Broadband Mobile Multimedia: Techniques and Applications

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Contents

Chapter 1

Video Communications over Wireless Sensor Networks

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This chapter addresses the problem of real-time video streaming over a bandwidth and energy constrained wireless sensor network (WSN). Since the compressed video bit stream is extremely sensitive to transmission errors, conventional single-path routing schemes typically based on shortest paths are not very effective to support video transmissions in unreliable and bandwidth-limited WSNs. Considering the constraints in bandwidth and energy in WSNs and delay in video delivery, we propose to divide a single video stream into multiple sub-streams, and exploit multiple disjoint paths to transmit these sub-streams in parallel. The multiple paths will facilitate load balancing, bandwidth aggregation, and fast packet delivery. For efficient multi-path routing of these parallel sub-streams from the source to the sink, we propose a hybrid video stream broadcasting and sub-streams unicasting scheme based on the construction of an application-specific number of multiple disjoint paths.

1.1 Introduction

With recent advances in wireless sensor networks (WSNs), it is foreseeable that video sensors will be supported in such networks, for applications such as battlefield intelligence, security monitoring, emergency response, and environmental tracking [1].

We investigate H.26L [2, 3] real-time video communications in video sensor networks (VSNs), where video streams are transmitted under a number of resource and performance constraints, such as bandwidth, energy, and delay. Though a high compression ratio makes H.26L real-time video applications suitable for low bit-rate channels, the received video quality is susceptible to transmission errors. It remains a challenging problem to deliver H.26L video data with a high quality of service (QoS) in WSNs with bandwidth-limited error-prone wireless channels. Due to the bandwidth limitation of a VSN, we consider only a small number of video-sensor nodes (VNs), which have video capture capability, taking turn to transmit video to a single sink; i.e., only one VN transmits video to the sink at any time.

Since the compressed video bit stream is extremely sensitive to transmission errors due to dependencies between video frames, error control techniques such as forward error correction (FEC) and automatic repeat request (ARQ) are necessary to obtain the high reliability required by video services [4]. Between these two error control mechanisms, FEC is generally preferred for real-time applications due to the strict delay requirements and semi-reliable nature of media streams [5]. However, links in a WSN may not have adequate bandwidth to satisfy the higher bandwidth requirement of FEC coding. Thus, conventional single-path routing schemes typically based on shortest paths [6, 7] are not very effective to support video transmissions in unreliable and bandwidth-limited WSNs, as they will cause either significant degradation in the perceived quality of the video at the sink nodes if FEC coding is not used, or large queuing delays due to insufficient bandwidth if FEC coding is used. Furthermore, transmitting a video stream using the shortest path will drain the energy of the nodes along this path and shorten the network lifetime. Thus, considering the constraints in bandwidth and energy in WSNs and delay in video delivery, we propose to divide a single video stream into multiple sub-streams, and exploit multiple disjoint paths to transmit these sub-streams in parallel. The multiple paths will facilitate load balancing, bandwidth aggregation, and fast packet delivery. For efficient multi-path routing of these parallel sub-streams from the source to the sink, we propose a hybrid video stream broadcasting and sub-streams unicasting scheme based on the construction of an application-specific number of multiple disjoint paths.

In WSNs, multipath routing is used to establish multiple paths between each source-sink pair. Most applications of multipath routing in WSNs aim to increase the reliability for a single flow [10, 11, 12, 13]. In contrast, multipath routing is used in the proposed scheme, i.e., directed geographical routing (DGR) [8], to support the delivery of multiple flows in a VSN, while the responsibility of reliable data delivery at the routing layer is relieved by the use of FEC coding.

Similar to many previous multipath routing schemes, the proposed DGR mechanism also encounters the route coupling problem [14], caused by interference between packets transmitted over different paths between the same source-destination pair. If the number of paths is small (e.g., 2 or 3), non-interfering paths may be established. However, if a large number of paths are required by a specific application, non-interfering paths cannot be guaranteed due to the limited spatial size in proximity to the source/sink. In such cases, the best approach is to spatially distribute these paths as evenly as possible.

Given the scenario presented in Section 1.4, Fig. 1.1 and Fig. 1.2 show the OPNET simulation results of DGR's path construction and illustrate DGR's adaptability to an application-specific path number (*PathNum*). As an example, with a minimum *PathNum* of 2 in Fig. 1.1, DGR tries to pick two paths that do not interfere with each other. Let N_s be the minimum number of neighbors among the source and sink nodes. In Fig. 1.2, $N_s = 11$; therefore the maximum possible value of *PathNum* is 11 if it is required that no two paths traverse the same node(s). This maximum *PathNum* value is only achievable in an ideal WSN where the node density is sufficiently high. Assuming that this is the case, DGR constructs all 11 paths as illustrated by the simulation result in Fig. 1.2. In practice, for a large *PathNum*, DGR spreads the paths in all directions in the proximity of the source and sink nodes, which implies that packets along some paths are likely to be forwarded to a neighbor farther to the sink than the node itself. Thus, DGR differs from traditional geographic routing schemes [15], in which each node forwards packets to a neighbor that is closer to the sink than the node itself until the packets reach the sink.

The rest of this chapter is organized as follows. Section 1.2 presents background of video transmissions over WSNs. Section 1.3 describes the proposed multipath based realtime video transmissions scheme in WSNs. Simulation model and experiment results are presented in Sections 1.4 and 1.5, respectively. Section 1.6 summarizes the chapter.

1.2 Background

Our work is closely related to video transmissions over wireless Local area networks (WLANs), QoS provisioning for time-constrained traffic in WSNs, and image/video transmissions over WSNs. We will give a brief review of the existing work in these areas.

1.2.1 Video Transmissions over WLANs

A survey is presented in [16] on video streaming over WLANs. Bucciol et al. [17] proposed a cross-layer ARQ algorithm for H.264 video streaming in 802.11 WLANs, which gives priority to perceptually more important packets at (re)transmissions. In [18], a transmission strategy is examined that provides adaptive QoS to layered video for streaming over 802.11 WLANs. In [19], [20] hybrid transmission techniques that combine ARQ and FEC are proposed for improved real-time video transport over WLANs. However, only single-hop network scenarios are investigated in [20]. By comparison, this chapter considers real-time video transmissions in multi-hop WSN environments. Mao et al. [23] combined multi-stream coding with multipath transport, and showed that, in addition to traditional error control techniques, path diversity provides an effective means to combat transmission errors in ad hoc networks. In [23], the dynamic source routing (DSR) protocol is extended to support multipath routing. With their extension, multiple maximally disjoint routes are selected from all the routes returned by a route query. However, only two paths are constructed in their simulation model and only two sub-streams are considered. By comparison, our scheme is adaptive to an application-specific *PathNum* that can be greater than two.

