Multi-Channel Multi-Path Video Transmission over Wireless Sensor Networks

Syed Muhammad Asad Zaidi[1], Jieun Jung[1], Byunghun Song[1], Hyungsu Lee[1], Hee Yong Youn[2]
[1]IoT Convergence Research Center, Korea Electronics Technology Institute (KETI)
[2]College of Information and Communication Engineering, Sungkyunkwan University
zaidix@gmail.com[1], {jejung, bhsong, hslee}@keti.re.kr[1], youn@ece.skku.ac.kr[2]

***Abstract*— Recently, various applications have emerged which utilize wireless sensor network (WSN) consisting of low cost and low power sensors in smart spaces. Here a great deal of research has been carried out on transmitting video over WSN. WSN has limited resources in terms of bandwidth and data processing capability, while video requires bulk data to be transmitted. In this paper we propose a two-stage Quality of Service (QoS) guaranteeing scheme for video transmission over WSN, called the Multi-Channel Multi-Path (MCMP) scheme. It selects the best paths from the source camera to the gateway based on hop-count, aggregated path energy, BER, and end-to-end delay. A failure recovery scheme is also provided to cope with link failure. Computer simulation reveals that the proposed scheme significantly outperforms the existing scheme in terms of channel utilization and delay.**

***Index Terms* — WSN; Multi-Channel Multi-Path; H.264; Channel Diversity; Video Transmission; Quality of Service.**

I. INTRODUCTION

The availability of low-cost hardware such as CMOS camera and microphone has fostered the development of Wireless Multimedia Sensor Networks (WMSNs). Such networks are becoming increasingly popular and are used in numerous areas, ranging from video surveillance to location-based service. WMSNs have some distinct features compared to the conventional sensor networks including high rate of data generation from the video sensors. This requires larger network bandwidth and power consumption, and this issue gets more serious if no efficient compression scheme is employed with the transmission. Moreover, various existing solutions developed for multimedia communication in wireless and internet environment cannot be directly applied to sensor network due to the unique characteristics and resource constraints [1].

Transmission of huge amounts of multimedia data, particularly video data, over bandwidth-constrained sensor network is a big challenge. A number of schemes and protocols for efficient transmission of video data over WSN have been proposed. This has been a hot research topic for the last few years, especially because of substantially increasing industrial applications. The basic aim of the schemes is to effectively deal with the high bandwidth requirement, prolong the network lifetime, and minimize the delay. Most of the existing schemes use multiple paths and Quality of Service (QoS) metrics including throughput and delay [2].

The Video data encoded with H.264 protocol is inherently composed of prioritized data. Each group of pictures in a H.264 video sequence consists of I, P, and B frames. The I-frames are intra-coded, i.e., coded independent of any other frames, and serve as a reference for the prediction of the subsequent P and B frames [3]. For this reason, the data pertaining to an I-frame is very important to the quality of video data. In this paper, we propose a composite QoS metric-controlled video transmission scheme for a wireless sensor network, called Multi-Channel Multi-Path (MCMP) video transmission scheme. It uses a two-stage process to find two best paths destined to the gateway, and the H.264 encoded video is transmitted over these paths using alternating orthogonal channels in such a way that the important video part (I-Frames) is transmitted over the best path. We employ a composite QoS metric, comprising hop-count, remaining energy, BER, and delay. The high bandwidth requirement is dealt with by using the Alternating Channel Duo Path (ACDP) technique. In the first stage, two best paths are selected along with the recovery path, which is used as a backup if any of the links goes down during the video transmission. Here, hop-count and the remaining energy of the intermediate nodes are used. The better of these two paths is selected for I-frame transmission in the second stage, using BER and delay as the decision-making parameters. A failure recovery scheme is also provided to tolerate any link failure. Computer simulation reveals that the proposed scheme significantly outperforms the existing scheme on channel utilization and delay.

The rest of the paper is organized as follows. The next section discusses some existing work related to WMSNs. In Section III, we briefly describe the H.264 video encoding scheme. Detailed explanation of the proposed MCMP scheme is presented in Section IV. Section V explains the metric calculation formulas used in both stages of the MCMP scheme and the performance of our ACDP technique, and Section VI concludes the paper.

II. RELATED WORK

In the transmission of video over wireless sensor network, the significant requirements are efficient utilization of available bandwidth and minimization of power consumption to maximize the network lifetime. In addition, the network should provide delay-tolerant transmission and quickly recover from link failure.

