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Multipath Routing Protocol of Wireless Multimedia Sensor Networks Based on Mobile Agent

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Abstract: Depending on wireless multimedia sensor networks with the coexistence of periodic scalar data and event-driven continuous video frames, we design proper filters of DD to establish paths for the two classified data and construct a path-independent cost model for multi-path routing according to path-oriented reliability and energy cost. Furthermore, we develop a path scheduling scheme for the multi-path transferring of video data based on the model and mobile agent. Extensive simulations show that the proposed protocol is very efficient in improving the transferring reliability, delay jitter and quality of video.

Key words: Wireless multimedia sensor networks, directed diffusion, mobile agent, multi-path routing

INTRODUCTION

With the increasingly complex detection environment, simple data such as temperature, humidity and light intensity, etc., acquired through the traditional WSN can not meet all the demands for environment detection. For a more visual and accurate environment detection, the medium with rich information of image, audio and video, are in urgent need to be introduced to WSN-based environment detection technology. Thus the Wireless Multimedia Sensor Network (WMSN) emerges. The challenge WMSN are faced with is to guarantee the Quality of Service (QoS). The QoS of the continuous multimedia-data transmission in WSN embodies in the quality of audio and video, end-to-end delay, delay jitter, network consumption, service time. So to establish an appropriate QoS security system is vital to the design of WMSN.

A routing protocol of WMSN based on directed diffusion and mobile agent is proposed in this study. Combining the established path-oriented reliability and energy cost balance model and with multi-path routing establishment and dispatch, the routing protocol has made great progress in the qualities of media like the reliability, delay jitter, PSNR of continuous media data transmission in WSN.

RELATED WORKS

DGR Chen *et al.* (2007), established directional geographical routing for real-time video communications in wireless sensor networks on the basis of the geographical position of every node and set up direction -sensitive multi-path with the concept of reference line and the dynamic adjustment of deflection angle. What's more, the FEC coding system is combined to restrain the unreliable transmission in wireless environment and meet the strict end-to-end delay demands. Savidge *et al.* (2005) introduced QGR, QoS-based geographic routing for event-driven image sensor networks. Imaging sensor is firstly adopted to obtain every visible sensor node and the direction information. Lari and Akbari (2010) held that, based on packet and path priority, video should be delivered according to its form, the more important division should be delivered through the better paths and the path condition should be estimated by the size of free cache, energy, hop number and division loss rate. Interference-Aware multipath routing for video delivery in Wireless Multimedia Sensor Networks is proposed by Nikseresht *et al.* (2012) to solve the problem that the network performance is seriously damaged owing to interference between multipath in spite of the adoption of multipath disjoint node routing.

DIRECTED-DIFFUSION-BASED PATHBUILDING

The path building of the ordinary data: The sink node regularly initiated interest floods containing interest packets' information and specific definition, as illustrated in Fig. 1. Every interest flooding will increase SeqNum. After receiving a new interest division, the middle node

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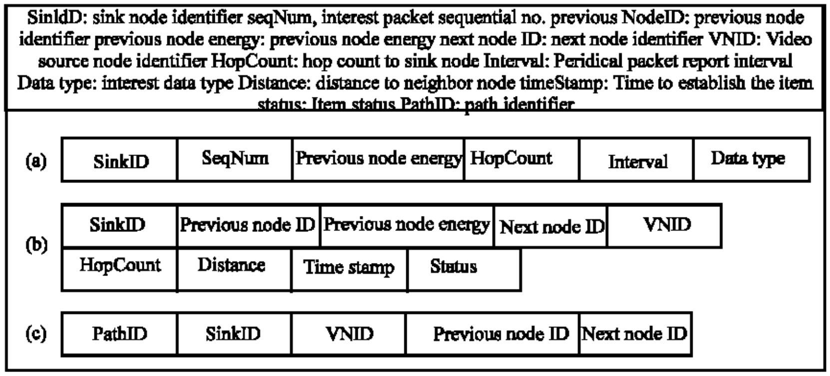


Fig. 1(a-c): (a) Interest Packet Format (b) Node Neighbor Information Entry (c) Node Path Information Entry

saves all the domains and ID of the source node of the interest division in NIE (Neighbor Information Entry) and sets timestamp in NIE to the current timestamp, Status to 0. Add1 to HopCount and continue propagation downward. If an interest packet is received from the same upstream node, new although it is, discard it directly. Repeat the above-said process until the source node of the event area occurs. Distance in NIE means the distance between a node and its neighbor node. When Distance is a positive number, the distance from the neighbor to the sink is farther than the distance between the node and the sink node, vice versa.