1.2.2 QoS Provisioning for Time-constrained Traffic in WSNs

Many applications of WSNs require QoS provisioning for time-constrained traffic, such as real-time target tracking in battlefield environments, emergent event triggering in monitoring applications, etc. Recent years have witnessed increasing research efforts in this area. SPEED [24] is an adaptive real-time routing protocol that aims to reduce the end-to-end deadline miss ratio in WSNs. MMSPEED [25] extends SPEED to support multiple QoS levels in the timeliness domain by providing multiple packet delivery delay guarantees. Akkaya et al. proposed an energy-aware QoS routing protocol to support both best effort (BE) and real-time (RT) traffic at the same time [26], by meeting the end-to-end delay constraint of the RT traffic while maximizing the throughput of the BE traffic. Weighted Fair Queuing (WFQ) based packet scheduling is used to achieve the end-to-end delay bound in [27]. Yuan et al. [28] proposed an integrated energy and QoS aware transmission scheme for WSNs, in which the QoS requirements in the application layer, and the modulation and transmission schemes in the data link and physical layers are jointly optimized. EDDD proposed in [29] provides service differentiation between BE and RT traffic by deploying BE and RT filters. The BE filter aims to balance the global energy and prolong network lifetime, whereas end-to-end delay is not a primary concern. The RT filter aims to provide better end-to-end delay performance for time-sensitive traffic. In this chapter, we use multiple paths to increase the end-to-end capacity and achieve the QoS requirements in terms of end-to-end latency.

1.2.3 Video Transmissions over WSNs

Recent advances in hardware miniaturazation have allowed the fabrication of sensor devices that support the use of specialized add-on modules for imagery applications. As an example, the Cyclops image capturing and inference module [30] is designed for extremely light-weight imaging, and can be interfaced with popular WSN devices, such as Crossbow's MICA2 and MICAz [31, 32]. The availability of such inexpensive imaging hardware has fostered the development of VSNs that allow collection and dissemination of video streams and still images. As surveyed in [1], it is clear that VSN research is a field of growing activity, in which innovations in applied signal processing interact with emerging applications and technology.

He and Wu [21, 22] studied the resource utilization behavior of a wireless video sensor and analyzed its performance under resource constraints. In [33], Wu and Chen proposed a novel collaborative image coding and transmission scheme for WSNs. Energy reduction is evidenced from the use of this collaborative approach to distributed image compression. A multiagent framework for video sensor-based coordination in surveillance applications was proposed by Patricio et al. [34]. Awad et al. [35] addressed the problem of action classification using multiple real-time video signals collected from homogeneous sites. Chow et al. [36] investigated the optimization of energy resources when transmitting visual data on-demand to a mobile node via judicious path selection for tracking applications. A distributed protocol requiring only local information was proposed and evaluated through simulations. In addition, mobile agents were found specially useful for image/video transmissions over WSNs [37]. Since the imagery data can occupy large memory spaces, transmitting whole pictures not only consumes a lot of energy, but may not be necessary if the sink only needs information on a certain region of interest (ROI) within the picture. Fig. 1.3 shows an application of mobile agent based image transmissions over WSNs [37]. Here, a mobile agent carries image segmentation code and is dispatched to the target region. It visits camera sensors one by one and collects only the ROI by segmenting the image; thus, the amount of imagery data sent by at each target sensor node is substantially reduced. Note that a single kind of image segmentation algorithm may not achieve good performance for all kinds of images to be extracted. Thus, the sink may dispatch multiple mobile agents carrying alternate image processing codes to the sensors of interest.

1.3 Multipath Based Real-Time Video Communications in WSNs

In this section, the architecture of a VSN being considered in the remainder of this chapter is described first. Then, we present the proposed multipath based video transmission strategy.

1.3.1 Architecture of Video Sensor Network

In a VSN, VNs equipped with video capturing and processing capabilities are tasked to capture digital visual information about target events or situations, and deliver the video streams to a sink node [21]. Generally, a VN should be equipped with a battery of higher energy capacity than an ordinary sensor node, since it is already equipped with a relatively expensive camera that would become useless if the VN ran out of energy.

However, it is economically infeasible and often unnecessary to equip all the sensor nodes with video capturing and processing capabilities, especially for large scale and/or dense WSNs. We consider a VSN architecture, as illustrated in Fig. 1.4, where a small number of VNs are sparsely deployed among a much larger number of densely deployed low-power sensor nodes. The set of VNs only cover the target regions remotely monitored by the sink. The inexpensive ordinary sensor nodes perform the simple task of forwarding packets that carry sensed video data to the sink. Due to bandwidth limitation of a typical WSN link, we consider that the VNs take turn to send video streams to the sink; i.e., at any instance only one of the VNs is actively sending video data to the sink.

To combat unreliable transmissions over the wireless environment and satisfy the strict end-to-end delay requirements, we assume that a FEC coding scheme is employed whereby each VN generates redundant packets to increase error resilience for real-time video transmissions.

We implement the FEC coding scheme proposed in [41], where $n - k$ redundant packets are generated to protect k data packets of a video frame, as shown in Fig. 1.5. The size of each FEC packet is equal to the maximum size of the data packets. If any k of the n packets in the coding block are received by sink, the corresponding video frame can be successfully decoded.

1.3.2 Multipath Based Video Transmission Strategy

The typical application of multipath routing in traditional WSN designs is to provide path redundancy for failure recovery. In [10], multiple disjoint paths are set up first, then multiple data copies are delivered using these paths. In [11], a protocol called ReInForM is proposed to deliver packets at the desired reliability by sending multiple copies of each packet along multiple paths from the source to the sink. The number of data copies (or, the number of paths used) is dynamically determined depending on the probability of channel error. Instead of using disjoint paths, GRAB [12] uses a path interleaving technique to achieve high reliability. These multipath routing schemes for WSNs aim at increasing the reliability for a single flow [10, 11, 12]. In contrast, in this chapter we propose to use multipath routing to support the delivery of multiple flows in a WSN, while the required level of reliability is achieved using FEC. Thus, in applying multipath routing, our goal is to maximize the load balancing effect by spreading traffic evenly over the network, and using all possible paths to maximize the end-to-end capacity.

