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Context-aware cross-layer optimized video streaming in wireless multimedia sensor networks

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Abstract The appearance of wireless multimedia sensor networks (WMSNs) requires a new generation transmission paradigm towards intelligent and ubiquitous communication. Video sensors are used in WMSNs to enhance the capability for event description. Multiple routing paths are often used for transmitting video streams. However, not every path found by multi-path routing algorithm is suitable for transmitting video, because a long routing path with a long end-to-end transmission delay may not satisfy the time constraint of the video. Furthermore, each video stream includes two kinds of information: image and audio streams. In different applications, image and audio streams play different roles, and the importance levels are different. Higher priority should be given to the more important stream (either the image stream or the audio stream) to guarantee the using of limited bandwidth and

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energy in WMSNs. In this paper, we propose a context-aware cross-layer optimized Multi-Path Multi-Priority (MPMP) transmission scheme, in which a Two-Phase geographic Greedy Forwarding (TPGF) multi-path routing protocol is used in network layer to explore the maximum number of node-disjoint routing paths, and a Context-Aware Multi-path Selection algorithm (CAMS) is used in transport layer to choose the maximum number of paths from all found node-disjoint routing paths for maximizing the gathering of the most valuable information to the base station. Simulation results show that the MPMP scheme can effectively maximize the gathering of the most valuable information and guarantee the end-to-end transmission delay.

Keywords Context-aware · Cross-layer · Optimization · Data gathering · Video streaming · Wireless multimedia sensor networks

1 Introduction

Using video sensor nodes in wireless multimedia sensor networks (WMSNs) [1–5] can drastically enhance the capability for event description. Thus, efficiently transmitting and gathering video streams in WMSNs is essentially necessary when the underlying infrastructure, e.g., 3G cellular networks or WLANs, does not exist. Generally, real time video streaming in WMSNs [6] poses the following three basic requirements: (1) *Guarantee end-to-end transmission delay*: Real time video streaming applications generally have a soft deadline which requires that the video streaming in WMSNs should always use the shortest routing path with the minimum end-to-end transmission delay; (2) *Bypass static or/and dynamic holes*: Static holes can easily exist in WMSNs, e.g., a water pool. *Dynamic hole*s may also occur if several sensor nodes in a small area overload due to the multimedia transmission, e.g., Fig. 1. Efficiently bypassing these holes is necessary for transmission in WMSNs; (3) *Use multiple routing paths for transmission*: Packets of video streams generally are large in size and the transmission requirements can be several times higher than the maximum transmission capacity (bandwidth) of sensor nodes. This requires that multi-path transmission should be used to increase transmission performance in WMSNs.

Many multi-path routing protocols have been studied in the field of WSNs [7]. However, most of the multi-path routing protocols focus on energy efficiency, load balance, and fault tolerance, and are the extended versions of DSR [8] and AODV [9]. These multi-path routing protocols do not provide a powerful searching mechanism to find the multiple optimized routing paths in terms of minimizing the path length and the end-to-end transmission delay as well as bypassing holes. TPGF [10–12] is the one of the earliest researches on multi-path routing in the field of WMSNs. It focuses on exploring the maximum number of optimal node-disjoint routing paths in network layer in terms of minimizing the path length and the end-to-end transmission delay. The TPGF routing algorithm includes two phases. Phase 1 is responsible for exploring the possible routing path. Phase 2 is responsible for optimizing the found routing path with the least number of hops. The TPGF routing algorithm finds one path per execution and can be executed repeatedly to find more node-disjoint routing paths. It successfully addressed four important issues: (1) *Hole-bypassing*; (2) *Guarantee*

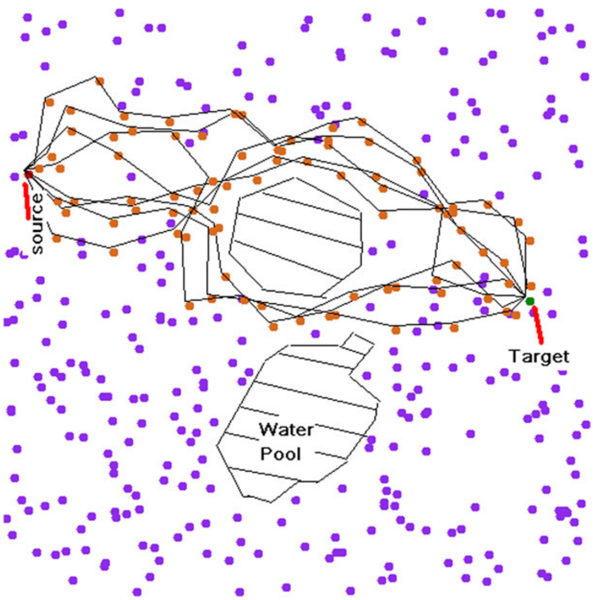


Fig. 1 An example of TPGF multi-path routing: Eight paths are found for transmission. A *dynamic hole* can be formed by a group of sensor nodes in the eight existing routing paths because these nodes are overloaded and cannot be used for forming other routing paths

path exploration result; (3) *Routing path optimization*; (4) *Node-disjoint multi-path transmission*. Figure 1 shows an example of TPGF multi-path routing in a geographic wireless multimedia sensor network with two water pools. These found routing paths have different numbers of hops. However, not every path found by TPGF can be used for transmitting video, because a long routing path with a long end-to-end transmission delay may not satisfy the time constraint of the video streaming data. This point motivates the research work presented in this paper, since a smart path selection method is essentially needed for choosing the appropriated paths to maximize the gathering of the most valuable information to the base station.

Furthermore, a video stream includes two kinds of information: image and audio streams. In different applications, image and audio streams play different roles, and the importance levels may be different. For example, in the applications of fire monitoring, image stream is more important than audio stream because it can directly reflect the fire event. But in the applications of Deep Ocean monitoring, the audio stream is more important than image stream, since the visibility in Deep Ocean is very low and the environment is extremely quiet. Even in the same application, e.g., desert monitoring, the image stream is more important than audio stream in day time, but the audio stream is more important than image stream in night time. Therefore, instead of transmitting a video stream back to the base station by using fewer routing paths with a stricter real time constraint, it is better to split the video stream into image and audio streams and give higher priority to the more important stream (either the image stream or the audio stream) to guarantee the using of the suitable paths, as shown in Fig. 2. The less important stream can be transmitted with a relatively looser real time constraint. Consequently, the routing paths with the longer end-to-end transmission delay can be used, which can increase the total received data in the base station, where the received data can be joined again or processed separately.

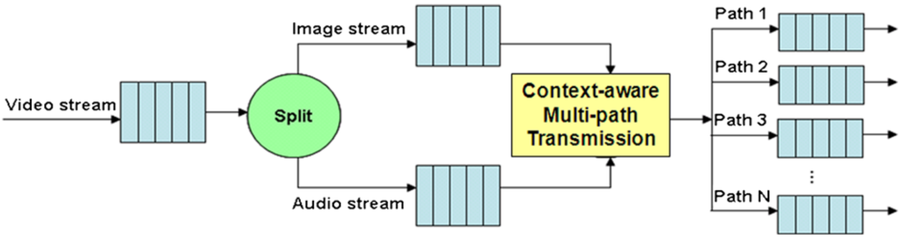


Fig. 2 The general model for context-aware multi-priority multi-path transmission: the context-aware module makes the decision for the importance levels of the audio and image streams

However, to automatically adjust the importance level of the image and audio streams requires that video source nodes must be context-aware [13]. In other words, the video source nodes must be able to utilize the sensor data gathered by attached light and sound sensors. When the light intensity is higher than a certain value and the sound intensity is lower than a certain value, then the higher priority is assigned to the image stream. Likewise, when the light intensity is lower than a certain value and the sound intensity is higher than a certain value, then the lower priority is assigned to the image stream.

How to split a video stream into an image stream and an audio stream has been widely solved by many programs [14], which is not the focus of this paper. In this paper, we propose a new context-aware cross-layer optimized Multi-Path Multi-Priority transmission (MPMP) scheme, in which a TPGF multi-path routing algorithm is used in network layer to explore the maximum number of node-disjoint routing paths, and a context-aware multi-path selection algorithm (CAMS) is used in transport layer to choose the maximum number of paths from all found node-disjoint routing paths for maximizing the *information value* [15] of video stream gathering. Here, the *information value* is defined as the product of the multiplication between the volume of gathered stream data and its *importance rate*.

This research work makes the following three major scientific contributions: (1) To the best of our knowledge, this research work is the first one that combines the concept of context-awareness and cross-layer optimization to facilitate the video streaming in WMSNs, which clearly positioned the novelty in the research community of wireless sensor networks; (2) The proposed MPMP scheme supports two types of priorities: a. End-to-end transmission delay based priority and b. Context-aware multimedia content-based priority, which also stands a breakthrough, comparing with traditional approach [16] that only the end-to-end transmission delay based priority is considered; (3) The proposed MPMP scheme tries to maximize the gathering of the most valuable information towards the *information value* instead of maximizing the throughput of the streaming data transmission, which further advanced than our previous research work [17].

