Interference-Aware Multipath Routing for Video Delivery in Wireless Multimedia Sensor Networks

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***Abstract*—Multiple paths are mainly used in order to achieve higher throughput and reduce the end-to-end delivery latency as well. However, the overall network performance greatly suffers from the available interference between paths, even if node disjoint multipaths are used. This problem is highlighted more when dealing with transmission of the video data where the timeliness is of primary concern. In this paper, we propose a novel Interference-Aware Multipath routing for Video Delivery (IAMVD) in the realm of wireless multimedia sensor networks. It constructs multiple paths while considering the effect of different QoS requirements of multi-priority packets, without needing any hardware support for location information. Simulation results in NS-2 show that our proposed protocol has much better performance than the existing ones in terms of frame delivery ratio, throughput, energy consumption, and frame delivery latency.**

***Keywords*-Wireless Multimedia Sensor Networks, Interference Awareness, Multipath Routing.**

I. Introduction

The availability of low-cost hardware such as CMOS cameras and microphones has fostered the development of Wireless Multimedia Sensor Networks (WMSNs) which typically use batteries for energy supply and often these batteries are non-chargeable [1]. Therefore, energy efficient communication is vital for prolonging the network lifetime. Several papers have addressed this issue by proposing energy efficient routing protocols most of which use the single optimal path for every communication [2] [3]. However, since the single path is prone to failure of all kinds (node/link), there always exists the necessity of discovering a new route for maintaining the flow of data from the source to the sink, which causes extra energy consumption. Hence, the use of multipath routing in WMSNs is tremendously growing mainly due to its various advantages including the improvements regarding network throughput, scalability and load balancing. Additionally, it can provide energy consumption balancing and improve the network reliability and robustness because of using the redundant paths. Most of multipath routing protocols are based on classic on-demand single path routing methods [4] [5], such as AODV [6] and DSR [7]. The only difference is the way forward multiple route requests and select multiple routes.

All of the multipath routing methods that have been mentioned above suffer from at least one of the following problems. First, they flood the route request to the whole network, which creates large communication overhead. Second, when the data is transmitted on several node disjoint paths simultaneously, there is still a potential for collisions that result in high packet loss rate and bad data transmission performance [8]. This phenomenon is known as interference. In general, there is a great degradation of network performance in case of interference availability between multiple adjacent paths. Mainly, the negative impact of interference concerns end-to-end latency which causes an indispensable performance reduction in WMSNs where packets need to be received on time or they are invaluable.

Authors in [9] have proposed an approach via geographic routing to restrict the route request flooding to the neighbors of the nodes and guarantee no collision between the routes where each pair of nodes has to be apart from each other by the transmission range. In [10], the proposed protocol aims to increase throughput by discovering zone-disjoint paths with the help of the localization hardware in every node as well as the received signal strength indication to estimate the relative distance between nodes.

In [11], an on-demand multipath routing protocol for multi-hop wireless networks which is capable of finding spatially disjoint paths without needing location information is proposed. This protocol is only possible by knowing the graph topology which may lead to energy loss in case of route maintenance.

In [12], authors have proposed an algorithm which tries to find two spatially disjoint paths for a single pair of source and sink where there is no need to any special hardware for the purpose of path construction.

Although a variation of interference-aware protocols has been introduced, none is suitable for the multimedia applications where the effect of different QoS requirements of different packets has to be considered at the time of path

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construction which is highlighted more in the previously proposed algorithms where either the algorithms intend to achieve interference awareness via nodes position or irrational assumptions like the transmission range is equal to the interference range.

In this paper, we propose an Interference-Aware Multipath Routing for Video Delivery (IAMVD) in WMSNs which is easy to implement. Our proposed method has a four-fold contribution: First, it tries to find two node-disjoint, interference minimized paths for a single pair of source and destination, efficiently. Second, the routing is done without a need for any special hardware support for localization (such as directional antenna or GPS in nodes), making it practical for resource-constrained WMSNs. In fact, IAMVD uses a sleeping mechanism to create a block area of nodes which must not participate in the process of routing, which prevents additional energy consumption. Third, the assumptions are rational (for example, the interference range is twice the transmission range). Fourth, the effect of different QoS requirements of multi-priority packets is considered in the process of path construction and video transmission by dedicating different paths to different priorities.

