected in 360° scope around the sink according to a certain algorithm. Therefore, it can effectively relieve the serious energy burden around the Sink and also make a balance between energy consumption and end-to-end delay. PWDGR uses GPSR routing scheme to forward packets from pair-wise hop node to sink node.

## 4 Comparison of methodologies

This section provides an overview about the advantages and disadvantages in the geographical routing methodologies whose functional scenarios are discussed in depth in the previous section. From the following table, a better approach can be determined that provides considerable improvement in the proposed scenarios.

Table 1 shows the overall comparison of the QoS aware and Energy aware routing protocols. In the table, the key features of the routing techniques, their drawbacks, the simulation environment and the simulation parameters with their theoretical results derived from the literature are shown for summarized understanding of the protocols. The fact is that these routing protocols are efficient in their own sense so most of the discussed protocols are used for different applications in the WSN with different levels of efficiency.

Table 2 shows the overall comparison of the Geographical routing protocols. In the table, the key features of the routing techniques, their drawbacks, the simulation environment and the simulation parameters with their theoretical results derived from the literature are shown for summarized understanding of the protocols.

To provide a clearer summarization of the geographical routing protocols, the most used protocols GPSR, DGR, GEAM, TPGF and PW-DGR protocols are compared in terms of different performance parameters from the literature. It is given in Table 3.

## 5 Experimental results

The experiments are conducted using the NS-2 simulator of version 2.34. NS-2 simulator is an open source simulation tool that supports many routing and queuing algorithms written in C++ with Object Tool Command Language interpreter as the frontend. In our work, the performance of the geographical routing techniques is evaluated and compared in terms of end-to-end delay, PSNR, energy per packet, hop count and network lifetime to determine the efficient technique. The most famous geographical routing techniques such as GPSR, DGR and PWDGR are compared in the following graphs.

### 5.1 Simulation environment

The evaluation of the geographical routing protocols GPSR, DGR and PW-DGR is performed in NS-2 of version 2.34 with the following simulation environment as shown in Table 4.

### 5.2 Simulation parameters

1.

$$\text{End-to-end delay} = \frac{\sum_{i=1}^{n}(t_{ri} - t_{si})}{n} \tag{1}$$

where $t_{ri}$ is the receive time of ith packet, $t_{si}$ is the sending time of ith packet and n is the total number of packets.

2.

$$\text{Peak signal-to-noise ratio (dB)} = 20\,log_{10}\frac{2^s - 1}{\sqrt{MSE}} \tag{2}$$

where s is the largest possible value of the signal and MSE is the mean square error given by

$$MSE = \frac{1}{N_1 \times N_2}\sum_{i}^{N_1}\sum_{i}^{N_2}\left[X(i,j) - \hat{X}(i,j)\right]^2 \tag{3}$$

$N_1 \times N_2$ is the number of pixels in an image, $X(i,j)$ and $\hat{X}(i,j)$ are the pixel value of the reconstructed image at the encoder and decoder.

3.

$$\text{Lifetime } \mathbb{E}[L] = \frac{\varepsilon_0 - \mathbb{E}[E_w]}{P + \lambda\mathbb{E}[E_r]} \tag{4}$$

where P is the constant continuous power consumption of the whole network, $\varepsilon_0$ is the total non-rechargeable initial energy, $\lambda$ is the average sensor reporting rate, $\mathbb{E}[E_w]$ is the expected wasted energy or unused energy when the network dies and $\mathbb{E}[E_r]$ is the expected reporting energy consumed by all sensors.

4.

$$\text{Hop count} = \frac{D}{\frac{W}{2}cos\left(\frac{1}{2}arcsin\frac{4}{\rho W^2}\right)} - 1 \tag{5}$$

where D is the distance to the sink node, W is the radio range, $\rho$ is the density of node deployment, $\frac{D}{\frac{W}{2}\cos\left(\frac{1}{2}\arcsin\frac{4}{\rho W^2}\right)}$ is the expected number of regions.

5.

$$\text{Energy per packet:} \quad E(i) = [(2*i - 1)(e_t + e_r)d \tag{6}$$

where i is the data packet, $e_t$ is the energy for transmission of packet i, $e_r$ is the energy for receiving the packet i and d is the distance between transmission node and destination node.

