Multipath routing protocols for wireless multimedia sensor networks: a survey

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Abstract: Recent advances in sensor networks have led to a new category of networks called wireless multimedia sensor networks (WMSNs). These networks can support a variety of multimedia applications that have more requirements than other kinds of applications in terms of latency, energy consumption and quality of service. However, routing protocols designed initially for sensor networks cannot fulfill these requirements specially those involving a single-path in the data delivery process. For this purpose, multipath routing protocols are considered as appropriate solutions to achieve these goals since they can efficiently reduce energy consumption, prolong network lifetime, reduce latency and enable load balancing. In this paper, we survey recent multipath routing protocols designed for WMSNs and present a general classification for the various approaches pursued. Moreover, we also compare them based on relevant metrics such as architecture, hole bypassing, path disjointness, load balancing, bandwidth aggregation, energy efficient, reducing delay and data reliability.

Keywords: energy-efficient; load balancing; multimedia applications; multipath routing; QoS requirements; wireless sensor networks; WSNs; wireless multimedia sensor networks; WMSNs.


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1 Introduction

Recent advances of multimedia source coding techniques such as multiple description coding and the availability of low-cost efficient miniature hardware, such as sensors, complementary metal-oxide semiconductor (CMOS) cameras and small microphones that are able to ubiquitously capture multimedia content from physical environment accelerates the development of wireless multimedia sensor networks (WMSNs) (Akyildiz et al., 2007).

WMSNs are a newly developed type of sensor networks. They consist of sensor devices wirelessly interconnected that are able to retrieve multimedia content such as video, audio streams, still images, and scalar sensor data from the physical environment unlike traditional wireless sensor networks (WSNs), which typically collect scalar data (such as temperature, pressure and humidity) from the ambient environment. Moreover, WMSNs will also be able to store, process in real-time, correlate, and fuse multimedia data originating from heterogeneous sources.

Furthermore, WMSNs will not only enhance existing WSNs applications but they can also produce some new applications such as multimedia surveillance, environmental monitoring, smart homes, intrusion detection, person locator services and applications in telemedicine, etc.

As descendant of traditional WSNs, WMSNs inherit most of their advantages including ease of deployment, scalability, fault-tolerance, and self-organising. Nevertheless, WMSNs have more additional requirements than WSNs, such as high bandwidth demand, short end-to-end delay, low packet loss rate, low latency, acceptable jitter and reliability. Thereby, these requirements impose more resource constraints in WMSNs involving limited energy, memory space and processing capabilities.

Routing in WSNs is a process of determining a path between the source node and the sink. Compared to traditional ad-hoc networks, routing is more challenging in WSNs due to their limited resources in terms of available energy, processing capability and communication, which are major constraints for most sensor networks applications.

Because multimedia applications in WMSNs are characterised by the exchange of a large amount of data compared to traditional WSNs applications, they consume more energy to accomplish this task, which leads to draining battery-life of the nodes in the network and thereby makes them unavailable. In addition, quality of service (QoS) has become a fundamental requirement for WMSNs where many works introducing QoS in WMSNs have been proposed (Dai et al., 2012; Lin et al., 2011; Hamid et al., 2008; Namazi and Faez, 2013; Lee et al., 2014, etc.).

There are mainly two types of routing techniques in WMSNs: single-path routing and multipath routing. In single path routing, each source sensor sends its data to the sink through only one path that is usually the shortest path. However, WMSNs are prone to failures due to node failure and/or link failure and if the path is unique, any failure in one
of its nodes will cause disruption, preventing the delivery data. Many routing schemes for WMSNs have been proposed in the literature, which deal with node failures as in Misra et al. (2011) and Misra et al. (2013) for respectively ad hoc networks and vehicular networks. The proposed solutions consist in repairing broken paths or discovering new routes to forward traffic around failed nodes. The both operations increase energy consumption and data delivery time. According to the features of WMSNs, single-path routing protocols cannot satisfy the requirements of WMSNs applications in terms of latency and load balancing because the multimedia data is voluminous. Recent researches (Li and Wang, 2010; Karp and Kung, 2000; Shin et al., 2007; Nayyar et al., 2011; Li et al., 2008, etc.) have shown that multipath routing protocols are promising to overcome the limitations of single-path routing protocols because they involve multiple paths to send data from a source node to a destination node. Moreover, they divide a data stream into several parts and sending them through different routes, which reduces the data delivery time, guarantees load balancing in the network and evenly distributes the energy consumption among the sensor nodes. Furthermore, multipath routing protocols increase throughput, aggregate bandwidth, ensures the reliability of delivery, etc.

