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POWER-RATE-DISTORTION ANALYSIS OF WIRELESS VISUAL SENSOR NETWORK

By

William Shaw

B.Sc., Tatung University, Taipei, Taiwan (China), 2005

A thesis
presented to Ryerson University
in partial fulfillment of the
requirement for the degree of
Master of Applied Science
in the Program of
Computer Network

Toronto, Ontario, Canada, 2008

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ABSTRACT

Power-Rate-Distortion analysis of

Wireless Visual Sensor Network

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Master of Applied Science

in the Program of Computer Network

Ryerson University

The emergence of low-cost and mature technologies in wireless communication, visual sensor devices, and digital signal processing, facilitates the potential of wireless sensor networks (WSN). Like sensor networks which respond to sensory information such as temperature and humidity, WSN interconnects autonomous devices for capturing and processing video and audio sensory information. This thesis highlights the following topics: (1) a summary of applications and challenges of WVSN; (2) the performance analysis of a wireless sensor network and wireless multimedia sensor network. To extend the system performance, two methods are provided in this thesis. First, mobile sink with node scheduling in multiple tracking targets is proposed. Second, a layered clustering model in sparing communication energy consumption in wireless visual sensor network is proposed. The experimental results validate our correlated approaches extend the system lifetime; (3) directions for Future Research are given.

ACKNOWLEDGMENT

First, I would like to express my sincere gratitude to my supervisor, Dr. Ivan Lee for his intellectual and editorial support over the past 2 years. His insights have been very valuable in enabling my exploration of new research directions as well helping me overcome the many problems that we encountered. I have also benefited vastly from his emphasis on improving both academic and industry knowledge. He has been a great teacher, motivator and research mentor.

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PUBLICATION LIST

1. **W. Shaw,** Yifeng He, and Ivan Lee, "Mobile Sink to Track Multiple Targets in Wireless Visual Sensor Networks," *IEEE International Symposium on Ubiquitous Multimedia Computing*, Oct 2008. (To appear)

2. I. Lee, **W. Shaw**, and X. Fan, "Wireless Multimedia Sensor Networks," *Handbook of Wireless Ad Hoc and Sensor Networks*. (To appear)

3. X. Fan, **W. Shaw**, and I. Lee, "Layered Clustering for Solar Powered Wireless Visual Sensor Networks", in Proc. of *IEEE International Symposium on Multimedia, pp. 237-244,* Dec. 2007.

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CHAPTER 1
INTRODUCTION

1.1 Motivation and Objectives

In the past decades, advances in wireless communication and miniaturization of hardware, wireless visual sensor network (WVSN) has been drawn attention by researchers. With the characteristics of low cost, low power, and small footprint, WVSN can be widely applied in applications such as battlefield surveillance, environmental monitoring, inventory control, human-centric applications, and robotics. Most of these applications are deployed in open space with a large order of wireless sensors, and each sensor is powered by battery. Due to energy restriction, the system life time of WVSN becomes a major issue. Therefore, most researchers are focused on improving the system life time and lowering the power consumption in each sensor node. Adopting a mobile sink is a method to prolong the lifetime in WVSN. By using the mobile sink, the cluster head structure can make WVSN communicate more efficiency than by using a stationary sink, hence the system life time can be improved.

In this thesis, our research focuses on wireless visual sensor networks with a mobile sink and a hierarchical clustering architecture. Typically, a sensor network is composed of three components: sensor nodes, cluster heads, and a sink. The sensor nodes are equipped with different sensors. For example, in wireless multimedia sensor networks, sensor nodes are capable of capture sounds, images, and temperature. To facilitate these features, sensor nodes need to equip with cameras and audio sensors. Moreover, for some military applications, sensors are also responsible to relay precise locations of the intruders to notify the actors, such that automatic weapon systems can target and destroy the intruders before damages are made. Once sensor nodes capture the data, data will be forwarded to the cluster heads. In addition to the function of capturing the multimedia data such as voices, texts, and images, the cluster head nodes also serve the functions of data aggregation. By implementing an aggregating function into cluster heads, duplicated data can be removed, hence reduce the total energy consumption during the transmission. After eliminating the redundant data, cluster heads will forward the data to a base station. Generally, the base stations have a larger energy capacity, a powerful computing capability and more communication resources. They act as a gateway between the sensor nodes and the end users. The visual data gathered from the wireless visual sensor network is saved in the sink. In this work, we put our research focus on:

- How to prolong and achieve the maximum system lifetime in WVSN for a multiple intruders situation?
- How to achieve an improved video quality for a restricted energy situation by using the power-rate-distortion analysis.

To address the above questions, we present the following in this thesis:

- We examined the performance of system lifetime in mobile sink in comparison with in stationary sink. In mobile situation, multiple intruders are concerned more close to reality situation. In addition, we proposed a node scheduling mechanism, mobile sink, and power-rate-distortion into the clustering model to deal with the restricted energy consumption. The system lifetime can be prolonged with our proposed scheme. By analyzing the simulation results of different speeds of single and multiple targets scenarios, we obtained the best speed in our proposed model. With the node scheduling mechanism, our simulation result shows that the cluster head architecture can support more events and conserve more bandwidth. The mobile sink system can also yield a better performance compared with the stationary sink for scenarios with multiple targets. Moreover, we also implement the previous history record to determine the starting point of sink. Our analysis of the experiment results demonstrates that with the combination of the hierarchical scheduling mechanism and the mobile sink architecture, the performance of the wireless sensor network can be enhanced with limited energy and computing capacities of visual sensors.

- In the second part of this thesis, we examined the performance of layered clustering applied in a solar-powered WVSN. We investigate a solar cell recharging model under a layered clustering architecture to deal with the restrict energy consumption while maintaining the video quality. The system lifetime can be prolonged by adopting rechargeable solar cells that can be recharged by solar panel during the daytime. In addition, we analyze the simulation results of energy consumption and total transmitted packets by changing the aggregation rate and gate energy (GE). With the aggregation rate decreasing, the cluster head in the inner layer can support more visual nodes and reserve more bandwidth. The lower GE can reduce the packets loss during the system charging process. The experiment results obtained in this thesis indicate that with the combination of layered clustering and solar recharging, the performance of wireless visual sensor network can be enhanced under the consideration of the restrict node's capacity and video distortion.

1.2 Thesis Organization

This thesis is composed of five chapters and the rest four chapters are organized as below. Followed the introduction in Chapter 1, Chapter 2 introduces the related work of WSN, wireless visual sensor networks (WVSN).