The remainder of the paper is organized as follows. Section II explains the proposed scheme and presents its specifications. Simulation results are presented and discussed in Section III. Finally, Section IV concludes our work and discusses some future directions.

II. IAMVD

In this section, we introduce the assumptions, interference model, and our interference-aware multipath routing protocol, respectively.

A. Assumptions and Interference Model

The network consists of N static nodes (each with a unique ID) which are spread out on a finite, two-dimensional planar region. The interference range I is twice the transmission range R (i.e., $I = 2R$). In addition, each node is assumed to know its two hop neighbors. This is done at the network deployment stage and through the use of hello packets. Based on [12], we have employed the same interference model where the interference occurs between two edges when either the endpoint node of one edge is within the interference range of an endpoint node of the other edge. Therefore, we say that edges ij and kl interfere if $\max\{dist(i,k), dist(i,l), dist(j,k), dist(j,l)\} \leq I$ where $dist(x,y)$ returns the distance between nodes x and y.

B. Basic Idea

As mentioned above, the shortcomings of the available interference-aware multipath routing protocols regarding the WMSN infrastructures have led us to thinking about a more appropriate form of interference-aware routing protocol in order to assure the timeliness of the video transmission

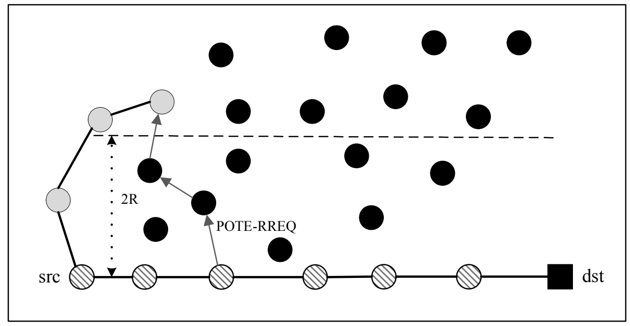

Figure 1. Example of the suitable interference minimized paths for WMSNs.

while keeping the advantages of the interference awareness to extend the network lifetime and reduce the end-to-end delivery latency. Unlike the previously stated algorithms, in a WMSN we need to construct two paths that are far from each other by $2R$ from which one needs to be the shortest path in order to assure the timeliness of the video packets.

Based on the interference model which has been introduced in the previous section, in order to minimize interference between two paths, each pair of nodes from the two paths (except the ones adjacent to source or sink nodes) need to be apart from each other for a distance of $I = 2R$, as in the case for the two constructed paths shown in Figure 1.

IAMVD is an on-demand interference-aware multipath routing protocol for the single source and destination in WMSNs that tries to construct two disjoint paths in two rounds of route request/reply. In the primary round of the route construction, the IAMVD discovers the shortest path and on the way back to the source it tries to block the neighbors which are not supposed to participate in the routing process. After the two last paths (which are away from the shortest path by 2R) are constructed in the second round, the ultimate path is selected as the one with the smallest number of hops. Moreover, IAMVD splits the video stream to I-frames, P-frames and B-frames and sends each one to the destination separately due to their respective priority. Based on this assumption, IAMVD assigns the shortest path to the most important frames of each video stream that are considered to be I-frames and the alternate path (which is of the less quality due to its longer hops) to the less important frames P and B.

C. The First Round of Request and Reply

The first round of request is initiated when the source has some data to send but there is no path to the sink. The first round is based on the flooding of the PRE-RREQ to the whole network, so that it reaches the destination. When the PRE-RREQ is heard by a middle node, a reverse path back to the source is established, the hop count is increased by one and finally the PRE-RREQ is re-broadcast after a random

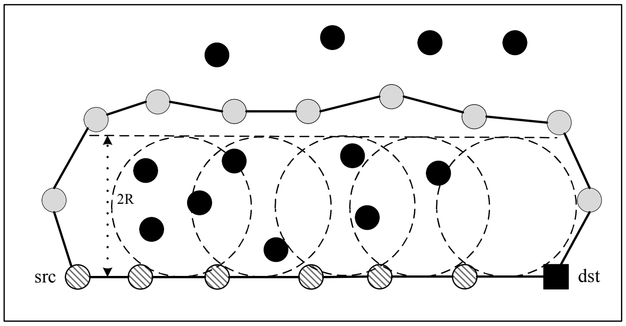

Figure 2. .Illustration of the construction of the second path while confirming the shortest path.