The rest of this paper is organized as follows. Section 2 discusses the related work. We present the network model in Sect. 3 and formulate the research problem in Sect. 4. In Sect. 5, we present the cross-layer optimized Multi-Priority Multi-Path (MPMP) scheme, including the TPGF routing algorithm in network layer and the CAMS algorithm in transport layer. We present the simulation results and comparison work in Sect. 6 and conclude this paper in Sect. 7.

2 Related works

2.1 Related work on context-aware multimedia streaming in WSNs

In [18–20], three surveys on multimedia communication in WSNs have been well conducted. The authors analyzed and discussed the existing research works from both mobile multimedia and WSNs fields. These surveys showed that current existing protocols from the mobile multimedia and WSNs fields did not consider the characteristics of multimedia streaming data and natural constrains of WSNs at the same time. These papers also concluded that there exists a clear need for a great deal of research effort to focus on developing new efficient communication protocols and algorithms. In [21], the authors also conducted a study on several typical transport protocols in the WSNs field. The performance evaluation results clearly show that the existing transport protocols far from satisfy the requirements of multimedia communication in WSNs. Hence, there is a need for new effective multimedia delivery protocols for WSNs.

Furthermore, adopting context-awareness to facilitate video streaming in WSNs is still a very new research direction. To the best of our knowledge, only two recent related publications are found. In [22], the authors developed a camera sensor network for situation awareness. In this network, normal sensor nodes are used as the *control network* and camera nodes are used as the *data network*; the camera nodes start to work only when other normal sensor nodes detect the changing of their surrounding environment. In [23], the authors propose a scheme to support video transmission in ubiquitous computing environment, in which five different packet sizes are employed for the video and only one is selected according to the SNR value and the data on the packet delay and loss. However, both researches in [22, 23] did not consider the video streaming inside WSNs.

2.2 Related work on geographic on-demand disjoint multi-path routing in WSNs

Only a few research works adopt the geographic information to facilitate the on-demand disjoint multi-path routing in ad hoc networks and WSNs, e.g., [24–26]. In [24], the authors proposed a Geography-based Ad hoc On-demand Disjoint Multi-path (GAODM) routing protocol in ad hoc networks. This GAODM uses the push-relabel algorithm [27] to convert the ad hoc network to a flow network. The focus of this research work is how to use the push-relabel algorithm to find multiple node/edge disjoint paths based on the flow assignment. The routing algorithm is similar to the first phase of TPGF, which actually can bypass holes. But, the authors did not mention this point in the whole paper. Furthermore, the routing paths found by GAODM are far from the optimal paths in terms of the end-to-end transmission delay. In [25], the authors proposed a directional geographic node-disjoint multi-path routing scheme DGR, which focuses on exploring maximum number of routing paths towards avoiding or reducing the interference among found routing paths. However, the routing paths found in this approach are likely to have very long end-to-end transmission delays, which are not suitable for real time video streaming with a transmission deadline. In [26], the authors proposed a node-Disjoint Parallel Multi-path Routing algorithm (DPMR). This DPMR actually uses the algorithm proposed in [29] to identify the hole boundary first, then divides the identified hole into two regions (*clockwise region* and *unclockwise region*). When the *Local Minimum Problem* [28] is met, the node always chooses a next hop only from either *clockwise region* or *unclockwise region*. Although this research work breakes through the use of facing routing and planarization algorithms in geographic routing, it still has a key problem: it relies on the algorithm proposed in [29], and the restriction of using only either *clockwise region* or *unclockwise region* actually limits the usable sensor nodes, consequently, limits the number of routing paths. The found routing paths in [26] are also far from the optimal paths in terms of the end-to-end transmission delay. Thus, the approaches in [24–26] are not suitable, since finding multiple routing paths with the shortest length and satisfying the end-to-end transmission delay are extremely important for multimedia streaming in WMSNs.

2.3 Related work on multi-path selection

To the best of our knowledge, no research has been done for multi-path selection in WMSNs. Although multi-path selection algorithms have not been studied in WMSNs yet, there still are some research works that have been done for multi-path selection in other networks. In [30], the authors proposed an energy-aware source routing algorithm to choose the multiple routing paths in wireless ad hoc networks; the goal of this research work is to maximize the network lifetime by minimizing the *overhearing ratio*. In [31], the authors considered the *concurrent packet drop probability* of multi-path in wireless ad hoc network, and proposed a path selection algorithm to minimize the *concurrent packet drop probability*. In [31], the authors investigated the problem of selecting multiple routing paths to provide better reliability in multi-radio, multi-channel wireless mesh networks with stationary nodes. In [32], a multi-path selection algorithm is proposed in an overlay network which focuses on minimizing the correlation of multiple paths. None of the above-mentioned multi-path selection algorithms has a research goal similar to ours, which is to choose the maximum number of paths from found node-disjoint routing paths for maximizing the gathering of the most valuable information and guaranteeing the end-to-end transmission delay.

3 Network model

The considered WSN can be represented as a graph $G(V, E)$, where $V = \{v_1, \dots, v_n\}$ is a finite set of sensor nodes (vertexes) and $E = \{e_1, \dots, e_n\}$ is a finite set of links (edges). One node is video source node. The base station can be randomly deployed in the WSN. The locations of sensor nodes and the base station are fixed and can be obtained by using GPS. Each sensor node has the knowledge of its own geographic location and the locations of its 1-hop neighbor nodes. All sensor nodes have the same maximum transmission capacity (bandwidth) *TC*. Each sensor node can have three different states: (1) *active and available*, (2) *active but unavailable*, and (3) *dead*. Each link can have two different states: (1) *available* and (2) *unavailable*. A subset $V_{Static\_Hole} = \{v_{SH1}, \dots, v_{SHn}\}$ of V is in the state *dead*. The nth routing path P_n from the source node to the base station can be represented by a subset of V as $P_n = \{v_{Pn1}, \ldots, v_{Pnm}\}$, which results in that a subset $V_{Dynamic\_Hole} = \{v_{DH1}, \ldots, v_{DHn}\} = P_1 + \cdots + P_n$ of V is in the state *active but unavailable* and a subset $E_{\text{Hole}} = \{e_{H1}, \ldots, e_{Hn}\}$ of E is in the state *unavailable*. The available sensor nodes and available links can be represented as $V_{\text{available}} = V - V_{Dynamic\_Hole} - V_{Static\_Hole}$ and $E_{\text{available}} = E - E_{\text{Hole}}$.

The video source node continuously produces sensed video stream S_{V} with a data generation rate R_{V} kbps. The source node can dynamically adjust (increase or decrease) its data generation rate by changing the sampling frequency. The video stream from the source node is sent to the base station for further processing. We assume that only the source node knows the location of the base station and other sensor nodes can only know the location of the base station by receiving the packet from the source node. Video stream can be split into image stream S_{I} with data generation rate R_{I} kbps and audio stream S_{A} with data generation rate R_{A} kbps ($R_{\text{I}} + R_{\text{A}} = R_{\text{V}}$). The soft real time deadline of the image stream is T_{I} and the soft real time deadline of the audio stream is T_{A}.

Because in different applications, the importance levels of image and audio streams are different, each type of stream is associated with an *importance rate* to reflect its importance level in the specific application. The *importance rate* for audio stream is denoted as I_{A}, and the *importance rate* for image stream is denoted as I_{I}. Both I_{A} and I_{I} are considered as constant values during a short streaming data gathering time, and they are decided by the source node itself according to its local circumstances. The values of I_{A} and I_{I} can be either 1 or 0.5 during the gathering time, respectively, which means that I_{A} and I_{I} cannot have the same value at the same time.

After source node repeatedly executing the TPGF routing algorithm, N number of node-disjoint routing paths $P = \{p_1, \ldots, p_n\}$ are found. Each routing path p_i has its own end-to-end transmission delay d_i based on the routing hops in the path. Only M_I number of routing paths $P_{Satisfy\_Image} = \{p_{SI1}, \ldots, p_{SImi}\}$ with transmission delay $D_{Satisfy\_Image} = \{d_{SI1}, \ldots, d_{SImi}\}$ can satisfy the soft real time deadline T_I, and only M_A number of routing paths $P_{Satisfy\_Audio} = \{p_{SA1}, \ldots, p_{SAma}\}$ with transmission delay $D_{Satisfy\_Audio} = \{d_{SA1}, \ldots, d_{SAma}\}$ can satisfy the soft real time deadline T_A. Here, we assume that a source node tries to use an additional path only when all its currently using transmission paths meet the maximum transmission capacity, and a routing path cannot be used for transmitting two different multimedia streams at the same time. Thus, the total number of chosen paths is $M (M = M_{\text{I}} + M_{\text{A}})$.