In DGR [8], using a deviation angle adjustment method, a path can be established successfully using any initial deviation angle specified at the source node. In order to set up an application-specific number of paths with different initial deviation angles, the source can transmit a series of control packets each specifying a different deviation angle. As an example, in Fig. 1.6 the source changes the absolute value of the deviation angle (i.e., α) from 0 to 90 degrees in steps of 22.5 degrees, and sends a different PROB message with each deviation angle. Thus, in total 9 paths are established with α equal to -90, -77.5, -45, -22.5, 0, 22.5, 45, 77.5, and 90 degrees, respectively.

To establish a direction-aware path, a probe (PROB) message is broadcast initially by the source for route discovery. A selected next hop will continue to broadcast PROB message to find its next hop, and so forth. A node receiving a PROB will calculate its mapping coordinates based on α and the positions of the node itself, the upstream node and the sink.

Then, DGR will select as the next hop node the neighbor whose mapping coordinates is closest to the Strategic Mapping Location, instead of the neighbor closest to the sink as in traditional geographical routing protocols. Since DGR is an existing geographical routing mechanism that is employed in the video transmission scheme presented in this chapter, in the above we only describe briefly the path setup mechanism of DGR. Interested readers are referred to [8] for a detailed description of DGR.

After the construction of multiple disjointed paths between the source VN and the sink as illustrated in Fig. 1.6, a hybrid video stream broadcasting and sub-streams unicasting scheme can be implemented based on these pre-established multipaths. An active VN first broadcasts a RTS (request-to-send) message to its one-hop neighbors where delayed broadcast [9] of CTS (clear-to-send) is used to solve the hidden terminal problem. Then, the VN will broadcast to its one-hop neighbors a packet concatenating all the data and FEC packets of a video frame, following the structure shown in Fig. 1.7(a). Those neighboring nodes that are the first intermediate nodes of individual paths to the sink are referred as *CooperativeNode*s.

Upon receiving the concatenated packet broadcast by the VN, each *CooperativeNode* selects its own payload according to the *CooperativeNodeList* in the concatenated packet. *CooperativeNodeList* contains the identifiers of the *CooperativeNode*s and the sequence numbers of the corresponding packets (denoted by *PkSeqNum* in Fig. 1.7) assigned to these nodes. Then these *CooperativeNode*s unicast the assigned packets to the sink via the respective individual paths using the packet structure shown in Fig. 1.7(b).

A simple example of the proposed transmission architecture is illustrated in Fig. 1.8, where the multipath routing layer sets up 3 paths between the source and the sink. Each path goes through a different *CooperativeNode* of the VN. To simplify the analysis, we consider that the VN encodes one video frame into two data packets and one FEC packet, and divides the video stream into three packet sub-streams: two data flows and one FEC flow. The structure of sub-stream entry is shown in Fig. 1.10. The *CooperativeNodeList* is highlighted in Fig. 1.10 and contains the list of *NodeID*s and *PacketToSend*s.

In general, the VN can intelligently specify the number of sub-streams and assign these sub-streams according to the number of available paths, the path length, and the number of data/FEC packets to send for each video frame. If the number of data/FEC packets of a video frame is larger than the number of available paths, some paths will deliver multiple packet flows. Otherwise, the VN can select a set of shorter paths to achieve faster delivery. The length of a path can be estimated by the value of the deviation angle. If the number of residual paths is high, the VN can adopt a Round-Robin path scheduling algorithm among the available paths to achieve load balance. To adapt to the fluctuations in channel quality, the VN also can adjust the number of FEC packets for each video frame and the number of paths used according to the feedback information from the sink.

Assume that the FEC scheme generates $n-k$ redundant packets to protect k data packets of a video frame. If the sink has correctly received the k data packets, it may decode the frame immediately to reduce latency, while the redundant packets are subsequently ignored and dropped. However, if there are errors in the data packets, then the redundant packets are applied in an attempt to correct the errors using the FEC scheme.

In Fig. 1.9, the DGR-based transmission scheme is compared with the traditional scheme where the whole video stream is transmitted over the shortest path.

1.4 Simulation Methodology

1.4.1 Simulation Model

In order to demonstrate the performance of the proposed video transmission scheme employing DGR, we compare it with GPSR [7] via extensive simulation studies. In this section, we present the simulation settings and performance metrics. The simulation results will be presented in the following section.

We implement the DGR protocol and the video transmission scheme using OPNET Modeler [42, 43]. The network consists of 500 nodes randomly deployed over a 300m × 500m field. We assume that all the nodes (VN, sensor nodes, the sink) are stationary. Fig. 1.11 illustrates the topology of a set of randomly generated sensor nodes, as well as the VN and the sink node in the network. As in [6], we use IEEE 802.11 DCF as the underlying MAC, and the radio transmission range (R) is set to 50m. As in [29], the data rate of the wireless channel is 2 Mb/s. We employ the energy model used in [8, 29, 37, 38, 39]. To model link failures, we simply block the channel between two nodes with a link failure rate p. Thus, a packet will be lost with a probability p.

The test video sequence is Foreman encoded by the H.26L video coding standard [2, 3] in QCIF format (176×144 pixels/frame) at a temporal resolution of 20 frames/s. The average bit rate of the video data is about 178kbps, and the average bit rate after packet encapsulation is about 200kbps. The first frame is intra-coded and the remaining frames are inter-coded. Each frame is packetized into 6 data packets. Three FEC packets are transmitted per video frame to protect the video data packets.

1.4.2 Performance Metrics

In this section, we defne five performance metrics as follows:

- *Lifetime* - We believe that the choice of the definition of network lifetime is dependent on the specific application. A lifetime can be measured by the time when the first node exhausts its energy or the network can be declared dead when a certain fraction of nodes die, or even when all nodes die. Sometimes, it's better to measure the lifetime by application-specific parameters, such as the time until the network can no longer relay the video. We define the network lifetime as the time until the first node dies due to energy depletion for the sake simplicity.

- *Number of Successful Frames Received by Sink before Lifetime* - It is denoted by n_{frame}. It is the number of video frames delivered to the sink before network lifetime is reached. Note that due to FEC coding, some packets of a video frame may be lost and the frame can still be correctly received. n_{frame} is an alternate measure of the network lifetime in this chapter.

- *Average End-to-end Packet Delay* - Let T_{dgr}, T_{gpsr}, and T_{gpsr}^{fec} be the average end-to-end packet delay of DGR, GPSR, and GPSR with FEC coding, respectively. They include all possible delays during data dissemination, caused by queuing, retransmission due to collision at the MAC, and transmission time.

