

# A Cross Layer Method for Efficient Video Delivery Based on TPGF Routing in WMSN

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**Abstract**—In this paper, we propose a QoS-aware method for multimedia streaming that uses cross-layer information (application layer and physical layer) in Wireless Multimedia Sensor Networks (WMSNs). Our goal is to use cross-layer information to route video packets efficiently and deliver a higher quality video in streaming applications. Our QoS-Aware Multi-Path Selection (QAMPS) method is based on multi-path multi-priority selection algorithm that uses Two-Phase geographic Greedy Forwarding (TPGF) as a routing algorithm. The proposed method improves QoS by splitting video streams into I-frames, P-frames and B-frames in the application layer and passes them to the network layer for routing packets in three different classes. The differentiation is based on Bit Error Rate (BER) and delay of the paths. These parameters determine the best paths for sending I, P and B-frame streams separately. Finally, the comparison of QAMPS with Context-Aware Multi-path Selection (CAMS) scheme that sends video stream without classification of frames shows a better quality. The proposed method has better PSNR and decreases the frame loss ratio by about 20 percent in average compared to CAMS.

**Keywords**-component; Wireless Multimedia Sensor Network, Cross Layer, QoS.

## I. INTRODUCTION

In recent years, the productions of cheap devices in wireless sensors and wireless visual sensors have led to using these devices and to raising many research problems in WMSN [1]. Due to inherent characteristics of multimedia streaming, it requires high bandwidth and low end-to-end delay. Therefore, many investigations have been performed to address these requirements by manipulating different parameters and optimizing different protocols at each layer of protocol stack individually or jointly [2, 3, 4].

Akyildiz and et al. 2007 in [1] believe that the design of a simple encoder and a complex or simple decoder which keeps performance and quality in usual compression methods is desirable.

QoS requirements are more challenging issues in WMSN for delivering the best quality of video stream to the end user because of low bandwidth in WMSN and burst data. WSNs have low amount of data to transmit in network such as humidity, temperature, pressure, etc. In this network the main data are scalar data and control bits. The comparison of amount of data in WSNs and WMSNs indicates that traditional solutions for WSNs are not sufficient for WMSNs.

Some researchers proposed different methods to use cross-layer information for better delivery of quality of service in visual sensor networks [3, 5]. These methods use a set of QoS-parameters of different layers to derive an optimize solution. The cross-layer methods allow manipulating parameters and changes in behavior of algorithms in each layer

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for low bandwidth and burst data environment to achieve better and better quality of service.

The manipulations can happen in one or several layers. The considering of multiple layers can allow deeply looking inside limitations, bad effects and incorrect configuration in that layer based on characteristics of the environment. One of these approaches is Multi-Path Selection (MPS) to select optimal paths for video streaming. In terms of MPS, there is an extension known as Context-Aware Multipath Selection (CAMS) in [5].

There are three requirements for a better quality of service delivery in WMSN: First, multipath transmission (for increasing transmission performance because of the large size of the multimedia packet), second, hole by-passing (ignoring dead and already used sensors) and the third, shortest path transmission (For having minimum end-to-end delay) [6]. In related work section, we can see that the most of the works suffer from lack of at least one of these requirements. Our proposed method uses a routing algorithm called Two-Phase geographic Greedy Forwarding (TPGF) algorithm. The algorithm can deal with above requirements [6]. The algorithm finds all disjoint paths from the source to the sink, so we do not have any congestion in networks that use TPGF. This routing algorithm in comparison with other multipath algorithms that use face routing has more average numbers of paths and less average number of hops (less delay).

In this paper, we propose a QoS-Aware Multi-Path Selection (QAMPS) method. It has two main contributions compared to most similar work that known as CAMS [5]. We cope with the shortcoming of CAMS by proposing our QAMPS method. Firstly, CAMS supports two levels of QoS for audio stream and video stream without considering the video stream content. As we know, I-frames, P-frames and B-frames are not in the same importance in a video stream. We take into account this information to propose a new content-aware routing. Secondly, in CAMS, BER of various network paths are the same, which is not the case in reality.

Our QAMPS uses cross-layer information from the application layer and the physical layer in the network layer. It splits video stream to I-frames, P-frames and B-frames that each one sends to the destination separately by respective priority from source to sink. The basic idea is to send important frames through more reliable and less delay path. For each type of frame, number of required paths is estimated by required bit rate of frames and sending bit rate of the sensors. The paths are selected by estimating of error bit rate and delay of each path. The method can be used in event based applications such as detecting and illustrating fire in a forest.

The rest of the paper is organized as follows: Section II presents an overview of the related works in terms of wireless multimedia sensor networks, QoS,

multi-path routing, our basic routing algorithm TPGF and cross-layer information in WMSNs. Section III illustrates the proposed method that contains: the network model and error bit rate model of our approach. Section IV shows the simulation results and section V concludes the paper and presents the future works.

## II. RELATED WORK

Multimedia streaming is very challengeable in WMSNs. In visual sensor networks some surveys have been presented on characteristics and services that support in each layer of WMSN. Also, in general surveys on WMSN several researchers have been referenced in the topic of QoS, routing and cross-layer protocol design [1, 2, 8]. Regarding to research topic, we concentrate on the most important ones.

C. Wen-Yu and Y. Hai-Bo in [7] proposed a hierarchical QoS framework by using a hybrid scheme that combines Adaptive FEC and ARQ-SR. This scheme distinguishes packet loss by error-prone wireless link or network congestion. If wireless link is bad, the sender generates more redundant FEC packets for reliability. Otherwise, it generates fewer FEC packets. When packet loss is caused by congestion, the sender reduces the transmission rate. Information about statistics of the network status is obtained by RTP and RTCP packets. It is good but it has not employed in WMSN yet. We considered it to investigate packet loss and bit error problems and solutions.

A multi-priority multi-queue model for differentiate service in WMSN has been proposed in [4]. The model is based on Priority based Congestion Control Protocol (PCCP) that assigns a priority to each sensor node. The article classifies traffic to four classes. Each node assigns a priority to each packet for identifying class of packet. Then queuing of packets is done by two mechanisms: Priority Queuing (PQ) and Weighted Round-Robin (WRR). PQ has better delay performance than WRR in real time traffic (about zero) but the throughput of both mechanisms is the same and good. If traffic load is high and one node is between several paths for transmitting traffic, it drops packets because of congestion.