Chen and Nasser have proposed Secure and Energy-Efficient Multipath Routing Protocol (SEEM) in [4]. SEEM consists of three phases, and uses multipath alternately as the path for sharing between two nodes. Quality of Service Multipath Routing Protocol (QOSMR) provides QoS guarantees that have a potential impact on the performance of the network in terms of throughput and network lifetime. The major focus is to eliminate congestion in the intermediate nodes.

The Multipath multi-SPEED protocol (MMSPEED) has been proposed in [5]. It uses multipath forwarding by transmitting duplicate copies of the packets, where a detour path of more hops is also taken rather than using only the shortest path. The protocol offers QoS guarantees on timeliness and reliability. Here the end-to-end delay requirement is supported in a localized way, which is desirable for large-scale dynamic sensor network with respect to scalability and adaptability.

Bhatnagar has classified different paths based on the route lengths in [6]. The traffic is organized in such a way that all the critical queries are forwarded via the paths of minimum route length, and the rest of the traffic is distributed uniformly over the network to extend the network lifetime and reduce the delay as needed. The algorithm proposed by Das et al. [7] adaptively discovers the routes before the occurrence of any routing error during transmission. It dynamically finds out a series of multiple paths to complete the data transmission.

A novel approach called Label-based Multipath Routing (LMR) has been proposed in [8] that can efficiently find a disjoint or segmented backup path to protect the primary path. [9] allows an effective balancing of traffic in the network without dealing with the interference issue. Wang et al. [10] presented a data gathering model based on agent mobility, where the station is stable and the agents distributed among the stations move around in the circular fashion. This method, however, cannot balance the load among the nodes separated over two hops. Lin et al. [11] proposed a clustering hierarchy based on cellular topology for WSN, in which the remaining energy and position of sensor nodes are considered when the clusters are constructed, and the desired cluster structure is obtained even when the nodes have no locating devices.

III. Overview of H.264

H.264, also known as MPEG-4 (Part 10) or AVC, is a next-generation video compression format, by which the digital video is converted into a format that takes up less capacity when it is stored or transmitted. The basic H.264 video encoder and decoder model is shown in Figure 1. The H.264 encoder carries out prediction, transform, and the encoding process, while the H.264 video decoder follows the reverse processes of decoding, inverse transform and reconstruction to produce a decoded video sequence.

The encoder processes a frame of video in units of a macroblock. It forms a prediction of the macroblock based on previously-coded data, either from the current frame (intra-prediction) or from other frames that have already been coded (inter-prediction). The encoder then subtracts the prediction from the current macroblock to form a residual. A block of residual samples is transformed using an approximate form of the Discrete Cosine Transform (DCT), and this is later quantized. Finally, bitstream encoding occurs, which includes a) quantized transform coefficients, b) information about the complete video sequence, and c) other necessary information required by the decoder. The output of this video coding process is a periodic combination of I-frames (Intra frames) as set by the encoding parameters, with P-frames (Predicted frames) and B-frames (Bi-directional frames) in between, as shown in Figure 2.

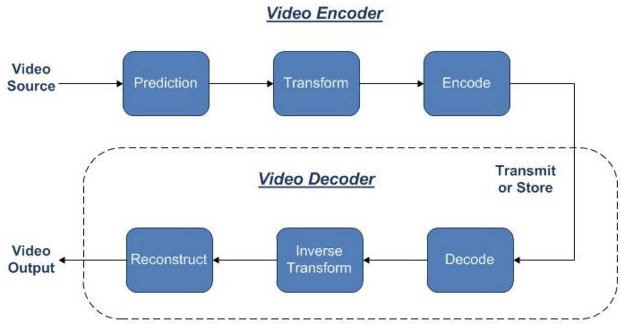

Figure 1. The H.264 video encoding and decoding process.

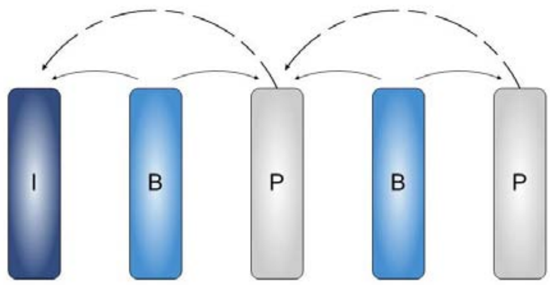

Figure 2. A typical IBP-based video frame.