The path building of the video data: For the event-driven video data delivery path, the study adopted DD two-phase pulling diffusion method and designed a new filter. Once the path is built, it will be converted to one-phase pushing diffusion mechanism. The filter is special because it will not filter any path during building path. Hence the name multi-path filter, MP for short.

During the interest flood phase, similar to the ordinary data, sink node floods the interest packet only once in a cycle and needs no distinguishing ordinary nodes from video nodes which is decided by the application because all VN interests are event-driven video or image data.

Now let's come to the situation when the interest packet reaches VN. The source node initiates detecting packet transmission immediately after receiving interest packet. The detecting packet only contains the source node id and hop count of the variable quantity (the original value is 0). Once receiving the detecting packet, the middle node chooses the node with the minimum timestamp and with Status of 0 from NIE as the next node. And the middle node transmits the detecting packet after filling NextNodeID in NIE with the source node ID of the detecting packet and the node ID padded with VNID, namely building video source node ID for the detecting packet. What's more, adding 1 to HopCount and changing Status to 1 means the item has already been used by the detecting packet. Repeat the above process until the detecting packet gets to sink node.

Sink node judges whether the delay (hop number) information outnumbers the configuration limitations after receiving the detecting packet. If not, sink node will intensify the detecting packet path and sending out the corresponding intensified packet, the triad of SinkID, PathID and HopCount. PathID is the unique number for all the paths from sink node to the source node. After receiving the intensified information, the middle node A will choose node B (NextNodeID) with the minimum TimeStamp and Status of 1 in NIE as the next node. Meanwhile, set Status to 2 and identify the item has already been used by the intensified division. And add a new item to PIE and fill in the corresponding SinkID and VNID and identifying the node has already been on the path from the SinkID to VNID. Adding 1 to HopCount and then transmit the intensified node to node B. if node B has already been on the path from SinkID to VNID, node B sends back an anti-intensified information to node A and discards the intensified information. Otherwise, node B will repeat the above process. Receiving the anti-intensified information, node A will keep reselecting a next node according to the above-said rule until the intensified packet reaches VNID.

Some time later, VNID will receive multi intensified packets which means multi disjoint paths have been built. These paths provide the delay (hop) as the user interface specified and the delay information of each path has been known to VNID. Illustrated as in Figure 2 is a specific example.

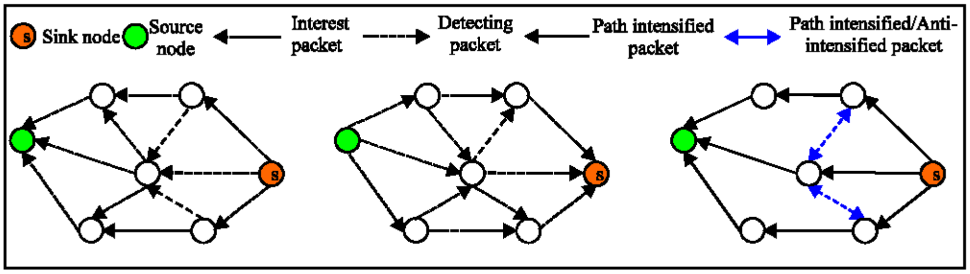


Fig. 2(a-c): Video source node multipath building process (a) Interest Diffusion (b) Path detecting (c) Path intensified (the dotted line means Path Anti-intensified)

THE TRADE-OFF BETWEEN ENERGY EFFICIENCY AND RELIABILITY IN MULTIPATH TRANSMISSION

Path-oriented reliablity mode: If $\bar{p}_{j,j+1}$ refers to bit error rate of node j-node j+1 link, the error rate of transmitting a packet with the size of m-bit should be:

$$p_{j,j+1} = 1-(1-\bar{p}_{j,j+1})^m$$

Accordingly, if the packet is transmitted successfully on path K with nk middle nodes, the rate should be:

$$P^{(k)} = \prod_{j=0}^{nk}(1-p_{j,j+1}^{(k)})$$

The reliability of path in the study is defined as the probability when L packets are received successfully by the destination after N packets are sent and transmitted through the path. Approximation value of reliability parameter of R(S) is introduced by Charfi *et al.* (2006) as follows:

$$\tilde{R}(S) = \sum_{l=0}^{N-L} \frac{e^{-\gamma(S)}\gamma(S)^l}{l!}$$

hereinafter:

$$\gamma(S) = -\sum_{i=1}^{N} \ln(P^{(ki)})$$

Path-oriented energy cost mode: On the basis of energy cost m de of sensor node in (Wang *et al.*, 2001), the study put forward building path-oriented energy cost mode. If we send the information of a m-bit sized packet between two nodes (the distance between the two nodes is d.), the transmission energy cost of sending node will be: $E_{Tx} = E_{elec} \times m + \varepsilon_{amp} \times m \times d^{\beta}$ and the receiving energy cost of receiving node should be: $E_{Rx} = E_{elec} \times m$. In the above two formulas, E_{elec}(J/bit) means the energy cost of the device sending and the circuit receiving one bit; ε_{amp} (J/bit/m2) refers to the energy the sending amplifier transmitting one bit in one square meter will consume. In the simulation, the study still adopts the parameter in (Wang *et al.*, 2001), namely $E_{elec} = 50\text{nJ/bit}, \varepsilon_{amp} = 100\text{pJ/bit/m}^2$. Here β, the propagation attenuation index, depends on the environment to a great extent and is often determined by in-site measurement method which proposed by Ghiasi *et al.* (2002). In the area with many buildings, factories and luxuriant vegetation, β reaches a high value from 3-5; in generally open ground, the value of β is 2.

To assess the path energy cost, we use the expected number of total energy consumption of the middle nodes on the path during packet transmission and introduce the following formula:

$$E_p^{(k)} = \sum_{l=0}^{nk-2}\left[\prod_{j=0}^{l}(1-p_{j,j+1})(E_{Tx}(j)+E_{Rx}(j)) + \prod_{j=0}^{l-1}(1-p_{j,j+1})E_{Rx}(j)\right]$$

Path priority judgment criteria: Charfi *et al.* (2006) deduced the energy-and-reliability-based path priority judgment criteria.

$$L_N(S,\lambda) = E(S) + \lambda\gamma(S) = \sum_{i=1}^{N} E_p^{ki} - \lambda\sum_{i=0}^{N}\ln(P^{(ki)}) = \sum_{i=1}^{N} L^{(i)}(k_i,\lambda)$$

in which $L^{(i)}(k_i,\lambda) = E_p^{ki} - \lambda\ln(P^{(ki)})$, i.e., Lagrangian cost of the path. And then it comes to a conclusion that the choice of multipath transmission strategy is independent for each path. In other words, the choice of transmission path is independent for each packet.