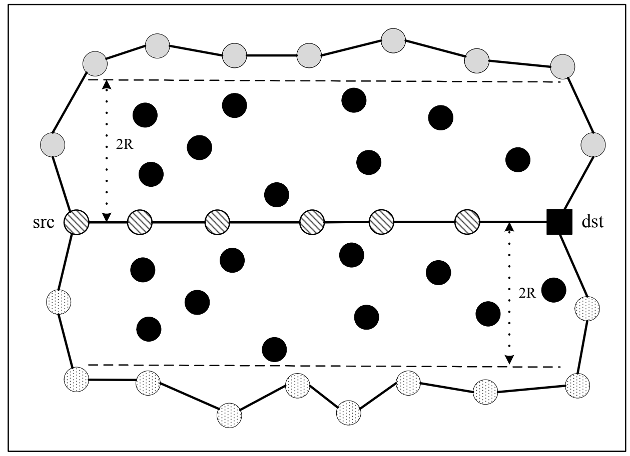

Figure 3. An example of the interference minimized paths.

latency. If any intermediate node receives a duplicate copy of the PRE-RREQ, it will first check to see if it is of shorter hop count and thus of shorter path. If yes, it will update the path, otherwise, it will discard the duplicate copy. After the destination receives the first PRE-RREQ, it will wait for a specific time to receive the other PRE-RREQs (since each node forwards the PRE-RREQ after a random latency). Then it selects the shortest path based on the number of hops.

The PRE-RREP packet is sent to the next neighbor towards the source by the sink via unicast after the shortest path is established. As each intermediate node on the shortest path will broadcast the PRE-RREP back to the source, the neighbors along this path will go to the sleep state after hearing it and updating their routing tables. In addition, each node which has one neighbor in the sleep state and one neighbor participating in the shortest path construction will eventually go to the sleep state as well. Since the primary path needs to be far from the other path by 2R; we have to manage its construction while we are sending the PRE-RREP on the shortest path back to the source as it is shown in Figure 2.

D. The Second Round of Request and Reply

As it has been mentioned above, the construction of the second path needs to be managed while constructing the primary one. When the PRE-RREP is only 2 hops away from the source, the neighbors who heard the PRE-RREP message routed on the shortest path will broadcast a potential route request (POTE-RREQ) to its neighbors along with the immediate neighbors of the source. The node receiving this message will first check its routing table and if it has one-hop neighbors asleep and a two-hop neighbor on the shortest path, it will drop the POTE-RREQ. Otherwise, it will forward it towards the source node. After the reception of the POTE-RREQs, the source waits for a random time and then sends the RREQ to each one of the senders. After the construction of the second round paths towards the sink finishes, the sink will select the path with the minimum number of hops as the final path and forwards the post route reply (POST-RREP) on it. Obviously, the second path could be located above or below the shortest path, depending on its length in terms of number of hops as it is shown in Figure 3, where the secondary path is the one above the shortest path due to its shorter length. It is also noticeable that knowing the exact location of the secondary path is of no importance since it will be the shortest one among the other paths from source to sink that is $2R$ away from the shortest path.

Upon the receipt of the RREQ (PRE/POTE) by any qualified node, the node will create a novel path entry in its reverse routing table as well as recording the shortest hop count as that of RREQ. It is noticeable that the routing table structure of IAMVD is similar to AOMDV [5] except for some changes in the updating rules. After the RREQ is updated in terms of its hop count by one, it is rebroadcast by the node after a random delay. As it has been mentioned earlier, the duplicate copies of RREQ will only be used in order to update the reverse paths in case the hop count is smaller than the one that is already reserved in the routing table. Otherwise, they will be dropped by the nodes.