At the decoder, a reverse process occurs: first, bitstream decoding occurs to extract quantized transform coefficients and prediction information, and then rescaling and inverse-transform are taken. Finally, the residual data obtained is reconstructed [8]. The decoding of I-frame is independent of any other frames, the decoding of P-frame depends on the successful decoding of I-frame and/or P-frame, while the decoding of B-frame depends on the decoding both I and P frames and the succeeding P frames [12].

IV. The Proposed MCMP Scheme

During the survey of different algorithms and schemes proposed to transmit multimedia content over WSN, it has been observed that most schemes use multiple paths and single channel. In addition, only a single metric is adopted to make a QoS decision. It is thus necessary to develop a scheme that uses multiple QoS metrics in making a decision.

The followings are assumed in the proposed scheme: i) all sensor nodes have some additional power compared to traditional sensor nodes for transmitting video data requiring more energy than regular data, ii) every node can frequently switch between the assigned orthogonal channels in the round robin fashion in order to transmit the packets as per the ACDP technique, iii) the source video cameras are equipped with a small microprocessor to encode the captured video into H.264 frames and later transmit them using the proposed MCMP scheme, iv) the header of each video frame is appended with a frame number and source camera ID for identification purposes, v) the gateway has a buffer of considerable size as it may receive out-of-order video frames.

The Multi Channel Multi Path (MCMP) video transmission scheme proposed in this paper considers channel diversity as well as space diversity to obtain maximum data rate and assign separate path to each camera for collision-free transmission. Furthermore, appropriate decisions are made by employing various QoS metrics. At the time of deployment, every sensor node is assigned a unique ID for identification and tuned to a common control channel. The proposed MCMP scheme consists of two stages as explained later. The Alternating Channel Duo Path (ACDP) technique used in the MCMP scheme is explained first.

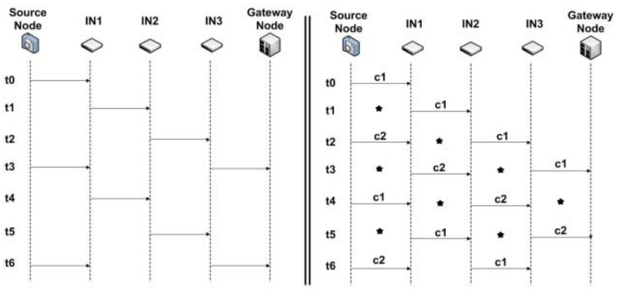

Figure 3. (a) Single channel transmission. (b) Transmission using alternating channels.

A. Overview of ACDP Technique

Spectral efficiency of traditional single path transmission is low mainly because of overhearing caused by neighboring nodes. As shown in Figure 3(a), at timeslot "t_1", the source node cannot send the next packet to intermediate node-1 (IN1) because it is busy in transmitting the first packet to intermediate node-2 (IN2). Here the nodes are assumed to be half-duplex. Similarly, at Timeslot "t_2", the source node still cannot transmit Packet 2 because the transmission from IN2 to IN3 is being overheard by IN1. Therefore, the source node has to wait for three timeslots before transmitting the next packet.

On the other hand, if two channels (c1 and c2) are scheduled in such a way that the nodes tune their radios in an alternate manner after every packet transmission, then every node can transmit the packet at the third timeslot as shown in Figure 3(b). Moreover, in order to further increase the packet transmission rate, the intermediate vacant timeslots (marked as *) need to be utilized. This is achieved by utilizing another pair of channels (c3 and c4) to transmit the packets in the same manner through a secondary path towards the destination. By using the ACDP technique, the data can be transmitted at every available timeslot towards the next hop, allowing maximum throughput.

B. Stage I - Paths Selection

After the network deployment, the path search algorithm is run and the source camera broadcasts a Gateway Search Message (GSM) on the control channel with a pre-assigned TTL. Every recipient of the message broadcasts it further to their neighboring nodes after appending its IDs and energy level to the GSM packet. In this way, the GSMs carry QoS-related information as they are flooded throughout the network. Ultimately, the GSMs reach the gateway along multiple paths, where the messages are processed. Here, the hop-count (known by IDs) and the energy-level enclosed in each GSM are used in selecting the paths.