**Table 1** Comparison of QoS aware and energy aware routing techniques

| Method | Approach used | Merits | Demerits | Type of data transferred | Simulation environment | Number of nodes considered | Results |
|---|---|---|---|---|---|---|---|
| SPEED [13] | SNGF algorithm back pressure re-routing last mile processing | Maintained packet delivery speed reduces congestion problems | Packet delivery speed cannot be increased<br>Consumption is increased | Real time data | GlomoSim | 100 | End-to-end delay-240 ms, control packet overhead 900, energy consumption-20 mW h, delivery ratio-95 % |
| MMSPEED [14, 15] | Multi path forwarding<br>Virtual isolation among the speed layers<br>Dynamic compensation of local decisions | Desirable scalability and adaptability is achieved<br>Reliability and timeliness is efficiently guaranteed | Energy delay trade-off problem occurs<br>High energy consumption | Real time data | J-SIM | 100 | End-to-end delay-0.8 s, data packets-4.9, control packets-2.2, reachability-0.6, PSNR-32 dB |
| QoS-R [16] | QoS-aware Packet Scheduling<br>Dynamic Bandwidth Adjustment | Maximized throughput<br>Reduced end-to-end delay | High switching delay<br>Multiple priorities not supported | Real time data, Non-real time data | NS-2 | 100 | End-to-end delay-0.6 s, average lifetime-355 s, network throughput-2.9 |
| EARQ [17] | Queuing model<br>k-least path algorithm | High reliability with tolerable delay in packet data delivery | Requires complete topology knowledge<br>Load balancing is not efficient | Real time data, non-real time data | GlomoSim | 100, 90, 80, 70, 60 | Average energy-0.2 mW h, Packet drop ratio-0.5, ratio of deadline missed lost packets- 0.62 % |
| LBHR [18] | Clustering algorithm<br>Ant colony optimization<br>Minimum spanning tree algorithm | Prolonged Network Lifetime<br>Guaranteed QoS in transmission of data | Transmission success rate varies with the situations | Real time data | NS-2 | 100 | End-to-end delay-0.05 ms, transmission success rate-95 %, remaining alive nodes-50, communication overhead-65 |
| AntSensNet [19] | Ant Colony Optimization<br>QoS Routing | Better QoS for multiple types of WMSN services<br>Reduced consumption of constraint resources<br>Better congestion control | Node mobility reduces the network lifetime | Real time data | NS-2 | 100 | End-to-end delay-0.044 s, Packet delivery ratio-0.95 %, routing overhead-0.5 bytes, PSNR-36.5 db |
| QoSNET [9] | Switching QoS routing<br>Resolution mapping | Improved network lifetime based on QoS constraints<br>Reduced end-to-end delay | Packet error problem occurs | Real time data, Non-real time data | Qualnet | 256 | Packet delay-72 ms, Packet delivery ratio-0.7, network lifetime-300 s, Number of alive nodes-130 |