Chapter 3 examines the performance of a mobile sink model in the WVSN. Since the bottleneck of stable sink cluster head is due to the energy of the cluster heads near to the sink in WSN. We applied the mobile sink clustering model into our system. The experiments are implemented under the considerations of multiple intruders and different number of clusters. The experimental result proves that the mobile clustering model can prolong the system lifetime of in most situations.

Chapter 4 proposes the layered clustering model in the WVSN. Since the energy consumption is the most critical issue in WVSN, by applying layered clustering model and rechargeable solar cell unit into the WVSN can improve the system lifetime. The experiments are implemented under considerations of visual quality and solar cell recharging. The experimental result proves that the layered clustering model can prolong the system lifetime of solar-powered WVSN in most situations.

Chapter 5 provides conclusions and directions for the future work. We first summarize and list our contributions in the thesis. Then future work on the homogeneous and heterogeneous solar-powered WVSN and advanced routing protocol in mobile sink are provided.

CHAPTER 2
RELATED WORK

This chapter introduces the related work of WSN. The remainder of this chapter is organized as follows,

Section 2.1	introduces background on WSN.
Section 2.2	introduces system metrics to measure the network lifetime.
Section 2.3	introduces the wireless platform and technologies in WVSN.
Section 2.4	summarizes the current schemes to solve the energy issue in WVSN.
Section 2.5	discusses quality of service in WSN.
Section 2.6	introduces the power-rate-distortion model

2.1 Background of Wireless Sensor Networks

WSN is sometimes considered as a subset of wireless ad-hoc networks [12]. Although WSNs share some similarities with wireless ad-hoc networks, there are several different features in WSN [32]: (1) the number of sensor nodes in a sensor network could be several orders of magnitude higher than that in a ad-hoc network; (2) the topology of a sensor network changes much more frequently due to the low power supply; (3) sensor nodes mainly use a broadcast communication paradigm, whereas, most ad-hoc networks are based on point-to-point communications; (4) sensor nodes are constrained by energy supply, computational capabilities and memory size; (5) sensor nodes may not have global ID because of the large amount of overhead and large number of sensors.

In general, the WSN can be classified into two categories: heterogeneous and homogeneous.

A heterogeneous wireless sensor network is made up of a large number of wireless sensor nodes that are randomly distributed in an open area. As shown in Fig 2.1, their responsibilities are to capture an event and generate the signal, process data and communicate with the other nodes or the base station. They are usually used in an open area such as battlefield and wild environment, and with human supervision. In addition, these sensor nodes are capable of self-organizing, event-detection, and event-activation.

2.1.1 The basic components of WVSN

Sensors may be used for various applications: some sensors record the temperature and humidity; others may detect noise level. These sensors may include wireless communication capabilities to simply the installation. In [32], a typical wireless sensor node is made up of four basic components: the sensing unit, the processing unit, the transceiver unit, and the power unit. Fig 2.1 shows the components of sensor nodes. A sensing unit usually consists of sensory devices and analog-to-digital converters (ADC). Sensing unit is responsible for sensory data capturing, which is fed into the processing unit. For multimedia sensor nodes, sensing units can extend audio and video sensing capabilities and able to perform rich data applications such as video surveillance and traffic monitoring. The role of a processing unit is to process the data captured by the sensing unit, encapsulates, and forwards to other sensors or base station. A transceiver unit plays the role to connect the node to the networks. The most important component of a sensor node is the power unit. In order to support computational complexity for processing multimedia data, a large power unit is required. There are two optional

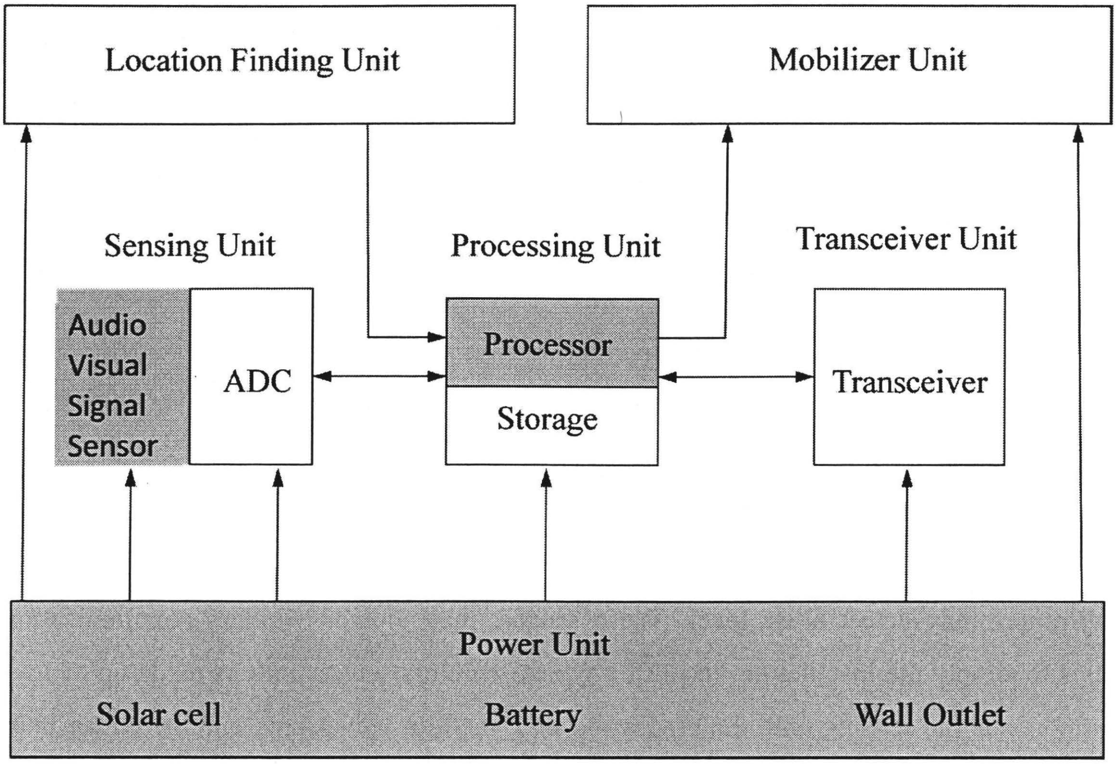

Fig. 2.1: Basic components of a wireless multimedia sensor (modified from [32])

subunits in sensors: mobilizer unit and location finding unit. For some routing protocols may require the location information. To deploy Global Positioning System (GPS) in sensor nodes can retrieve neighbor locations which can be used to compute routing metrics and improve the performance of the WSN. Although most sensor nodes are placed in a fixed location, it is possible to embed a mobilizer to move sensor nodes when they need to track moving objects.