Based on the remaining energy and hop-count of each path, the gateway decides three best paths, two of which are used for transmission by the source camera using the ACDP technique discussed above, while the third one is marked as the recovery path used as a backup if any of the primary links fails. The formula used for selecting the paths based on the two metrics is presented in Section V. Notice here that for any GSM packet reaching the gateway, if the hop-count is equal to or greater than a predefined threshold, then it is discarded. This is not only for limiting the length of the transmission path but also for decreasing the computation overhead of gateway.

Prior to the measurement of the QoS attributes, the gateway ensures that the nodes in the paths are disjoint, i.e., none of the nodes is included in more than one path, or there will be a bottleneck in the proposed ACDP technique. Additionally, the paths of the same number of hop-counts are given preference. After selecting three paths, the gateway sends a Preferred Multipath Message (PMM) back to the source camera on the control channel of the reverse path. This lets the source camera identify the path on which it transmits the video frames (Refer to Figure 4). Each PMM has information on the orthogonal channel pair, and the PMMs sent through the two best paths assign orthogonal channel pairs (a,a') and (b,b') to the nodes in the path. However, the PMMs sent through the recovery path do not have any information on the channel pair. The PMM also sets the Reserved (R) flag on all the intermediate nodes to avoid GSM forwarding for other source cameras. Hence, the nodes in the two best paths are assigned the channels the gateway decided upon receiving the PMM message and implicitly refrain from receiving/forwarding any GSM message sent on the control channel.

If the source camera does not receive the PMM within time "T", or if it receives an Inadequate Information Message (IIM) from the gateway, it resends the GSM message with an increased TTL. The gateway now has a larger picture of the network topology, and can make a better decision on path selection. The whole process of stage-I path selection is depicted in Figure 5.

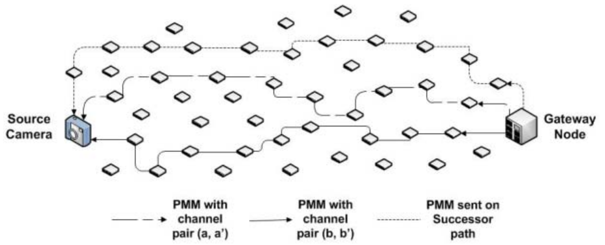

Figure 4. The flow of PMM sent by the gateway along the selected paths.

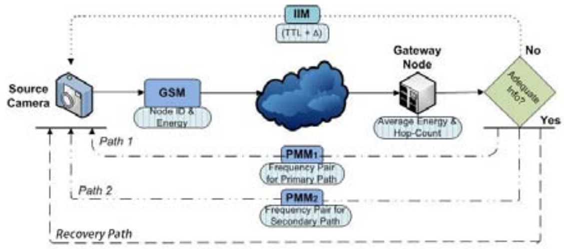

Figure 5. The flow of control packet exchange during path selection of Stage I.

C. *Stage II – Selection of Primary Path*

In the second stage the source camera and gateway together pick a primary path from the two paths selected in Stage-I based on the QoS metrics of BER and delay. The source camera simultaneously sends multiple copies of same RAW (predefined) data to the gateway on the assigned channels of the two paths. From the received data, the BER and delay of both the paths are approximated and later assigned a weight in the selection of best path. If quality is more important than delay, more weight is given to BER than to delay. However, for time-sensitive applications such as real-time display, delay is given preference. A primary path is decided based on the composite metric, and it is notified back to the source camera through the Best Path information Message (BPM). In case of any event or in response to any query, the source camera sends important data (I-frames) on the best path (primary path) and P and B frames on the secondary path. As a result, video can be efficiently transmitted to the gateway with a high data rate and better quality. Note that the gateway (of large buffer size) needs to place the frames in-order for each video stream before feeding it to the decoding unit. The process of the best path selection is described in Figure 6.

D. *Failure Recovery and Network Maintenance*

stage operation described above, allowing non-overlapping paths. During transmission of data, if one of the links goes down, the gateway instructs the source camera to transmit data through the recovery path decided in Stage-I. If the primary path goes down and the gateway receives δ_{BP} frames on secondary path or if the secondary path goes down and the gateway receives δ_I frames on the primary path, then the gateway declares the target path as down and sends a Recovery Active Message (RAM) through the recovery path in the reverse direction. (Note that δ_I and δ_{BP} are threshold numbers set by the administrator considering H.264 encoding parameters). The purpose of RAM is to:

- inform respective source video camera of the failed path,
- perform switchover from the failed path to the recovery path, and
- provide the intermediate nodes of the recovery path with the relevant information on the channel pair.