- *Energy Consumption per Successful Data Delivery* - It is denoted by e, and is given by the ratio of network energy consumption to the number of data packets delivered to the sink during the networks lifetime. The network energy consumption includes all the energy consumed by transmitting and receiving during a simulation. As in [44], we do not account for energy consumption in the idle state, since this element is approximately the same for all the schemes being compared.
- *PSNR* - The peak signal to noise ratio is a measure of the received video quality.

Among the performance metrics defined above, we believe that n_{frame} is the most important metric for WSNs, while PSNR and T_{ete} are important indicators of QoS for real-time video transmissions.

1.5 Performance Evaluations

In this section, the simulation results for three video transmission techniques are evaluated; i.e., DGR, GPSR (GPSR without FEC coding), and GPSR with FEC coding. In each group of experiments, we change the link failure rate from 0 to 0.3 in step size of 0.05.

In Fig. 1.12, T_{dgr} is always lower than T_{gpsr}, though the average path length in DGR is higher than the length of the shortest path. This is due to the fact that the average bandwidth provided by the shortest path is very close to the bandwidth required by a video stream, so that link congestion and video frame corruption due to burst packet losses are inevitable when single path routing is employed. T_{gpsr}^{fec} is much higher than T_{dgr} and T_{gpsr}, especially at low packet loss rates, which shows that the limited link bandwidth cannot accommodate the additional transmission overhead of FEC packets. As the packet loss rate increases, more packets are lost before they reach the sink. The lost packets do not affect the average end-to-end delay (which only accounts for correctly received packets), but they do help to alleviate congestion. Therefore both T_{gpsr} and T_{gpsr}^{fec} show a reduction as the packet loss rate is increased. However, congestion is not a problem for DGR due to the load balancing effect of multipath routing; therefore T_{dgr} stays relatively constant as the packet loss rate changes.

Fig. 1.13 compares n_{frame} values for DGR, GPSR, and GPSR with FEC coding as the packet loss rate is varied. When the packet loss rate increases, n_{frame} of all the schemes increases since some sensor nodes save the energy of packet transmissions if they fail to receive the packets. DGR has higher n_{frame} values compared with that of GPSR and GPSR with FEC coding, because DGR distributes the traffic load of each video frame evenly over multiple paths. Thus, energy consumption of each path in DGR is much smaller than that of GPSR. In DGR, though 9 paths are exploited, only 6 paths are used to transmit data sub-streams while the remaining 3 paths are used to transmit FEC sub-streams. Ideally, DGR should achieve about 5 times more n_{frame} than that of GPSR (without FEC). However, the cooperative neighbors of the VN are the bottlenecks with respect to energy consumption, since they receive the long concatenated packets from the VN, while other sensor nodes receive much shorter packets with only a single data/FEC payload. The end result is that n_{frame} of DGR is about 3 times more than that of GPSR. With GPSR, if FEC coding is adopted, more energy is consumed to transmit the FEC packets. Thus, n_{frame} of GPSR with FEC is about 40 lower than that of GPSR.

Fig. 1.14 shows the comparison of PSNR for these three schemes. It can be seen that DGR has the highest PSNR, which on average is about 3dB higher than that of GPSR with FEC and 5db higher than that of GPSR. Though the PSNR of GPSR with FEC is higher than GPSR, the delay and lifetime performances of GPSR with FEC are worst, as we have described above.

Fig. 1.15 compares the PSNR of each frame resulting from the test sequence Foreman with packet loss rate = 0.05. Since GPSR does not take any measure to prevent error propagations, the PSNR of the reconstructed image decreases rapidly as more frames are received, and the subjective quality of the received video is poor. At a higher packet loss rate (0.2 in Fig. 1.16), the received video quality degrades rapidly for all the schemes due to packet losses. Nevertheless, DGR still achieves the highest perceived quality for the video frames received at the sink.

Fig. 1.17 shows that e_{dgr} is always higher than that of GPSR and GPSR with FEC under varying packet loss rates. This is because the average path length of DGR, which is equal to total path length (accounting for all the paths used to delivery the video stream) divided by $PathNum$, is larger than that of GPSR. GPSR with FEC has a higher e than GPSR due to the additional energy consumed to transmit the FEC packets. However, for real-time service in WSNs, e is not as important as the other performance metrics.

For comparison purposes, it is important to consider the lifetime, PSNR and average delay for real-time video applications. Thus, we adopt the following metric to evaluate the integrated performance of n_{frame} as an indicator for lifetime, PSNR and delay:

$$\eta = \frac{n_{frame} \cdot PSNR}{delay}. \tag{1.1}$$

The higher is η, the better is the composite QoS provided by the WSN to support real-time video services. No matter whether FEC coding is adopted or not, DGR achieves a much higher η than GPSR. Since GPSR with FEC obtains small improvements of PSNR by sacrificing the energy-efficiency and delay performance, the η of GPSR with FEC is lower than that of GPSR.

Note that the above simulation scenarios do not reflect the impact of multiple active video sources. When multiple video sources are active, the complexity of our scheme is higher than that of a single path routing scheme such as GPSR. We believe that this is a price well paid for improved video quality. Furthermore, DGR may not work efficiently when the number of source-sink pairs is larger, while GPSR is suitable for the general cases where any sensor could be a source. When multiple data sources exist, GPSR is expected to maintain its performance while that of DGR may degrade due to path interference. This poses a severe limitation on the range of applications that can be supported by DGR, such as in a VSN as proposed in this chapter. Due to the bandwidth limitation of a typical WSN, it is reasonable, as we have assumed in this chapter, that video sources do not transmit data simultaneously to the sink. Instead, they may make requests to the sink when there are video streams to send, and take turn to send video packets when instructed to do so by the sink. The protocol for making/granting these initial requests is a subject for further study.