The reminder of the paper is organised as follows. In Section 2.1, we discuss and explain how multipath routing plays a significant role in WMSNs and can work efficiently in the presence of resource constraints. We discuss in Section 2.2 the major factors influencing multimedia communication in WSNs. Then we classify the main existing multipath routing protocols proposed in the literature for WMSNs into five categories and describe protocols of each category in detail in Section 2.3. A comparative summary of these protocols is also provided in a tabular form. Finally, we conclude our paper in Section 3.

2 Multipath routing in WMSNs

2.1 Advantages of multipath routing

The use of multipath routing where multiple paths may exist between the source node and the base station is highly recommended for WMSNs applications. This routing scheme takes into account the QoS requirements of various WMSNs applications in terms of delay, reliability, fault-tolerance, throughput, etc. Before presenting the most recent multipath routing protocols and highlighting their advantages, we first outline the key advantages of multipath routing:

- **Load balancing:** To provide load balancing, it should be avoided that there would be nodes and links over-utilised, thereby it would involve a large number of nodes in the routing process and use multipath routing schemes. Therefore, the energy consumption will be distributed evenly among the nodes thus the network lifetime increases. Moreover, the congestion will be prevented because the packets are sent through alternative different paths, which alleviates nodes over-utilised.

- **Fault-tolerance:** Wireless networks are subject to failures: the wireless devices are often unreliable, they have limited battery life, transmissions may be blocked by changes in the environment, and the devices may be damaged, e.g. by weather,
wildlife or human intervention (Sitanayah et al., 2011). Thereby, for dealing with failures, the network topology should provide alternative routes to the sink so when failures occur the routing protocol can still ensure reliable delivery.

- **Bandwidth aggregation:** Multipath routing strategy divides a data stream into several parts and each part is routed through a different path to the same destination, hence this strategy can offer the bandwidth aggregation.

- **Reduced delay:** In single-path routing protocols, when a node fails a route discovery process to the base station is triggered, this affects the delivery delay. However, in multipath routing protocols, delay can be minimised because backup paths are determined an advance during route discovery process.

- **Data reliability:** Reliability can be defined as the probability that packets arrive from the source to the destination successfully (Akan, 2007). Multipath routing can increase data reliability by sending multiple copies of the same data on different paths.

- **Data security:** Wireless networks may be subject to attacks. However, a malicious user does not have the ability to listen to all radio links in a network. Multipath routing schemes can increase the level of security in the network since several copies of a message can be sent through various paths. Thereby, even in the presence of malicious paths, at least one copy of the message could be delivered successfully to the destination node via a secure route. Moreover, by incorporating the coding technique with multipath routing schemes, the data can be transmitted in an encoded form and only decoded at the destination node, which prevents eavesdropping on the sensing data during transmission (Sha et al., 2012). Multi-path data transfer (MPDT) is an algorithm used in WMSNs (Poojary and Pai, 2010). It provides simultaneous multiple paths for communication between any pair of nodes. This feature prolongs network lifetime since retransmissions are avoided and enables MPDT to be robust to other malicious attacks.

- **Energy-efficient:** Energy consumption of energy-constrained nodes in WSNs is a critical weakness of these networks because the sensor nodes are equipped with batteries that are generally not rechargeable and non-replaceable when the sensor nodes are deployed in hostile environments. Therefore, energy-efficient communication is an important feature to increase the network lifetime. Moreover, multipath routing scheme is an efficient solution to improve the network lifetime because it allows load balancing.

### 2.2 Factors influencing communication in WMSNs

The design of WMSN applications is mainly influenced by several factors such as QoS requirement, high bandwidth demand, multimedia source coding techniques, energy consumption, scalability, sensor network topology, localised processing and data fusion etc. These factors are addressed by many researchers as surveyed in Akyildiz et al. (2007) and Sharif et al. (2009). In this section, we outline the main challenging factors that need to be addressed in order to improve communication efficiency in WMSNs.
• **QoS requirement:** One of the most important challenges in the design of WMSNs applications is to satisfy the specific QoS requirements of these applications. The variety of multimedia applications may have various requirements such as delay, reliability, bandwidth, jitter, latency and energy efficiency, which required efficient routing solutions dealing with various QoS requirements.

• **High bandwidth demand:** In the design of WMSNs applications, especially video streams applications are well known with their high bandwidth requirements than other kinds of WMSNs applications. Hence, high data transmission rate of sensor nodes must be utilised to accommodate the high bandwidth demand.

• **Power consumption:** In WMSNs, energy-efficient is an important performance metric even more than in traditional WSNs. In fact, sensor nodes are battery-constrained devices whereas multimedia applications are characterised by the transfer of a large amount of data, which requires high transmission rate and processing capabilities.

• **Multimedia source coding techniques:** Since sensor nodes in WMSNs capture a large amount of traffic generated by multimedia devices such as cameras, it is obvious that the multimedia source coding techniques are required for multimedia WSNs. To ensure efficient transmission of multimedia data, multimedia source coding techniques must enable reducing the amount of data to be transmitted and use high performance compression algorithms.