E. Data Transmission

Prior to the data transmission, the source intends to separate each video stream's frames, I, P and B. I-frames are known to be the least compressible frames which do not rely on other ones to get decoded. Unlike the I-frames, the P- and B-frames can use data from previous, previous and forward frames in order to get decoded, respectively. Hence, the dependability of other frames to I-frames is much higher than that of P and B ones. Since I-frames are of the greatest importance in any video stream, the path length calculation is vital for assigning optimum paths to I-frames and near optimum paths to P-frames and B-frames that are of the second and third levels of importance for a video stream reconstruction process. The optimum paths, which is concerned to be the shortest paths, in our method are defined as the paths with minimum latency in the set of paths constructed. On the other hand, the near optimum path is dedicated to the P- and B-frames. Since the aforementioned frames are of lower importance, in case of their absence either due to latency or loss, the overall quality of the reconstructed video is not affected as is the case with the latency of I-frames. In this way, the probability of on-time delivery of the frames to the sink is highly promoted compared to the case where the packets are routed from the two paths by the round robin manner [12].

III. PERFORMANCE EVALUATION

In order to evaluate the proposed scheme, we have compared our protocol to AOMDV [5], the most well-known multipath routing method, to show the interference effect and IAMR [12], a recent Interference-Aware Multipath Routing protocol, to show the efficiency of IAMVD for video delivery in WMSNs. We have used the NS-2 [13] simulator. The comparison is done in terms of frame delivery ratio, throughput, energy consumption, frame delivery latency, and frame loss ratio.

The simulation parameters are mostly chosen in reference to [12]. In every simulation, there are 200 static nodes which are uniformly placed in an area of 2000m by 1000m. Moreover, the area is divided to 200 cells with a dimension of 100m by 100m where each node is randomly placed within a cell. The total number of video frames is 500. The video encoding method is considered as MPEG4 and the MPEG traffic is generated via EvalVid [14]. The video injected is 100 seconds long. The transmission range is set to 500m and the frame generation rate is set to 300 Kbps. In addition, the power drained for each transmission is 1.6 W for omni-directional transmission range of 250m and the power drained for reception is constant and equal to 1.2 W based on the default configuration of NS-2. IEEE 802.11 has been used as the MAC layer protocol. A Constant Bit Rate (CBR) has been utilized in order to generate a fixed workload for all the simulation scenarios. The CBR source and the CBR destination are selected randomly.

There have been ten groups of simulation for each CBR with the various data rates from 10 to 100 frames per second.

Figure 4 shows the average frame delivery ratio of IAMVD, IAMR and AOMDV versus the data rate. The average frame delivery ratio is defined as the number of frames received at the sink node at each time unit. As it can be seen, there is no significant degradation in the performance of the three protocols when the data rate is less than 20 frames per second. But instead, it occurs when the data rate reaches 30, 40 and 45 frames per second for AOMDV, IAMR and IAMVD, respectively. The frame delivery ratio of the IAMVD outperforms that of the AOMDV by approximately 66 percent for the data rate more than 40 frames per second and by 24 percent for the IAMR case. This outperformance is due to severe interference between multiple paths found by

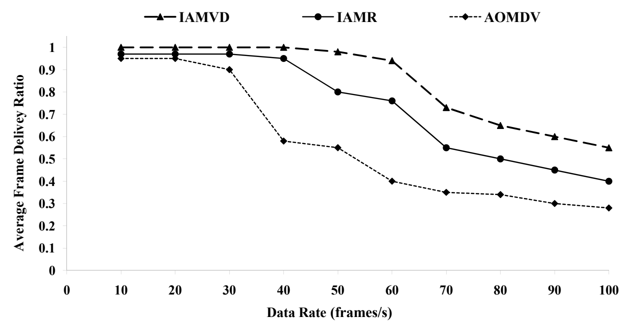

Figure 4. Average frame delivery ratio vs. data rate.