4 Problem formulation

The research problem in this work is to optimize the gathering of the most important streaming data to best reflect the event in WSN. In other words, the goal of this research is to maximize the *information value* in the base station as $V_{\text{Info}} = T * TC * (M_{\text{I}} * I_{\text{I}} + M_{\text{A}} * I_{\text{A}})$. Here, T is the time duration for the streaming data gathering, which is considered as a constant value. It is obvious that maximizing V_{Info} means maximizing $(M_{\text{I}} * I_{\text{I}} + M_{\text{A}} * I_{\text{A}})$, since TC is also a constant value in the WSN. Thus,

Table 1 A list of terms used in problem statement

Term	Definition
M	The total number of chosen paths
M_{I}	The number of routing paths that can be used for image stream transmission
M_{A}	The number of routing paths that can be used for audio stream transmission
I_{I}	The *importance rate* of image stream
I_{A}	The *importance rate* of audio stream
N	The total number of routing paths found by using TPGF multi-path routing algorithm
R_{I}	The data generation rate of image stream
R_{A}	The data generation rate of audio stream
TC	The maximum transmission capacity of sensor node (bandwidth)

the above optimization problem can be converted to a simple linear optimization problem as:

$$\text{Maximize:} \quad M_{\mathrm{I}} * I_{\mathrm{I}} + M_{\mathrm{A}} * I_{\mathrm{A}}, \tag{1}$$

$$\text{Subject to:} \quad M = M_{\mathrm{I}} + M_{\mathrm{A}}, \tag{2}$$

$$M \leq N, \tag{3}$$

$$M \leq \ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner \tag{4}$$

We can further analyze the listed equations in the problem. A list of terms used in the problem statement is given in Table 1. Equation (1) actually indicates that the values of *importance rate* I_{A} and I_{I} show the direction for increasing either M_{I} or M_{A}, which means the stream with the larger *importance rate* should have the higher priority to use more routing paths. Equations (2) and (3) show that the maximum number of paths M is bounded by the found node-disjoint routing paths N, and (4) shows that a routing path cannot be used for transmitting two different multimedia streams at the same time. Moreover, based on (3) and (4), we can have the following theorem.

Theorem 1 *For the given source node S_{Source_Node}, the maximum number of final chosen paths M has the upper bound* $\mathrm{Min}(N, \ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner)$, *where* $\mathrm{Min}(para1, para2)$ *is the function which returns the smaller value.*

Proof When the end-to-end transmission delays of all node-disjoint routing paths satisfy the real time constraints of image and audio streams, all these node-disjoint routing paths can be chosen for transmitting data. However, the actually required number of routing paths is decided by the $\ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner$. When $N \geq \ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner$, the final number of chosen paths is $\ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner$. When $N < \ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner$, although more routing paths are required for transmitting data, but only N number of routing paths can be used. Thus, the upper bound on the maximum number of final chosen paths M is $\mathrm{Min}(N, \ulcorner R_I/TC \urcorner + \ulcorner R_A/TC \urcorner)$. □

By having the above analysis, it is obvious that two important factors should be clear before solving the formulated linear optimization problem: (1) the found node-disjoint routing paths N, and (2) the values of *importance rate* I_A and I_I. Thus, we can further break down this optimization problem into the following two sub-problems:

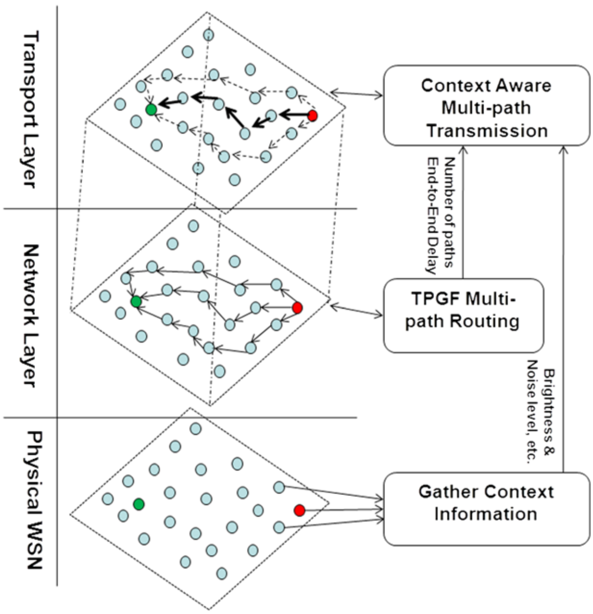
(1) Creating a new routing algorithm to find the maximum number of node-disjoint routing paths for the source node in network layer. This algorithm can help to enlarge the upper bound of M, which is essentially important for this linear optimization problem. However, the exploring of the maximum number of node-disjoint routing paths in a WSN is a NP-hard problem [12], which actually drastically increases the difficulty for solving the formulated optimization problem in this paper.
(2) Creating a new context-aware algorithm in transport layer to select the right number of routing paths for each stream to maximize the *information value*. This sub-problem is relatively easier to solve than the first sub-problem, and it also represents the additional contribution of our research work with respect to the TPGF routing algorithm.

5 Cross-layer design and MPMP scheme

To solve the identified research problem, we design a context-aware cross-layer optimized Multi-Path Multi-Priority transmission (MPMP) scheme as shown in Fig. 3.

In physical layer, the context information can be gathered from the video source node itself directly or from other neighbors, e.g., a neighbor node with light sensor. In network layer, the TPGF multi-path routing protocol is used to explore the maximum number of routing paths that can connect the source node to the sink node. After using

Fig. 3 The cross-layer framework of MPMP scheme



TPGF, the total number of available routing paths and each routing path's end-to-end transmission delay can be easily gathered. In transport layer, a context-aware multi-path selection algorithm (CAMS) is used to choose the maximum number of paths from all found node-disjoint routing paths for maximizing the *information value* of video stream transmission and guaranteeing the end-to-end transmission delay.

5.1 TPGF routing algorithm

Definition 1 *Node-disjoint routing path* A node-disjoint routing path is defined as a routing path which consists of a set of sensor nodes, and excluding the source node and the base station none of these sensor nodes can be reused for building another routing path.

The Two-Phase geographic Greedy Forwarding (TPGF) routing algorithm for WMSNs has been presented in [10–12] and its effectiveness has been proved by using simulation and theoretical analysis. In this paper, we only briefly introduce the TPGF routing algorithm.

The flowchart of TPGF routing algorithm is shown in Fig. 4. The inputs of TPGF are: (1) location of the current forwarding node; (2) location of the base station; (3) locations of 1-hop neighbor nodes. The outputs of TPGF are: (1) location of the next-hop node; or (2) successful acknowledgement; or (3) unsuccessful acknowledgement. The description of TPGF routing algorithm is as follows:

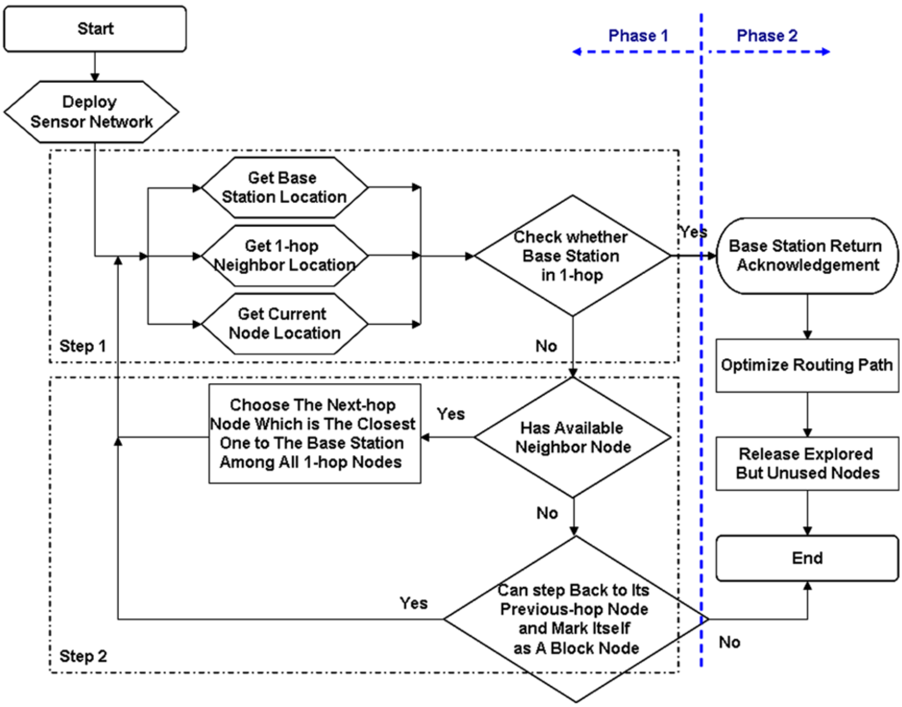


Fig. 4 The flowchart of TPGF routing algorithm

Phase 1: Geographic forwarding

Step 1: The source node checks whether it has usable one-hop neighbor node. If no, the source node produces an unsuccessful acknowledgement and stops transmitting. If yes, then the source node checks whether the base station is in its one-hop neighbor nodes. If yes, then it builds up a routing path. If no, then the source node tries to find the next-hop node that is the closest one to the base station among all its neighbor nodes that have not been labeled (occupied). A digressive number-based label is given to the chosen sensor node along with a path number.