Hamid and et al. 2008 in [9] designed a QoS-aware routing mechanism for WMSN. In this article, the goal is to use a multi-path multi-channel routing algorithm. Routing decision is according to dynamic adjustment of the required bandwidth and path-length-based proportional delay differentiation for real time data. They introduced a mechanism that supports high data rate while keeping delay reachable, since packets can be delivered to target with their bandwidth and delay requirements. Also a queue scheduler classifies packets that arrive at each node. It has compared results with multi-r and single-r that are two mechanisms for bandwidth adjustment. The results in average delay, throughput and life time for buffer size, packet lost, real time and none real time are better than multi-r and single-r. In this mechanism, impact of real



TABLE 1. COMPARISON TABLE OF SOME VARIOUS METHOD IN RELATED WORK

	Framework	Working Layers	Pros	Cons	Method Approach
[2]	Hierarchical, Heterogeneous, doesn't belong to cross-layer protocol	Data Link, Transport and Network	Extensibility, adaptability to dynamic and heterogeneous network	Not yet employed in WMSN	Distinguish packet loss caused by error prone or congestion using TCP-friendly rate control and combining FEC and ARQ-SR.
[9]	Multi-channel multi-path, distributed, Homogeneous, flat, fixed	Network	Throughput of none-real time data is maximized, ensure QoS requirements of real time data	Impact of real time data generation rate on average delay per none-real time data is not attractive	Dynamic bandwidth adjustment and PPDD calculation, packet scheduling
[10]	Multi-priority multi-path, homogeneous, fixed	Transport, Network	Choose maximum number of all found paths, maximum throughput of streaming data	Dividing data stream is related to number of paths and streaming data rate, synchronization of audio and image is not specified	Splitting data stream to audio and image, and uses maximum number of paths for transmission them by applying priority to specify urgent data.
[11]	Multimedia-aware Multi-path multi-speed,	Application, MAC and Network	Network capacity unsaturated, better PSNR	Average delay increased, in high traffic not better performance than basic MMSPEED	Sending P and I-frames from marginal and near optimum paths respectively, load balancing based on network-wide speed
[13]	Cross-layer, 4G heterogeneous environment	Transport, Internet, Network access layer	Good average delay, jitter, packet loss ratio	Low throughput, it seems has high power consumption	Uses QoS engine that contain some components to classify packets and monitor status when a cross-layer algorithm monitor and control them.
[4]	Heterogeneous, Multi-priority Multi-queue	Application, Network	High priority data have zero queuing delay with PQ model and maximum throughput, changing traffic load in PO model not effect in throughput	If network have high traffic one node that is between several path for transmitting real time data than it drops packets	Each node classifies packets in queues and splits real and non-real time data
[5]	Multi-path, context-aware	Transport, Network	High throughput and utilization	It not considered a error model for network and content of image stream	Split audio and image from video stream and choose best path respect to delay for important stream

time data generation rate on average delay per non real time data is not attractive.

In wireless sensor networks, the transport layer of traditional protocol stack is not fully developed. But Zhang and et al. 2008 in [10] described multi-path multi-priority selection for video streaming in transport layer of WMSN. TPGF (Two-Phase geographic Greedy Forwarding) is used in this method. The mechanism is based on multi path selection that explores maximum number of paths while uses minimum path length and end-to-end delay and limiting energy is as well considered. The Multi-

path Multi-priority Selection (MPMPS) scheme in transport layer chooses the maximum number of paths from all found node-disjoint paths for maximizing throughput and minimizing end-to-end delay by splitting video stream to image stream and audio stream. Each stream finds its paths with relative priority and transmits over the network. The bit error rate and real environment of WMSN is not considered.



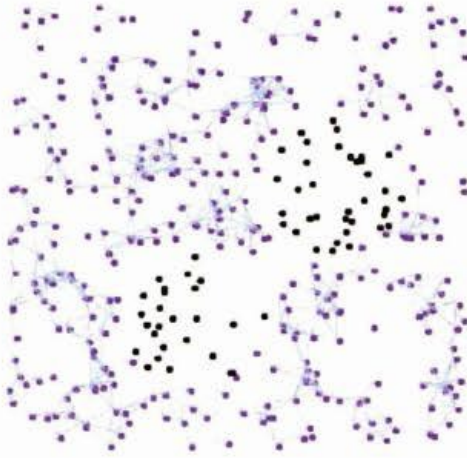


Figure 1. Static holes in wireless sensor network

As our basic algorithm is TPGF, we explain the algorithm in this section. The Two Phase Greedy Forwarding (TPGF) routing algorithm is our basic routing algorithm that has two phases: first phase is to explore possible routing paths by being repeatedly executed to find multiple disjoint routing paths. Second phase is to optimize the found path with the least number of hops. The first phase has two steps. First step is finding node, base station and neighbor's locations. The second step is choose closest neighbor to base station. For explaining of steps and phases, we explain some basic terms.

TPGF is a geographic greedy forwarding routing algorithm that does not use face routing [16] like Greedy Perimeter Stateless Routing (GPSR) [17] that uses planarization algorithm like Gabriel Graph (GG) and Related Neighborhood Graph (RNG). The planarization algorithms suffer from local minimum problem. This problem is a situation that a node does not have the next hop that is closer to the base station than itself.

TPGF has some good advantages. TPGF does not use face routing supports multipath transmission, hole-bypassing and the shortest path transmission. The drawback is that a sensor unable to use by more than one transmission path simultaneously. From another view, this drawback is an advantage, because this feature avoid network from congestion.

The hole in WMSN includes two types: Dynamic hole and Static hole (Fig. 1). The dynamic hole is a set of sensors that are currently used for sending data and the static hole is a set of sensors that are dead. In terms of hole-bypassing, there are two classes. The first one is hole-bypassing without knowing the holes information that uses planarization algorithm in advance. The other one is hole-bypassing with identifying the holes or boundary nodes information in advance. In the first class some research work like GPSR [17], GOAFR [18] and GPVFR [19] use face routing that is not suitable for WMSNs. The second class uses graph theory. In TPGF hole-bypassing is done in the first phase (greedy forwarding) and uses the second class hole-bypassing.

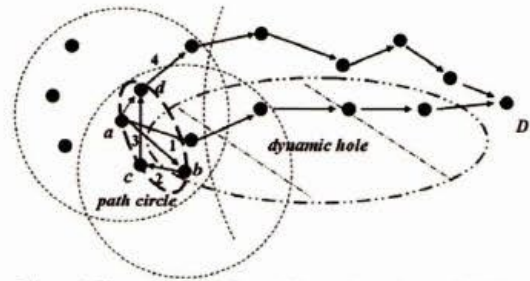


Figure 2. The path circle formed by nodes a, b, c and d [6].

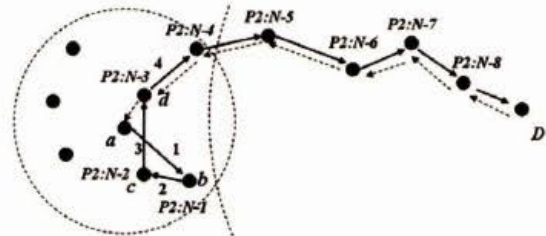


Figure 3. The dash line shows the reverse travelling in the found path [6]

In greedy forwarding, when a node forwards the packet, it chooses a neighbor that is geometrically closest to the destination. Whenever forwarding the operation reaches a void area, most of the routing algorithms such as GPSR run face routing. Face routing (perimeter mode) uses right-hand rule to pass a void. It marks the packet with a node that enters the perimeter mode until it finds a node that is close to destination than the node that enter the perimeter mode [20].

Because the wireless environment is none-planar, a mechanism is needed for creating a planar graph for wireless networks. Planarization algorithms are for this purpose. Planarization is based on unit graph assumption which means that an edge always exists between two nodes if and only if the Euclidean distance between them is less than the radio range. It includes obstacles and location inaccuracy. Planarization can create a planar graph from non-planar physical topology by selecting a subset of the links [16]. We note that each sensor knows location of itself and sink by GPS.

TPGF uses step back and mark approach for block situation when a node has no neighbor available for transmission expect the previous hop. Then the node marks itself as a block node and steps back to the previous node.