• **Integration with IP architecture and other wireless technologies:** It is more important to retrieve useful information from anywhere and at any time. For this reason, future WMSNs will be support several heterogeneous wireless technologies like Wi-Fi, Bluetooth, etc. and will be accessible from the internet as will be integrated with the IP architecture.

2.3 **Multipath routing protocols in WMSNs**

Several multipath routing protocols were developed for WMSNs. In this paper, we classify the main existing multipath routing protocols proposed in the literature for WMSNs into five categories as shown in Figure 1. We review each of these categories in the next subsections.

2.3.1 **Load balancing**

Load balancing is a very important feature to prolong network lifetime since it aims to involve a large number of nodes in the process of delivering data. Therefore, the energy consumption will be evenly distributed among the nodes and consequently network lifetime will be extended. Furthermore, multipath routing protocols greatly promote load balancing, by forwarding traffic through several paths to avoid having nodes or links overused.
2.3.1.1 Optimised node-disjoint multipath routing

The optimised node-disjoint multipath routing protocol (TinyONDMR) proposed in Jung et al. (2008) is an on-demand routing protocol that finds more node-disjoint routing paths to avoid congestion on common links and nodes. TinyONDMR is an improved version of split multipath routing (SMR) algorithm (Lee and Gerla, 2001). This protocol mainly uses three schemes to find node-disjoint multiple paths between the source and the destination: a source routing approach, the smallest hop count and filtering overlapped paths. In source routing approach, the information of the nodes that consist of the route is included in the RREQ (ROUTEREQUEST) message. When the source node needs a route to the destination node but no route information is known, it broadcasts a RREQ message to all nodes of the network. Therefore, the destination node is reached through several paths, thus it selects multiple disjoint routes and sends RREP (ROUTE REPLY) messages back to source node via chosen routes. An example of source routing is shown in Figure 2.

In on-demand routing protocols, the source node usually broadcasts RREQ packets to find a routing path to the destination node. When an intermediate node receives a RREQ message for the first time, it broadcasts it in turn. After receiving this message for the first time, duplicate RREQ messages are dropped. However, duplicate RREQ messages should be forwarded to the destination to build multiple routing paths. But the problem is that if all duplicate RREQ messages are forwarded, it causes high routing overhead. It
will result in a degradation of protocol performance. To overcome this limitation, TinyOND MR uses a packet forwarding method based on the smallest hop count. In this method, the intermediate nodes receive all RREQ packets for a predefined period and then they broadcast the duplicate RREQ packets that have the smallest hop count i.e. the hop count is the number of nodes contained in RREQ packets. Figure 3 shows an example of propagation of the RREQ messages with the smallest hop count.

Figure 2  Node-disjoint multipath

![Node-disjoint multipath](image1)

Figure 3  RREQ propagation with shortest hops

![RREQ propagation with shortest hops](image2)

Moreover, to reduce overhead routing, this protocol introduces a method to filter overlapped routing paths by the intermediate nodes. The example presented in Figure 4 illustrates the principle of this method. In this example, node g will receive three RREQs, which indicate three routing paths [S-a-d], [S-c-d], and [S-c-f]. These paths have the same hops, 3. Before forwarding, node g check whether or not routing paths are node-disjoint. If there are overlapped routing paths, one of them will be discarded for disjointness. Routing path [S-c-d-g] has a common overlapped link [d-g] compared with the path [S-a-d-g]. It also has an overlapped link [S-c] compared with the path [S-c-f-g].
Therefore, in TinyONDMDR, we discard the routing path [S-c-d-g] that has more than two common overlapped links when it is compared with the others. Hence, we just rebroadcast two RREQs including the information of routing paths [S-a-d-g] and [S-c-f-g].

Figure 4  RREQ propagation with no overlapped

TinyONDMDR supports node-disjoint multiple routing paths. This routing scheme enables to provide better performance since load balancing is carried among all nodes in the network.

2.3.1.2 Load balancing-based hierarchical routing

Li and Wang (2010) proposed load balancing-based hierarchical routing (LBHR) algorithm for WMSNs. First, the network is divided by a novel clustering algorithm wherein the cluster head is selected according to the weight of each node within a cluster, and the node with the smaller weight has the higher priority to become cluster head. The weight of a node is calculated according to its degree and its remaining energy. After the cluster heads selection, cluster heads send a CH_Msg message to their neighbours requesting them to join them. Each neighbour selects the appropriate cluster to join it and sends a Join_Req message to its cluster head. If the cluster head accepts its request of adhesion, then it will send an Allow_Join message to it, otherwise, it will send a Rej_Join message. If the node receive Rej_Join message and does not receive any Allow_Join message from other cluster heads during a predefined period, it will declare itself as an independent cluster head. Then the inter-cluster routing scheme is built by using of the improved ant colony optimisation algorithm to find a primary path and some backup paths. When the amount of data is greater than the maximum throughput of the primary path, the source cluster head implies another suboptimal path for transmitting the multimedia data. Finally, the intra-cluster routing scheme is established using the minimum spanning tree algorithm, wherein a hierarchical routing tree is constructed by
the algorithm above. The abilities of the cluster members in the tree descend from the top to the bottom. The cluster members send the aggregated data to the cluster head using the intra-cluster hierarchical routing tree, while the cluster heads send the aggregated data to the base station using the inter-cluster routing scheme. The theoretical analysis and simulation results show that LBHR can achieve load balancing, reduce the end-to-end delay and improve the success rate of transmission. Therefore, LBHR has better adaptability, scalability, effectively prolongs the network lifetime and guarantees the QoS of data transmission compared with other similar algorithms.