Step 2: The chosen sensor node checks whether the base station is in its one-hop nodes. If yes, then it builds up a routing path. If no, then the chosen sensor node always tries to find the next-hop node that is the closest one to the base station among its all neighbor nodes that have not been labeled (occupied). A digressive number-based label is given to the found next-hop node along with a path number. When this sensor node finds that it has no neighbor node which is available for the next-hop transmission, which means the *block situation* is met, it will step back to its previous-hop node and mark itself as a *block node*. The previous-hop node will attempt to find another available neighbor node as the next-hop node. The *step back & mark* will be repeatedly executed until a sensor node successfully finds a next-hop node which has a routing path to the base station.

Phase 2: Path optimization

Step 3: Once the routing path is built up, a successful acknowledgement is sent back from the base station to the source node. Any sensor node that belongs to this path only relays packets to its one-hop neighbor node which is labeled in Step 2 with the same path number and the largest node number. A release command is sent to all other one-hop neighbor nodes which are labeled in Step 2 but are not used for transmission. After receiving the successful acknowledgement, the source node then starts to send out multimedia streaming data to the successful path with the pre-assigned path number.

The time complexity of TPGF is $O(n)$, where n is the number of nodes in the WMSN. The number of found node-disjoint routing paths N is restricted by three factors as the following:

(1) For any given source node S with M number of 1-hop neighbor nodes, it can have maximum M number of node-disjoint routing paths.
(2) The maximum number of node-disjoint routing paths is restricted by the 1-hop neighbor nodes of the base station.
(3) For any given source node, the maximum number of possible node-disjoint routing paths is affected by the routing algorithms. For example, in Fig. 5, if TPGF is used, the number of routing paths can be only one (dashed path) with a short end-to-end transmission delay. However, if the label-based multi-path routing (LMR) [33] is used, the number of routing paths can be two (dotted path) with a relative longer end-to-end transmission delay.

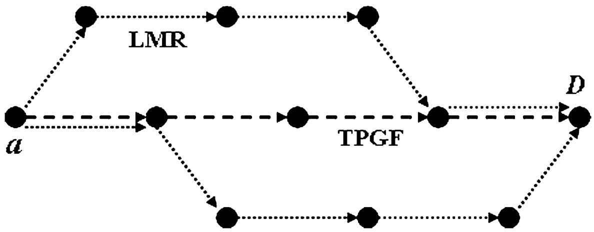


Fig. 5 Using the TPGF, the found number of routing paths can be only 1. But, using the LMR, the found number of routing paths can be 2

TPGF and LMR actually demonstrate a confliction between two different design principles: (1) always explore the shortest routing path in each round; (2) explore more redundant routing paths with longer end-to-end transmission delays. TPGF uses "always explore the shortest routing path in each round" as the criteria and then explores the possible number of multiple paths. The primary motivation is that the shortest transmission path generally has the shortest end-to-end transmission delay, which may satisfy the delay constraint of multimedia streaming data. If the data cannot be transmitted to the base station within the delay constraint, it is useless.

In short, repeatedly using TPGF can explore more routing paths than that of repeatedly using the protocols in [34–36], e.g., GPSR, GOAFR, GOAFR+, and GPVFR [12]. The number of routing paths found by using the TPGF is not larger than that of some other non-geographical routing algorithms, e.g., LMR. But, TPGF is more suitable for transmitting multimedia data in WMSNs, because it always tries to satisfy the delay constraint of multimedia streaming data.

Practically, TPGF gives the following three major contributions: (1) *Supporting multi-path transmission*: TPGF can find one routing path per execution and can be executed repeatedly to find more on-demand *node-disjoint* routing paths; (2) *Supporting hole-bypassing*: TPGF provides a better solution for hole-bypassing in both 2D and 3D sensor networks than any other related research work; (3) *Supporting shortest path transmission*: TPGF can find the shortest routing path (or near-shortest routing path when holes exist) for minimizing the end-to-end transmission delay.

5.2 Context-aware multi-path selection (CAMS) algorithm

Definition 2 *Context* The context information in this paper is defined as (1) the brightness level and noise level of the surrounding environment where a video source node is deployed, (2) the number of node-disjoint routing paths and the end-to-end delay of each routing path that can be gathered after running TPGF in network layer.

Incorporating context information to facilitate the video transmission in WMSNs is one of the most important features of MPMP scheme. The essential motivation for using context in Context-Aware Multi-path Selection (CAMS) algorithm is: sending the right multimedia stream at the right time through the right transmission path based on the information of surrounding environment to maximize the gathering of the most appropriated multimedia data that can precisely reflect the event in WMSNs. Based on the gathered context information, two types of priorities can be supported in CAMS algorithm: (1) End-to-end transmission delay based priority and (2) Context-aware multimedia content-based priority, as defined in Definitions 3 and 4.

Definition 3 *End-to-end transmission delay based priority* For any two paths p_i and p_j within the N number of node-disjoint routing paths $P = \{p_1, \ldots, p_n\}$ that are found by repeatedly executing the TPGF routing algorithm, if their end-to-end transmission delays meet $d_i < d_j$, we assign the higher priority to path p_i.

Definition 4 *Context-aware multimedia content-based priority* In any situation where a video sensor node is deployed for gathering information, for both image and audio streams, if the image stream is more important for reflecting the event, we assign higher priority to the image stream. Likewise, if the audio stream is more important for reflecting the event, we assign higher priority to the audio stream.

Thus, it is clear that in CAMS algorithm the routing path with the higher priority should always be chosen first to reduce the end-to-end transmission delay, and the stream with the higher priority should always be sent first to reflect the events. The higher priority stream is assigned to the *importance rate* 1, and the lower priority stream is assigned to the *importance rate* 0.5.

Because the goal of CAMS algorithm is to optimize the *information value* by selecting the right number of routing paths for each stream, we have a further analysis on the following three situations:

Case 1: When the end-to-end transmission delay of each found routing path does not satisfy the requirement for transmitting video stream before its deadline, it is meaningless to send any type of stream back to the base station.

Case 2: When the end-to-end transmission delay of each found routing path satisfies the requirement for transmitting video stream before its deadline, the routing path allocation method follows the simple Best-Effort principle. In other words, the more important stream has the higher priority to be transmitted first, and after finishing the transmission of the more important stream, if there are still remaining routing paths, then the less important stream will be transmitted. If there is overwhelming transmission requirement for the higher priority stream, the lower priority stream will be discarded.

Case 3: When the end-to-end transmission delays of only a part of the found routing paths satisfy the requirement for transmitting video stream before its deadline, the satisfied routing paths will be selected to transmit the more important stream, and an acceptable released transmission deadline will be given to the less important stream to allow it to use the further satisfied routing paths.

After having all this analysis, we present the Context-Aware Multi-path Selection (CAMS) algorithm. The workflow of CAMS is shown in Fig. 6. In CAMS, the more important multimedia stream always chooses the routing path with the higher priority to transmit. CAMS algorithm also has two phases: (1) searching the maximum number of paths for the stream with the higher priority; (2) searching the maximum number of paths for the stream with the lower priority. For the situations when both the light intensity and the sound intensity are higher (or lower) than the certain values, the CAMS algorithm chooses not to change the stream priorities but impliedly inherit the already assigned priorities. The reason for adopting this processing is that CAMS algorithm will try to keep the video streaming in WMSNs be as stable as possible,