2.1.2 Design challenge of WSN

Since the sensor nodes are aimed at low-cost, low-power, and multifunctional development, all the subunits may need to fit into a small sized module. Apart from the size, there are also other constraints to implement a WSN into an open area. (1) Most applications in the field of

WSN are designed under the constraints for communication energy and bandwidth. Data formats such as raw image and audio may cause rapid energy depletion or bandwidth congestion. [13][14]. (2) In WSN, the processing power and battery life are scarce resources in sensor nodes. A complexity coding technique can significantly increase the power consumption and delay. Thus, advanced coding methods such as source coding and distributed coding can prolong the system lifetime and reduce the bandwidth usage [15]. (3) Security in WSN becomes a problem because of a lack of physical protection in wireless channels. Conventional security mechanisms in 802.11 wireless LANs are not suitable for WSN. Moreover, resource constraints such as limited computation power become a major challenge to deploy security mechanism into WSN. In [16][17], various attacks in data link layer and network layer are given. (4) Routing in WSN is challenging due to the huge amount of sensor nodes. Building global addressing schemes such as IPv4 and IPv6 are not suitable. Moreover, most routing protocols for WSN focus on energy saving rather than QoS. For applications such as remote medicine, high packet loss and delay can be a catastrophic. Thus, specific routing techniques and physical layer protocol should be designed in WSN.

2.1.3 Applications of WVSN

Although sensor nodes are low-cost, low power devices with limited sensing, computation, and wireless communication capabilities, they provide more flexibility in comparison with traditional surveillance system. Thus, these networks can support a wide range of applications such as military and environmental monitoring. In [18], authors survey the numerous applications that utilise wireless sensors, or wireless sensors networks and classify them in appropriate categories.

- **Security**: For scenarios such as temporary indoor exhibitions, installing traditional surveillance cameras is expensive and difficult to remove [19]. Deploying the WSN can act as temporary surveillance systems or online tour guide. In addition, multimedia sensor nodes can be placed close to the entrance, and they can monitor and record customers, and then transmit the video and audio data to the base station.

- **Wild animal tracking:** In a national park, it is difficult to tracking the habitual behaviors of wild animals by using fixed surveillance system due to the high cost of installation. Wireless sensors can provide mobility for moving object. Furthermore, in the case of direct transmission from sensors to base station is blocked; a multiple hop scheme embedded in WSN can be utilized to carry over the transmission. Therefore, an information loss or delay can be avoided

- **Traffic monitoring and environmental measurement:** Multimedia sensors can be applied into downtown area to monitor rush hour traffic and help drivers avoiding the congested roads. In addition, sensors can measure the noise level and air pollution for research purposes.

- **Remote Medicine:** In a desolate area, sensors can transmit video and audio of the patient to the doctors who resides in metropolitan areas. With these data, doctors can provide the first aid to someone is injured such as telemedicine, prescription, and monitoring the patient continually on heart beat, pulse, body temperature, and blood pressure [20].

- **Climate and sea shore monitoring:** Sensors can continually record the video data on the climate, such as, the cloud, sunrise, sunset, moon, and temperature. In addition, for sea shore monitoring [21], WSN can provide more flexibility and low cost devices.

- **Battlefield surveillance:** For battlefield surveillance, visual sensors can be used to monitor the enemy remotely. In addition, WSN can be coupled with actor nodes to launch reactive missile attacks once certain sensory events are triggered [22].

- **Airport Surveillance:** After 911 terrorist attacks, the attention of airport secu-rity has been significant raised. Low cost sensors can be used for monitoring the registration desk, luggage delivery, plane arrival or departure, and customer density.

- **Fire alarm and control:** Sensor and actor networks can be integrated into fire alarm systems. Water sprinkler actors can be extinguished before a fire becomes uncontrollable based on sensory information [23].

2.2 System Evaluation Metrics

In WSN, battery life time is the most important factor that affects the system performance. Therefore, researchers try to find the most efficient way to prolong the lifetime. There are several ways to measure the lifetime of WSN. In this section, we summarize the most common definitions in form of a survey on lifetime definitions.

2.2.1 Network lifetime based on the number of alive nodes

The most frequently found definition in the literature is n-of -n lifetime. In this definition, the network lifetime can be shown in (1).

$$T_{n}^{n} = \min_{v \epsilon V} T_v \quad (1)$$

T_v is the lifetime of node v. T_{n}^{n} is easy to compute and the algorithm can avoid the topology changes. The only reasonable case to use this definition is if all nodes are of importance and critical to the network [1]. Several variants of the T_{n}^{n} are introduced as follows.

[2] is a variant of n-of-n lifetime in clustering scheme. An important assumption for this approach is the cluster heads are chosen beforehand- more powerful nodes and remain unchanged throughout the network lifetime. Then, the network lifetime is defined as the time until the first cluster head fails.

Another variant of n-of-n is to define the network lifetime as the time until the fraction of alive nodes falls below a thread β [3]. However, the drawback of this definition is that the network is still alive but the data can't be transmitted to sink (perhaps the nodes around the sink failed).

In [12] the author summarized the evaluation metrics of lifetime based on alive node.

- Time until the first node dies: This metric indicates the duration for which the sensor network is fully functional.

- Time until a β fraction of nodes die: The suitability of this measure is application dependent. Across applications, choosing $\beta = 0.5$ seems to be appropriate. Unless specified otherwise, we use this metric to indicate the lifetime of the network.
- Total number of messages received: Total number of messages received until a β fraction of the nodes die indicates the amount of information collected until that time. This measure is an indicator of the total amount of information collected during its lifetime.
- Energy spent per round: The total amount of energy spent in routing messages in a round is a short-term measure designed to provide an idea of the energy efficiency of any proposed method in a particular round.