2.3.1.3 Multipath routing algorithm for WMSN within expected network lifetime

This algorithm is performed in two steps by Xie and Gu (2010). In the first step, a set of node-disjoint multiple routing paths is determined using amazing search method, which consists of wave front expansion and path back tracking. In wave front expansion, the initial obstacle set is composed of all nodes lied in a closed or opened loop hole which are marked and when wave-front is expanded, the involved valid nodes from source to destination are labelled in a decreasing tag number and they are merged into the obstacle set as temporary obstacles. During the wave-front expansion, if the wave-front reaches a blocked node (node which cannot find the next hop during routing exploring) it is immediately merged into the obstacle set. In path backtracking, the algorithm starts with the destination node to the source node and selects the node whose tag number is greater than that of current node as a next hop. When the source node is reached, the routing path is generated and all temporary obstacle nodes except the nodes belonged to the new routing path are removed from the obstacles set. The algorithm is still running until there are no new routing paths. Then, it selects a routing path from the set of multiple routing paths found. In this step, a new congestion control message, a gradual increase strategy based on paths and a gradual increase strategy based on flows are introduced to balance load and energy consumption.

2.3.1.4 Adaptive greedy-compass energy-aware multipath

Medjiah et al. (2009, 2010, 2012) proposed adaptive greedy-compass energy-aware multipath (AGEM) which is suitable for transmitting multimedia streaming over WMSNs. In AGEM, at each hop, a forwarder node decides through which neighbour it will send the packet based on its position. Moreover, AGEM exploits the multipath capabilities to make load balancing of traffic and minimises energy consumption among nodes. The AGEM routing protocol has two modes: the smart greedy forwarding and the walking back forwarding. The first mode is used when there is always a neighbour closer to the sink node than the forwarder node, while the second one is used to get out of a blocking situation in which the forwarder node can no longer forward the packet towards the sink node. Figure 5 presents an overview diagram of AGEM routing ‘switching mode’.

- **Smart greedy mode:** In AGEM, nodes are aware of their geographic coordinates and each sensor node stores some information about its one-hop neighbours. Information includes the estimated distance to its neighbours, the distance of the neighbour to the sink, the data-rate of the link, and the remaining energy. Based on this information, a forwarder node will give a score to each neighbour according to an objective function called ‘f(x)’. This scheme tries to select the neighbours with best angular
offset towards the destination. At the beginning, the forwarder node chooses only neighbour nodes that are closest to the destination and which are in the angle $\alpha < 30^\circ$. A minimum of ‘n’ neighbour nodes (neighbouring set whose size is greater than or equal to 2) must be found to perform load balancing. If (n = 1) then there is just one node in neighbouring set, hence no load balancing can be achieved. If no node is found, the angle is incremented by steps of 10° until it reaches 180°. At this phase, if no node is found then a walking back forwarding is needed since the forwarder is facing a hole. Figure 6 illustrates this adaptive forwarding policy.

- **Walking back forwarding mode:** When a forwarder node may face a void where there is no closest neighbour to the sink, this node enters the walking back forwarding mode in order to bypass this void. In such a case (see Figure 7), the forwarder node will inform all its neighbours that it cannot be considered as a neighbour to forward packets to the sink. This node will also delegate the forwarding responsibility to its nearest neighbour to bypass the void. This process does recursively step back until a node is found that can forward the packet successfully.

**Figure 5** AGEM routing with switching mode (see online version for colours)

**Figure 6** AGEM adaptive compass policy (see online version for colours)
Li and Chuang (2013) proposed a geographic energy-aware non-interfering multipath (GEAM) for effective multipath routing of multimedia transmission in WMSNs. 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. It also manages the load in each district based on the remaining energy status of the nodes and thereby the performance of the routing is maintained even when the topology changes. To send a packet, GEAM will assign the packet with district boundary and sends 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. However, the use of many source-sink pairs may reduce the overall efficiency.