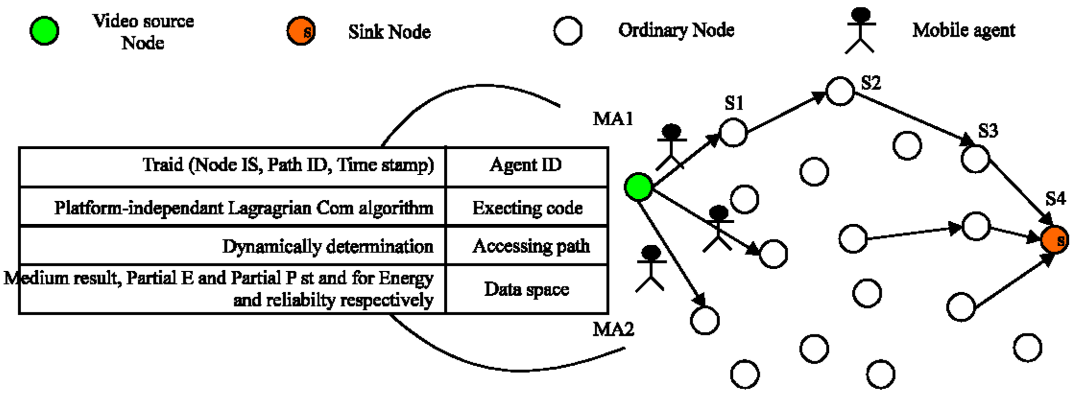


Fig. 3: Structure of mobile agent

MOBILE-AGENT-BASED PATH SCHEDULING

Mobile agent: Mobile Agent (MA) is a special software model which can access path preset nodes and process the node data. It includes four main parts: Agent ID, Executing Code, Accessing Path and Data Space. By virtue of AgentID triad (AgentID, NodeID, TimeStamp), Mobile Agent is uniquely identified. NodeID can be preset or agreed, AgentID can be appointed by the distribution node and TimeStamp is to show when the node distribute mobile agent. Executing Code provides network access and information process instruction which is a Lagragrian cost algorithm realized by portable code like JAVA. Accessing path, i.e., access node entry of MA, determines dynamically the accessed nodes and the current node and indicates the next target node. Figure 3 shows that {S1, S2, S3, S4} are accessing path of MA1. Data Space is usded to store information-processed intermediate results, such as energy and reliability parameters.

Path cost calculation: Supposed that video source node has already gained N paths sorted by delay and distributes N MAs. Each MA pads its ID triad: NodeID is ID of the video source node, TimeStamp is to show when the node distribute mobile agent and AgentID is composed of the agent total number N and PathID.

The path of MA is dynamically determined. The first target node of MA is the upflow node on the path of VN. Reaching middle node A, MA inquires gradient cache of the node and gains next node B toward sink node and corresponding to the path. And then MA moves to node B. The above process will be repeated until MA reaches sink node.

When MA reaches the middle node, it determines the next node dynamically. What's more important is to download executing code in MA and complete the corresponding calculation. We will have to calculate $P^{(k)}$ and $E_p^{(k)}$ according to the corresponding formulas introduced in above of the study in order to calculate the Lagrangian cost of path. The two path parameter values are the multiplication or sum of part results of each middle node. So the calculation of path reliability can be distributed into the corresponding performance calculation of each middle node. After the calculation, fill the two results in MA data space and move to the next node until sink node. Through the disassembly, centralized calculation can make use of MA moving to each node on the path and realize load balancing more easily.

After receiving one MA, sink node reads P and E values from MA data space, calculates the final Lagragrian cost and stores the pair of <PathID, Cost> in path cost cache. When receiving multi MA at the same time, sink node will apply the rule of the earlier reaching the earlier processing and the later reaching MA will be stored in MA cache entry. Once having processed one MA, sink node will take out next MA to process until the entry is empty. MA disappears after it is processed.

When sink node received and processed all MAs (judging by the total number of agents in AgentID) or time is out, sink node starts to construct result packet in order to sort N paths from VN to sink node in Lagragrian cost ascending order. The result packets contain VNID of these MAs, TimeStamp to show when the result packet is built and the pairs of PathID and PathCost sorted in CostSN ascending order, among which the number of the pairs equals the number of received MAs. The result packet transmits along the shortest delay path from sink node to VN. It means that to choose next node, the packet should choose the node whose RSN value is the smallest in gradient cache entry until the packet gets to the corresponding VN.

Path scheduling: After receiving the result packet, VN stores the pairs of <CostSN,PathID,MPE> in the local candidate path entry in CostSN ascending order. Besides, when sink node receives no video data in some time, in other words when Sink Node is at leisure, it will transmit MPE detecting packet periodically along the paths to VN in order to collect MPE information on the path. If any crash with video data occurs during the transmission, the MA will be stored in the current node temporarily and transmitted continuously until no other video data is passing. MPE information collected by MA provide VN path scheduling model with feedback mechanism whose format is the pair of <PathID,MPE>.

If the total number N of paths is smaller than the number K of packets, all the paths take part in packet transmission at the same time. Because the co-encoding can be conducted only after all the paths arrive, it is unnecessary to schedule path by use of MA. That's why the study only take the situation when the total number N of paths is bigger than the number K of packets into consideration.