1.6 Conclusion

In this chapter, we have presented a novel architecture for video sensor networks, and investigated the problem of real-time video transmissions over WSNs in general. Compressed video is susceptible to transmission errors. However, the limited bandwidth in a WSN may not allow video sensor nodes to transmit additional FEC packets to protect the video data without subjection all packets to excessive queuing delay. It is challenging to simultaneously achieve delay guarantees and obtain a high perceived video quality at the sink. To solve this problem, we have proposed a novel video transmission scheme which efficiently combines multipath routing with FEC coding to tackle the natural unreliability of WSNs as well as their bandwidth constraints. After the construction of an application-specific number of multiple disjointed paths, the proposed hybrid video stream broadcasting and sub-streams unicasting scheme is applied. This study has also provided insights into novel usage of multipath transmissions in WSNs. Instead of the typical application of multipath routing in traditional WSN designs to provide path redundancy for failure recovery, our scheme employs multipath routing to increase aggregate source-to-sink bandwidth and achieve better load balancing. Performance evaluations have shown that in combination with packet-level FEC coding, the proposed multipath based video transmission scheme simultaneously achieves reliability, energy-efficiency and timely packet delivery to support real-time video service over WSNs.

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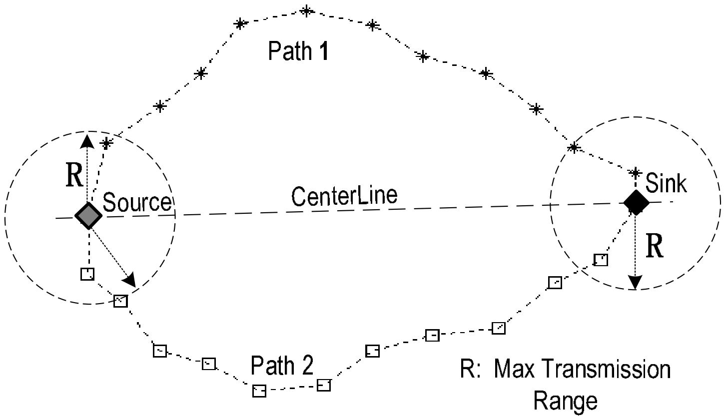

Figure 1.1: Minimum number of paths constructed in DGR.

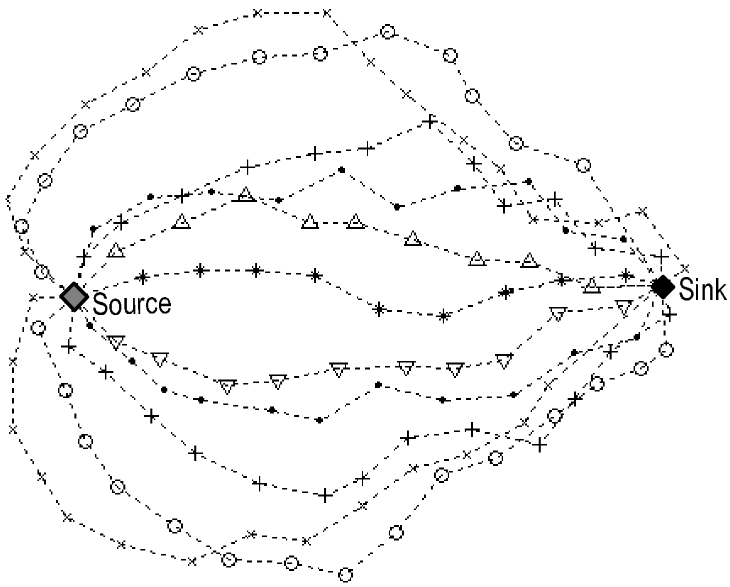

Figure 1.2: Maximum number of paths constructed in DGR.

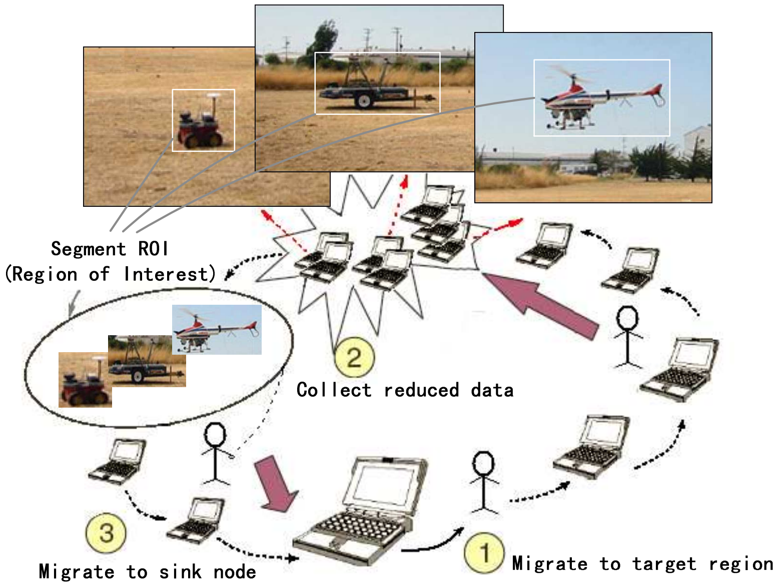

Figure 1.3: Mobile Agent Based Image Sensor Querying.

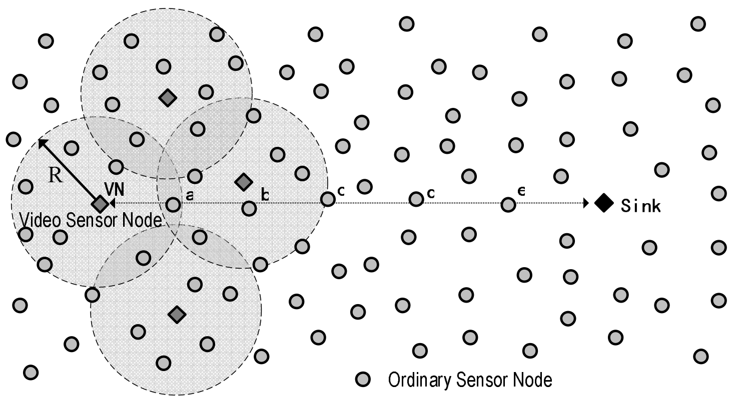

Figure 1.4: System architecture of video sensor network.