2.2.2 Network lifetime based on sensor coverage

Another frequently used definition to measure the lifetime of WSN is based on sensor coverage. In WSN, sensor nodes are randomly deployed in a larger physical area, sensor nodes may capture the have duplicate data. Therefore, a sensor node failed may not affect the whole network. It is important to know the coverage of the network is not equal to the range of the wireless communication links. The coverage can be defined in different ways depending on the region of interest. For instance, it could be a two dimension area or three dimension space. In [4]-[7], it defined 100 % coverage as the alive system. [4] [5] assume each event is covered by at least one sensor node. [6] [7] define the lifetime as the whole area is covered by at least one node. The design challenge of this measurement is the schedule when the multiple sensors are active. Since the duplicate data may consume the energy and bandwidth, local aggregation method can be applied to achieve the maximum system lifetime.

2.3 Wireless platform

Unlike wired networks, packets in wireless networks are easily interfered by noise and lost during the transmission. In WSN, since the nodes may run out of the energy or might be damaged, it should provide certainly robustness mechanisms to guarantee that end user can still receive information. For instance, redundant nodes in the networks can solve the case of damaged nodes or node run out of energy. Moreover, the packet loss and collision should also be considered in WSNs. The packet losses are inevitable due to the wireless characteristics and limited bandwidth; interference and collision error are easily occurred during transmission which result in an increase of damaged data. In [24], the authors classified existing MAC protocols of WSN into four categories: scheduling based, collision free, contention based, and hybrid schemes. They also summarize the challenges for designing MAC in WSN. By eliminating collisions during transmission, the power for retransmission and end-to-end delay will be reduced. In addition, current wireless MAC protocols are not feasible for WSN because they only focus on throughputs instead of power consumptions. In [26], the authors studied the drawbacks of collision free medium access in WSN such as Time Division Multiple Access (TDMA), Carrier Sense Multiple Access (CSMA), and Frequency Division Multiple Access (FDMA). The difficulties of TDMA systems are node synchronization, topology change adaptation and throughput maximum issue. On the other hand, CSMA needs to employ additional collision detection mechanisms to achieve collision free and FDMA requires the additional circuitry to dynamically communicate with different channels. In addition, [25] uses seven different channels to avoid co-channel interferences. However, this method needs extra hardware to support the collision free feature and will increase the cost of production.

WVSN targets to handle rich media data such as video and audio using sensors. In this section, a number of popular wireless communication standards are will discussed; these standards include IEEE 802.11, Bluetooth, ultra wide band (UWB) and Zigbee. Bluetooth is a standard for Wireless Personal Area Network (WPAN), and it provides a universal short range wireless capability by using the 2.4-GHz spectrum. Bluetooth can be implemented between devices such as headphone sets, video game controllers and printers where data can be exchange over a secure radio frequency. In Bluetooth, nodes are organized into a piconet, consisting of a master and up to seven active slaves. The master can make the determination of the hopping sequence. However, two drawbacks of Bluetooth are provided [27]. Firstly, Bluetooth needs to constantly have a master node, spending much energy on polling his slaves. Secondly, Bluetooth is limited by the number of active slave per piconet and some important data will be dropped during inactive time. Because of the two factors above, Bluetooth is less favorable for WSN applications.

The IEEE 802.11 is another well known standard using in WLAN. There are three physical media are defined in original 802.11 standard: direct sequence spread spectrum, frequency-hopping spread spectrum and infrared. In [12], 802.11b has the maximum data rate at 11 Mbit/s. 802.11b is normally used in a point-to-multipoint configuration and an access point communicates via an omni-directional antenna with one or more clients that are located in a coverage area around the access point. 802.11-based WSN benefits from simple hardware requirement, high date rate, and the use of direct sequence means to avoid the problems of frequency hopping systems [22]. However, the cost and power consumption of 802.11 systems is far beyond the feasibility of wireless multimedia sensor networks [29]. IEEE also defined 802.11e to support the local area network applications with quality of services, including voice and video over WLAN. By deploying enhanced distributed channel access (EDCA) and hybrid coordination function (HCF) into 802.11e, traffic can be delivered based on predefined priorities.

Zigbee is a standard suite of a high level communication protocols that aims at small, low-power digital radio based on IEEE 802.15.4. ZigBee fulfills most of WSN application requirements, such as a low data rate, a long battery life, and a secure networking. Zigbee operates in the ISM radio bands: 868 MHz in Europe, 915 MHz in the USA and 2.4 GHz in worldwide. This technology is intended to be simpler and cheaper than the competing WPAN standards such as Bluetooth. Although Zigbee is intended to be deployed in embedded applications that demand low data rate, low cost, and low power consumption, it is not feasible for WSN: the best effort multi-hop transmission of JPEG and JPEG2000 images over Zigbee networks is examined in [14][15]. The result shows that multi-hop transmissions of JPEG2000 images are unfortunately not completed due to adverse environment with interference from uncontrolled IEEE 802.15.4 and IEEE 802.11 wireless devices [15]. In addition, [16] implemented the face recognition applications in wireless image sensor networks. The image transmission speed and power consumption is considered in this paper. The result shows that most power is consumed on the radio transceiver, and transmission speed is reasonably low for systems that are not demanding a high frame rate. In [21], the wireless cameras networks over Zigbee are developed. The interaction between different subsystems of wireless cameras is proposed to reduce the overhead for inter-layer communication and thus increase the performance.

Ultra wide band (UWB) [17] aims at facilitating high speed, low power, low-cost multimedia applications. Two differences between UWB and other traditional narrow band are specified in [17]. Firstly, the bandwidth of UWB system is more than 25% of an arithmetic centric frequency. UWB is intended to provide an efficient bandwidth for multimedia transmission. Secondly, UWB is typically implemented in a carrier-less fashion. UWB is apart from the conventional "narrowband" system use the Radio Frequency (RF) carriers to move the signal [18].

In [19], a practical example of UWB WSNs is investigated. By applying UWB for wireless sensor networks, it ensures low-power, low cost, and wide-deployment sensor networks. Although the UWB transmission has been discussed for several years, the IEEE 802.15.3a task group still cannot reach a consensus. In [20], the open research issue was presented. The cross layer communication based on UWB with the objective of delivering the QoS to WSNs should be designed. A comparison between the above mentioned standards is summarized in Table. 2.1.

