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Opportunistic Cooperative QoS Guarantee Protocol Based on GOP-length and Video Frame-diversity for Wireless Multimedia Sensor Networks

Yong Jin

School of Computer Science and Engineering
Changshu Institute of Technology
Changshu 215500, China
jinyong@cslg.cn

Ruigang Li

Changshu Museum
Changshu 215500, China
rgangli@163.com

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Abstract. *In wireless multimedia sensor networks, there are some problems, such as how to guarantee stability of multimedia sensors, how to maintain the reliable multimedia stream transmission, as well as how to establish the cooperative route of multimedia data with multimedia sensors. To address the above issues, we researched the characteristics of multimedia sensors based on throughput, packet error rate and average delay, building upon which we proposed the opportunistic cooperative QoS analysis model based on the threshold values such as the GOP length, UDP datagram size, relay sensor scale and video Frame density. Then the opportunistic cooperative QoS guarantee protocol based on GOP-length and Video Frame-diversity (OCQ-GF) was proposed. More importantly, the sender and relay sensors would do the QPSK modulation scheme with 12 frequency division to further improve the performance of the proposed OCQ-GF mechanism. The mathematical and simulation results show the proposed OCQ-GF could perform better in terms of throughput, packet error rate and average delay, as well as Peak Signal to Noise Ratio (PSNR), compared with the traditional cooperative QoS guarantee approach.*
Keywords: Wireless multimedia sensor networks, Real time performance, Quality of Service guarantee, Opportunistic cooperative control.

1. Introduction.

For sensing, storing, broadcasting, processing the real time multimedia data, the Wireless Multimedia Sensor Networks (WMSN) are widely used in environmental monitoring, traffic monitoring and industrial automation line etc. However, on the view of the constraints of computing and storing capacity of multimedia sensors [1, 2], e.g. dynamic wireless link, high redundancy of multimedia data stream, as well as low broadcasting reliability, it is difficult to provide the reliable and robust QoS (Quality of Service) provisioning for WMSN. Specially, the network performance was easily and seriously influenced by the dynamic topology of sensors [3] and longtime transmission of multimedia stream [4]. There is one core issue of real time data transmission over the WMSN, how to build and maintain the optimal reliable multimedia stream transmission. First, in article [5], a QoS routing model and ant-based multi-QoS routing metric were presented and researched for the WMSN. According to the theory of compressed sensing, S. Pudlewski,

et al [6] proposed the networked system design scheme for joint compression, rate control and error correction of video over resource-constrained embedded devices. Second, Kim Jin-Woo et.al [7] proposed one new multimedia streaming scheme for n-screen service in wireless USB networks. The secure MQ coder was presented by article [8] for efficient selective encryption of JPEG 2000 images, which only selective encrypts tiny and constant volume of data in JPEG 2000 coding regardless of image size. Third, Huang HP et.al [9] formulated a generalized QoS-aware routing model on the basis of multiple routing metrics and priorities of packets and presented one clustering-based routing algorithm. The spectrum-aware energy-efficient multimedia routing protocol with cluster was researched by Shah GA et.al [10] for cognitive radio sensor networks by overcoming the formidable limitations of energy and spectrum. Based on the enhanced parallel cat swarm optimization, a balanced power consumption algorithm was proposed by Lingping Kong et. al [11] for wireless sensor networks. A compact altricial bee colony optimization scheme was proposed by Thi-Kien Dao et. al [12] for controlling the topology of wireless sensor networks. The congestion control algorithm was proposed by Luo Cheng et. al [13] based on the traffic regulation in wireless sensor networks. In a word, because of the special physical and electrical properties of multimedia sensors and dynamic WMSN topology, it is difficult to meet the QoS requirements by the guarantee method with direct transmission or fixed cooperative transmission. Therefore, the study and research of opportunistic cooperative QoS guarantee scheme play an important role of multimedia stream communication in WMSN, which can establish the optimal opportunistic cooperation multimedia transmission scheme and provide the reliable and real time QoS provisioning.
The rest of the paper is organized as follows. Section 2 describes the performance analysis model and results of multimedia communication in WMSN. In Section 3, we design the opportunistic cooperative QoS guarantee protocol based on GOP length and video Frame density. Mathematics and simulation results are given in Section 4. Finally, we conclude the paper in Section 5.