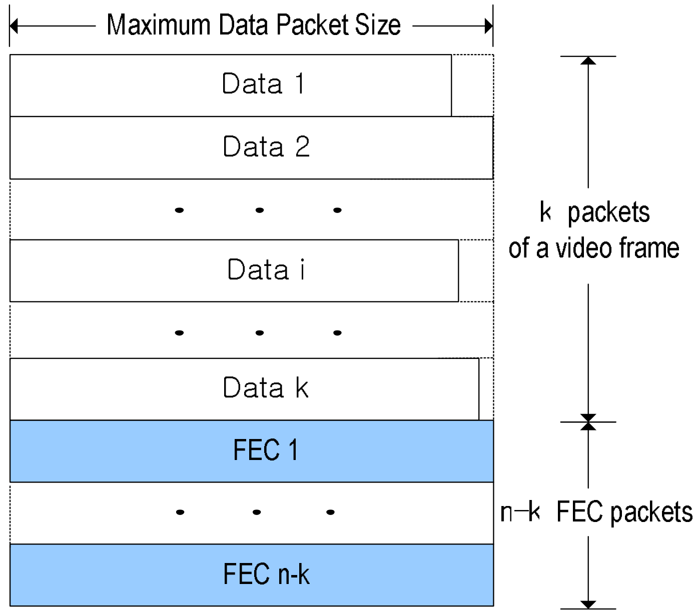

Figure 1.5: FEC coding scheme.

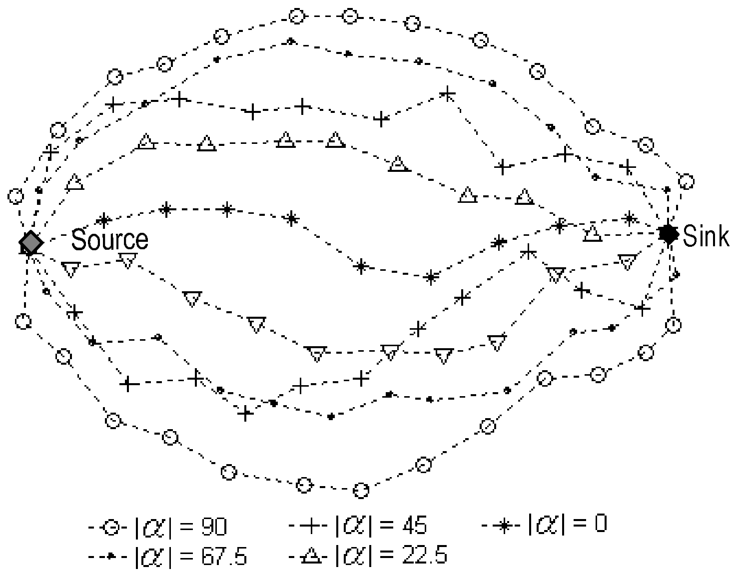

Figure 1.6: Example of 9 disjointed paths using DGR.

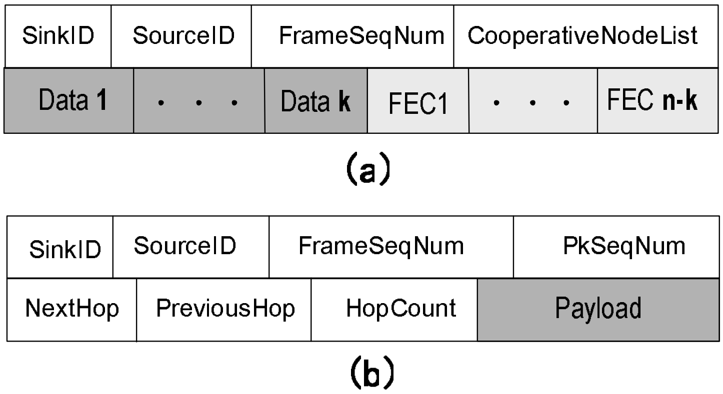

Figure 1.7: Data packet formats: (a) Concatenated data broadcast by VN; (b) Data unicast by ordinary sensor node.

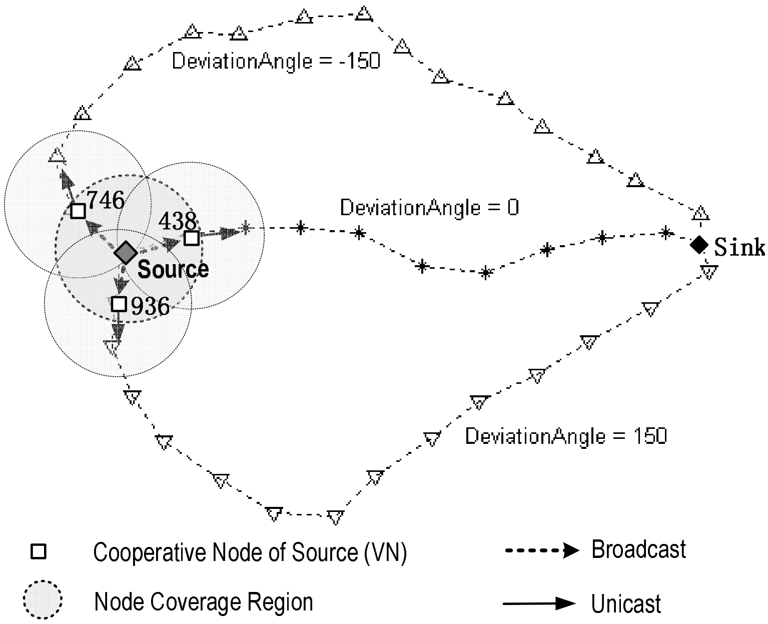

Figure 1.8: Illustration of DGR based multipath video transmission.

Sub-stream Entry of VN

SubStreamSeq	PathSeq	DeviationAngle	NodeID	PacketToSend
1	1	-150	746	Seq(Data 1)
2	2	0	438	Seq(Data 2)
3	3	150	936	Seq(FEC)

CooperativeNodeList

Figure 1.9: Comparison of video transmissions: (a) DGR; (b) Traditional scheme.