**Table 1** continued

| Method | Approach used | Merits | Demerits | Type of data transferred | Simulation environment | Number of nodes considered | Results |
|---|---|---|---|---|---|---|---|
| QoS-R for UMSN [20] | Forward error correction coding, Watermarking-based EC algorithm, Disjoint multipath image transmission, Retransmission based hop by hop error recovery | Mitigates packet loss due to node failures<br>Achieves desired quality of transmitted image with controlled pixel error in the packets | Energy efficiency, network model parameters are not considered | Real time data | Not specified | Not specified | Packet error rate-0.012, probability of node failure-0.1, PSNR-35 db, energy-0.55 J |
| PEMuR [21] | Energy efficient hierarchical routing, video packet scheduling | Efficient utilization of limited available bandwidth by selective dropping of less significant packets | Bandwidth is not considered | Real time data, Non real time data | TrueTime software, Matlab/Simulink | 100 | PSNR-39db, Number of alive nodes-44 |
| BP-CMPR [10] | Cooperative communication<br>Distributed BP-CMPR | Better power consumption<br>Optimal solution for bandwidth power aware cooperative multipath routing problem | High delay | Real time data, Non-real time data | Matlab/Simulink | 100 | Power consumption-110 mW, end-to-end delay-15 ms |
| CAQR [22] | Video In-Network Compression,<br>Correlation-aware inter-node<br>differential coding scheme and correlation-aware load balancing | Minimized network traffic with better congestion control<br>Minimized energy consumption<br>subject to delay and reliability constraints | Need for separate compression schemes | Real time data | Not specified | Not specified | End-to-end delay-275 ms, energy consumption-10 mJ, frame delivery ratio-0.55 |
| PRTR [23] | Maximum force rule, delay bound analysis | Minimizes delay for real time traffic<br>Better congestion control | Expensive to implement | Real time data, Non-real time data | TOSSIM | 600 | End-to-end delay-2.5 s, throughput ratio-86 %, energy consumption-250 mJ |
| EE-QoS-R [24] | Routing table construction algorithm | Minimizes the routing control messages and reduces energy consumption<br>Low congestion | Transmission in all directions may increase the energy consumption | Real time data | Visual Studio 2010 | 25 | Congestion level-2, node routing count-3,4, residual energy-10 |

**Table 2** Comparison of Geographical Routing Protocols

| Method | Approach used | Merits | Demerits | Type of data transferred | Simulation tool | No. of nodes considered | Results |
|---|---|---|---|---|---|---|---|
| GPSR [11] | Greedy forwarding<br>Perimeter forwarding | Improves forwarding efficiency even in void regions through perimeter forwarding | Unable to eliminate the edge nodes without obstacles<br>Energy hole problem | Real time data | NS-2 | 50, 112, 200 | Packet delivery success rate-0.99, path length-0.95, routing overhead-15,000 packets |
| GPVFR [25] | Greedy forwarding, PVEX, OPVFR | Improved data forwarding with limited routing state | High energy consumption | Real time data | NS-2 | 100 | Hop stretch-3, path stretch-1.5, proportion of hops-0.95 |
| DGR [12] | Forward error correction, deviation angle adjustment | Reduced route coupling problems<br>Less delay, longer network lifetime, and better received video quality | Does not support multiple active video sources<br>Energy Bottleneck problem | Real time data | OPNET | 500 | End-to-end delay-0.45 s, PSNR-20 db, energy consumption-1.95 mW s, PSNR lifetime-1.25 |
| GOAFR plus [27] | Boundary circle decision, greedy forwarding, Face routing | Improved route discovery without unnecessary expansion of boundary circles | Does not support multiple active sources | Real time data | OPNET | 50–2600 | Mean cost-2 hop counts |
| GEAMS [28] | Smart greedy forwarding, walking back forwarding | Reduces overall energy consumption | Low routing efficiency due to non-adaptive path selection | Real time data | OMNeT++ 4.0 | 30, 50, 80, 100 | End-to-end delay-40 s, packet transmission delay variance-600, packet drop rate-60 packets, mean energy-80 % |
| AGEM [29] | Smart greedy forwarding, walking back forwarding | Improves routing with considering node energy constraints and QoS needs of audio and video streams | Depends on beacon exchange for neighborhood state maintenance | Real time data | OMNeT++ 4.0 | 30, 50, 80 | End-to-end delay-0.004 s, packet drop rate-0.004 %, residual energy-0.098 % |
| TPGF [30] | Geographical routing, path optimization | Selection of optimal routes with hole-bypassing | Geographic routing phase is less efficient | Real time data | NetTopo | 100–1000 | Hop count-22, path count-25 |
| GEAM [31] | District adjustment and hole avoidance | Better routing with interference free transmissions | Many source-sink pairs scenario reduces routing performance | Real time data | NS-2 | 300 | End-to-end delay-125 ms, Hop count-17, energy consumption-0.097, data received-270 kbps |
| PWDGR [32] | Directional Geographical routing, GPSR | Reduces energy hole problem<br>Effective energy balancing in the nodes nearest to sink | Use of GPSR for routing from pair wise nodes to sink increases the energy consumption | Real time data | OPNET | 800 | End-to-end delay-100 ms, Hop count-11, network life-55, energy-400 mJ |