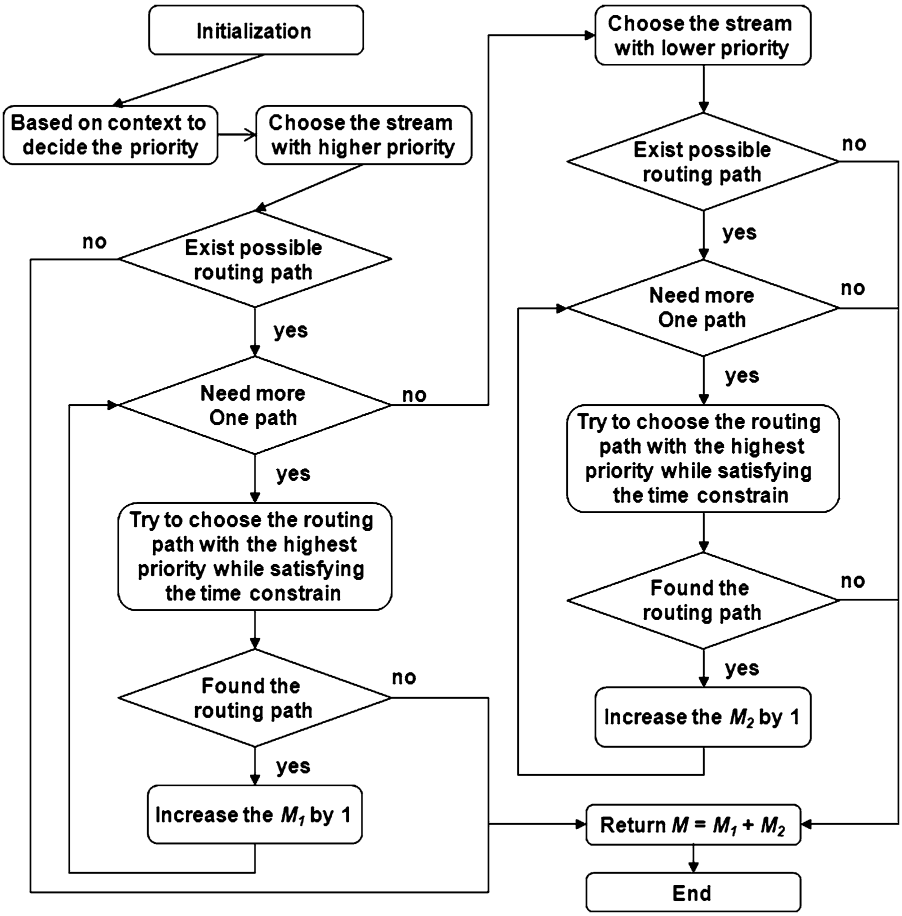


Fig. 6 The flowchart of the CAMS algorithm

since most of the time the video streaming in WMSNs will continue for a relatively long duration.

The CAMS algorithm should be executed after TPGF explored all node-disjoint routing paths. The time complexity of CAMS algorithm is $O(n^2)$ where n is the number of possible routing paths that can be found by repeatedly executing TPGF. The most remarkable feature of CAMS algorithm is the supporting for Case 3: because the releasing on the deadline to a tolerable/acceptable constraint of the less important stream allows the using of more routing paths and sending more data, this can essentially enlarge the *information value*. Furthermore, Case 3 is the most general situation in the WSN, when using TPGF algorithm to explore the maximum number of node-disjoint routing paths.

6 Simulation and evaluation

To demonstrate and evaluate the MPMP scheme, we use a new open source WSNs simulator called NetTopo [37], in which the TPGF is implemented, as shown in Fig. 7. Furthermore, NetTopo is implemented to allow the using of real sensor network test-beds, in which the real context information can be gathered, e.g., as shown in Fig. 8, Crossbow sensor nodes can provide the intensity of light. Readers are welcome to download NetTopo from [38] to see its full functionalities.

In this simulation, we consider a WMSN for a fire monitoring application in a forest in which the image stream is more urgent and important than the audio stream in terms of reflecting the fire event. Thus, the *importance rate* of image stream is 1 and the *importance rate* of audio stream is 0.5. The end-to-end transmission delay in WSNs is actually determined by the number of hops [39]. Thus, to find out the path with the shortest transmission delay D_{e2e} is to find out the path with the smallest number of hops: $D_{\mathrm{e2e}} = H * D_{\mathrm{hop}}$, where H is the number of hops and D_{hop} is the average delay of each hop.

The parameters used in our simulation are shown in Table 2. The time constraint of video stream is 280 ms. After splitting into image stream and audio stream, because the image stream actually plays the key role in the simulation for reflecting the fire event, it should inherit the time constraint of video stream which is also 280 ms. The

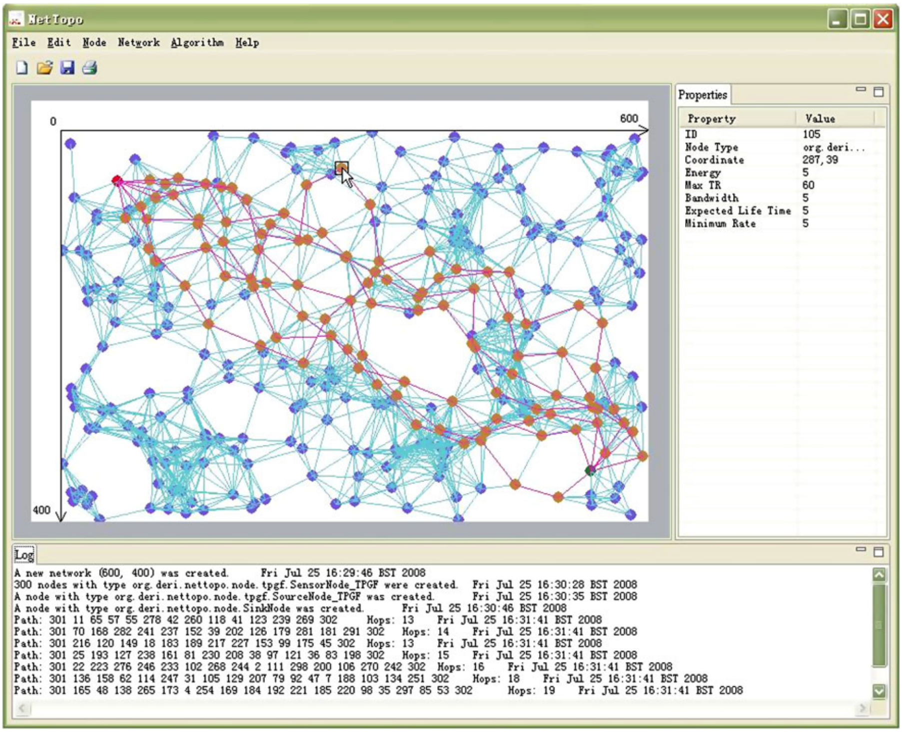


Fig. 7 NetTopo main GUI (the TPGF multi-path routing algorithm is executed in the WSN)

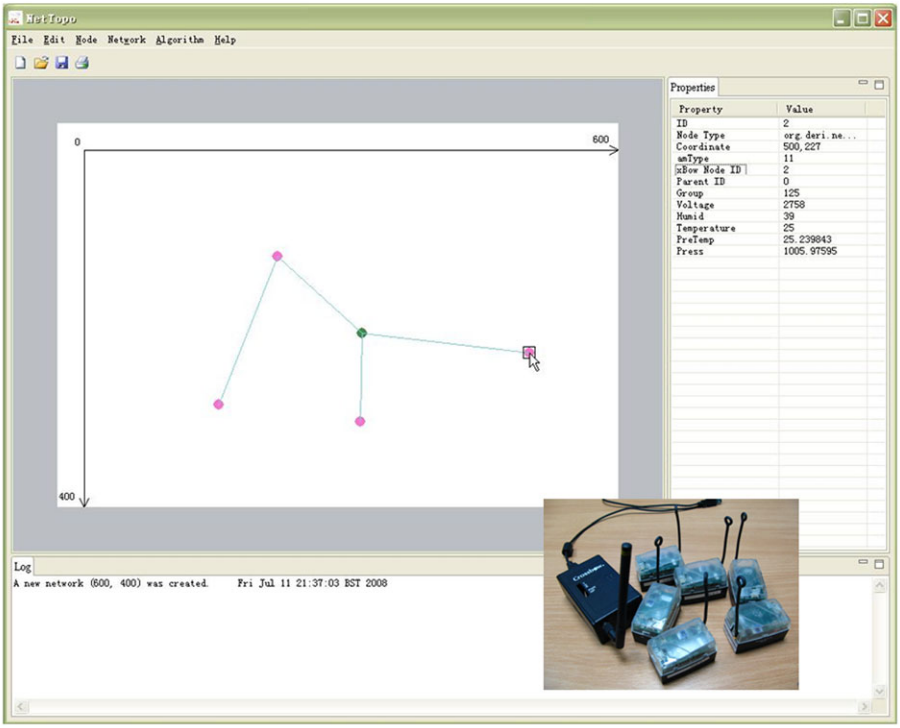


Fig. 8 NetTopo main GUI (Crossbow sensor network is visualized in NetTopo)

Table 2 Simulation parameters

Parameter	Value
Network size	500 m ∗ 500 m
Number of base station	1
Number of sensor node	399
Number of source node	1
Video sensor generation rate R	72 kbps
Sensor node maximum TC	12 kbps
Sensor node transmission radius	48 m
Delay of each hop D_{hop}	20 ms
Video stream time constraint	280 ms
Split image stream time constraint	280 ms (Inherit from video)
Split audio stream time constraint	280 ms (Inherit from video)
Split audio stream time tolerable constraint	320 ms (Released constraint)

original time constraint of audio stream should also be 280 ms, but according to the supporting in CAMS algorithm for Case 3, the time constraint of audio stream can be further extended to a tolerable constraint of 320 ms, which allows it to use the routing path with relative longer transmission delay.