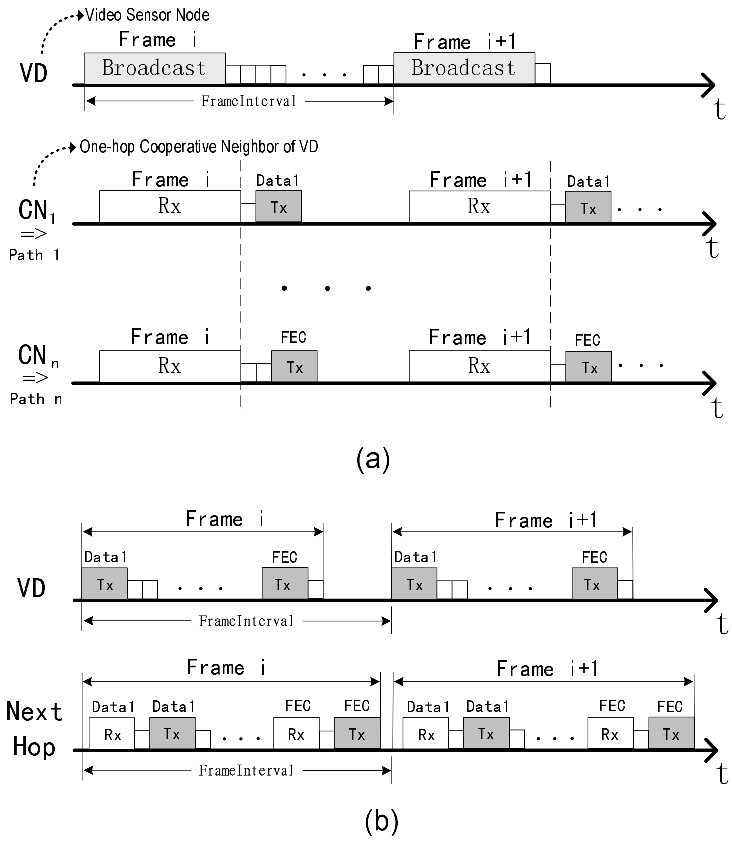

Figure 1.10: Example of sub-stream entry of the VN (NodeID as in Fig. 1.8).

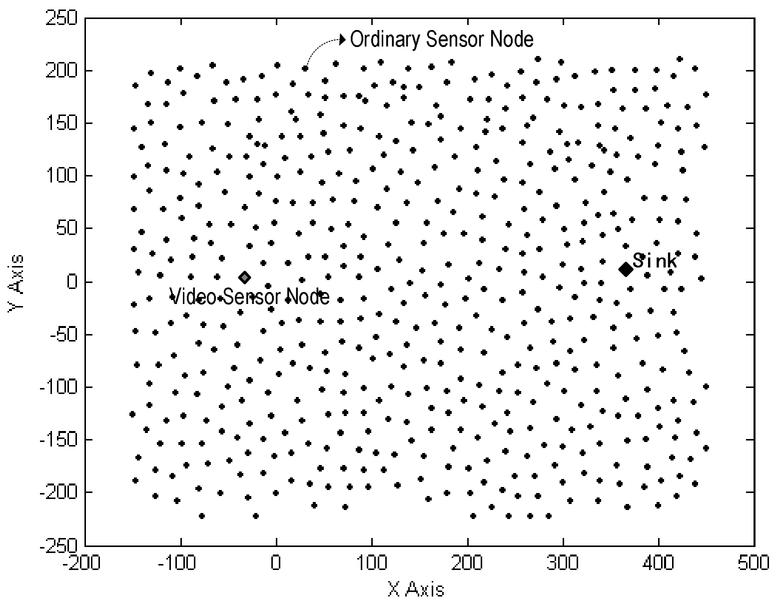

Figure 1.11: Example of network topology in simulation.

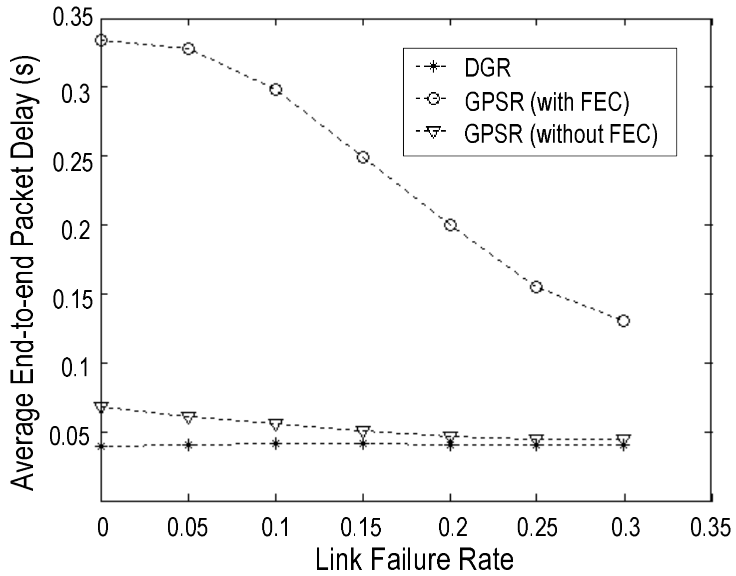

Figure 1.12: Comparisons of T_{ete}.

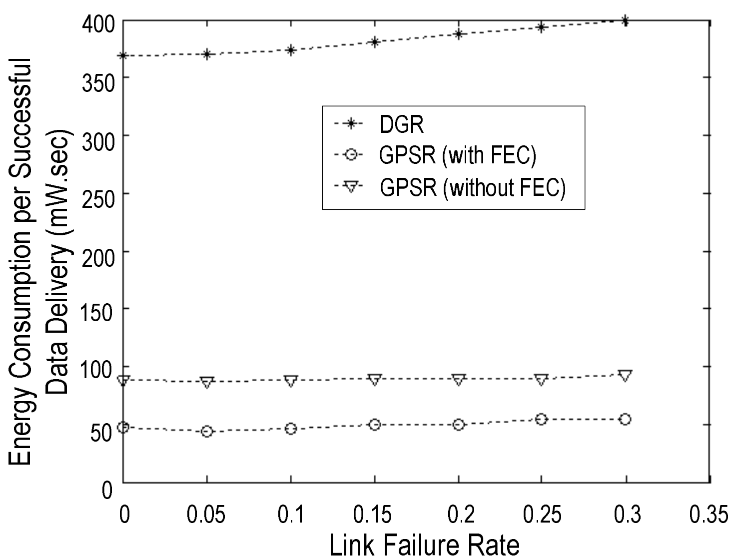

Figure 1.13: Comparisons of n_{frame}.

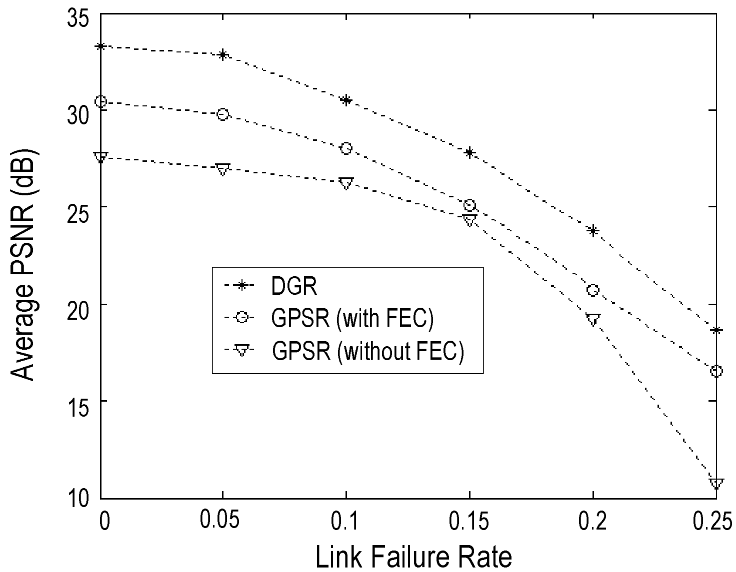

Figure 1.14: Comparisons of $PSNR$.