2.3.2 Bandwidth aggregation

Because the multimedia data is voluminous in WMSNs, multipath routing consists in dividing a data stream into several parts and to route each part through a different path to the same destination. This strategy can provide the bandwidth aggregation.

2.3.2.1 Directional geographical routing

Directional geographical routing (DGR) proposed by Chen et al. (2007) is an improved version of greedy perimeter stateless routing (GPSR) (Karp and Kung, 2000). DGR establishes multiple disjoint paths for video-sensor nodes to transmit parallel FEC-protected H.26L real-time video streams over a bandwidth-limited, unreliable networking environment. For this purpose, DGR divides a single video stream into
multiple sub-streams and exploits multiple disjoint paths between video-sensor nodes and the sink to transmit these sub-streams in parallel manner. Therefore, this strategy allows it to provide load balancing, bandwidth aggregation, and fast packet delivery. Furthermore, DGR provides a small delay, a relatively long network lifetime and better video quality compared to GPSR. Nevertheless, DGR does not permit load balancing close to the base station successfully since multiple disjoint paths will converge to a close proximity to each other when approaching to the base station. Thus, there is still much contention between the paths when close to the sink.

2.3.2.2 Maximally radio-disjoint multipath routing

The main purpose of MR2 proposed by Maimour (2008) is to provide necessary bandwidth for multimedia applications through non-interfering radio disjoint paths while increasing the network lifetime. To achieve these goals, an incremental approach has been adopted, wherein all sensor nodes are in the active state and route discovery is triggered by the sink by sending a route request message whose address (path ID) is that of the base station. Upon the reception of a route request message, a sensor node creates a new path entry if the reported path id does not appear in its table. Moreover, if the route request message is directly from the base station, then the path ID of the entry is the ID of this node; otherwise, it uses the id’s path reported by the current request. The nextNode field is simply the last crossed sensor node by the request and the inUse flag is set to zero. The metric field is also updated depending on its nature. If the reported path id is already stored in the path table, the corresponding entry is replaced if the current request provides a better quality metric; otherwise, the request is ignored. A request needs to be rebroadcast only if it induces path table update. Every time, the source receives a request, it records it in its path table. When all routes from all of its active neighbours are received, the source node selects the path having the best metric value. Then, it begins transmitting data through this selected path. Moreover, when a sensor node receives a data packet to be forwarded on a given path P, it sets the inUse flag and sends (only once per session) a bePassive message to its neighbours excepting its next and previous nodes belonging to path P. On the reception of a bePassive message, a node switches its state to passive mode. However, in case of path congestion or lack of bandwidth, the additional path formation process is triggered. In this process, passive nodes do not react to requests and hence they will not take part in the formation of an additional path. Thereby, a maximum radio disjointness among built paths is guaranteed, and consequently the throughput will be improved.

2.3.2.3 Bandwidth-power aware cooperative multipath routing

Xu et al. (2012) proposed a bandwidth-power aware cooperative multipath routing (BP-CMPR) protocol based on a cooperative communication paradigm. In this protocol, the authors consider QoS, bandwidth and energy efficiency for selecting the routing paths. The approach defines BP-CMPR problem and considers it as NP-hard which can be solved by a polynomial-time heuristic algorithm CMPR. In the proposed protocol Sturbaale’s method is used to find k minimal-weight node-disjoint paths from source to destination on a weighted graph and 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 (Kandris et al., 2011).

2.3.3 Energy-efficient

Wireless sensor nodes have limited energy resources; therefore, the use of energy-efficient protocols for this kind of devices leads to increase the system lifetime. Moreover, energy-aware routing (EAR) protocols in WMSNs are promising to minimise energy consumption throughout the network, since they use the best path in the data delivery process to the base station, which prolongs the network lifetime.

2.3.3.1 Real time energy aware routing

Shin et al. (2007) have proposed an energy-efficient QoS-based routing protocol called real time energy aware routing (REAR) for WMSNs. In REAR, metadata is used in the routing setup to establish multipath routing to reduce energy consumption, while the advanced Dijkstra algorithm and a cost function are used to make QoS routing decision. Firstly, the core step of the standard Dijkstra algorithm is used to select a link with the lowest weight among marked nodes. This process requires a scan of all the nodes. However, when there are a large number of nodes, the calculation may take too much time. Thereby, the optimised Dijkstra algorithm chooses neighbour nodes through consultation mechanism to reduce the number of neighbour nodes at first, and excludes those link nodes with insufficient remaining energy. Secondly, standard Dijkstra algorithm uses a single parameter (the length of path) to select a path, while in the process of QoS determination, several parameters are taken into consideration such as delay, bandwidth, remaining energy, etc. Moreover, the advanced Dijkstra algorithm implies these parameters to calculate the cost function (combination of these parameters) as comprehensive evaluation index to evaluate the load over the transmission link.