To prove the effectiveness of MPMP scheme, we compare MPMP with two different schemes, which are the varied versions of MPMP scheme:

(1) TPGF-based Multi-path Video Streaming, named as MVS scheme, which does not split the video stream (72 kbps) into image stream (48 kbps) and audio stream (24 kbps). In MVS scheme, only the end-to-end transmission delays of all node-disjoint routing paths are used as the parameters for choosing the qualified routing paths. This MVS scheme is very similar to the approach that was proposed in [16]. The only difference is that [16] used DGR multi-path routing algorithm [25] in network layer, which explores maximum number of routing paths towards avoiding or reducing the interference among found routing paths, and the routing paths found by DGR are likely to have very long end-to-end transmission delays, which are not suitable for real time video streaming with a transmission deadline. Thus, we use TPGF as the routing algorithm in network layer for comparison, instead of the DGR, to highlight the contributions of CAMS algorithm.
(2) TPGF-based Multi-path Multi-stream Streaming, named as MMS scheme, which splits the video stream (72 kbps) into image stream (48 kbps) and audio stream (24 kbps). In MMS scheme, the time constraint of the less important stream is not released to the tolerable time constraint. Bringing the MMS scheme to the simulation on fire event monitoring, in this case, the deadline of audio stream is not released.

6.1 Comparison results

The simulated sensor network is shown in Fig. 9. When a fire event is detected, after repeatedly executing the TPGF routing algorithm, six node-disjoint routing paths are found in total from the video source node (red color node) to the base station (green color node). The end-to-end transmission delays of these six routing paths are shown in Table 3.

Within these six node-disjoint routing paths, if the MVS scheme is used, only 4 paths (paths Nos. 1, 2, 4 and 5) are qualified for transmitting video stream since the deadline of video stream is 280 ms. Thus, for every one second, the received data by the base station can be 48 kb (image stream 32 kb, audio stream 16 kb) as shown in Table 4, and the *information value* for every one second is $8 \times 4 \times 1 + 4 \times 4 \times 0.5 = 40$.

For the same six node-disjoint routing paths, if the MMS scheme is used, still only 4 paths (paths Nos. 1, 2, 4 and 5) are qualified for transmitting image stream since the deadline of image stream is also 280 ms. Although the video stream is split into image stream (48 kbps) and audio stream (24 kbps), the time constraint of audio stream is not released in MMS scheme. Thus, the audio stream will not be transmitted, because the end-to-end transmission delays of the remaining two paths do not satisfy the time constraint of the audio stream. Finally, for every one second, the received data by the base station can be 48 kb (image stream) as shown in Table 5, and the *information value* for every one second is $12 \times 4 \times 1 = 48$.

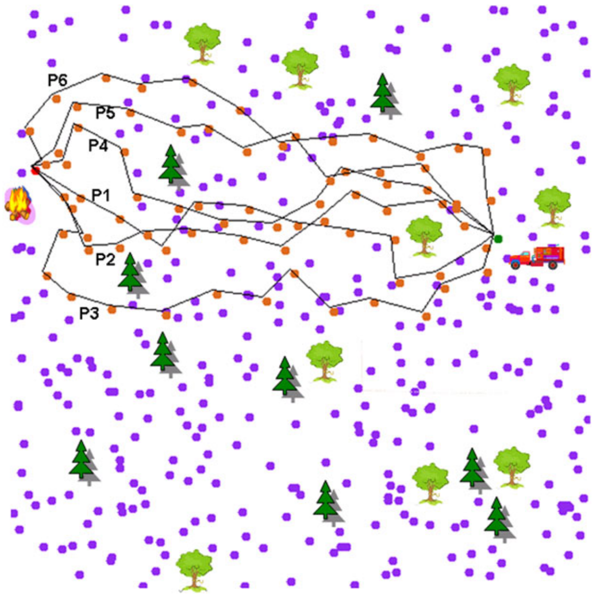


Fig. 9 Six available routing paths are found by using the TPGF routing algorithm. The picture is produced by using NetTopo simulator, and the trees, fire, and fire engine are added additionally to this picture

Table 3 The end-to-end transmission delay

Routing path	End-to-end transmission delay
Path No. 1	240 ms
Path No. 2	260 ms
Path No. 3	320 ms
Path No. 4	260 ms
Path No. 5	240 ms
Path No. 6	300 ms

Table 4 Data received by the base station for every one second when using MVS scheme

Path	E2E delay	Used	Image stream	Audio stream
No. 1	240 ms	Yes	8 kb	4 kb
No. 2	260 ms	Yes	8 kb	4 kb
No. 3	320 ms	No	0 kb	0 kb
No. 4	260 ms	Yes	8 kb	4 kb
No. 5	240 ms	Yes	8 kb	4 kb
No. 6	300 ms	No	0 kb	0 kb

When using the MPMP scheme, the video stream (72 kbps) is split into image stream (48 kbps) and audio stream (24 kbps), and the time constraint of audio stream is released to the tolerable/acceptable constraint. Among these six found routing paths, four of them are chosen (in pink color) for image stream transmission and the remaining two paths are used for audio stream transmission, as shown in Fig. 10. For every one second, the received data by the base station can be increased from

Table 5 Data received by the base station for every one second when using MMS scheme

Path	E2E delay	Used	Image stream	Audio stream
No. 1	240 ms	Yes	12 kb	0 kb
No. 2	260 ms	Yes	12 kb	0 kb
No. 3	320 ms	Yes	0 kb	0 kb
No. 4	260 ms	Yes	12 kb	0 kb
No. 5	240 ms	Yes	12 kb	0 kb
No. 6	300 ms	Yes	0 kb	0 kb

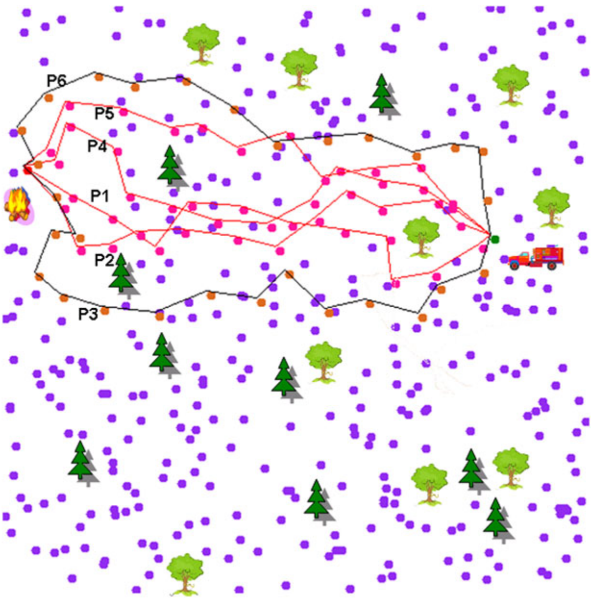


Fig. 10 Video streaming with MPMPS, four paths (P1, P2, P4 and P5) are chosen for image stream, and two paths (P3 and P6) are used for audio stream

Table 6 Data received by the base station for every one second when using MPMP scheme

Path	E2E delay	Used	Image stream	Audio stream
No. 1	240 ms	Yes	12 kb	0 kb
No. 2	260 ms	Yes	12 kb	0 kb
No. 3	320 ms	Yes	0 kb	12 kb
No. 4	260 ms	Yes	12 kb	0 kb
No. 5	240 ms	Yes	12 kb	0 kb
No. 6	300 ms	Yes	0 kb	12 kb

48 kb to 72 kb (image stream 48 kb, audio stream 24 kb) as shown in Table 6, and the *information value* for every one second is $12 \times 4 \times 1 + 12 \times 2 \times 0.5 = 60$.

The simulation results in Figs. 11 and 12 show the results on received streaming data and *information value*s in the base station: (1) Using MVS scheme and MMS scheme can receive the same amount of streaming data, but their *information value*s are different; (2) Comparing with both MVS and MMS schemes, using MPMP

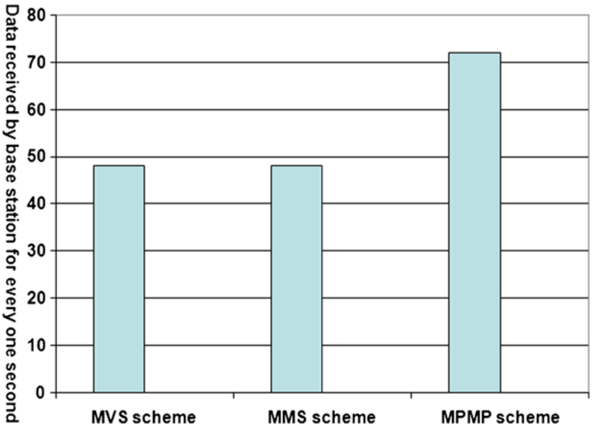


Fig. 11 Data received by the base station (kb) for every one second

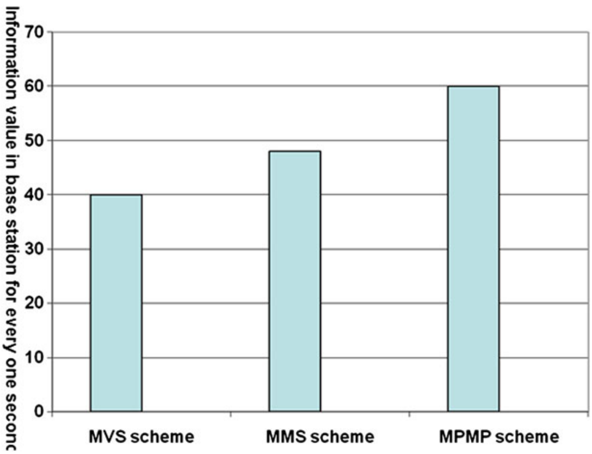


Fig. 12 Information value received by the base station (kb) for every one second

scheme can greatly increase both the total received multimedia streaming data and the *information value* in the base station, which essentially proves the effectiveness of the proposed MPMP scheme.