**Table 3** Comparison of geographical routing protocols during an energy-hole scenario

| Parameter | Protocol | | | | |
|---|---|---|---|---|---|
| | GPSR | DGR | GEAM | TPGF | PW-DGR |
| Packets drop ratio | 0.012 | 0.04 | 0.06 | NA | NA |
| Delay (ms) | 300 | 215 | 200 | 160 | 120 |
| Energy per packet ($w/10^6$) | 330 | 240 | 455 | 380 | 230 |
| Residual energy at the ending of network life (w) | 0.098 | NA | 0.097 | 0.098 | NA |
| Number of HOP | 21 | 18 | 17 | 22 | 11 |
| Path length | 32 | NA | NA | 25 | NA |
| Average remain energy of sinks neighbors (w) | NA | 0.065 | NA | NA | 0.11 |
| PSNR (dB) | 24 | 29 | NA | NA | 32 |
| Network life | 27 | 38 | NA | NA | 55 |

*NA* not applicable

**Table 4** Simulation environment

| | |
|---|---|
| Network area (size) | $1000 \times 1000\ m^2$ |
| Network topology | Flatgrid |
| MAC layer (IEEE standard) | IEEE 802.11 |
| IFQ type | Queue/DropTail/PriQueue |
| IFQ length | 50 |
| Antenna type | Antenna/OmniAntenna |
| Physical type | Phy/WirelessPhy |
| Channel type | Channel/WirelessChannel |
| Energy model | EnergyModel |
| Bandwidth | 2 MB |
| Application type | Constant bit rate (CBR) |
| CBR interval | 1.0 (s) |
| No. of packets | 1500 |
| No. of sink nodes | 1 |
| No. of source nodes | 1 |
| No. of sensor nodes | 30 |
| Transmission range | 250 m |
| Packet size | 2 MB |
| No. of paths | 9 |
| Transmit power | Random |
| Receiving power | Random |
| Idle power | Random |
| Initial energy | 1000 mJ |

### 5.3 Performance analysis

#### 5.3.1 End-to-end delay

Figure 3 shows the comparison of GPSR, DGR and PWDGR in terms of End-to-end delay. When the number of nodes is 20, GPSR has End-to-end delay of 300 ms; DGR has 215 ms while PWDGR has 120 ms. There is considerable reduction of delay in PWDGR because of the efficient selection of pair wise node. This clearly shows that the PW-DGR has better performance than GPSR and DGR in terms of End-to-end delay.

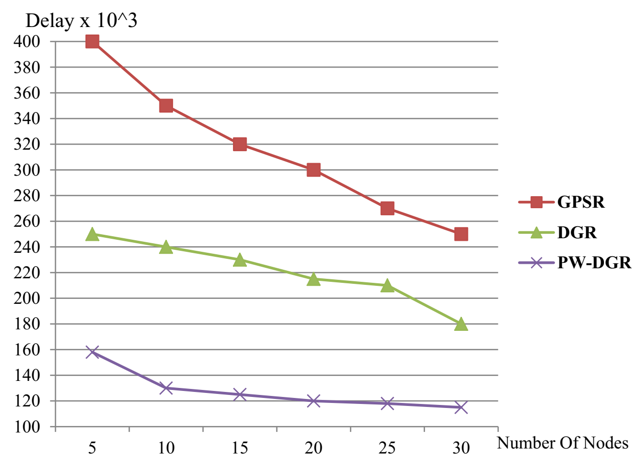


**Fig. 3** End-to-end delay

The comparison of GPSR, DGR and PWDGR in terms of end-to-end delay with respect to number of nodes is shown in Table 5.

#### 5.3.2 PSNR

Figure 4 shows the comparison of GPSR, DGR and PWDGR in terms of PSNR value. When the number of nodes is 20, GPSR has PSNR of 24; DGR has 25 while PWDGR has 32. PWDGR has improved PSNR value as the transmitted content has reduced error propagations. This clearly shows that the PW-DGR has better performance than GPSR and DGR in terms of PSNR.