The second phase of TPGF is path optimization. To introduce it first consider a problem called path circle (Fig. 2). Path circle occurs when two or more sensors in the path are neighbors of another sensor in the path and is eliminated by a mechanism called label based optimization. It assigns a label to each node with a path number and a digressive node number.

When the sink sends acknowledgment to source each node, it sends it to 1-hop neighbor node with the same path number and largest node number (see Fig. 3). Then a release command is sent to nodes labeled in the previous step but it is not used for transmission. Although, CAMS [5] uses TPGF algorithm for routing multimedia, but it does not suitable in all situations for



splitting audio and video in equal parts, because TPGF algorithm is used without considering in bit error rate and quality of video.

S. Darabi and et al. in [11] proposed a solution for routing in WMSN. The article used Multi-path Multi-SPEED Protocol (MMSPEED) and improved it. MMSPEED is involved with the network and MAC layers. It supports QoS-provisioning in timeliness and reliability. Packets are classified into layers based on delay requirements. Nodes estimate distance and link delay of neighbors. Depending on these parameters each sensor assigns a speed value to neighbors. The proposed method finds paths that satisfy required QoS and then sends I-frames to the sink by optimum paths and sends P-frames by near optimum paths. Some notes for MMSPEED is consuming more energy for route computation, longer frame overhead and redundant long paths that cause reduced lifetime. This approach has more average delay and in high traffic and more data flow is the same as MMSPEED.

A. R. Lari and B. Akbari in [12] used a MPEG-4 video encoder for its multi path routing mechanism that is called Ad-hoc On-demand Multipath Distance Vector (AOMDV). To better schedule, path priority scheduling balances energy and bandwidth consumption. If packets priorities are the same round-robin scheduling and for real time application weighted round-robin is used. Control packets for monitoring path condition are used and paths that have better condition get higher scores and scores change over time. Coded stream is partitioned to multi stream and each stream is assigned to a path according to the packet content and path status. If the required bandwidth is not provided, the sender drops packets by order of B frames, P frames and I-frames. Additionally, I-frame loss in congestion situation is very high in this method and causes degrading in quality of video.

N. Saxena and A. Roy, J. Shin in [3] proposed a cross-layer algorithm for QoS enhancement in WMSN. They believe that most of papers about QoS enhancement suffer from two constraints. First, only a single parameter for QoS is considered. Second, Multiple parameters is combined to a single scalar parameter. It provided MAC and network layer for sending data. While the goal of the network layer is to obtain optimal QoS routing, MAC layer uses this information for packet classification and delivery by adjusting the contention window. There is no parameters combining for getting a single parameter but authors tackle the problem from the perspective of multi-objective optimization. It used Weibullian distribution to model long range dependency among data. It simulated the proposed model with low quality of data and compares it with the exiting SPEED and cluster-QoS based protocols.

The cross-layer design is used in all networking technologies. For example, Jiann-Liang et al. proposed a mechanism using cross-layer information from transport, internet and network access layer for better throughput, jitter, and packet loss ratio in 4G

heterogeneous environments [13]. The authors use a QoS engine that contains some components to classify packets and monitor status when a cross-layer algorithm monitors and controls them. It has low throughput and seems high power consumption but has good average delay and jitter.

The Context-Aware Multipath Selection (CAMS) is an algorithm that splits images and audio of a video for better throughput in WMSN [5]. This algorithm uses TPGF algorithm to find all node disjoint path from source to sink. It uses information value that depends on transmission capacity, satisfied paths and importance value to show better throughput of the algorithm by maximizing it. The information value is calculated by assigning an importance value to important stream and multiplication of it by transmission capacity and the number of found paths. In fact, the proposed method uses application and transport layers for routing the image and audio streams. It does not consider error bit rate of each path. It uses only delay constraint for the application.

Last but not least, as our cross-layer method is based on TPGF routing algorithm, we can see that in related works TPGF algorithm is used without considering in bit error rate and quality of video. Our proposed method considered bit error rate, delay and quality of video like a real environment. Although, the authors in [14] and [15] research on some aspects of TPGF, but they focus only on duty-cycling and security of algorithm, respectively. We can see a comparison of various methods that are analyzed in Table 1.

### III. THE PROPOSED METHOD

In this section, we introduce the network model and the proposed method that is called QoS-Aware Multi-Path Selection (QAMPS). The WMSN in QAMPS is an event-based detection network like a fire alarm in a forest. When the sensor senses a temperature that reaches a threshold, then the sensor senses the environment by capturing the video. The sensor node first finds all node disjoint paths to the sink by the TPGF algorithm, and then calculates error bit rate and the delay of each path. Finally, the best paths based on the required number of paths are selected for sending I, P and B-frames separately.

#### A. The Network Model

The network model for our WSN can be represented by graph  $G(V, E)$  where  $V = \{v_1, v_2, \dots, v_n\}$  is the set of numbers of sensor nodes and  $E = \{e_1, e_2, \dots, e_n\}$  is the set of links between the sensor nodes. Both sets are finite. In this model we have different types of nodes and links in the WSN. Each sensor node can be in one of the three statuses: functional and reachable, functional but unreachable and dead status. We define unreachable node as a sensor that is functional but it has been already used to stream data for a path. These nodes form a dynamic hole where  $V_{Dynamic\_Hole} = \{V_{DH1}, V_{DH2}, \dots, V_{DHn}\}$  and dead sensors form static hole where  $V_{Static\_Hole} = \{V_{SH1}, V_{SH2}, \dots, V_{SHn}\}$ .