6.2 Demonstration of CAMS algorithm execution

The execution of CAMS algorithm is demonstrated in Figs. 13–16. Four routing paths are chosen for image stream transmission. In Fig. 13, path No. 1 is chosen for image stream transmission first, since it has the shortest end-to-end transmission delay. In Fig. 14, path No. 5 is chosen after the path No. 1 because it has the second shortest end-to-end transmission delay. In Figs. 15 and 16, paths No. 2 and No. 4 are chosen respectively for image stream transmission.

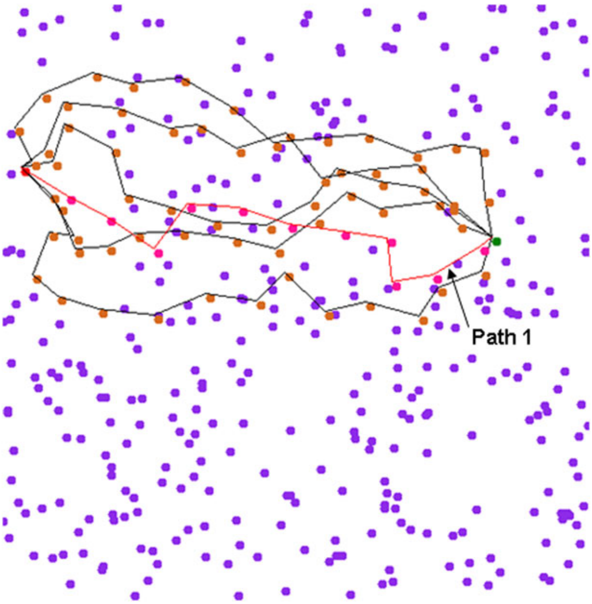


Fig. 13 Choose the path No. 1

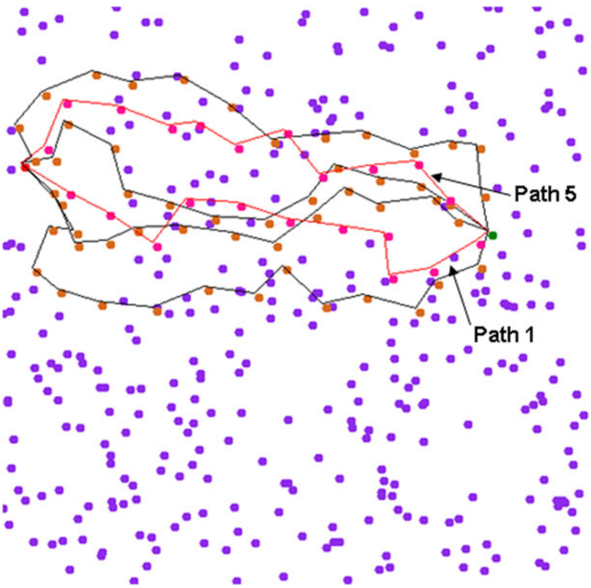


Fig. 14 Choose the path No. 5

7 Conclusions and future work

In this paper, we presented a context-aware cross-layer optimized Multi-Path Multi-Priority transmission (MPMP) scheme to facilitate the information gathering in WM-SNs, in which a video sensor node is used to capture more comprehensive information than scalar sensor readings. The formulated simple linear optimization problem

Fig. 15 Choose the path No. 2

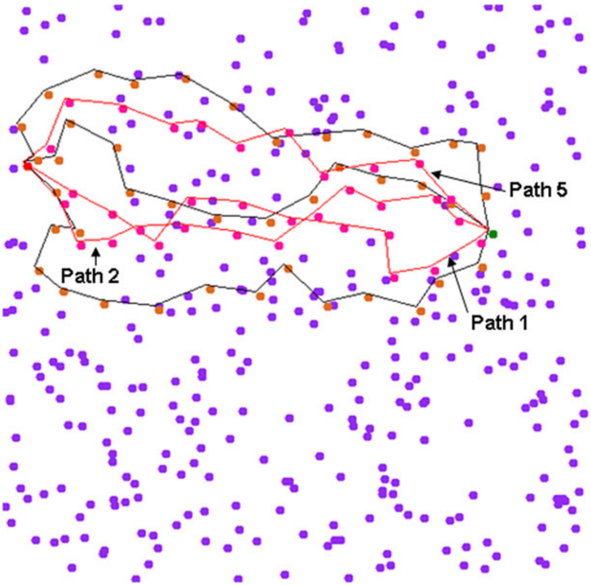
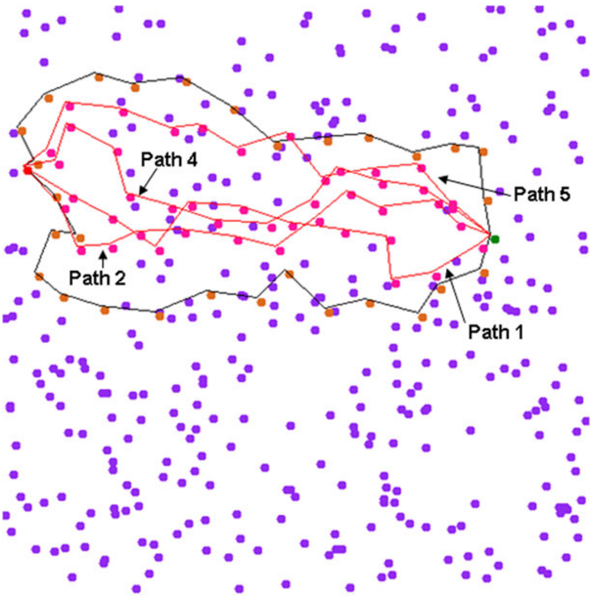


Fig. 16 Choose the path No. 4



is further broken into two sub-optimization problems, which motivated the creating of the TPGF multi-path routing algorithm in network layer and the CAMS path selection algorithm in transport layer, respectively. Context information of the video sensor node, e.g., brightness level and noise level, is used to decide the *importance rate*s for image and audio streams to reflect their importance level in the specific application. The more important stream is given to the higher priority to choose the found node-disjoint routing paths, first to guarantee the using of limited bandwidth and energy in WMSNs. The time constraint of the less important stream is released to a tolerable/acceptable time constraint to allow the using of more routing paths. Simulation results show that using MPMP scheme can effectively maximize the gathering of the most valuable information and guarantee the end-to-end transmission delay.

Research work in wireless multimedia sensor networks still have a lot of challenging issues, and we are very interested in the following four research issues as our future work:

(1) Congestion control problem: when multiple multimedia source nodes are deployed in WMSNs, and they try to send out the streaming data to a single base station at the same time, a well-designed congestion control scheme is essentially necessary [40].
(2) Mobility support problem: when both multimedia source nodes and sink node can be mobile, authors can see an opportunity to apply the game theory to further solve some of the more complicated optimization problems [41].
(3) Duty-cycle support problem: when sensor nodes in the WMSNs are random duty-cycled based, the network topology and connectivity of WMSNs can change from time to time. It is important to further investigate a cross-layer optimized sensor node sleeping scheduling scheme to guarantee the network connectivity for packet delivery [42].
(4) Target tracking problem: when multiple video sensor nodes are deployed to tracking a certain target in the WMSNs, it is important to further explore the collaboration between multiple video sensor nodes for facilitating the target tracking task [43].