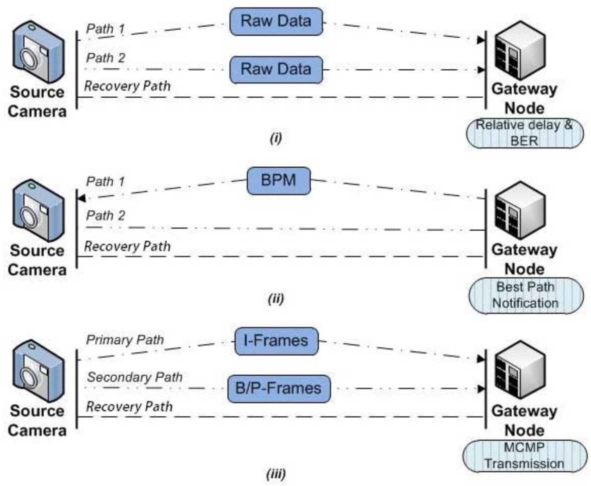

Figure 6. The flow of best path selection in Stage I.

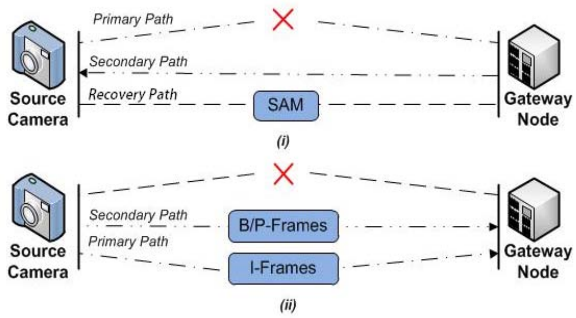

Figure 7. Path switchover in case of path breakdown.

Finally, a switchover is performed as shown in Figure 7, and the interrupted transmission is resumed by transmitting the frames on the recovery path.

After the transmission is completed, the failed path is checked. If it is recovered, then future transmission will be made through the path. Otherwise, Stage II is applied to the recovery path and the remaining path, and a better one among the two is chosen based on BER and delay. In addition, the intermediate nodes of the failed path are set to provide control channels so that they can later take part in

GSM forwarding for other source cameras. Moreover, after a predefined period, the MCMP scheme is run again on each source camera to decide the primary path based on the updated QoS metrics such as energy level and BER.

I. PERFORMANCE EVALUATION

II. In Stage-I several GSM packets reach the gateway after traversing multiple paths, which then uses hop-count and remaining energy to select three best paths between the source camera and gateway. As described in the previous section, one path among the three is marked as a recovery path while the remaining two paths are used for video frame transmission scheduled as per the decision made in Stage-II. The selection of three paths is made in Stage-I using the metric ($M1$) calculated by:

$$M1(j) = \begin{cases} \left[\sum_{n \in N(j)} (100 - E_n) \right] * e^{\frac{h_j}{|h_{thr} - h_j|}}, & h_j < h_{thr} \\ \infty \quad , & h_j \geq h_{thr} \end{cases} \quad (1)$$

where:

$M1$: Stage-I metric
j: Path index
$N(j)$: Set of nodes in path-j
h_j: Hop-count of path-j
E_n: Remaining energy of node-n (pct)

Metric $M1$ is evaluated using the energy and hop-count metric collected by the GSM packets. Three disjoint paths of the smallest $M1$ value are selected. If PI is the set of three selected paths, then:

$$PI = \{ j \mid \text{three smallest } M1(j) \} \ \& \ |PI| = 3$$

Figure 8 shows the possible value of Stage-I metric ($M1$) drawn against the number of hops, while each line represents a different concentration of node energy level. In the simulation the nodes are assigned uniform distribution of remaining energy level with mean values of 35pct, 55pct and 75pct (denoted by μ) and variance (σ^2) of 20 in all three cases for fair comparison.