Protocol	Frequency operation	Range	Data rate	QoS support
802.11b	2.4 GHz DSSS	Up to 110 m	Up to 11 Mbit/s	Yes with 802.11e
802.15.1(Bluetooth)	2.4 GHz FHSS	Up to 10 m	1Mbit/s	Yes
802.15.3	2.4GHz	30-50m	10 -55Mbit/s	Yes
802.15.3a (UWB)	3.1~10.6GHz	Up to 10m	100-500 Mbit/s	Yes
802.15.4 (Zigbee)	868-868.6MHz, 902-928MHz, 2400-2483.5MHz	10 - 75 m	20 kbps, 40 kbps, 120 kbps	No

Table 2.1: Physical layer Protocol comparisons

2.4 Current proposed methods

Due to the restricted energy issue, researchers propose various methods to deal with the energy consumption. In [3], power saving techniques can be classified in the following categories:

- Schedule the wireless nodes to alternate between active and sleep mode.
- Power control by adjusting the transmission range of wireless nodes
- Energy efficient routing, data gathering
- Reduce the amount of data transmitted and avoid useless activity

For example, [8]-[12] propose the routing protocols to enhance the system lifetime. In [8], a cluster-based protocol is proposed by Heinzelman et al. It is a self-organizing, adaptive clustering protocol that minimizes energy dissipation in sensor nodes. SPIN is an adaptive protocol proposed in [9] [10]. Unlike conventional protocols such as flooding and gossiping which transmit the duplicate information and resource blindness, SPIN integrated negotiation and resource-adaptation mechanisms to overcome duplicate information. A spatiotemporal communication protocol for sensor network called SPEED was introduced [11][12]. SPEED provides three types of real time communication services: real time unicast, real time area multicast and real time area any-cast. SPEED can maintain a desired delivery speed and reroute the traffic during the congestion by employing neighborhood feedback loop (NFL) and Backpressure Routing.

Another method to prolong the system lifetime relies on the renewable energy. Modern solar cells can produce up to 10 mW per square inch in direct sunlight. For some outdoor WSN applications, the energy collected during the day can last through the night. In chapter 4, we applied the solar cell model into the clustering multimedia sensor networks and retrieve a better system lifetime. The other common method to reduce the energy consumption is to remove the duplicate data locally. Since the wireless sensor nodes may capture the same events (temperature, sounds, and image etc), to aggregate this data locally and forward to end-users can save bandwidth and energy.

In [30], the coverage and routing cost are integrated into an application-aware routing protocol. The result shows that the lifetime of video sensor networks can be prolonged because of the unique way that cameras capture data. The position of the cameras' field of views (FoVs) is unpredictable. Thus, the application-aware protocol behaves differently in a video sensor. In addition, node scheduling mechanism can enhance the performance of system lifetime. By scheduling the node into sleep mode or idle mode, it can reduce the traffic and forward duplicated data.

The processing unit and the power unit are scarce resources for visual sensors. Therefore, a complexity source coding technique can significantly increase the power consumption and delay. Unlike wired networks, wireless communication is subject to a high error rate due to channel interference, multi-path fading, and other loss mechanisms. Therefore, efficient and effective source and channel coding techniques are crucial to resolve the issues. Image and video are popular types of media used on multimedia sensors. Several image/video coding technologies are studied in video sensors or surveillance systems such as JPEG, differential JPEG [90][91] and H.264 [92]. Comparisons of JPEG and JPEG2000 over ZigBee networks [90], and JPEG2000 has shown a superior error-resilience in terms of PSNR because of its improved multiple layer coding. JPEG and differential JPEG are applied to construct a video sensor platform which delivers a high quality video over 802.11 networks with a power consumption of less than 5 watts [91]. For reducing the traffic load, H.264 [92] may be applied to yield a high compression ratio. Additional feature such as object tracking may apply a median filter algorithm to improve the computational speed [92]. However, its encoder complexity raises the power consumption issue [93], which may be inappropriate for WMSN applications since the sensors has limited processing power and memory space.

Another promising coding technique for wireless sensor is distributed coding, which shifts the complexity of the encoding algorithm to the decoder [94]. Popular distributed coding techniques include the PRISM technique, Slepian-Wolf coding, and Wyner-Ziv coding [95] [96]. Slepian-wolf coding is a lossless source coding for compression two independent identically distributed (i.i.d) correlated random variables X and Y [97]. The minimum achievable rate in a point-to-point lossless communication system is specified by the Slepian-Wolf theorem. The basic concept of Slepian-Wolf is code binning which means information sources are separately encoded and jointly decoded. Wyner-Ziv coding is an extension of Slepian-Wolf coding [98]. Wyner-Ziv coding gave the rate distortion function when the encoder and the decoder both access to the side information. In addition, Wyner-Ziv coding can provide an error-resilient transmission [99], which is suitable for many-to-one uplink video communication systems such as wireless video and distributed sensor networks [99]. Paper [99] presents a WMSN system which maximizes the audio compression ratio while minimizing the energy consumption using a wavelet-based distributed audio coding (WDAC) technique.

2.5 Quality of Service

In visual applications, sparing the energy consumption on the one hand and yet guaranteeing the image quality that system requires on the other hand, are two vital facts for wireless visual sensor network. For real time video applications such as battlefields monitoring, delays in video and audio transmission may cause severe or even catastrophic impacts on critical decisions. Factors causing latencies in WSN include in-network processing, queuing delay and transmission delay [31]. In general, the transmission delay is relatively small in comparison with the delay for data processing; therefore, the latency of processing time should be minimized. In addition, multi-hop transmission helps reducing the power consumption with reduced node-to-node distances, and hence improving the lifetime for WSN [32]. However, the drawbacks of this approach include the extended end-to-end delay, security vulnerability, and difficulties in queue scheduling [28]. Furthermore, most delay is due to the waiting period for collecting the image data in the similar area and processing time of decrypting, uncompressing, and aggregating image data [33]. Hence, reducing the delay is a crucial task for time-critical WSN applications.

Reducing power consumption is an important topic for ensuring an improved network lifetime. Aggregating the redundant video data captured by sensory de-vices helps eliminating excessive bandwidth usage and consequently reducing the transmission power. However, the complex aggregation algorithms processed by cluster head sensors take additional processing power and memory. Another strategy for reducing energy consumption is by putting sensors into the sleep mode, which might however introduce additional latencies such as sleep delay [34].

Exploring the optimal energy-latency trade-offs is therefore an important issue in QoS.