2. **Performance analysis of multimedia communication.** In WMSN, multimedia stream would be transmitted with a long time transfer status, which could be defined as "G_L, F_d, U_L, M".G_L is the length of one GOP (Group of Pictures). Let F_d denote video Frame diversity factor. Let U_L denote the length of UDP datagram. M is the scale of relay sensor nodes. The values of the above parameters could be set up according to the Table I. On the basis of the above status definition and previous research achievements

Table 1. Settings of multimedia status parameters

Parameters	Value	Parameters	Value
G_L	1, 2, 3, 4, 12	F_d	0.2, 0.3, 0.5
U_L	[1, 8]KB	M	1, 2

[14] [15], the performance metrics for analyzing the QoS of WMSN are listed as follows.
(1) Average delay: the average delay of datagram transmission from the sender to the receiver.
(2) Throughput: Statistical size of the received data packets successfully at receiving sensor.
(3) Packet error rate: Ratio of the data packets size belonging to a video frame fail to be decoded to the total size received packets at the receiver.
The packet error rate P_U could be obtained by formula (1) and (2). Here, P_b is the bit error rate of multimedia sensor. S_i is the activity probability of relay sensors. Let E_t denote the factor of multimedia signal transmission consumption. d is the distance between

sending sensor and receiving sensor. Let γ denote the factor of error control. N_{max} is the maximum retransmission time of data packets.

$$\begin{cases} P_b = 1 - \left(0.5e^{g(G_L)\gamma}\right)^{U_L} \\ g(x) = \frac{1}{d}\sum_{i=1}^{M} S_i[(2M-1)E_t]x \end{cases} \tag{1}$$

$$P_U = 1 - (1 - p_b^{N_{\max}+1})^{F_d} \tag{2}$$

The analysis results of packet error rate with G_L F_d and U_L are shown as Figure 1, 2 and 3. The conclusions are as follows:
(1) The value of P_U is increasing with the enlargement of U_L when the value of M, F_d and G_L are constant.
(2) When U_L belongs to the interval [2, 6] KB, the larger M the smaller P_U.
(3) When U_L is smaller than 2 KB or larger than 6 KB, the smaller M the smaller P_U.
(4) The smaller G_L the smaller P_U.
(5) The smaller F_d the smaller P_U.
So, we should select the optimal value of WMSN parameters for decreasing the packet error rate.

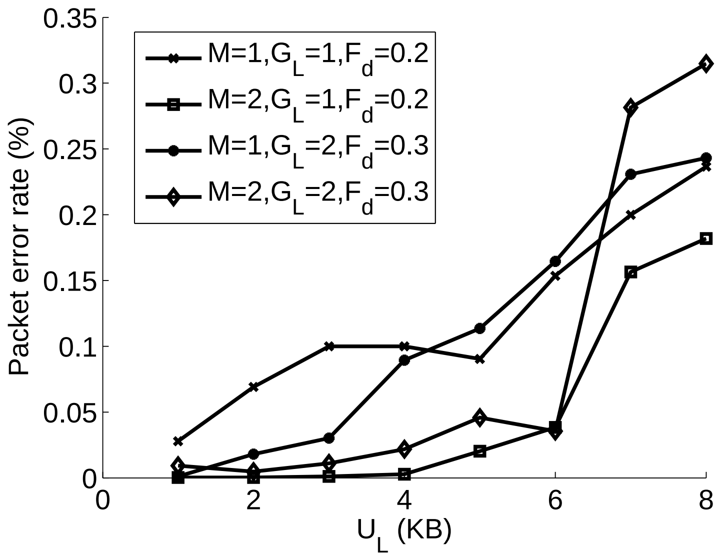

FIGURE 1. P_U with G_L

We can calculate the average delay T_{avg} according to formula (3).

$$T_{avg} = MT(\frac{U_L}{G_L})\frac{\left(1 - P_b^{N_{\max}+1}\right)^{F_d}}{1 - P_b}T \tag{3}$$

Here, T is the average transmission delay of single datagram. The analysis results of average delay with G_L, U_L and F_d are shown as Figure 4, 5 and 6. The conclusions are as follows:
(1) The larger the scale of relay sensors the longer the average delay with the increasing of G_L, F_d and U_L.
(2) As shown in Figure 5, the delay would be significantly increased when M is constant and U_L and F_d are increasing at the same time.