2.3.3.2 An energy-efficient multipath routing protocol for WMSNs

In Sutagundar et al. (2010), an energy-efficient multipath routing protocol has been proposed for WMSNs. In this article, the authors aimed to determine the minimum energy path in order do not quickly exhaust the energy of nodes and do not increase the time required to determine an alternative route. This protocol utilises multiple paths between the source sensor node and the sink with low routing overhead. Moreover, it aims to provide a reliable transmission environment with low energy consumption, by efficiently utilising the energy availability and the received signal strength (RSSI) of the nodes to identify multiple routes to the destination.

In path discovery phase, the sink broadcasts the route request message to create neighbouring nodes status table that is to maintain the addresses of all the nodes, which are able to communicate the data with the source node. During this process, each sensor node broadcasts the route request message initially and maintains its own routing table. When the sensor node receives the information to be transmitted, it will forward it to its neighbours. Furthermore, the routes are established between the source node and the destination node only when required thereby the overhead is reduced. In multipath routing, a sensor node is selected to forward the data, based on its available remaining energy and the received signal strength. Ideally, the neighbour node that has more energy
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and being farther from its previous one, is a better candidate to be selected as the next hop. The sensor nodes that are not selected in this process are moved to the sleep mode in order to conserve their energy. This protocol replies with multiple routes from the source node to the sink quickly, and determines the paths that efficiently balance the energy of the nodes. It also enables the selected nodes in the path to aggregate all the received packets during a short period of time and to transmit only the aggregated packet to the upstream node. Each node maintains a routing neighbour table, which contains an entry of all the selected neighbouring nodes using to transmit data to the sink.

2.3.3.3 Power efficient multimedia routing

Kandris et al. (2011) proposed a power efficient multimedia routing protocol (PEMuR). PEMuR is a dual scheme for efficient video communication over WMSNs, which is based on the combined use of hierarchical routing and video packet scheduling models. This protocol proposed a routing technique that is based on the QoS and also energy efficiency. Moreover, 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. However, the approach can be further improved by including bandwidth aggregation parameter.

2.3.3.4 Load-based energy aware multimedia routing protocol

Load-based energy aware multimedia routing protocol (LEAR) (Nayyar et al., 2011) makes modification on AODV (Usop et al., 2009). LEAR is a reactive, self-organising, energy-efficient protocol having the ability of hole avoidance. This protocol assumes that the network contains scalar sensors and multimedia sensors. When an event occurs, the source node sent a RREQ message to its neighbouring nodes. Each node that receives this message and it is not the destination node, broadcasts it in its vicinity. Moreover, to distinguish between multimedia data and scalar data, a bit is added in the RREQ message. If the bit is set then it is multimedia data otherwise, it is scalar data. The scalar data is routed like in AODV protocol. However, multimedia data need to be routed in special manner because multimedia data require more bandwidth, energy and memory space. When the message RREQ arrives at the destination node, this latter sends a RREP message to the source node. Thereby, the route is established between the source node and the destination node, the source node sends data along this path. This route is chosen from existing routes between the source node and the destination node based on remaining energy and active routes used by the node.

2.3.3.5 Energy aware TPGF

Bennis et al. (2013) have proposed an improved version of two-phase geographical greedy forwarding (TPGF) (Shu et al., 2010), called energy aware two-phase geographical greedy forwarding (EA-TPGF). TPGF implies the distance in selecting the next hop. Thereby, if there is no change in the topology, the protocol will always choose the same path for fixed source and destination. This could have a negative effect on the nodes belonging to this path because they will quickly consume their batteries and thus the network lifetime is minimised. To overcome this limitation, EA-TPGF modifies the
manner in which the protocol chooses paths. Thereafter, it takes into account the residual energy of the nodes in the path selection process. This selection process balances the use of nodes and thus the network lifetime is extended.

2.3.3.6 Multipath routing method supporting QoS

Bae et al. (2013) have proposed a multipath routing method (MPRM) that supports QoS and enhances the energy efficiency in WMSNs. In the proposed protocol, the selection of multipath is done according to the path cost. The path cost designates the weight value as different value according to priority of packets referring the information for the distance to the sink node, remained energy of nodes and link quality. Packet’s priority is determined in two ways: by the application originating the packet or by predefined field in the packet.

According to the packet’s priority, the packet will be transmitted faster or slower. Packet’s priority is marked at the source node by setting service quality pattern and service quality level depending on traffic pattern and data contents. Indeed, the source node sets the multipath referring link quality indicator (LQI) value with which the number of hops to sink according to the marked priority, information for remained energy of neighbour node and link quality could be secured. Since the neighbour node is selected with the least path cost by each packet priority as a result of verification, the differentiated service to guarantee the QoS of packet and an energy efficient routing service could be supported.

2.3.4 Reducing delay

In single-path wireless networks, when a route failure occurs, a new route discovery process is triggered to ensure the continuity of services in the network. This will increase the delivery time. However, this delay can be reduced in multipath routing schemes since other paths can be used when a failure occurs on the main path.