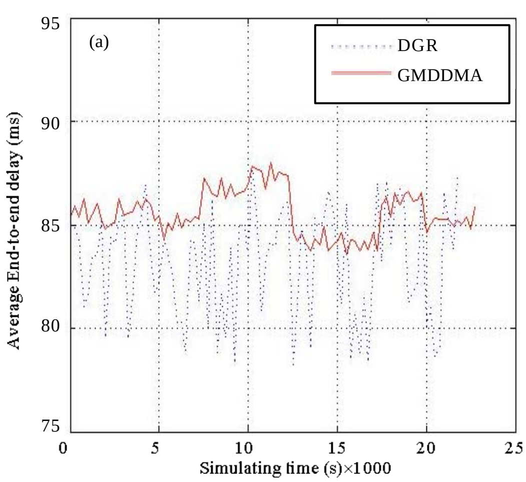
Now let's analyze VN path scheduling mechanism when N = 15, K = 6. Firstly, VN transmits video data through 6 paths in CostSN 1-6 ascending order. When some path MPE value is lower than the threshold, for instance MPE<= 20%E0, the path will be replaced by path 7 and so on. If all paths MPE values are lower the threshold, VN will rechoose 6 paths from No.1 to No.6 for data transmission on one hand; on the other hand, VN will send alarming information to sink node and report to user interface.

SIMULATION EXPERIMENT AND RESULT ANALYSIS

NS2 is used as simulation tool. In this chapter, GMDDMA stand for the Multipath Scheduling Mechanism Protocol proposed in this study. The experiment mainly aims at testing and verifying GMDDMA performance of video data transmission. In order to be consistent with DGR's processing scene, we discuss the following extremum situation: there is no periodically data transmission but video flow being pushed periodically from VN to sink node. The specific experiment mode can be consulted in (Chen *et al*., 2007).

The left one of Fig. 4 shows the average end-to-end delay performances of GMDDMA and DGR with network lifetime. It is easy to find that GMDDMA's average delay is a bit longer than DGR's and the former's curve has several phases for when the rate of joint paths to total paths is larger than some threshold like 70% in GMDDMA, VN will respond to sink node interest packet again and rebuild totally disjoint path and dispatch MA for routing scheduling. It is noticeable that in each phase, its delay jitter extent is much smaller the DGR's so its average end-to-end delay jitter curve is relatively stable except for a few abnormal points with very small amplitude vibration, as illustrated in the right one of Fig. 4. Furthermore, the ends of the curves in Fig. 4 indicate that GMDDMA's lifetime is slightly longer than DGR's.

Figure 5 shows PSNR values of 50 video frames collected by sink node. GMDDMA's PLR is much smaller because of its key consideration of reliability which will



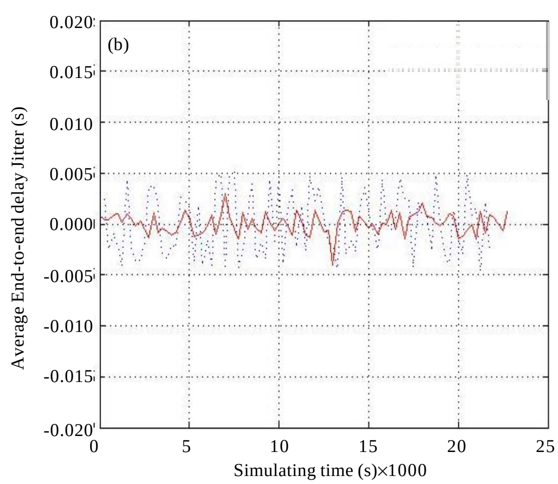


Fig. 4(a-b): Compare delay and delay jitter between GMDDMA and DGR

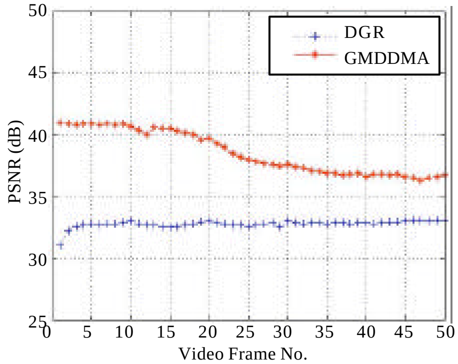


Fig. 5: Compare PSNR between GMDDMA and DGR

result in the increase in PSNR during video delivery, i.e., the improvement in video quality of receiving end.

To sum up, in the aspect of pure video transmission, GMDDMA, on the premise of guaranteeing energy efficiency or lifetime, has made great progress in transmission reliability, delay jitter and video quality at the cost of small delay performance.

CONCLUSION

In the study, based on directed diffusion mechanism, designed GE filter and MP filter for ordinary data transmission and video data transmission respectively and built the establishment of corresponding path. Besides, MA mechanism was introduced to finish multipath scheduling of video transmission. Last, the study compared GMDDMA with DGR through an experiment which proved GMDDMA is effective in enhancing transmission reliability and video quality.

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