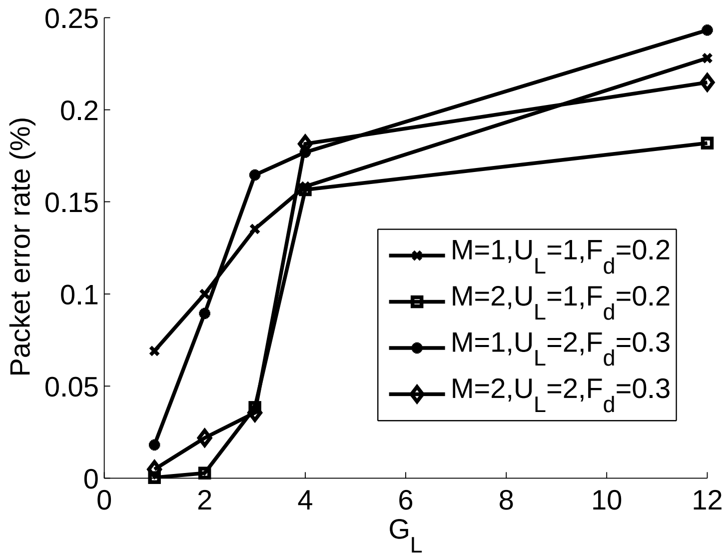

FIGURE 2. P_U with U_L

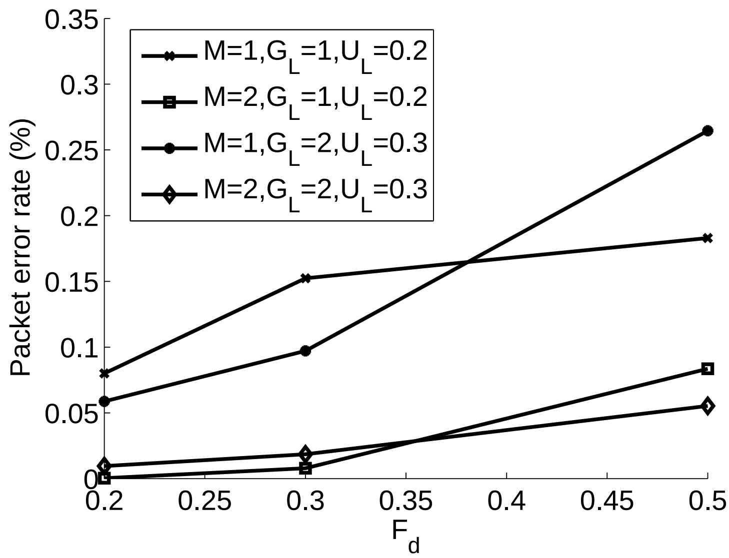

FIGURE 3. P_U with F_d

(3) As shown in Figure 4, the average delay could be reduced by decreasing the value of M, G_L and F_d when U_L is larger than 1KB and smaller than 9KB.
(4) The average delay could be reduced by decreasing the value of M, F_d and U_L when G_L is smaller than 12.

According to formula (4), we could obtain the throughput, the metric unit of which is KB/s.

$$S_U = \frac{U_L G_L}{T_{avg}\sqrt{\frac{2P_U}{3}} + 4T_{avg}P_U\left(1 + MP_U{}^2\right)} \tag{4}$$