2.3.4.1 Delay-constrained high throughput protocol for multipath transmission

Li et al. (2008) have proposed a delay-constrained high throughput protocol (DCHT) for multipath transmission in WMSNs. DCHT aims to find multiple disjoint paths with high throughput and low end-to-end delay. It makes modification on directed diffusion protocol by:

1. using Costp as the metric instead of pure delay
2. reinforcing multiple links at the sink to obtain disjoint paths from the source node.

The parameter Costp is associated to each path and it used as a metric path. It calculated using the following formula:

\[
Cost_p = ETX_p^a \cdot delay_p^b
\]

\[
ETX_p = \max_{i=0}^{N-1} \left( \sum_{j=1}^{N} ETX_{ij} \right)
\]

(1)
where $N$ is the number of hops in the path and $\text{ETX}_j$ is the expected transmission count (ETX) value of the $j^{th}$ hop.

In DCHT, the sink stops putting exploratory data packets in the candidate pool when it received one that cannot meet the deadline or when the multipath timer expires. Then, it sorts the candidate paths in ascending order of the path metric $\text{Cost}_p$ and selects the first $\rho$ paths to reinforce, where $\lambda > \rho$ and $\lambda$ is the number of paths needed at the source. Furthermore, DCHT needs to find more than the required number of paths because some candidate paths may not be reinforced if disjoint nodes cannot be found or the delay exceeds the playout deadline. If two nodes try to reinforce a link that converges to the same node, the first one to reinforce would win to break the tie. In addition, delay constraints must be satisfied by computing the difference between two local timestamps. This technique does not only guarantee disjoint nodes, but also ensures loop-free path since loops are broken when selecting the next candidate in the local table.

### 2.3.4.2 Adaptive multi-constraint multipath routing protocol

Agrakhed et al. (2012) have proposed an adaptive multi-constraint multipath routing protocol (AMPMCR) which aims to minimise loss rate, energy consumption and delay. AMPMCR is based on a clustered architecture wherein inter-cluster routing is performed according to on a weighted cost function. The cost function is based on the parameters such as loss rate, residual energy and delay. In order to save energy, nodes that do not take part in routing operation are put to sleep mode. In inter-cluster routing: initially, a cluster is formed in the WMSN which consists of three layers. All the three levels of cluster are connected to each other and the last level is connected to the sink. In each level, the clusters are arranged with cluster head (CH) and cluster members (CM). A primary path is selected to perform the inter-cluster routing. The CHs in each level selects its higher level cluster with the cost function value. CHs of each layer broadcast its interface to know the CH satisfies the cost function. The link that connects the CHs from the adjacent layers with minimum delay, minimum loss rate and maximum energy is selected for data transmission and the process is continued from bottom layer to top layer until it reaches the sink. Thus the path connecting the CH of each layer reaching sink is chosen as the best cost function and the data is transferred through this path. However, in multipath routing, AMPMCR makes use of path tables at the sensor nodes. The sink floods the network with a request until the node, referred to as the source, having the requested data is reached. The sensor nodes are classified as active or passive state. The node in the passive state is put into idle or even a sleep mode to save the energy so that the network lifetime is increased. Each sensor node is able to create, maintain and update a path table that records the different paths to the sink.

AMPMCR achieves lower average delay and higher delivery ratio as there is significant reduction of the dropped packets involved in the critical real-time data.

### 2.3.5 Data reliability

Multipath routing can ensure reliable data delivery. This can be done by generating multiple copies of the same packet and send each copy through a different path. Thereby, with this redundant data, the probability is large enough that at least one copy of the message arrives at destination successfully.
2.3.5.1 Minimum hop disjoint multipath routing algorithm with time slice load balancing congestion control scheme

Guanan et al. (2011) have proposed a minimum hop disjoint multipath routing algorithm with time slice load balancing congestion control scheme (MHDMwTS) to ensure reliability in WMSNs.

MHDMwTS is a fully disjoint multipath routing protocol. In MHDMwTS, sensor nodes only have local knowledge of neighbour nodes and their hop counts. Furthermore, MHDMwTS considers multiple sources need to construct paths to the sink and will have joint nodes between different sources. Three paths will be built up for each source: primary path, alternative path and the backup path. The algorithm is performed in two phases:

- **Built up the path:** when a video sensor is activated, it will send out the path build request package to the neighbours where hop count is smaller than the sink. Each neighbour that receives the request package, adds its ID into the package, also adds the timestamp of the sender node, then sends out to its smaller hop count neighbours. This process is repeated until the request package reaches the station. The first package that reaches the sink is the one whose delay is the smallest, therefore the set of nodes that have sent this packet, represents the primary path. After the arrival of the first package at the base station, other packages still arrive at the base station. Thereby, when a package arrives nodes therein are compared with those of the main path. If there is at least one common node between the two packages, the package will be discarded, if not all of the nodes of the second package, forms the alternative path. Analogously, the search of the backup path is done until the path is found or the timeout expires and in the second case the search path will be stopped.