QoS-based routing is another important topic in WSN. Conventional QoS routing protocols used in wireless ad hoc networks [38]-[40] may be inadequate for WSN due to its severe resource constraints. Sequential Assignment Routing (SAR) [8] is one of the first QoS-based routing protocols in WSN. To balance between the energy consumption and the image quality, SAR uses three factors for making routing decisions: energy resource, QoS on the each route, and the priority level of packets. Furthermore, SAR also employs the multipath transmission. SPEED is another well-known routing protocol used in WSNs which guarantees a soft real-time requirement [8]. In addition, to solve the scarce resource issues such as limited bandwidth and energy in WSNs, SPEED use a non-deterministic for-warding to balance the flow among multiple routes. Although SPEED uses a novel back-pressure rerouting to overcome packet congestion, it does not have a packet prioritization scheme. MMSPEED [35] is a protocol based on SPEED, and it is designed for handling multimedia traffic with embedded scalability and adaptability. The energy-aware QoS routing mechanism proposed in [41] deals with real time traffic in WVSN. By finding a least cost, delay-constrained path in terms of link cost, it captures nodes' energy reserve, transmission energy, and other parameters as routing metric. With this method, traffics will be divided into two classes: non real-time and real-time. The drawback for this method is that it does not support multiple priorities for real-time traffics [24].

The QoS measure in WVSN should also consider the relationship between image quality and energy consumption [37]. Others suggest that the trade-offs between power, rate, and distortion [42] play an important role for designing wireless sensor networks. Another study also suggests that the balance between complexity, rate, and distortion should be examined [44]. To study the impact of system resources to the overall system performance, resource-distortion analysis was proposed as an alternate measure of the conventional rate-distortion analysis [36]. In addition, the concept "accumulative visual information" (AVI) was introduced to measure the amount of visual information collected in wireless video sensors [36], and it jointly evaluates entropy, image distortion, encoding efficiency and energy consumption as a measure of the system's quality measure [36].

While WVSN may be used to facilitate surveillance or monitoring applications, visual coverage is another important QoS parameter. Since sensors may be randomly placed in an open space, there may be different overlapping density covered by different sensors. This overprovision of sensors will make the energy consumption inefficient [30]. By coordinating sensors' activation status using a cost function and alternatively switching sensors into the sleep mode, the overall network lifetime can be prolonged and the bandwidth demand is reduced [30]. Similar results were found for scenarios extended to three dimensions [45]. In [43], the trade-off between the network lifetime of WSN and image distortion is discussed. By deploying the hybrid or adaptive camera selection into the WVSN, the optimal lifetime-distortion trade-off will be provided. Although the overlap-ping coverage increases energy consumption, it provides more information to the end users. For example, with more sensor nodes in action, the tracked object can be viewed from different angle. Malicious attacks such as sending unrealistic images through the wireless transmission can be prevented.

2.6 Power Rate Distortion

Unlike WSN whose data rate is often low, data processing is simple. The video encoding and data transmission are the two dominant power-consumption operations in wireless visual sensor networks. The efficient video compression significantly reduces the video data to be transmitted and saves the energy in data transmission. However, more efficient video compression also requires more complexity computation and power in computing. The two most important factors in transform coding of images are coding bit rate and the image quality. One direct and widely used measure for the image quality is the mean squared error (MSE) between the coding image and the original image. Unlike the traditional wireless network, WVSN operates under a set of unique resource constants such as energy supply, computational capability, and transmission bandwidth. The existing performance metric for conventional WSN is not applicable to WVSN. To find the best trade-off among the bandwidth, video quality, and power consumption, [76] [77] develop the Power-rate-distortion (P-R-D) behavior of video encoding system.

To analyze the energy consumption of video encoding and its impact to the R-D, the R-D

(a) Original frame

(b) Distortion is 82.0874

(c)Distortion is 43.5453

(d) Distortion is 7.1588

Fig.2.2 The original frame and the reconstructed frames with different distortion in Foreman sequence

of practical data compression system is given in [78]. In [76] [77], the end-to-end distortion consists two parts: source coding distortion and transmission distortion. The source coding distortion is caused by lossy video compression and it relates to the amount of power allocated for video coding and the source bit rate. The transmission distortion is caused by transmission error and it relates to the transmission power and transmission distance. With limited energy, to maximize R-D performance under the power constraint, an optimum allocation of the computing power among different encoding model should be found.Fig.2.2 shows the different distortion of Foreman frame. Fig. 2.2(a) is the original frame. Fig. 2.2(b) is the reconstructed frame with 1-layer quality. The distortion is 82.0874 and PSNR is 28.988 dB. Fig. 2.2(c) is the reconstructed frame with 2-layer quality. The distortion is 43.5453 and PSNR is 31.7414 dB. Fig. 2.2(d) is the reconstructed frame with 3-layer quality. The distortion is 7.1588 and PSNR is 39.5824 dB. In this thesis, the main distortion is due to the different quantization approach and frame rate. The power-rate distortion can be listed in (1)

$$D_s = \sigma^2 e^{-\gamma R_s \cdot g(p_v)} \quad (1)$$

Parameter	Description
$g(P_v) = (P_v)^{2/3}$	Energy consumption model
$P_v \in [0, P_0]$	Energy consumption of video processing
$R_s \geq 0$	Bit rate
$\gamma = 11.54$	Model parameter related to encoding
$\sigma^2 = 350$	Input variance

Table 2.2 Power-Rate-Distortion Parameters

2.7 Security issue in WVSN

WVSN in general is more vulnerable to malicious attacks in comparison with wired solutions due to the lack of physical medium protections [100][101]. Applications such as battlefield monitoring and surveillance, insecure communications may potentially be a catastrophic issue.

Thus, delivery of sensitive multimedia data using an efficient and effective encryption technique while sustaining a low power consumption should be treated as a major design aspect for developing WVSN. With such design aspect, applying the security mechanisms in popular WLAN standard such as IEEE 802.11e in WVSN may not be feasible.

Apart from confidentiality, another security issue of WVSN is related to the integrity and legitimacy of the multimedia content such as video and audio. Techniques such as digital watermarking and multimedia fingerprint may be applied to resolve these issues in WLAN. In [102], a security mechanism using digital right management (DRM) is presented for video sensor networks. If the video content is transmitted over the Internet instead of private leased lines, the DRM technique serves two major benefits: (1) DRM can effectively shield its protected data from unauthorized access. For example, for patient monitoring applications, the access to patient's private profile such as patient's appearance could be limited to certain individuals. (2)Some sensor content may hold significant commercial values such as highway traffic monitoring, airport surveillance, and industry control monitoring. DRM provides a set of solutions for abuse of access account for trading, accounting, and transaction processing of digital contents as commodities [102].