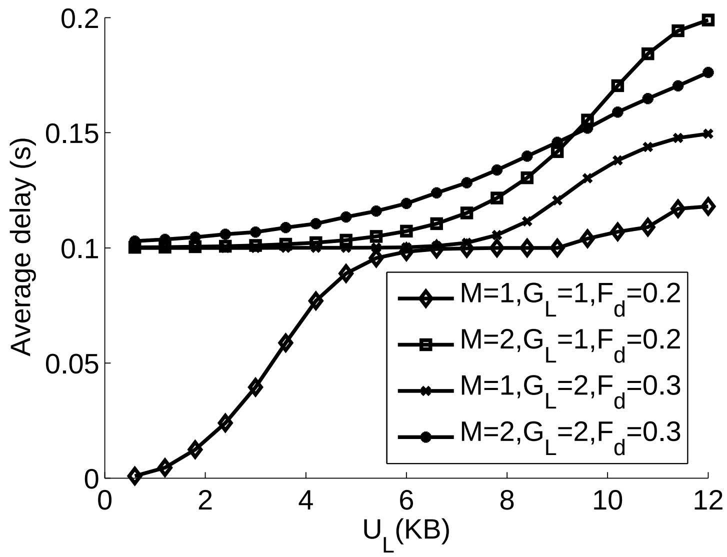

FIGURE 4. T_{avg} with U_L

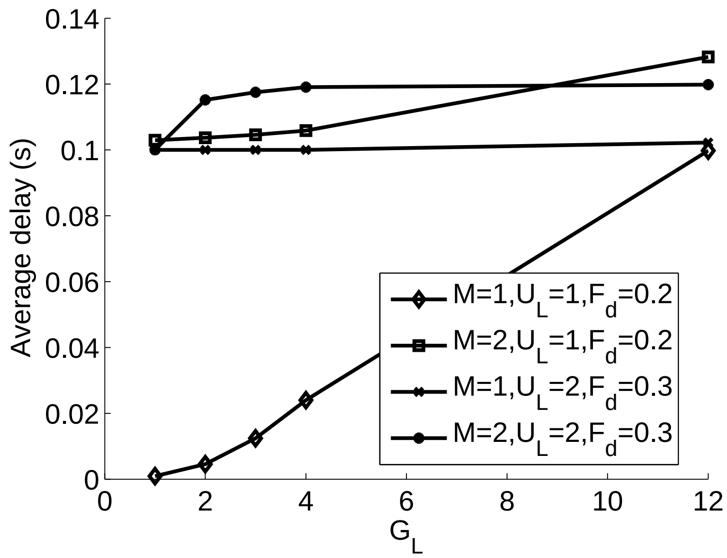

FIGURE 5. T_{avg} with G_L

The analysis results of throughput with G_L, U_L and F_d are shown as Figure 7, 8 and 9. The conclusions are as follows:
(1) As shown in Figure 7, we could improve the throughput by increasing the value of G_L and F_d when U_L is larger than 1KB.
(2) When G_L is larger than 2 and smaller than 4, the throughput could be improved by increasing the value of M and decreasing the value of U_L.
(3) The larger the throughput the larger the value of U_L and F_d.
(4) When F_d is smaller than 0.3, the throughput could be improved by increasing the value of M and U_L.
(5) When F_d is smaller than 0.3, the throughput could be improved by increasing the

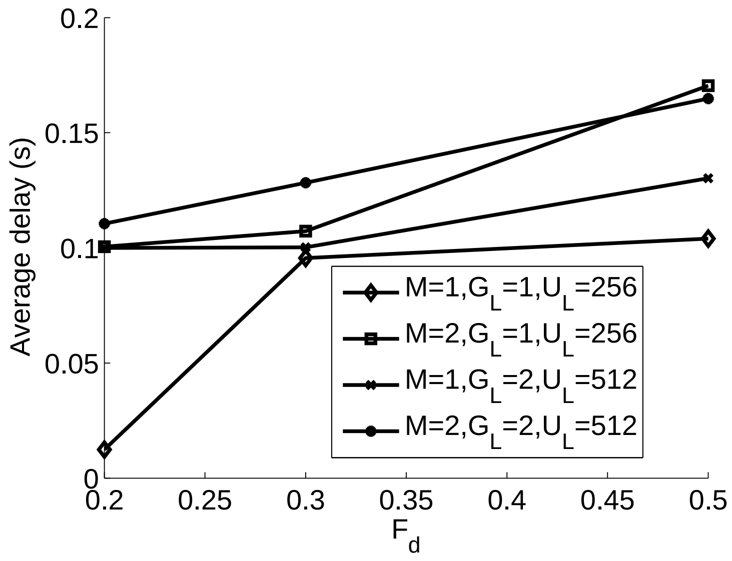

FIGURE 6. T_{avg} with F_d

value of M and U_L.