As discussed in Section IV-C, the better one between the two paths is selected in terms of BER and delay in Stage-I. I-frames playing a vital role in decoding the video are transmitted through it. Inspired by the EIGRP metric formula with default k values [13], the $M2$ metric formula is derived with BER and delay as the constituent parameters in Stage-II as shown in Equation (2).

$$M2\ (j) = (W_{BER} * BER_{scaled}) + (W_{Delay} * Delay) \quad (2)$$

where:

BER_{scaled}: Scaled BER ($BER_{scaled} = BER * 10^4$)
W_{BER}: Weight of BER
W_{Delay}: Weight of delay
$0 \leq W_{BER}, W_{Delay} \leq 1$
$W_{BER} + W_{Delay} = 1$

Here the unit of delay is microsecond. The reason for scaling BER is to map the values close enough to the range of the delay metric. Otherwise, BER would have a much smaller effect on the $M2$ metric even if the weight assigned to it is quite high. This is because the values of BER are quite small between 0 and 1. Mathematically, the primary and secondary paths can be expressed as:

$$\text{Primary Path} = \arg M2(i) \triangleq S_1$$

$$\text{Secondary Path} = \arg M2(i) \triangleq S_2$$

Figure 9 shows possible values of the Stage-II metric ($M2$) calculated by Equation (2) for different values of BER and delay. In the simulation the weight of delay and BER is 0.15 and 0.85, respectively. As shown in the figure, at a particular delay value, the value of $M2$ increases slightly even if the BER approaches 1. This is because the weight assigned to BER metric is quite low, and therefore has less effect on $M2$.

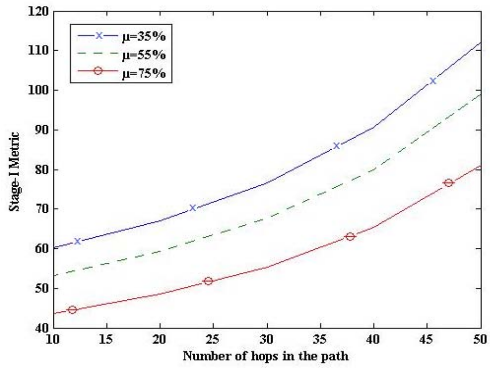

Figure 8. Stage-I metric ($M1$) calculated with different energy level of intermediate nodes on the path.

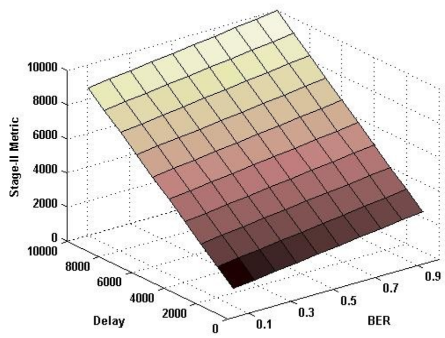

Figure 9. Stage-II metric ($M2$) with weight of 15:85 assigned to W_{BER} and W_{delay}.

Figure 10 shows significant delay improvement achieved by the proposed ACDP technique. The ACDP technique is compared with the single channel duo path transmission technique used commonly for video transmission over WSN. The end-to-end delay for each frame was estimated while four videos of different resolutions were sent to a six-hop distance gateway. For low resolution, the delays are almost the same. However, as the resolution or the number of bits is increased, the delay with the proposed ACDP technique increases only slightly while that with a single channel increases sharply. Similarly, in Figure 11, channel utilization is compared. Observe from the figure that the channel utilization increases as the number of packets increases. This is achieved by using alternating channels, which prevents collisions between successive packet transmissions.

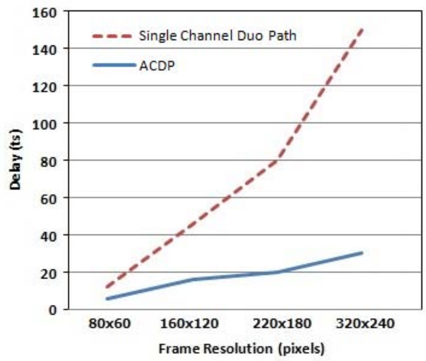

Figure 10. Delay factor improved by ACDP technique.

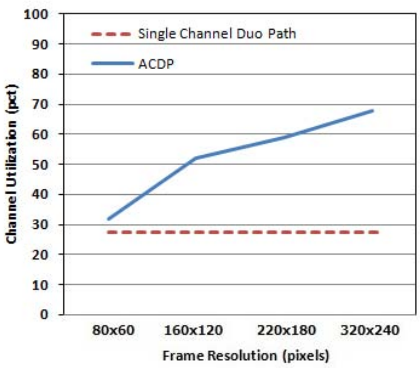

Figure 11. Channel utilization with different frame resolution.