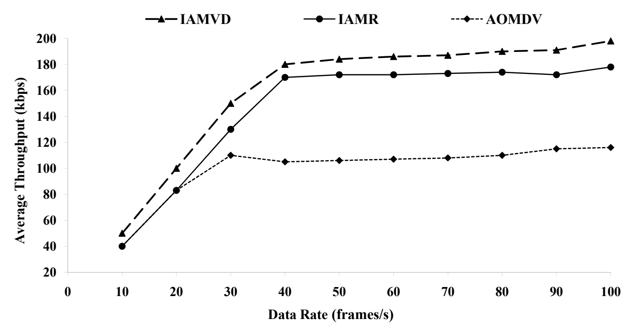

Figure 5. Average throughput vs. data rate.

the AOMDV protocol, resulting in exceeding retransmission limits of intermediate nodes along the paths where the queue overflow happens. As in the case of IAMR, since the quality of both disjoint paths is equal, there is no priority given to the I-frames over the P-frames and B-frames which is not appropriate for the video delivery since the dependency of the data reconstruction to the I-frames is much higher than its counterparts. In contrast, the IAMVD dedicates the shortest path to the routing of I-frames and the other path which is of longer length is dedicated to the P-frames and B-frames.

The average throughput of IAMVD, IAMR and AOMDV versus the data rate is shown in Figure 5. Throughput is assumed to be the average rate of successful frame delivery over a communication channel. We can see that the throughput of IAMVD achieves more than 19 percent gain over IAMR and 50 percent over AOMDV when the data rate is greater than 40 frames per second. Clearly, IAMVD attains lower average latency than AOMDV for all data rate configurations, especially when the data rate is higher than 40 frames per second. This is because the paths established by IAMVD are far away enough to transfer frames with less contention while paths established by AOMDV suffer from serious path interference, resulting in frequent packet retransmission. Although, the quality of the second path in the IAMVD is not as high as that of the IAMR, since it

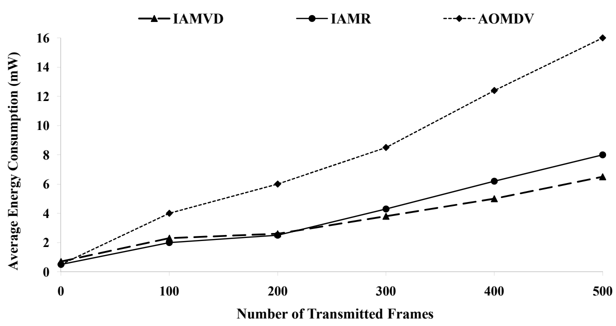

Figure 6. Energy consumption for different number of transmitted frames.

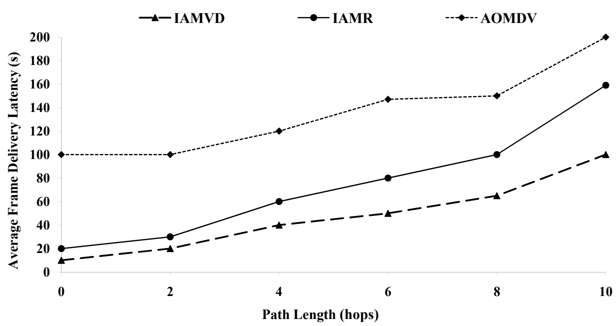

Figure 7. Delivery latency of I-frames.

uses the shortest path as its alternate option, the average number of hops of both paths are comparable. Additionally, since the IAMVD transmits the I-frames (frames of higher dependability) on the shortest path and the other two frames on the longer path, it sheds light on the fact that the absence of P- and B-frames (due to latency or loss) does not affect the quality of the reconstructed video at the sink as much as it affects the quality of video in absence of I-frames.

Energy consumption has been calculated based on the average energy consumed per each number of transmitted frames in Figure 6. Obviously, the average energy consumption of the AOMDV is higher than the other two algorithms due to the high level of interference between the provided paths of this algorithm and the need of packet retransmissions as well. The Energy consumption of the IAMR is less than that of the IAMVD when performing the route construction since the number of RREQs and RREPs sent and received is slightly less than that of the IAMVD. However, as the routes are established and the data transmission takes place, due to the frame extraction property of the IAMVD, it consumes less energy on the retransmission of the packets in the case of frame loss either because of the latency or the frame drop. As a result, we can indicate that the IAMVD has improved the energy consumption by 38 percent compared to AOMDV and 10 percent compared to IAMR.