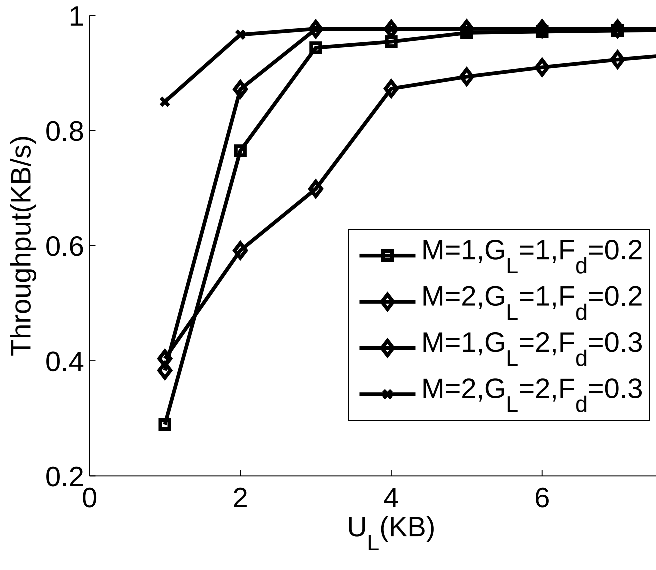

FIGURE 7. S_U with U_L

3. **Opportunistic cooperative QoS guarantee protocol.** According to the analytical results of M, G_L and U_L parameters, the opportunistic cooperative QoS guarantee scheme with a single metric or a comprehensive metrics could be established. The sender node and the relay sensors can establish the best opportunistic cooperative transmission scheme in accordance with the principles illustrated in section 2. Receiving sensor will receive the composite signal from the sender and some relay sensors, which would be processed with texture signal multiplexer, in order to resolve the multiplexed signal interference caused by noise, delay distortion and deformation problems. Figure 10 gives the

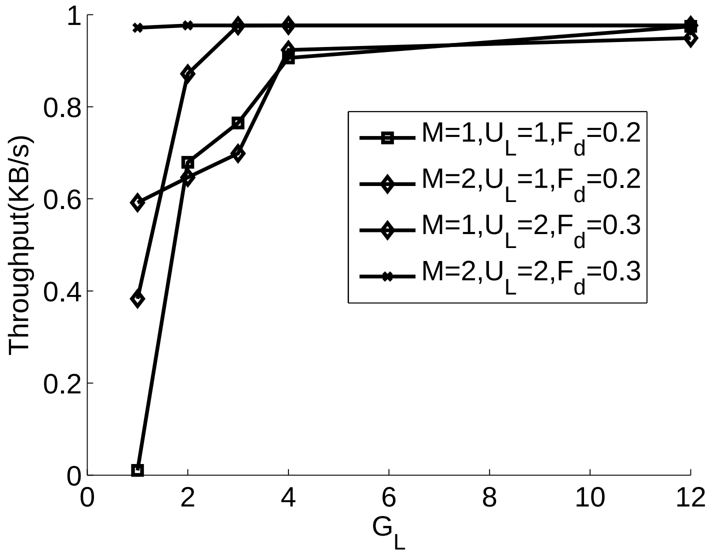

FIGURE 8. S_U with G_L

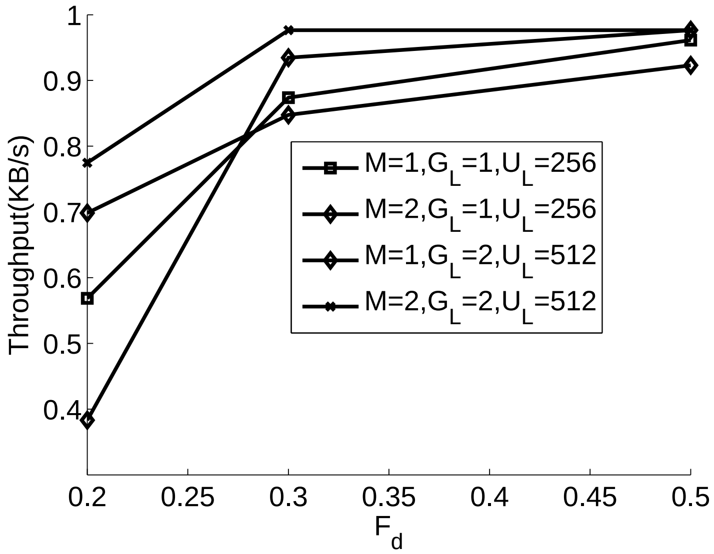

FIGURE 9. S_U with F_d

modulation principle with 12 frequency based on the QPSK. Figure 11 shows the modulation process of the proposed QoS guarantee protocol. The implementation of circuit signal modulation and application demonstration of the proposed scheme are illustrated by Figure 12 and 13 respectively. The implementation steps of the proposed modulation scheme are as follows:

(1) Combined with the WMSN status and QoS guarantee requirements, the optimal opportunistic cooperative solution would be developed according to GOP-length and video Frame-diversity.