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References

1. Holman R, Stanley J, Őzkan-Haller T (2003) Applying video sensor networks to nearshore environment monitoring. IEEE Pervasive Comput 2(4):14–21. doi:10.1109/MPRV.2003.1251165
2. Chu M, Reich J, Zhao F (2004) Distributed attention in large scale video sensor networks. In: Proceedings of the second IEE workshop on intelligent distributed surveillance systems, London, UK, February 2004
3. Qin M, Zimmermann R (2005) Maximizing video sensor network lifetime through genetic clustering. USC Technical Report USC-CS-TR05-844, University of Southern California
4. Agathangelou D, Lo BPL, Wang JL, Yang GZ (2005) Self-configuring video-sensor networks. In: Proceedings of the 3rd international conference on pervasive computing (Pervasive 2005), Munich, Germany, May 2005, pp 29–32
5. Little TDC, Konrad J, Ishwar P (2007) A wireless video sensor network for autonomous coastal sensing. In: Proceedings of the conference on coastal environmental sensing networks (CESN 2007), Boston, MA, USA, April 2007
6. Gerla M, Xu K (2003) Multimedia streaming in large-scale sensor networks with mobile swarms. ACM SIGMOD Rec 32(4):72–76. doi:10.1145/959060.959073
7. Tsai J, Moors T (2006) A review of multipath routing protocols: from wireless ad hoc to mesh networks. In: Proceedings of the ACoRN early career researcher workshop on wireless multihop networking, Australia, 2006

8. Johnson DB, Maltz DA (1996) Dynamic source routing in ad hoc wireless networks. In: Mobile computing. Kluwer Academic Publishers, Dordrecht
9. Perkins C (2003) Ad hoc on-demand distance vector (AODV) routing. RFC 3561
10. Shu L, Zhou ZB, Hauswirth M, Phuoc DL, Yu P, Zhang L (2007) Transmitting streaming data in wireless multimedia sensor networks with holes. In: Proceedings of the sixth international conference on mobile and ubiquitous multimedia (MUM 2007), Oulu, Finland, December, 2007. doi:10.1145/1329469.1329472
11. Shu L, Zhang Y, Yang LT, Wang Y, Hauswirth M (2008) Geographic routing in wireless multimedia sensor networks. In: Proceedings of the 2nd international conference on future generation communication and networking (FGCN 2008), Hainan, China, December 2008. doi:10.1109/FGCN.2008.17
12. Shu L, Zhang Y, Yang LT, Wang Y, Hauswirth M, Xiong N (2009) TPGF: geographic routing in wireless multimedia sensor networks. Telecommun Syst 44(1–2)
13. Paul RS, Ali B, Dave B, Duncan MS, Jun Y, Nigel RS (2007) Semantic technologies and enhanced situation awareness. In: Proceedings of the first annual conference of the international technology alliance (ACITA 2007), MD, USA, September 2007
14. Video Stream Codec (2009) http://www.exefind.com/video-stream-codec/
15. Shu L, Yang J, Zhang L, Xu H, Wu X, Hauswirth M (2007) Reward oriented packet filtering algorithm for wireless sensor networks. Wirel Commun Mobile Comput. doi:10.1002/wcm.549
16. Chen M, Leung VCM, Mao S, Li M (2008) Cross-layer and path priority scheduling based real-time video communications over wireless sensor networks. In: Proceedings of the 68th IEEE vehicular technology conference (VTC 2008), Calgary, Alberta, Canada, September 2008
17. Zhang L, Hauswirth M, Shu L, Zhou Z, Reynolds V, Han G (2007) Multi-priority multi-path selection for video streaming in wireless multimedia sensor networks. In: Proceedings of the fifth international conference on ubiquitous intelligence and computing (UIC 2007), Oslo, Norway, July 2007. doi:10.1007/978-3-540-69293-5_35
18. Gurses E, Akan OB (2005) Multimedia communication in wireless sensor networks. Ann Télécommun 60(7–8):799–827
19. Akyildiz IF, Melodia T, Chowdhury KR (2007) A survey on wireless multimedia sensor networks. Comput Netw 51(4):921–960. doi:10.1016/j.comnet.2006.10.002
20. Misra S, Reisslein M, Xue G (2008) A survey of multimedia streaming in wireless sensor networks. IEEE Commun Surv Tutor 10(4):18–39. doi:10.1109/SURV.2008.080404
21. Akan ÖB (2007) Performance of transport protocols for multimedia communications in wireless sensor networks. IEEE Commun Lett 11(10):826–828. doi:10.1109/LCOMM.2007.061811
22. Shin J, Kumar R, Mohapatra D, Ramachandran U, Ammar M (2007) ASAP: a camera sensor network for situation awareness. In: Proceedings of the 11th international conference on principles of distributed systems (OPODIS 2007), Guadeloupe, French West Indies, December 2007
23. Hyung SL, Hee YY, Jung H (2006) Context-aware cross-layered multimedia streaming based on variable packet size transmission. In: Proceedings of the international conference on computer science and its applications (ICCSA 2006), Glasgow, UK, May 2006
24. Zeng K, Ren K, Lou W (2005) Geographic on-demand disjoint multipath routing in wireless ad hoc networks. In: Proceedings of the military communications conference (MILCOM 2005), Atlantic City, USA, October 2005
25. Chen M, Leung VCM, Mao S, Yuan Y (2007) Directional geographical routing for real-time video communications in wireless sensor networks. Comput Commun. doi:10.1016/j.comcom.2007.01.016
26. Li S, Wu Z (2005) Node-disjoint parallel multi-path routing in wireless sensor networks. In: Proceedings of the second international conference on embedded software and systems (ICESS 2005), Xi'an, China, December 2005
27. Cormen TH, Leiserson CE, Rivest RL, Stein C (2001) Introduction to algorithms. The MIT Press, Cambridge
28. Karp B, Kung HT (2000) GPSR: greedy perimeter stateless routing for wireless networks. In: Proceedings of the annual international conference on mobile computing and networking (MobiCom 2000), Boston, USA, August 2000
29. Fang Q, Gao J, Guibas LJ (2004) Locating and bypassing routing holes in sensor networks. In: Proceedings of the 23rd conference of the IEEE communications society (INFOCOM 2004), Hong Kong, China, March 2004
30. Hwang DY, Kwon EH, Lim JS (2006) EASR: an energy aware source routing with disjoint multipath selection for energy-efficient multihop wireless ad hoc networks. In: Proceedings of the fifth IFIP international conference on networking (NETWORKING 2006), Portugal, May 2006

31. Wei W, Zakhor A (2006) Path selection for multi-path streaming in wireless ad hoc networks. In: Proceedings of the international conference on image processing (ICIP 2006), Atlanta, GA, September 2006
32. Tsai JW, Moors T (2007) Interference-aware multipath selection for reliable routing in wireless mesh networks. In: Proceedings of the first IEEE international workshop on enabling technologies and standards for wireless mesh networking (MeshTech 2007), Pisa, Italy, October 2007
33. Hou X, Tipper D, Kabara J (2004) Label-based multipath routing (LMR) in wireless sensor networks. In: Proceedings of the international symposium on advanced radio technologies (ISART 2004), Boulder, USA, March 2004
34. Kuhn F, Wattenhofer R, Zollinger A (2003) Worst-case optimal and average-case efficient geometric ad-hoc routing. In: Proceedings of the fourth ACM international symposium on mobile ad hoc networking and computing (MobiHoc 2003), Annapolis, MD, USA, June 2003
35. Kuhn F, Wattenhofer R, Zhang Y, Zollinger A (2003) Geometric ad hoc routing: of theory and practice. In: Proceedings of the 22nd ACM international symposium on the principles of distributed computing (PODC 2003), Boston, MA, USA, July 2003
36. Leong B, Mitra S, Liskov B (2005) Path vector face routing: geographic routing with local face information. In: Proceedings of the 13th IEEE international conference on network protocols (ICNP 2005), Boston, MA, USA, November 2005
37. Shu L, Wu C, Zhang Y, Chen J, Wang L, Hauswirth M (2008) NetTopo: Beyond simulator and visualizor for wireless sensor networks. In: Proceedings of the second international conference on future generation communication and networking (FGCN 2008), Sanya, Hainan, China, December 2008. doi:10.1109/FGCN.2008.18
38. NetTopo (2009) http://lei.shu.deri.googlepages.com/nettopo
39. Chang SY, Chen C, Jiang CJ (2007) Minimum-delay energy-efficient source to multisink routing in wireless sensor networks. In: Proceedings of the 13th international conference on parallel and distributed systems (ICPADS 2007), Hsinchu, Taiwan, December 2007
40. Chen J, Cao X, Xiao Y, Sun Y (2008) Simulated annealing for optimizations with wireless sensor and actuator networks. Electron Lett 44(20), September 2008
41. Chen J, Li S, Sun Y (2007) Novel deployment schemes for mobile sensor networks. Sensor 7(11):2907–2911. doi:10.3390/S7112907
42. Cheng L, Chen C, Ma J, Shu J, Chen H, Yang LT (2009) Residual time aware forwarding for randomly duty-cycled wireless sensor networks. In: Proceedings of the 7th IEEE/IFIP international conference on embedded and ubiquitous computing (EUC 2009), Vancouver, Canada, August
43. Chen J, Cao K, Sun Y, Shen X (2009) Adaptive sensor activation for target tracking in wireless sensor networks. In: Proceedings of the 2009 international conference on communications (ICC 2009), Dresden, Germany, June 2009

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