Figures 7 and 8 represent an overview of the delivery

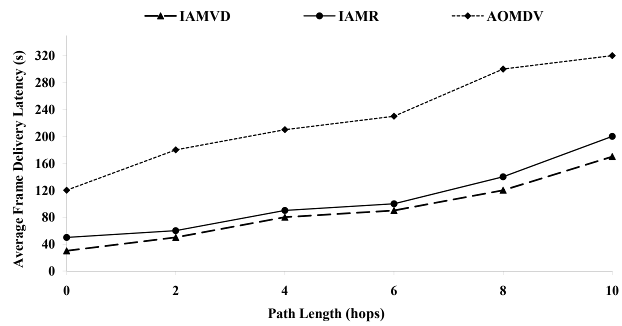

Figure 8. Delivery latency of P- and B-frames.

latency of different types of frames in the network for various path lengths. The highest delivery latency is for AOMDV, since it routes the I-frames (frames of highest importance) on the paths which are neither interference minimized nor, are of shorter length compared to the ones that other frames are routed from. Based on the aforementioned reasons, the delivery latency of these frames ascends. The second highest delivery latency is of IAMR due to the uniform types of paths it provides and the fact that it has to route the I-frames on the similar type of paths where it routes other frames affecting the delivery latency of this algorithm to a great extent. Hence, the IAMVD has reduced the delivery latency of AOMDV by 68 percent and that of IAMR by 37 percent. As it has been already mentioned, the importance of the P-frames and B-frames is less than that of the I-frames in the reconstruction of the video streams and hence, their absence at sink either due to latency or loss does not affect the network performance as much as that of I-frames. That is the reason why IAMVD has not improved the IAMR drastically and instead, it only reduces the delivery latency of P-frames and B-frames by 17 percent. In addition, it reduces the delivery latency of AOMDV by 62 percent. Furthermore, Figures 9 and 10 show the frame loss ratio for different algorithms in various error rates on each link. Obviously, the maximum ratio belongs to the AOMDV which is rational due to the interference between the paths as well as the assignment of the same paths to all of the relative frames of each video stream. In case an I-frame loss happens, the reconstruction of the related packets at the sink node is not possible. Moreover, since P- and B-frames are also depending on the I-frames to be reconstructed, a considerable number of packets are lost. However, IAMVD has got the smallest frame loss ratio because of taking the multi-priority attribute of frames into consideration in the path construction and video transmission.

IV. Conclusion

In this paper, we introduced a novel interference-aware multipath routing protocol for video delivery in WMSNs. Our proposed method tries to find two node-disjoint interfer-

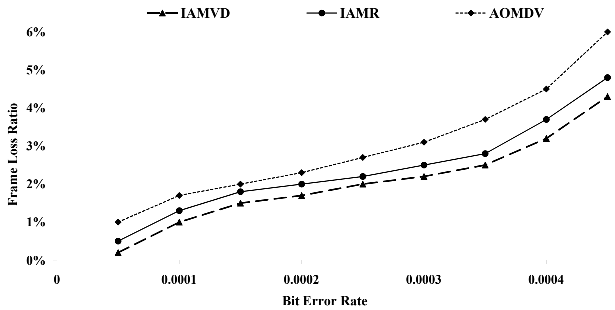

Figure 9. Number of I-frame losses.

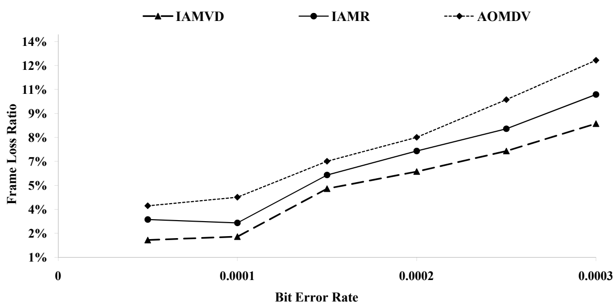

Figure 10. Number of P- and B-frame losses.

ence minimized paths for a single pair of source and destination, efficiently under rational assumptions, without needing any special hardware support for localization. Moreover, it considers the effect of different QoS requirements of multi-priority packets in the process of path construction and the video transmission by dedicating different paths to different priorities. The simulation results demonstrated a significant performance improvement in terms of frame delivery ratio, throughput, energy consumption, frame delivery latency, and frame loss ratio.

In the future, we will consider the construction of the interference minimized paths in a hop-by-hop manner while routing data, without a need for any special hardware support.

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