(2) The solution is recorded by "001" and imported to "74LS90" module.

(3) The 6 frequency division signal is imported to a "74LS74" module with 2 frequency division, in order to achieve 12 frequency division signal.

(4) When relay sensor receives the signal from the sender node, the step (1) and (2) should

be performed.
(5) The solution of relay sensor is recorded by "010" and imported to "74LS90" module. Then the step (3) should be performed.
(6) There are two solutions at receiving sensor by checking the head type. The valid signal Sig_R could be obtained by the QPSK demodulation principle with 12 frequency division and the formula (5). Here, M is the number of relay sensor nodes. The symbol of signal is the signal of 2 frequency division.

$$Sig_R = \sum_{i=1}^{2} signal \Big/ M \tag{5}$$

FIGURE 10. QPSK modulation principle with 12 frequency division

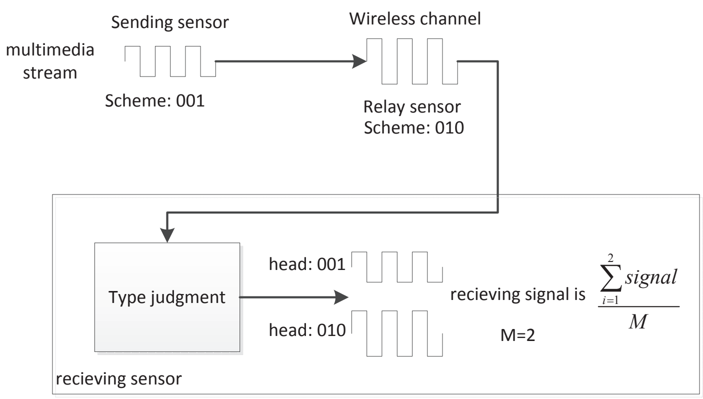

FIGURE 11. Modulation process

4. **Performance Evaluation.** In this work, the proposed opportunistic cooperative QoS guarantee protocol based on GOP-length and video Frame-density (OCQ-GF) and cooperative QoS guarantee protocol (CQ) are simulated, analyzed and evaluated with two group experiments, which include four metrics: packet error rate, average delay, Peak Signal to Noise Ratio (PSNR) and throughput. The parameter settings and environment condition is shown as Table II and III respectively. The GOP structure of experiment 2 is listed in Table IV.

Figure 14 gives the performance of packet error rate and average delay as a function of U_L in experiment 1. The result illustrates that the greater the UDP datagram the higher packet error rate. The packet error rate of CQ increases more greatly than one of OCQ-GF. When U_L is larger than 8 KB, the packet error rate of CQ is 0.0025 and