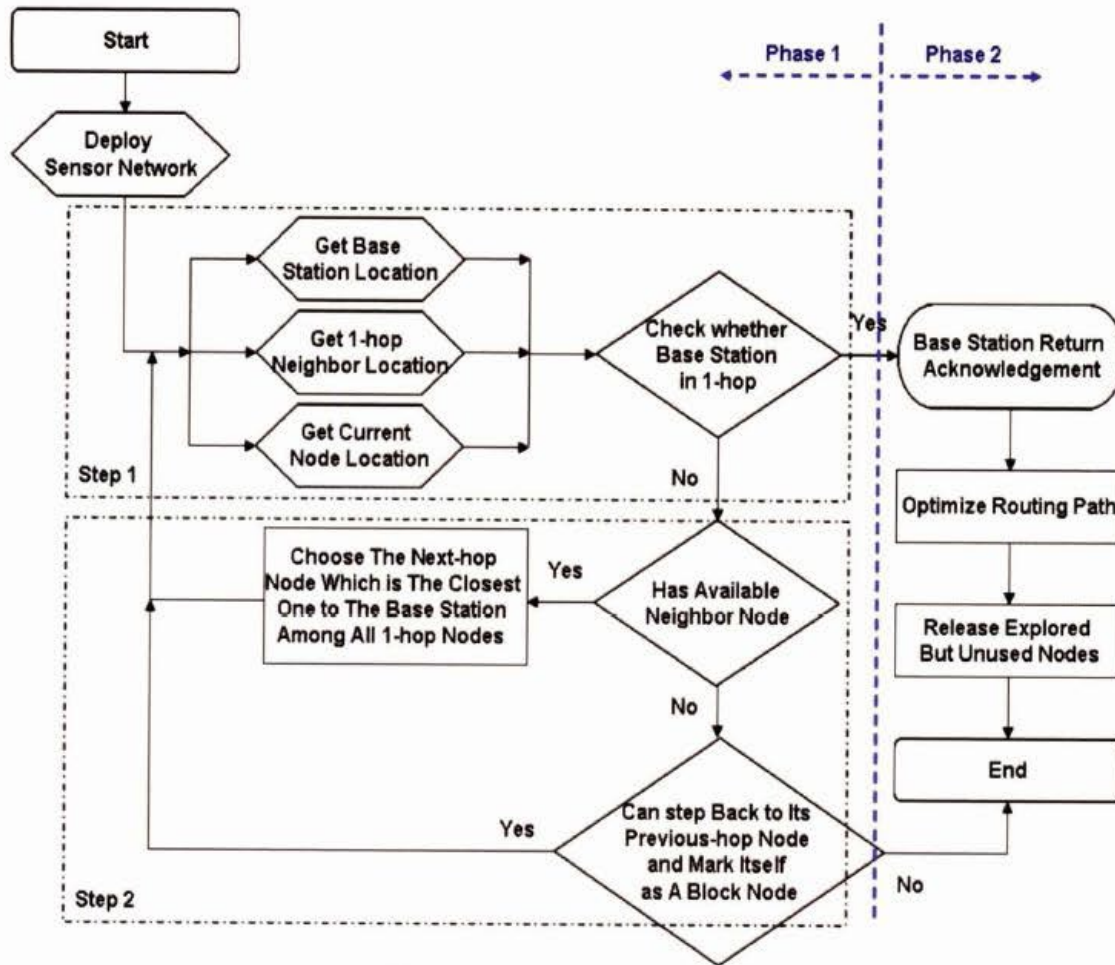


Figure 4. Flowchart of TPGF algorithm [6]

So, functional and attainable nodes can be presented as  $V_{Attainable} = V - V_{Dynamic\_Hole} - V_{Static\_Hole}$ . Each link in the network can be attainable or unattainable. We define unattainable links as a link that is used by the sensors which are selected by the previous finding paths. Also, the attainable link means a link between two sensors that are unused. Unattainable links can be presented by  $E_{Hole} = \{e_{H1}, e_{H2}, \dots, e_{Hn}\}$  and  $E_{Attainable} = E - E_{Hole}$ .

A video source node  $S_V$  can generate video stream with rate  $R_V$  Kbps where  $S_V = S_I + S_P + S_B$  and  $R_V = R_I + R_P + R_B$ . Also,  $S_I$ ,  $S_P$  and  $S_B$  are frame streams and  $R_I$ ,  $R_P$  and  $R_B$  are frame bit rates for I, P and B-frames, respectively. We have a transmission capacity for each node denoted by  $TC$ . The number of required paths for sending I, P and B-frames can be computed by  $N_I = \lceil \frac{R_I}{TC} \rceil$ ,  $N_P = \lceil \frac{R_P}{TC} \rceil$  and  $N_B = \lceil \frac{R_B}{TC} \rceil$  respectively where  $R$  is the generation rate of I, P and B frames. Each frame has a soft real time deadline.  $T_I$ ,  $T_P$  and  $T_B$  can be represented as soft deadlines for I, P and B-frames respectively. The TPGF routing algorithm finds  $N$  number of paths from source to sink. The flowchart of TPGF routing algorithm is shown in Fig. 4.  $M$  is the total number of paths that can satisfy delay constraint where,  $M = M_I + M_P + M_B$ . Our model defines two constraints for streaming video. One of the constraints is error bit rates and the other is end-to-end delays that differ for each type of

frames.  $M_I$  is the number of paths that is shown by  $P_{Satisfy\_Iframe} = \{P_{SI1}, P_{SI2}, \dots, P_{SIM_I}\}$  with error bit rate of  $ER_{Satisfy\_Iframe} = \{er_{SI1}, er_{SI2}, \dots, er_{SIM_I}\}$  and delay  $DL_{Satisfy\_Iframe} = \{dl_{SI1}, dl_{SI2}, \dots, dl_{SIM_I}\}$  that satisfy  $T_I$ .  $M_P$  and  $M_B$  are number of paths  $P_{Satisfy\_Pframe} = \{P_{SP1}, P_{SP2}, \dots, P_{SPM_P}\}$  and  $P_{Satisfy\_Bframe} = \{P_{SB1}, P_{SB2}, \dots, P_{SBM_B}\}$  with error bit rate  $ER_{Satisfy\_Pframe} = \{er_{SP1}, er_{SP2}, \dots, er_{SPM_P}\}$  and  $ER_{Satisfy\_Bframe} = \{er_{SB1}, er_{SB2}, \dots, er_{SBM_B}\}$  for  $DL_{Satisfy\_Pframe} = \{dl_{SP1}, dl_{SP2}, \dots, dl_{SPM_P}\}$  and  $DL_{Satisfy\_Bframe} = \{dl_{SB1}, dl_{SB2}, \dots, dl_{SBM_B}\}$  that can satisfy  $T_P$  and  $T_B$  respectively.

The final path is selected from  $P_{Satisfy}$  of each frame that can be represented as  $P_{Final\_Path_I}$  for I-frames,  $P_{Final\_Path_P}$  for P-frames and  $P_{Final\_Path_B}$  for B-frames.

**B. The Bit Error Rate Model**

In our proposed model that is used for outdoor usage in WMSN, some errors can be produced in the environment because of inherent characteristics of wireless networks. The evaluations of geographic routing protocols have commonly assumed an ideal network connectivity graph based on the unit-graph assumption (a pair of nodes is connected if and only if the distance between them is below a certain



threshold) like the CAMS scheme [5]. The unit-graph assumption is valid under some ideal conditions such as the availability of accurate location information, the nonexistence of obstacles, and an ideal spherical wireless radio range. In reality these conditions are violated: obstacles do exist, experimental studies have shown that wireless channels have irregular shape and location measurements (in systems that either rely entirely on GPS, or infer location using ad-hoc localization systems) are often noisy and incur some error [20].

Our aim here is to find total average error of a path to select the best path for the highest priority video stream.

The distance and environment noise are the basic reasons of errors in wireless networks. Some found paths by routing algorithm can go from more noisy environments and more distances between source node and sink. The simplest method of relating the received signal power to the distance is to state that the received signal power  $P_r$  is proportional to the distance between transmitter and receiver  $d$ , raised to a certain exponent, which is referred to as the distance power gradient; that is,

$$P_r = \frac{P_s}{d^\alpha} \tag{1}$$

,where  $P_s$  is the received power 1 m from the transmitter and  $\alpha$  is 2 for free-space path [21]. For each path,  $P_i$ , we have distance between each sensor node that  $D_{Pi} = \{d_{Pi1}, d_{Pi2}, \dots, d_{Pin}\}$ . The distance is an important parameter for attenuation of a signal. Errors resulted by attenuation can be estimated between each two nodes from the source to the sink and finally we calculate average error of the whole path.