III. CONCLUSION

In this paper, we have presented the MCMP scheme by which the H.264 encoded video can be effectively transmitted through the sensor network by considering multiple QoS parameters in two stages. A high effective packet transmission rate is attained by employing the ACDP technique, by which the source camera transmits packets using frequently changing orthogonal channels on two disjoint paths. In the first stage, three best paths are identified based on the hop-count and remaining energy, and in the second stage, the primary path is identified among the two paths on the basis of BER and delay so that the vital I-frames can be transmitted through it. Transmission of I-frames over the low BER and low delay path definitely increases the transmission efficiency as the I-frames play a vital role in fetching a good quality video with high SNR at the receiver end.

A failover scenario has also been incorporated into the proposed scheme. The third path selected in Stage-I is termed as a recovery path, which takes over a failed path during transmission. Moreover, periodic maintenance is also carried out in which the QoS metrics are recalculated and the choice of best paths is updated based on the current status. Simulation of the ACDP technique shows the superiority of our scheme over available schemes through reduction in delay and increased channel utilization.

ACKNOWLEDGMENT

This work was supported in part by a grant (10CCTI-A052535-03-000000) from the Ministry of Land, Transport and Maritime of the Korean government through the Core Research Institute at Seoul National University for Core Engineering Technology Development for Super Long Span Bridge R&D Center, Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology(2012R1A1A2040257), and Korea Association of Industry, Academy and Research Institute (C0017380). Corresponding author: Hee Yong Youn

REFERENCES

[1] Afshin Fallahi, Ekram Hossain: QoS Provisioning in Wireless Video Sensor Networks: A Dynamic Power Management Framework (2007)

[2] Yunfeng Chen, Nidal Nasser: Enabling QoS Multipath Routing Protocol for Wireless Sensor Networks (2008)

[3] ITU-T Recommendation H.264 & ISO/IEC 14496-10 AVC, Advanced Video Coding for generic audio visual services (2009)

[4] Nidal Nasser, Yunfeng Chen SEEM: Secure and energy-efficient multipath routing protocol for wireless sensor networks (2007)

[5] E. Felemban, C.-G. Lee, E. Ekici "MMSPEED: Multipath multi-SPEED protocol for QoS guarantee of reliability and timeliness in wireless sensor networks", IEEE Trans. Mobile Comput. (2006)

[6] S. Bhatnagar, B. Deb and B. Nath, "Service differentiation in sensor networks", Fourth Intl. Symposium on Wireless Personal Multimedia Communications (2001)

[7] S.R. Das, A. Mukherjee, B. Bandyopadhyay, K. Paul and D. Saha, Improving quality-of-service in ad hoc wireless networks with adaptive multi-path routing, IEEE Globecom (2000)

[8] X. Hou, D. Tipper, and J. Kabara, "Label-based multipath routing (LMR) in wireless sensor routing", In Proceedings of the 6th International Symposium on Advanced Radio Technologies (ISART 04), Boulder, CO, March 2-4 2004.

[9] Ye Ming Lu and Vincent W. S. Wong, "An energy-efficient multipath routing protocol for wireless sensor networks", Int. J. Commun. Syst. 2007, 20:747–766.

[10] F. Wang, D. Wang, and J. C. Liu, "Traffic-aware relay node deployment for data collection in wireless sensor networks," in Proc. 6th Annu. IEEECommun. Soc. Conf. Sensor Mesh Ad-HoC Commun. Netw., Jun. 2009, pp. 351–359.

[11] K. Lin, K. Q. Li, W. L. Xue, and Y. G. Bi, "A clustering hierarchy based on cellular topology for wireless sensor networks," Int. J. Comput. Sci.Eng., vol. 5, no. 5, pp. 51–59, May 2009.

[12] Wei Wang, Michael Hempel, Dongming Peng, Honggang Wang, Hamid Sharif, Hsiao-Hwa Chen: On energy efficient encryption for video streaming in wireless sensor networks (2010)

[13] Performance Analysis of Dynamic Routing Protocol EIGRP and OSPF in IPv4 and IPv6 Network, by Wijaya, C. IEEE Informatics and Computational Intelligence (ICI), 2011.