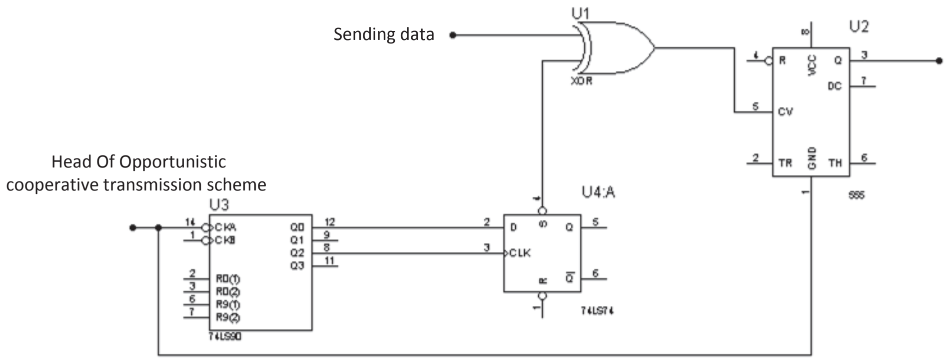

FIGURE 12. Implementation of circuit signal modulation

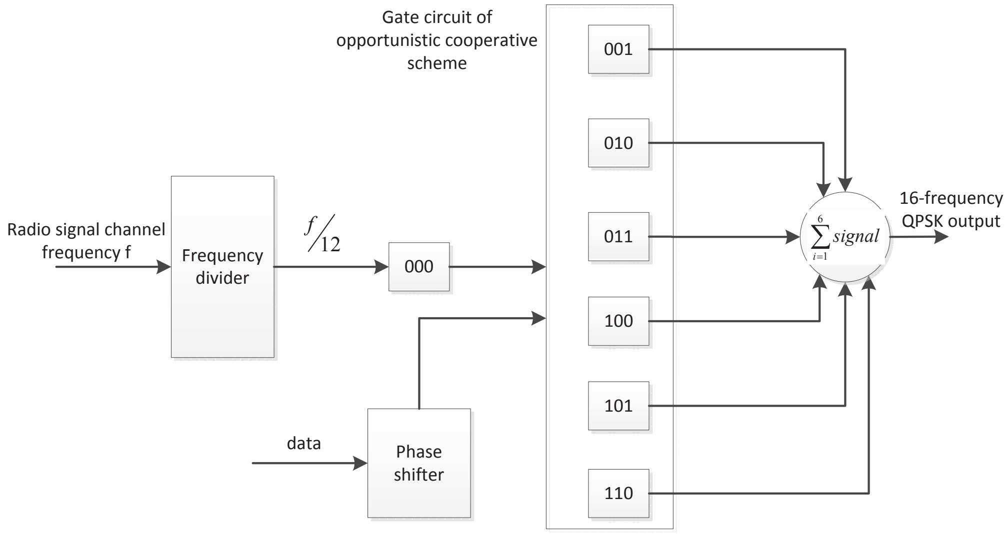

FIGURE 13. Application demonstration

TABLE 2. Parameter settings

Parameters	Value	Parameters	Value
U_L	1, 2, 3, 4, 5KB	γ	0.1, 0.3, 0.5
E_t	0.1, 0.3, 0.5	d	from 100 m to 300 m
N_{max}	1, 2		

TABLE 3. Conditions of video frames

Parameters	Value	Parameters	Value
Total number of video frames	89998	Frame number with F_d is 0.2	59998
Frame number with F_d is 0.3	22500	Frame number with F_d is 0.5	7500

CQ protocol is not able to provide the effective QoS guarantee. At this time, one of the proposed OCQ-GF is 0.0005, which can provide the reliable and stable QoS guarantee as shown in Figure 14 (a). This because that the sending sensor with the proposed OCQ-GF could select the optimal relay sensor and its scale according to the UDP datagram size and video Frame density, as well as the channel state quality. In addition, the average delay of CQ protocol is easily influenced by the U_L. There are the obvious jitter. The

TABLE 4. GOP structure of video frames

GOP structure	G_L	GOP structure	G_L
IIIIIIIIIII	1	IPIPIPIPIP	2
IPPIPPIPP	3	IPPPIPPP	4
13IBBPBBPBBPBBI	12		

average delay of CQ protocol is larger than 0.11 second when U_L is larger than 3 KB. However, the proposed OCQ-GF can eliminate the obvious jitter and has the better real-time guarantee ability than CQ protocol. In experiment 2, the sender sensor sent a video of 60 minutes. We can observe tremendous improvement of PSNR and throughput using OCQ-GF with the QPSK modulation principle of 12 frequency division (QPSK12FD), as compared with OCQ-GF alone. There are a severe jitter between 30 minute and 50 minute, which affects the sensor state or channel quality of the WMSN. The performance of OCQ-GF with QPSK12FD always keeps good state, while the PSNR and throughput with OCQ-GF alone maintain a low value almost. The reasons are that not only the 12 frequency division method could improve the execution efficiency of the proposed OCQ-GF, but also the QPSK12FD scheme improves the time and space complexity at sender or relay sensors.