We use IEEE 802.15.4 ZigBee in the physical layer at 868 MHz that uses binary phase shift keying (BPSK) modulation and our model for noisy channel is the additive white Gaussian noise (AWGN) channel. AWGN channel serves as an important reference on the performance evaluation of communication systems [22], [23], [24], [25]. The 802.15.4 ZigBee like 802.11b version of Wi-Fi uses error detection and repeat transmission for reliable communication, but no error correction [26]. Our network does not use retransmission, because of real time specification of our application. So bit error rate,  $P_B$ , can be expressed as [27]:

$$P_B = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{2}$$

, where  $\frac{E_b}{N_o}$  is average energy per information bit to the noise power spectral density at the receiver input and  $Q(x)$  is

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty \exp\left(-\frac{u^2}{2}\right) du \tag{3}$$

, where  $x$  and  $u$  are random variables and  $Q(x)$  is probability that a Gaussian random variable  $X$  with

mean zero and variance one is bigger than  $x$  [31]. So, for each path,  $P_i$ , we can get bit error rate  $ER_{pi}$  by [28]

$$ER_{pi} = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_{oi}}}\right) \tag{4}$$

,where  $\operatorname{erfc}(x)$  is the complementary error function.

This procedure is calculated by Gaussian function in our simulator.

The total frame loss contains frames that are lost and dropped. This parameter calculates separately for each frame stream. The frame lost number for I-frame is equal for drop number of frames, but frame lost number for P-frames and B-frames is depend on the I-frame loss ratio.

### C. QoS-Aware Multi-Path Selection (QAMPS)

Our QAMPS has four stages: 1- Finding disjoint paths from source to sink. 2- Delay estimation for each found path. 3- Error estimation for each found path. 4- Path selection for video stream. We mention that all stages are run in the source node. After finding all disjoint paths by TPGF, in phase one, delay of each path  $P_i$  is estimated by  $D_{Pi} = H \times D_{hop}$ , where  $H$  is the number of hops from source to sink and  $D_{hop}$  is delay of each hop [5]. So, we have  $DL_{Pi} = \{dl_{p1}, dl_{p2}, \dots, dl_{pn}\}$  that contains estimated delay of all found node disjoint paths. The best estimated delay is total of propagation delay, transmission delay and delay caused by congestion. As we mentioned in subsection A, each sensor node can be in one of the three statuses: functional and reachable, functional but unreachable and dead status. We define unreachable node as a sensor that is functional but it has been already used to stream data for a path. Since TPGF routing algorithm finds disjoint paths, we will not have any congestion. The involved sensors in transmission cannot be selected by other paths. Also, in our application more bandwidth is allocated to the sink for congestion avoidance in the sink. Therefore, we can assume a fix delay for each hop for simplicity.

The delay constraints for I-frame  $DL_{Pi}$  is defined as

$$DL_{Pi}(I) = \begin{cases} \infty & DL_{Pi} > T_I \\ DL_{Pi} & DL_{Pi} \leq T_I \end{cases} \tag{6}$$

, similarly for P-frames and B-frames, the  $DL_{Pi}$  are defined as

$$DL_{Pi}(P) = \begin{cases} \infty & DL_{Pi} > T_P \\ DL_{Pi} & DL_{Pi} \leq T_P \end{cases} \tag{7}$$

and

$$DL_{Pi}(B) = \begin{cases} \infty & DL_{Pi} > T_B \\ DL_{Pi} & DL_{Pi} \leq T_B \end{cases} \tag{8}$$

respectively.

The third stage is error estimation that bit error rate of each path is estimated and can be represented as



$ER_{pi} = \{ er_{p1}, er_{p2}, \dots, er_{pm} \}$ . These errors estimate based on error bit rate model that explained in this section in subsection C.

Finally, in the fourth stage, we first assign the paths with minimum delay for I-frames and among selected paths choose the paths with minimum BER. After assigning best paths for I-frames, these steps are repeated for P and B-frames.

If  $N$  is the number of all found node disjoint paths and  $M$  is the number of all satisfied paths then we can trivially show that  $M \leq N$ . For example, we have  $M_I$  number of paths for I-frames and  $N_I$  minimum number of required paths which are chosen from  $P_{Satisfy\_Iframe} = \{P_{SI1}, P_{SI2}, \dots, P_{SIM_I}\}$  and finally we reach to the final set of paths for I-frame stream is  $P_{Final\_path\_I} = \{P_{SI1}, P_{SI2}, \dots, P_{SIN_I}\}$ . So, the set of available paths is reduced to  $P_{new} = P - P_{Final\_path\_I}$ .

The P-frame is in the second importance level in the stream. The rest of the paths is selected by considering  $DL_{pi}(P)$  and  $ER_{pi}$  restriction on all paths except the paths that are used for sending I-frames. For P-frame same procedure just like I-frame path selection is done.  $P_{Final\_path\_P} = \{P_{SP1}, P_{SP2}, \dots, P_{SPN_P}\}$  is final number of paths for P-frame that number of it calculates by  $N_P$ .

For the least important frame in the stream, B frame, QAMPS selects best paths from remaining available paths that is  $P_{Final} = P_{new} - P_{Final\_path\_P}$ . Also, for B-frame same procedure just like I-frame and P-frame is done for rest of the available paths.

IV. SIMULATION RESULTS

We use the NS-2 simulator to compare our QAMPS algorithm with the CAMS algorithm. NS-2 is a discrete event simulator targeted at networking research. NS-2 provides substantial support for simulation of TCP, routing and multicast protocols over wired and wireless (local and satellite) networks [29]. Also, we integrate EvalVid [30] in NS-2 that is a framework and tool-set for evaluation of the quality of video transmitted over a real or simulated communication network. It is targeted for researchers who want to evaluate their network designs or setups in terms of user perceived video quality.

In our simulation, 400 sensor nodes are randomly placed in 400 X 400 m capable of capturing, encoding and sending live video to a sink node. The sensors maximum transmission radius is 50m and the sink maximum transmission radius is 100m. We use Micaz sensor nodes that work in the physical layer with 868 MHz frequency in 802.15.4/ZigBee protocol. The data rates of each sensor node and the sink are 20 Kbps and 250 Kbps respectively. The transmission power of each sensor node is 52.2 mW and their maximum life time is 6 hours. Moreover, we use video sequence Highway at QCIF resolution at a frame rate of 30 fps. Our sensors encoder is MPEG-4 and group of picture

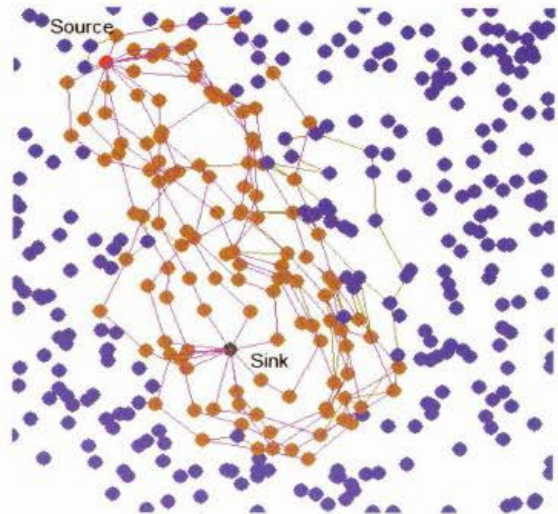


Figure 5. A sample view of simulation results that find 12 paths

TABLE 2.SENSOR NODES SIMULATION PARAMETERS

Simulation Parameters	Value
Bandwidth	20 Kbps
Transmission Radius	50 m
Maximum Lifetime	6 hours
Minimum Rate	20 Kbps

(GOP) size is 16. The Table 2 shows the parameters of sensor nodes.