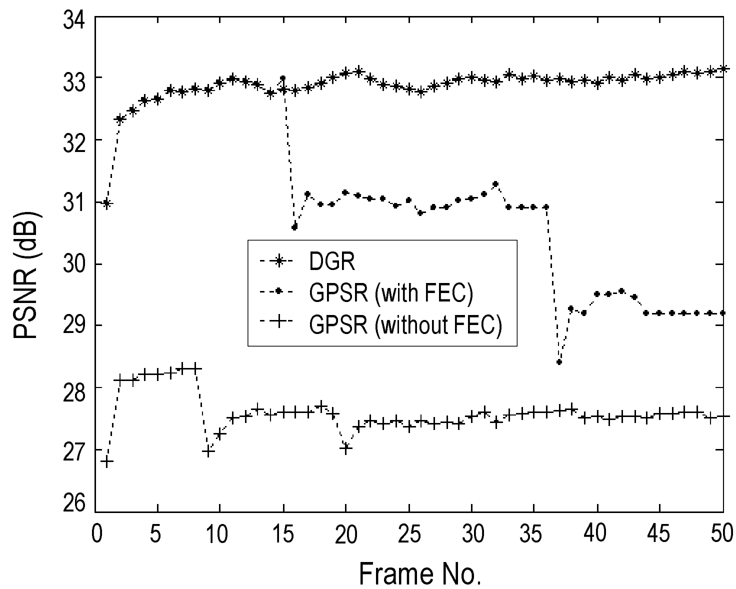

Figure 1.15: Comparisons of PSNR with link failure rate = 0.05.

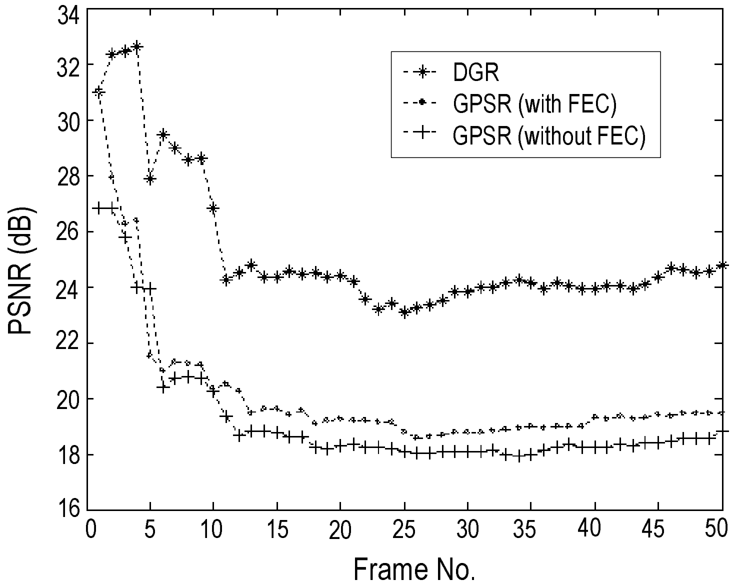

Figure 1.16: Comparisons of PSNR with link failure rate = 0.2.

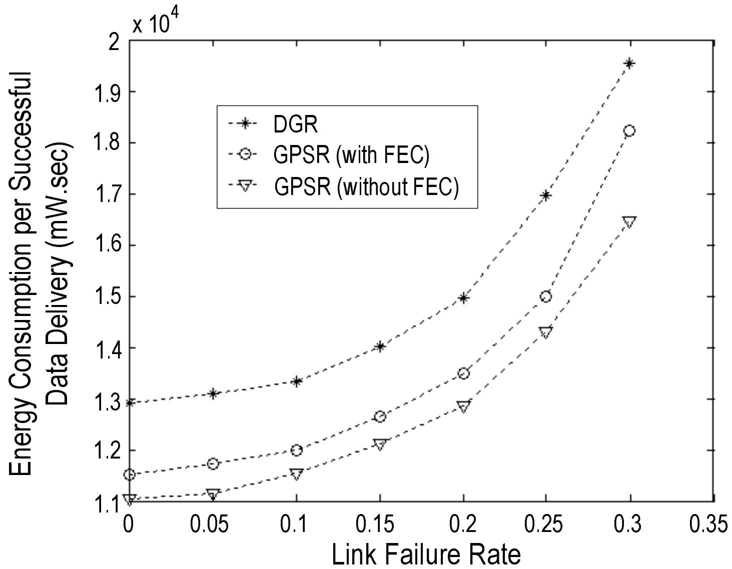

Figure 1.17: Comparisons of e.

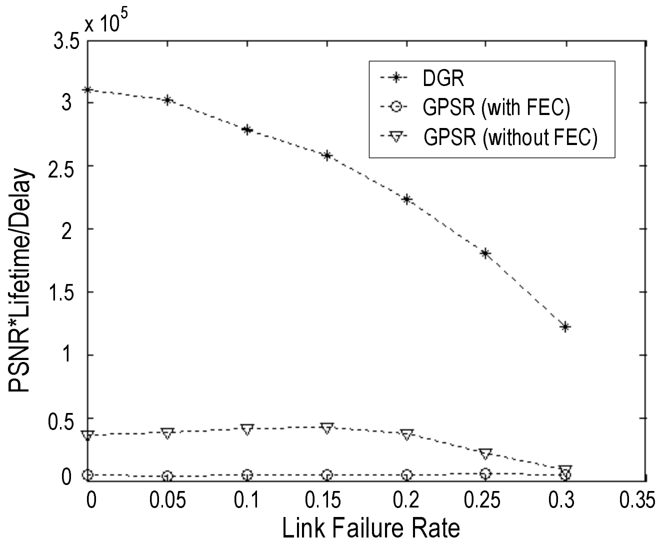

Figure 1.18: The Comparison of η.