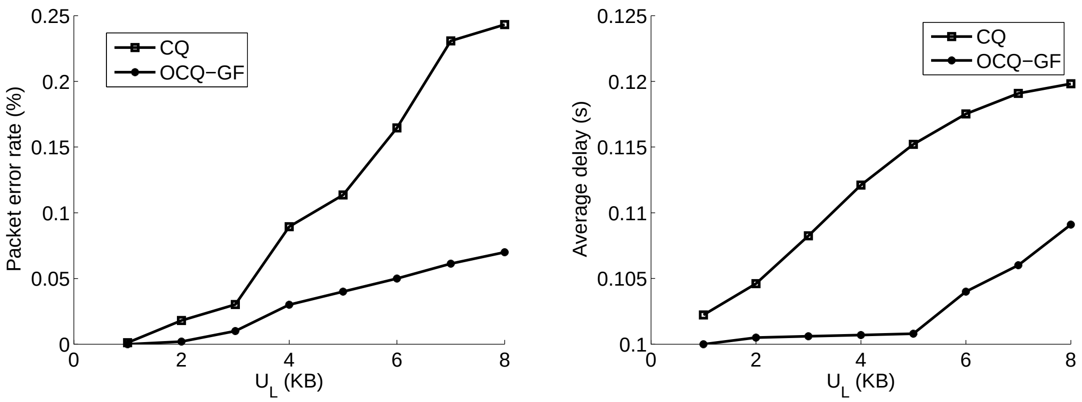

FIGURE 14. Performance with CQ and OCQ-GF. (a) Packet error rate,(b) Average delay.

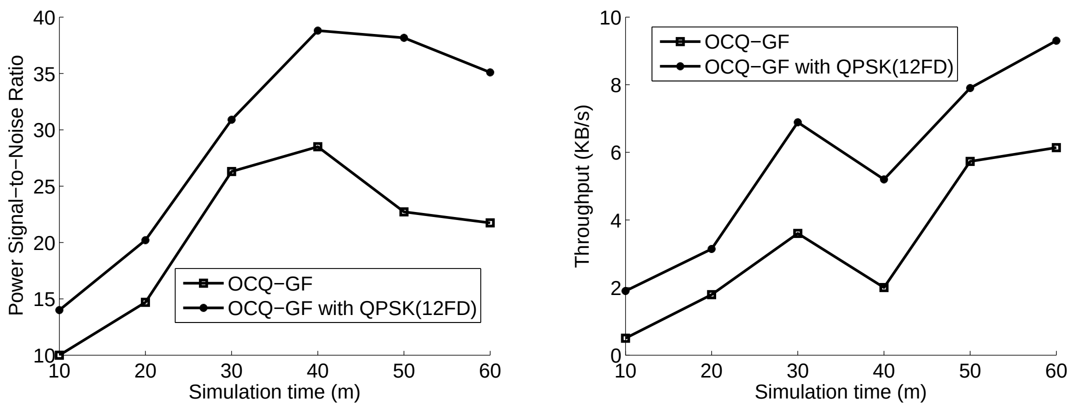

FIGURE 15. Performance with OCQ-GF and OCQ-GF with QPSK (12FD). (a) PSNR,(b) Throughput.

5. **Conclusions.** Combining the multimedia transmission control and opportunistic cooperative control is able to improve the performance of multimedia stream in WMSN. The target of this research is to consider the limitations of multimedia sensors and characteristics of video Frames. Then we proposed the OCQ-GF with the QPSK modulation principle of 12 frequency division (QPSK12FD) based on GOP length and video Frame density. The main contributions of this work are as follows. First, analyzing the characteristics of GOP length, UDP datagram size and video Frame density, we researched the performance analysis model of multimedia communication in WMSN. Second, the opportunistic cooperative QoS guarantee control strategy with threshold values of G_L, M, U_L and F_d is designed to ensure that UDP datagrams have the optimal wireless transmission routing and control strategy. Third, the QPSK modulation scheme with 12 frequency division was proposed, which is used to improve the execution efficiency of the OCQ-GF protocol and reduce the complexity. Finally, we present the opportunistic cooperative QoS guarantee protocol, working together with the above QPSK modulation scheme. The mathematical and simulation results illustrate that, compared with the existing cooperative QoS guarantee protocol, the proposed protocol can achieve the significant gains in terms of average delay, reliability and throughput, as well as PSNR. As a result, the proposed OCQ-GF with the QPSK12FD modulation scheme was determined that it is reliable and efficient for multimedia stream transmission in WMSN.

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