In this paper, we compare the proposed method with CAMS method based on the frame loss ratio that is a well-known measurement for demonstrating better quality of video, because CAMS is the nearest method to our proposed method QAMPS. The possible paths for video transmission are found by TPGF. After that a bit error rate is assigned to each path between 0.000001 and 0.00001 randomly by Gaussian function that is mentioned in section III.

To compare our method with CMAS the average bit error rate is replaced by the average bit error rate for each frame stream in the QAMPS method. Estimating the bit error rate can be calculated by some techniques that we mentioned above, but BER in the formulations is an assumptive bit error rate between 0.000001 and 0.00001 in our simulations. Fig. 5 shows a sample view of one of our network where TPGF algorithm has found 12 paths from the source to the sink. The red sensor is the source and the green sensor is the sink. We run 20 times our method with 20 different seeds and the results are in average.





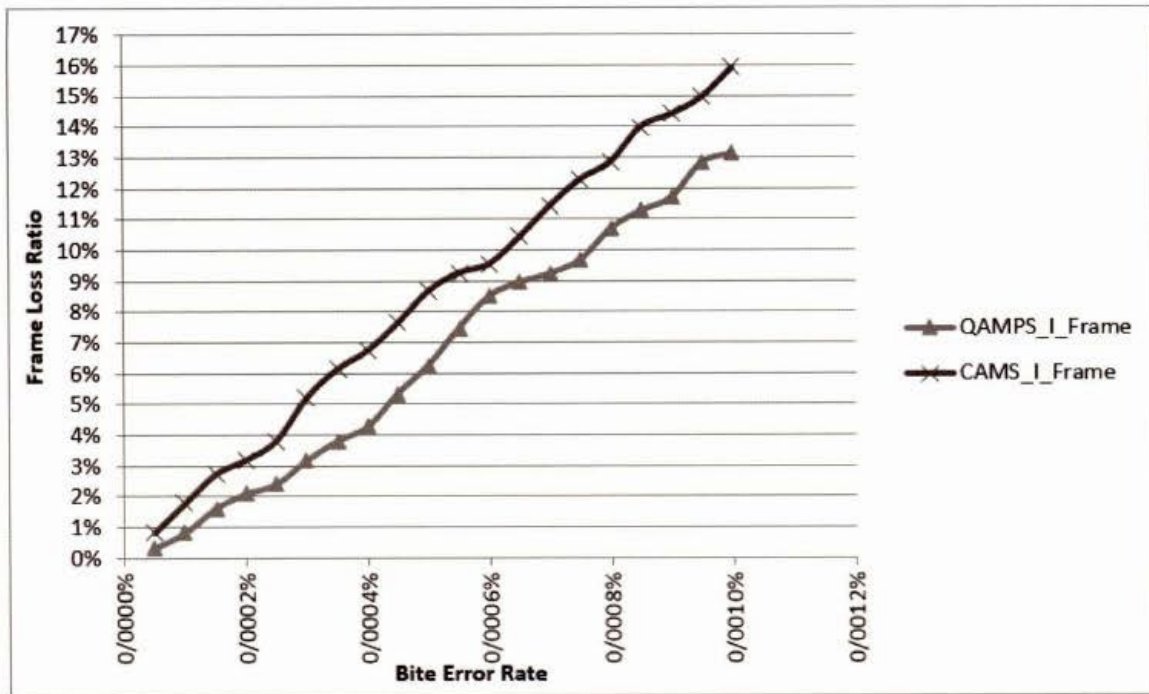


Figure 6. Loss rate of I-frames in QAMPS and CAMS against bit error rate

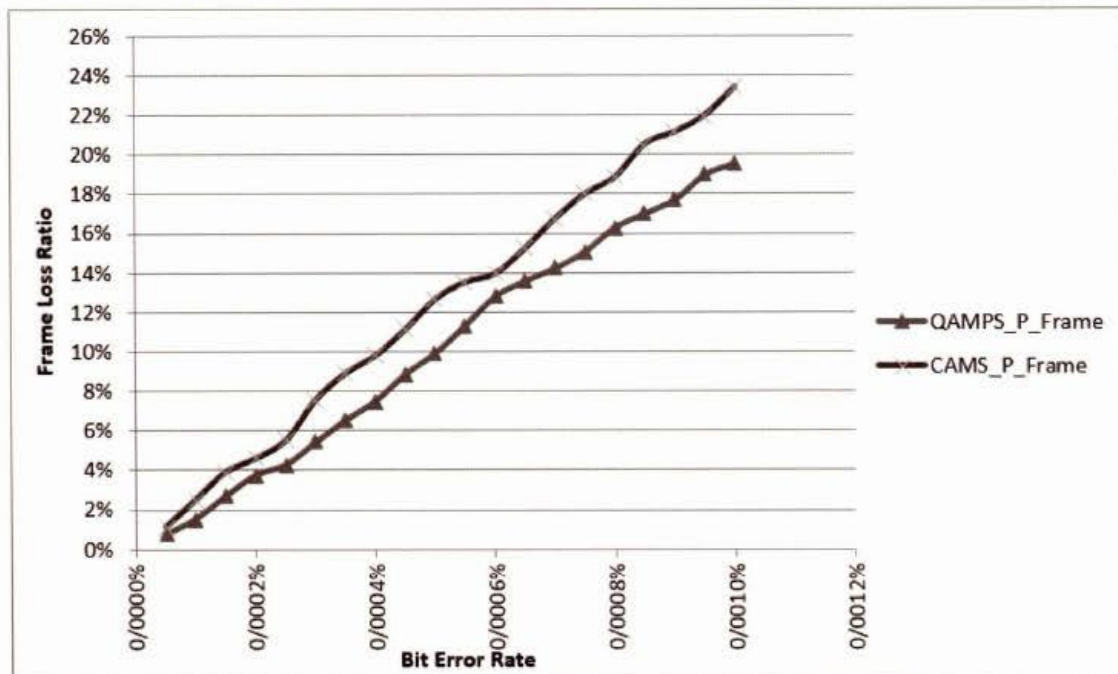


Figure 7. Loss rate of P-frames in QAMPS and CAMS against bit error rate

The time constraint in our method for getting real-time video and its comparability with the CAMS algorithm is 280 milliseconds. The difference is use delay tolerant constraints that can be used for video transmission. As the delay constraint is different in various real time applications (e.g. some application is 100 ms or another is 400 ms) and related to application usage, network topology and their environments, we assume the delay constraints for I-frames, P-frames B-frames are 280, 300 and 320 milliseconds, respectively. But the CAMS scheme only uses 280 milliseconds, because it uses all paths for sending all types of frames and the constraint cannot be more than 280 milliseconds.

These delays are estimated by an assumption from the CAMS algorithm that assumes 20 milliseconds delay for each hop in the network. In this paper, to better demonstrate the quality of video in our method, we use two measurements that are common for testing a stream of video. The first measurement is the frame loss ratio of the video stream. We compare our results with CAMS for each type of frames (I-frame, P-frame and B-frame) separately. The second measurement is PSNR (Peak Signal-to-Noise Ratio). For achieving the results, we ran 12000 times the algorithm for 100 different seeds for 12 different transmission radiuses on 10 different number of nodes separately and jointly.