The comparison of GPSR, DGR and PWDGR in terms of PSNR with respect to number of nodes is shown in Table 6.

#### 5.3.3 Lifetime

Figure 5 shows the comparison of GPSR, DGR and PWDGR in terms of Network lifetime. When the maximum transmission range is 60, GPSR has lifetime of 27; DGR has 37 while PWDGR has 55. The lifetime is improved because PWDGR reduces the average energy consumption of node around the sink and also decreases the probability of forming energy hole around the sink node. This clearly shows that the PW-DGR has better performance than GPSR and DGR in terms of Lifetime parameter.

The comparison of GPSR, DGR and PWDGR in terms of Lifetime with respect to Maximum transmission range is shown in Table 7.

#### 5.3.4 Hop count

Figure 6 shows the comparison of GPSR, DGR and PWDGR in terms of Hop count value. When the maximum transmission range is 60, GPSR has Hop count of 21; DGR has 17 while PWDGR has 11. PWDGR transmits the packets with flexible distance and transmitting angle that reduces the overall hop count. This clearly shows that the PW-DGR has better performance than GPSR and DGR in terms of Hop count value.

The comparison of GPSR, DGR and PWDGR in terms of Hop count with respect to Maximum transmission range is shown in Table 8.

#### 5.3.5 Energy per packet

Figure 7 shows the comparison of GPSR, DGR and PWDGR interms of Energy per packet value. When the maximum transmission range is 60, GPSR has Energy per packet value of 330; DGR has 240 while PWDGR has 230. PWDGR has better energy consumption per packet due to the low utilization ratio of node around sink. This clearly shows that the PW-DGR has better performance than GPSR and DGR interms of Energy per packet.

**Table 5** Comparison in terms of end-to-end delay (ms)

| Number of nodes | GPSR | DGR | PW-DGR |
|---|---|---|---|
| 5 | 400 | 250 | 158 |
| 10 | 350 | 240 | 130 |
| 15 | 320 | 230 | 125 |
| 20 | 300 | 215 | 120 |
| 25 | 270 | 210 | 118 |
| 30 | 250 | 180 | 115 |

**Table 6** Comparison in terms of PSNR (dB)

| Number of nodes | GPSR | DGR | PW-DGR |
|---|---|---|---|
| 5 | 30 | 34 | 42 |
| 10 | 29 | 31 | 39 |
| 15 | 27 | 28 | 35 |
| 20 | 24 | 25 | 32 |
| 25 | 20 | 22 | 29 |
| 30 | 17 | 20 | 26 |