In WVSN, sensors are limited by power, computational ability, storage, and transmission range. Attackers can use the powerful laptop with high energy and long distance communication to perform attacks by these design aspects. Furthermore, several design challenges of secure WVSN are raised [103]:

Physical attacks will be a risk for WVSN due to the fact that sensor nodes are accessible in open areas. Thus, adversaries can easily locate and destroy the sensor nodes. Since nodes could be physically captured, attackers may compromise the cryptographic keys from the sensor nodes and then install malicious node into the network to perform attacks such as sinkhole attack [104]. In addition, some sensors equipped with solar cell may rejoin the network later. Thus, a mechanism to guarantee new joining sensors are not malicious nodes should be provided in WVSN.

The key establishment will be more difficult due to the large scale of sensor nodes. For example, it is undesirable to deploy the public key algorithms such as Diffie-Hellman key agreement [106] or RSA [105] because of their computational complexities. In addition, using different keys for each individual sensor will enlarge the memory size and increase the cost of production. Shared keys, on the other hand, has less overhead than public keys. The drawback of shared key is once attackers compromise a single node in a network would reveal the secret key and then the network traffic can be easily decrypted [103].

WVSN can be considered as a specialized WSN for multimedia applications. Because of carrying rich image content, the energy consumption and end-to-end transmission delay should be minimized in WVSN. In [107], a link layer security architecture is studied. By detecting unauthorized packets when they first inject, the authors presented authenticity, integrity and confidentiality of message exchanges between neighboring nodes. In [108], network layer attacks such as sinkhole attacks in sensor networks are discussed. In addition, by discussing these attacks, the possible solutions are also provided.

As indicated earlier, the key establishment and trust setup can deeply affect the WVSN security. Public key and share key approaches are not suitable for large scale WVSN due to resource constraints [89]. Therefore, key distributions have been an active research topic in WVSN. Cheng et al [112] classify enhanced key pre-distribution mechanisms into three categories: (1) random key pre-distribution schemes, (2) polynomial-key pre-distribution schemes, and (3) location based key pre-distribution schemes. Random key pre-distribution [116] allows nodes deploying at later time joining the network securely. By picking a random pool of keys from the total possible key space, nodes perform key discovery to find out a common key within their respective subsets, and it is used as their shared secret key to initiate a secure link. Random key pre-distribution solve the computational over-head in public key and provide a secure link between two nodes; however it also increases the overhead of communication during key discovery. Polynomial-key pre-distribution, on the other hand, not only requires a lower communication overhead, but have less sufficient security than random key pre-distribution. Location based key pre-distribution [111] uses the location deployment of sensor node to improve the networks performance. As indicated earlier, WVSN is vulnerable to various types of attacks because of hardware constraints of sensors. Below we summarize the attacks in the network layer and possible solutions for these attacks.

- **Replay attack:** In [109][114], replay attacks in WVSN is studied. An adversary that eavesdrops on a legitimate message sent between two authorized nodes and replays it at same later time. For surveillance applications, adversary can spoof the system by simply placing pictures in front of the camera and play recording. In [107], a common defense includes a monotonically increasing counter with message and reject message with old counter value. However, the main drawback is the cost of maintaining the neighbor table and extra device memories are required.
- **Cut and paste attack**: In [117], the cut and paste attack is investigated. By breaking apart an unauthenticated encrypted message and constructing another message which decrypts to something meaningful, cut and paste attack is a type of message modification attack that attackers removes a message from network traffic, alters message, and reinserts message into the network. The possible solution of cut and paste attack is integrated watermarking scheme into image [115]. Main drawbacks of this solution include the increase in distortion and energy consumption.
- **Selective forwarding:** In multi-hop WVSN, sensors are based on the assumption that participating nodes will faithfully forward the received messages. However, an attacker may create malicious nodes that receive the data from the neighbor and refuse to forward any further. In WVSN applications such battlefield surveillance, sensed data can be easily corrupted and caused a catastrophic problem. In [119], the detection method of selective forwarding is provided. By deploying a multi-hop acknowledgement technique to launch alarms, the responses from intermediate nodes can be obtained. An intermediate node can report abnormal packet loss and suspect nodes to both the base station and the source node. The main drawback of this approach is that extra processing demand will consume more energy.
- **Sinkhole attack**: An attacker can send unfaithful routing information to the neighbours, and then perform selective forwarding or alters the data passing through. To resolve the issue of this problem, a two-step algorithm for detecting sinkhole attack is presented in [116]. Firstly, it locates a list of suspected nodes by checking the data consistency, and then identifies the intruder in the list through analyzing the network traffic flow. The drawback of this approach is its extra processing demand which also causes additional delay.

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- **Sybil attack**: Analysis of Sybil attacks and its defence strategies are studied in [118]. An attacker can employ a physical device with multiple identities, to generate Sybil attack during the data aggregation, voting and resource allocation. Furthermore, Sybil attack can reduce the effectiveness of fault-tolerant schemes significantly. The possible defence is to validate an identity to the corresponding physical devices. Newsome et al [118] provided methods such as radio resource testing, random key pre-distribution, registration, position verification and code attestation. The random key pre-distribution is the most promising technique to prevent Sybil attack without additional overhead [118].
- **Wormholes**: An attacker records a packet at one location in the network, tunnels the data to another location, and replays the packet there. The attacker can perform the attack even if the attacker does not have any cryptographic keys [113]. In addition, a malicious node could announce that a shortest path through this node and create a black hole in this region. Temporal leashes are possible solutions for the wormhole attack, and the TIK provides an instant authentication of the received packets. A MAC using TIK can efficiently protect against reply, spoofing, and wormhole attacks without additional processing demand at the MAC layer [113].
- **HELLO flood attack**: For protocols that require HELLO messages to build the association and to announce their presence to their neighbours, an adversary may perform the HELLO flood attack [110]. In HELLO flood attack, a malicious node can transmit a message with an abnormally high power so as to make all nodes to believe that it is their neighbours. When normal sensors hear the HELLO message from this malicious node, they will treat the malicious node as the next hop and then a routing loop may be created. The authors also presented the suspicious node information dissemination protocol (SNIDP) to deal with this problem. The concept of SNIDP is that node A detects a suspicious through the signal strength. Once suspicious node S is detected, node A will the identity of node S to its neighbours and then perform a suspicious vote. With this process, malicious node can be detected. However, the drawback of this approach is the energy consumption associated with additional message checking, message transmissions and receptions incurred by the execution of SNIDP.
- **Node capture attack**: The node capture attacks are studied in [104]. Because of the physical constraint of sensor nodes, an attacker may physically capture some sensor

nodes and compromise their data and communication keys. In [116], instead of requiring sensors to store all assigned keys, the authors deploy the random key pre-distribution into WVSN. Although attacker can compromise the cryptographic, only partial information will be decrypted.