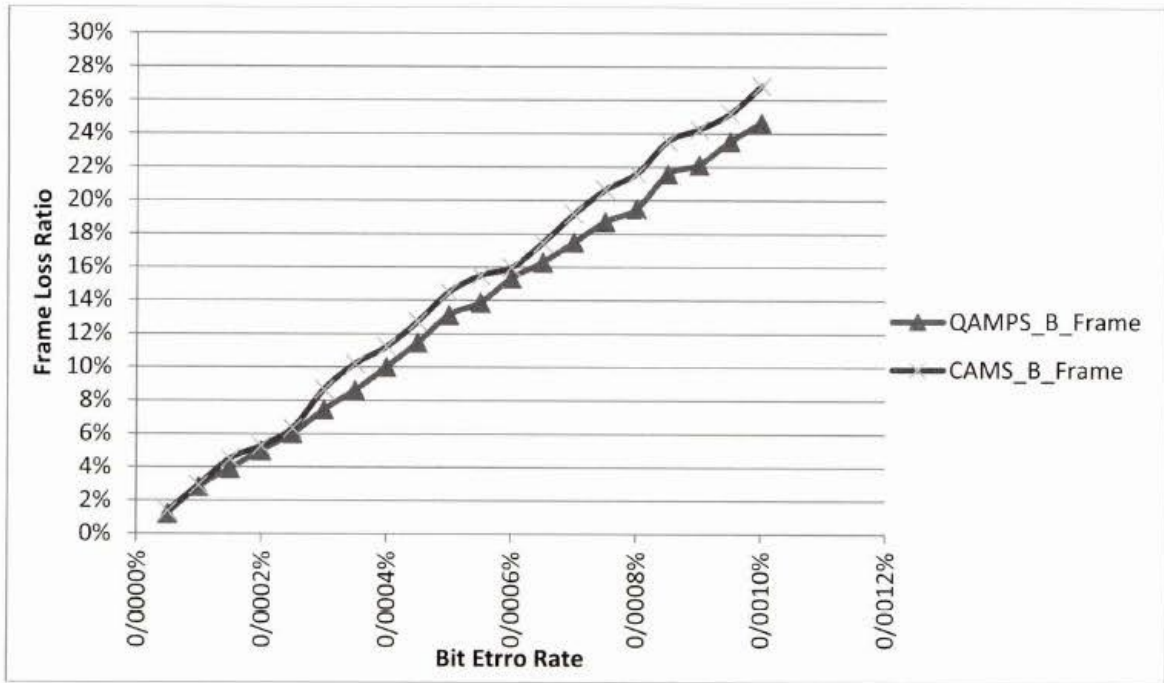


Figure 8. Loss rate of B-frames in QAMPS and CAMS against bit error rate

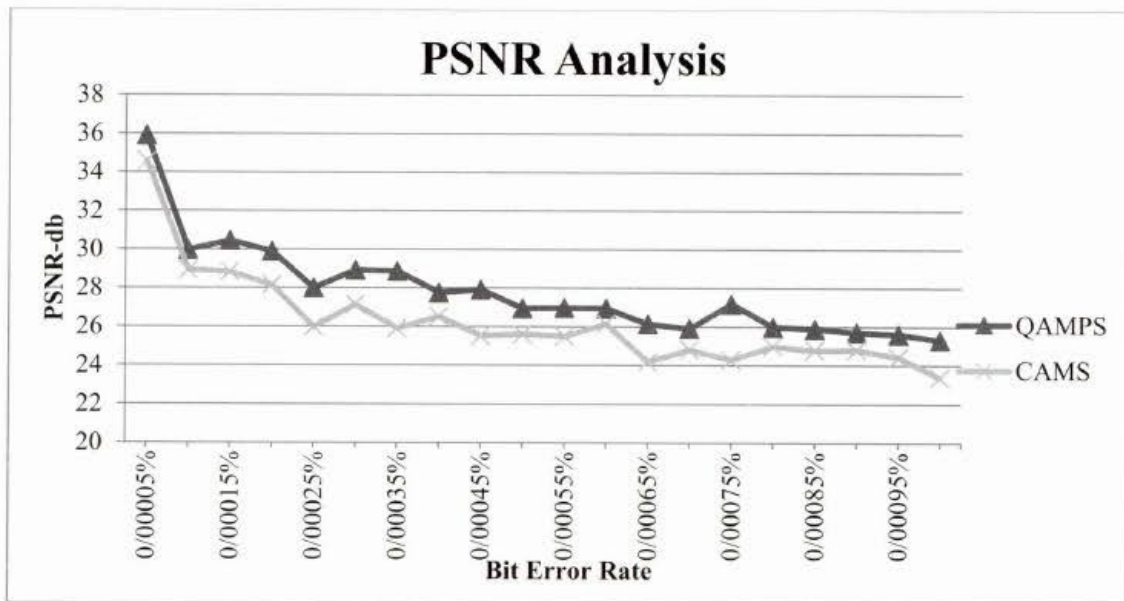


Figure 9. PSNR analysis of QAMPS method compare to CAMS method

In Figs. 5, 6 and 7 we can see the frame loss ratio for I, P and B-frames for QAMPS in comparison with the CAMS algorithm. As mentioned earlier, CAMS is not aware of the frame's type and sends GOPs instead of separate in multipath. The diagrams show that our proposed method has less frame loss ratio than the CAMS algorithm for all I, P and B-frames.

In best case for I-frames we have about 22.5 percent less frame loss ratio. Also, P-frames loss ratio in our method is in best case about 17 percent less than CAMS. But in best case, B-frames loss ratio has about 7.5 percent better than CAMS. Because the worst paths are for transmitting B-frames, it has not very interesting improvement. But the delay constraint and using of less bit error rate paths, makes our result better than CAMS. Fig. 9 shows the final results for PSNR analysis of QAMPS compared to CAMS. We can see that in the

best case the QAMPS method has about 3 db more PSNR than CAMS method.

V. CONCLUSION AND FUTURE WORKS

In this paper, we proposed a cross-layer approach for efficient video delivery based on TPGF routing algorithm that classified multimedia content based on I, P and B-frames which was called QAMPS.

The proposed method considers a time constraint for each frame stream based on the importance of the frame. The less important frames that are P-frames and B-frames have a tolerable time constraint than I-frames. This causes better quality of receiving video in the network. We simulated our proposed method with assigning an error bit rate to each channel to demonstrate it in comparison with CAMS algorithm that show less number of frame loss and frame loss



ratio. Also, we demonstrate our claim by PSNR that is a common measurement for video quality. We showed that our method has about 15% better PSNR than CAMS method.

The simulation results demonstrated that if the most important frames are sent from more reliable paths and we use tolerable delay constraints for less important frames, then we have more numbers of frames that are valuable for reconstructing the original video on the receiver side.

Finally, we list some important topics left for future work:

- Power consumption is a challenging issue in WSNs and WMSN. The proposed method especially in calculation phase for getting better paths and finding all node disjoint paths must be evaluated for consuming power.
- Fault tolerance can be a problem in the network for active nodes when a node finds its own paths for sending frames and middle sensors are dead after a moment time later.
- Error correction mechanisms can be used in the proposed method for getting better quality of service in this method. One solution is considering memory for sensors and using retransmission mechanisms from middle sensors to the sink in case of frame loss.
- Congestion control in the sensors that are close to the sink when multiple nodes send multimedia content to the sink if we assume that the sensors can be used by multiple paths.