- **Path acknowledgement:** sink should send back acknowledgment message (ACK) to the sources. The ACK message, which contains the path info, including nodes and related time info, will transmit right through the path nodes and mark the used nodes. The time info is calculated by the sink from the timestamp contained in the package. Each node belonging to the path should maintain a table after receiving the ACK message. The contents of this table are illustrated in Figure 8 wherein major joint node: is the first joint node near sources side will affect following nodes on both paths.

After path build up, each source has two paths in use: primary path and alternative path. Since primary path with less time delay, it should take a lead to transmit data. So when allocate time on paths, primary path should get more time than alternate path. Moreover, after path ACK is received from sink, the source begins to transmit data. After using up one path’s time slice, sink switch transmit data on another path. Set a time of buffer between switch, so in this buffer time both path transmit data.

<table>
<thead>
<tr>
<th>pid</th>
<th>inUse</th>
<th>pState</th>
<th>nextHop</th>
<th>preHop</th>
<th>time</th>
<th>major</th>
</tr>
</thead>
</table>

Figure 8 Node path table
Considering $S_{pri}$ is the primary path time slice, $S_{alt}$ is the alternate path time and $S_{buf}$ is the buffer time. The relation between these parameters is illustrated by the equation (2).

\[ S_{pri} > S_{alt} > S_{buf} \] (2)

MHDMwTS can provide load balancing congestion control mechanism in WMSNs. Congestion detection is fulfilled by monitoring the reception queue of nodes as in CODA (Wan et al., 2003).

### 2.3.5.2 QoS-aware multi-sink opportunistic routing

The main purpose of QoS-aware multi-sink opportunistic routing (QMOR) proposed by Shen et al. (2014) is to efficiently deliver multimedia information under QoS constraints for WMSNs. The focus of this protocol is on selecting and prioritising forwarder list to achieve an energy-efficient delivery of video data under QoS constraints. Firstly, QMOR discuss how to efficiently reduce redundancy multimedia traffic using differential coding, by taking advantages of the benefits from multiple sinks. Then, it focuses on selecting and prioritising forwarder list such that the transmission efficiency could be enhanced. Finally, the multi-sink-aware operations are integrated into an optimisation opportunistic routing framework, with a goal to minimise energy consumption and fulfil the constraints of time and reliability. The obtained results have shown that QMOR achieves significant performance improvement, in terms of the energy consumption, delay and reliability.

### 2.3.5.3 Energy aware routing for real-time and reliable communication in WISNs

Heo et al. (2009) have proposed an energy aware routing protocol for real time large data transmission in wireless industrial sensor networks (WISNs), called energy aware routing for real-time and reliable communication (EARQ). EARQ enables to guarantee reliable packet delivery in WISNs. In EARQ, a node determines the energy cost, delay, and reliability of a path to the sink node, based only on information from neighbouring 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. However EARQ is no suitable for other types of networks such as WLAN, Bluetooth, etc. because with EARQ, the video data becomes less compatible due to inefficient load balancing in these networks.

### 2.3.5.4 Quality-aware image transmission over UMSNs

Sarisaray-Boluk et al. (2011) proposed a QoS aware routing approach for underwater multimedia sensor networks (UMSNs) 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. The proposed approach is efficient in terms of QoS and reliability, but energy-efficiency is not considered in this approach.

Table 1 presents the comparison of various multipath routing protocols in WMSNs.
<table>
<thead>
<tr>
<th>Protocols</th>
<th>Architecture</th>
<th>Hole bypassing</th>
<th>Path disjointness</th>
<th>Load balancing</th>
<th>Bandwidth aggregation</th>
<th>Energy efficient</th>
<th>Reducing delay</th>
<th>Data reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>REAR</td>
<td>Flat</td>
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<td>/</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>DGR</td>
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<td>Node-disjoint</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>TinyONDMDR</td>
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<td>No</td>
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<td>No</td>
<td>No</td>
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<tr>
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<td>/</td>
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<td>Yes</td>
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<tr>
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<td>/</td>
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</tbody>
</table>
3 Conclusions

Multipath routing is the routing technique that involves multiple paths in the data delivery process, which improves the network capacity. This paper presented a comprehensive analysis of multipath routing protocols in the literature for WMSNs. We have listed the benefits of using multipath schemes in routing, factors influencing communication in WMSNs and described the various classes of multipath routing protocols according to their benefits. The mentioned comparison is very important to understand the existing protocols and design new multipath routing protocols for WMSNs.

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References


Multipath routing protocols for wireless multimedia sensor networks