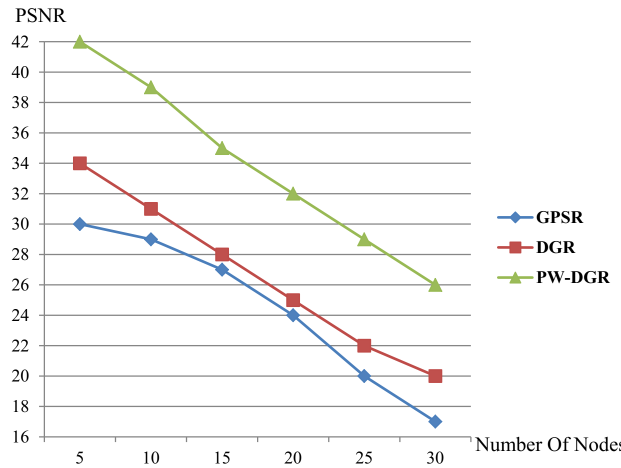


**Fig. 4** PSNR

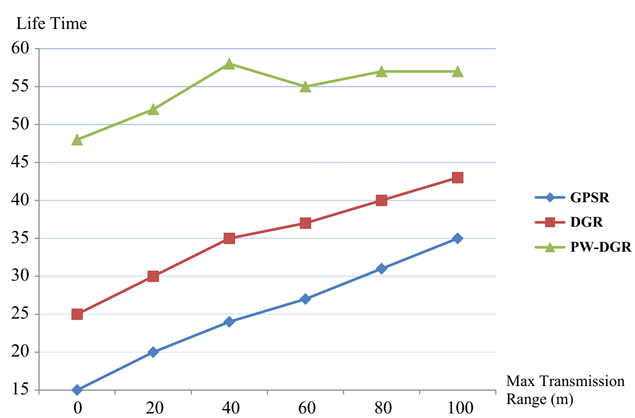


**Fig. 5** Lifetime

**Table 7** Comparison in terms of lifetime

| Maximum transmission range (m) | GPSR | DGR | PW-DGR |
|---|---|---|---|
| 0 | 15 | 25 | 48 |
| 20 | 20 | 30 | 52 |
| 40 | 24 | 35 | 58 |
| 60 | 27 | 37 | 55 |
| 80 | 31 | 40 | 57 |
| 100 | 35 | 43 | 57 |

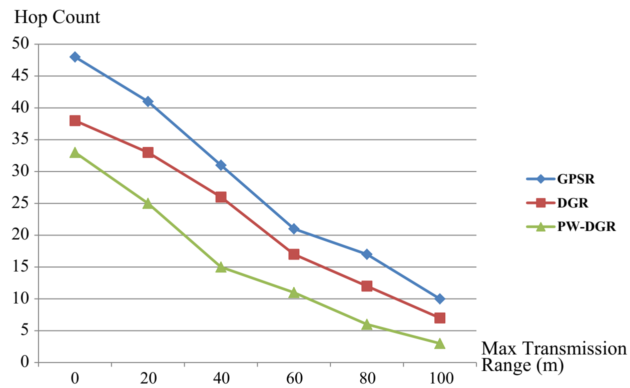


**Fig. 6** Hop count

**Table 8** Comparison in terms of Hop count

| Maximum transmission range (m) | GPSR | DGR | PW-DGR |
|---|---|---|---|
| 0 | 48 | 38 | 33 |
| 20 | 41 | 33 | 25 |
| 40 | 31 | 26 | 15 |
| 60 | 21 | 17 | 11 |
| 80 | 17 | 12 | 6 |
| 100 | 10 | 7 | 3 |

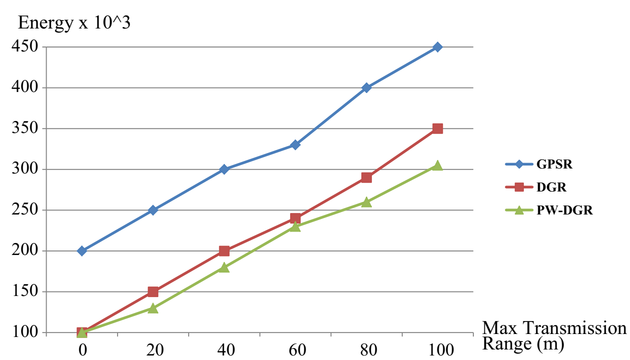


**Fig. 7** Energy per packet

**Table 9** Comparison in terms of energy per packet (w/106)

| Maximum transmission range (m) | GPSR | DGR | PW-DGR |
|---|---|---|---|
| 0 | 200 | 100 | 100 |
| 20 | 250 | 150 | 130 |
| 40 | 300 | 200 | 180 |
| 60 | 330 | 240 | 230 |
| 80 | 400 | 290 | 260 |
| 100 | 450 | 350 | 305 |

The comparison of GPSR, DGR and PWDGR in terms of Energy per packet with respect to Maximum transmission range is shown in Table 9.

## 6 Conclusion

In this research, the multipath routing techniques namely QoS aware and Energy aware routing protocols and geographical routing protocols for wireless sensor networks and wireless multimedia sensor networks are studied and analyzed for the efficient transmission of multimedia content. From the analysis, it is clear that the PWDGR is the better routing approach for multimedia transmission in terms of different performance parameters. But even PWDGR has some drawbacks which mean still there is scope for improvement. The problem of high energy consumption in PWDGR is because of using GPSR routing and GPS for locating the nodes. This can be reduced by using energy efficient node localization systems other than GPS. The energy consumption can also be reduced by modifying the GPSR routing technique which will be our future work.

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