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#### REFERENCES

- [1] I. F. Akyildiz, T. Melodia, and K. R. Chowdhury, "A survey on wireless multimedia sensor networks," *Comput. Netw.*, 2007, vol. 51, no. 4, pp. 921-960.
- [2] C. Wen-Yu, Y. Hai-Bo, "A hierarchical QoS framework for wireless multimedia network," *International Conference on Communications, Circuits and Systems*, May 2008, pp. 732-736.
- [3] N. Saxena, A. Roy, J. Shin, "Cross-layer algorithms for QoS enhancement in wireless multimedia sensor networks," *IEICE Trans. Communication*, August 2008, vol. E91-B, no. 8, pp. 2716-2720.
- [4] M.H. Yaghmaee, D. Adjeroh, "A Model for Differentiated Service Support in Wireless Multimedia Sensor Networks," *Proceedings of 17th International Conference on Computer Communications and Networks*, Aug. 2008, pp. 1-6.
- [5] L. Shu, Y. Zhang, Z. Yu, L. T. Yang, M. Hauswirth, N. Xiong, "Context-aware cross-layer optimized video streaming in wireless multimedia sensor network," *Springer Journal of Special issue on intelligent systems for future generation communications*, 2009, vol. 54, pp. 94-121.
- [6] L. Shu, Y. Zhang, L.T. Yang, Y. Wang, M. Hauswirth, N. Xiong, "TPGF: Geographic Routing in Wireless Multimedia Sensor Networks", *Springer Journal of Telecommunication System (TelecommunSyst)*, 2010, vol. 44, No. 1-2, pp. 79-95.
- [7] [7] S. Soro, W. Heinzelman, "A Survey of Visual Sensor Networks," *Advances in Multimedia*, 2009, vol. 2009, pp. 1-22.
- [8] A. Sharif, V. Potdar, E. Chang, "Wireless multimedia sensor network technology: A survey," *7<sup>th</sup> IEEE international conference on Industrial Informatics, INDIN 2009*, June 2009, Cardiff, Wales, pp. 606-613.
- [9] M. A. Hamid, M. M. Alam, ChoongSeon Hong, "Design of a QoS-Aware Routing Mechanism for Wireless Multimedia Sensor Networks," *Global Telecommunications Conference*, 2008. *IEEE GLOBECOM 2008*, pp. 1-6.
- [10] L. Zhang, M. Hauswirth, L. Shu, Z. Zhou, V. Reynolds, G. Han, "Multi-priority Multi-path Selection for Video Streaming in Wireless Multimedia Sensor Networks," *Lecture Notes In Computer Science; Vol. 5061 archive, Proceedings of the 5th international conference on Ubiquitous Intelligence and Computing*, Oslo, Norway, 2008, pp. 439 - 452.
- [11] S. Darabi, N. Yazdani, O. Fatemi, "Multimedia-aware MMSPEED: A routing solution for video transmission in WMSN," *2nd International Symposium on Advanced Networks and Telecommunication Systems*, 2008. *ANTSapos 2008*, vol. 15-17, pp. 1 - 3.
- [12] A. R. Lari, B. Akbari, "Network-Adaptive Multipath Video Delivery over Wireless Multimedia Sensor Networks Based on Packet and Path Priority Scheduling," *In International Conference on Broadband, Wireless Computing, Communication and Applications (BWCCA)*, Tehran, Iran, Nov. 2010, pp. 351-356.
- [13] C. Jiann-Liang, C. Ming-Chiao, L. Shih-Wei, J. Jyun-Yu, "Cross-layer QOS architecture for 4G heterogeneous network services," *11th International Conference on Advanced Communication Technology*, 2009, *ICACT 2009*, vol. 01, issue, 15-18, pp. 73 - 77.
- [14] L. Shu, Z. Yuan, T. Hara, L. Wang, Y. Zhang, "Impacts of duty-cycle on TPGF geographical multipath routing in wireless sensor networks," *In 18th International Workshop on Quality of Service (IWQoS)*, Beijing, China, June 2010, pp. 1-2.
- [15] T. Mulugeta, L. Shu, M. Hauswirth, Z. Zhou, S. Nishio, "Secured Geographic Forwarding in Wireless Multimedia Sensor Networks," *Journal of Information Processing*, 2012, vol. 20, no. 1, pp.54-64.
- [16] K. Seada, A. Helmy, R. Govindan, "Modeling and Analyzing the Correctness of Geographic Face Routing under Realistic Conditions", *Ad Hoc Networks Journal - Elsevier, Special issue on Recent Advances in Wireless Sensor Networks*, August 2007, vol. 5, issue 6, pp. 855-871.
- [17] B. Karp, H. T. Kung, "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks," *In Proceedings of the Sixth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom 2000)*, Boston, MA, August, 2000, pp. 243-254.
- [18] F. Kuhn, R. Wattenhofer, A. Zollinger, "Worst-case optimal and average-case efficient geometric ad-hoc routing," *In Proceedings of the 4th ACM international symposium on mobile ad hoc networking and computing (MobiHoc 2003)*, Annapolis, MD, USA, June, 2003.
- [19] B. Leong, S. Mitra, B. Liskov, "Path vector face routing: geographic routing with local face information," *In Proceedings of the 13th IEEE international conference on network protocols (ICNP 2005)*, Boston, Massachusetts, USA, November, 2005, pp. 6-9.
- [20] S. L. Wu, Y. C. Tseng, "Wireless Ad Hoc Networking in Personal-Area, Local-Area, and the Sensory-Area Networks," *Auerbach Publication*, 2007.
- [21] K. Pahlavan, A. Levesque, *Wireless Information Networks*, John Wiley and Sons, 2<sup>nd</sup> Ed. 2005, p. 96.
- [22] V. K. N. Lau, Y. K. R. Kwok, *Channel-Adaptive Technologies and Cross-Layer Designs for Wireless Systems with Multiple Antennas*, John Wiley & Sons, 2006, p. 4.
- [23] D. G. Yoon, S. Y. Shin, W. H. Kwon, H. S. Park, "Packet error rate analysis of IEEE 802.15.4 under IEEE 802.11b interference," *In proceeding 63<sup>rd</sup> IEEE conference on vehicular technology*, Melbourne, 2006, pp. 1186-1190.
- [24] L. Li, R. G. Maunder, B. M. Al-Hashimi, L. Hanzo, "An energy-efficient error correction scheme for IEEE 802.15.4



- wireless sensor networks," In proceeding IEEE transactions on circuits and systems II, March 2010, vol. 57, issue 3, pp. 233-237.
- [25] T. Wang, W. Heinzelman, A. Seyedi, "Minimization of Transceiver Energy Consumption in Wireless Sensor Networks with AWGN Channels," In proceeding 46<sup>th</sup> annual allerton conference on communication, control and computing, Urbana-Champaign, 2008, pp. 62-66.
- [26] R. Morrow, *Wireless Network Coexistence*, McGraw-Hill, 2004, p. 137.
- [27] B. Sklar, "Digital Communications," Prentice Hall, 1995.
- [28] H. Stern & S. Mahmoud, "Communications Systems," Pearson Prentice Hall, 2004, p283.
- [29] NS2. (2010) <http://www.isi.edu/nsnam/ns/> [accessed on: April 2010].
- [30] <http://www.tkn.tu-berlin.de/research/evalvid/> [accessed on: june 2010].
- [31] A. Goldsmith, "Wireless Communications," Cambridge University Press, Stanford University, 1st edition edition.



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