CHAPTER 3

MOBILE SINK TO TRACK MULTIPLE TARGETS IN WIRELESS VISUAL SENSOR NETWORKS

This Chapter introduces the background knowledge of clustering model with mobile sink. Based on the mobile sink, the experiments are illustrated respectively. The reminder of this chapter is arranged as follows,

Section 3.1	introduces the background knowledge of WVSN
Section 3.2	presents the system models, which are made of clustering model, mobile sink, and scheduling mechanism.
Section 3.3	shows the experiments of the mobile clustering model under the consideration of multiple targets situation and scheduling model.
Section 3.4	summarizes the proposed schemed in WSNs and future work.

3.1 Background

Recently, with the increasing use of wireless networks, mobile computing has drawn an attention by researchers. Wireless sensor network (WSN) is one of interesting and important fields in mobile computing because of its flexibility, low-cost, and low-power. In WSN, sensor nodes are small devices equipped one or more sensors and possible actuators which are used for observing an event, generating the data, and relaying the data to the end users. With this feature, WSN can be used in national defense (tracking troop movement) and surveillance applications.

However, unlike the conventional sensor networks which have continuous power supply, sensor nodes in WSN are limited by energy and bandwidth, large and dense network. A critical issue in WSN is power scarcity due to the battery size and weight limitations. Therefore, management of the energy resources can directly impact the performance of application.

In [48], power saving techniques can be classified in the following categories:

- Schedule the wireless nodes to alternate between active and sleep mode.
- Power control by adjusting the transmission range of wireless nodes.
- Energy efficient routing, data gathering.
- Reduce the amount of data transmitted and avoid useless activity.

Wireless visual sensor networks (WVSN), on the other hand, provide rich data such as image and video in the academia and in the industry. With the low cost, low power, and small footprint characteristics, wireless sensors can be used in various applications, such as battlefield surveillance, distance monitoring, product inspection, inventory management, virtual keyboard, and smart office. Most of these applications span over an open area, and a large number of wireless visual sensors may be required for an adequate coverage. One of the important applications of WVSN is target-tracking. Since the sink can be unmanned ground vehicles (UGV), mobile sink can perform intruder detection, collect sensed information, and then destroy the intruders. In the recent literature, the paper in [55] provides an automated intrusion detection and inventory assessment capability to detect anomalous conditions and intruders. Based upon sensory feedback from remote sensory input such as video cameras, the prevention of intrusion can be the response of the UGV. Due to the mobility of the sink, dynamic routing is also required of WVSN.

In WVSN, visual sensor nodes collect and transmit the data to the cluster heads, which then forward the data to the sink node via multi-hop relays. In the literature, a sink node is usually deployed in the center point without any mobility. Consequently the lifetime of the entire network is limited by the cluster heads close to the sink, since those cluster heads have larger power consumptions. When the cluster heads deplete its energy, the sensed data are dropped and a blind area is created. To extend the network lifetime, LEACH is proposed in [46] by rotating the cluster head and local aggregation. In [47], Mobility-Based WSN is proposed. By deploying the mobile sink into WSN, two isolated sensor networks are connected. Furthermore, it reduced the energy consumption of multi-hop communication. In [48, 49], mobile sink for target tracking in WSN is proposed. By using sensed information, the mobile sink moves toward the target, thus reducing the communication cost.

Although the in-networking processing such as data aggregation removes the redundant information, it will consume more energy in computation. In a densely deployed network, the monitoring area covered by sensor nodes may be similar or overlapped. Therefore, turning off redundant nodes does not reduce the overall system coverage. In [50], a node scheduling algorithm is proposed in WSN to effectively extend network lifetime. Based on the local neighbor information, a node decides to turn itself off when it discovers that its neighbors can cover the sensing area of itself. Scheduling the number of on-duty sensors can improve the performance of each cluster head.

In this chapter, we proposed mobile sink scheme with node scheduling mechanism in WVSN. The node scheduling mechanism removed the duplicate sensed data before it is sent to cluster head, thus reducing the energy consumption for data aggregation and enhancing the lifetime of cluster head. In addition, since the duplicate data is removed by the node scheduling mechanism, the bandwidth usage is also reduced. Secondly, by using the sensed information, sink can move to the position which is the average shortest distance to each target and then obtain a longer system lifetime in the equal-weight multiple-object scenario. To obtain the best result of our model, the different speeds of sink are investigated in our simulations. Furthermore, since sink is assumed to have unlimited energy, history record is used to determine the starting point of sink.

The rest of this chapter is organized as follows. The mobile sink with node scheduling on multiple targets situation is described in section 2. The simulation results of single-target situation and multiple-target situation are presented in section 3. Finally, section 4 draws the concluding remarks and proposes future work.

3.2 The Related work and System Setup

Data dissemination is an important function accomplished by sensor nodes. Collected data are normally forward to a central gathering point, called sink. Unlike the generic wireless networks, the number of sensor node may be orders of magnitude higher than generic wireless networks. In addition, sensor nodes are unattended and thus limited by energy. Management of the energy resources can directly impact the performance of application. For these reasons, traditional networking paradigms may not directly applicable to WSN. In this section, several concepts are introduced as following paragraphs.

3.2.1 Mobile sink model

In most of literatures, sink nodes are usually deployed statically. As the sensed data are forwarded to the sink node (data collect center) in WSN, the drawback of static sink is that the lifetime is always decided by the sensor nodes or cluster heads close to the sink. To solve this problem, two major categories are used in WSN. LEACH is a cluster-based protocol proposed by Heinzelman et al. [49]. In LEACH, sensor nodes will organize themselves into local cluster based on the minimum communication energy. Once all the nodes grouped into the corresponding cluster, sensor nodes start collecting the data and then transmit to their cluster head. Since the cluster head receive all the data from its cluster, it aggregates the data and then transmits them to the base station. LEACH is localized coordination and control for cluster setup, rotation of the cluster head to enhance the system lifetime, and local aggregation and compression to reduce the overhead of communication. It solving the problem of farthest node to base station will drain the battery first and easily managing sensors locally due to sensors are split into clusters. In addition, in order to spread this energy usage over multiple nodes, LEACH also provided dynamic routing mechanism. The cluster head will not be fixed and the position will rotate at different interval based on the cost function. However, there are still some drawbacks of LEACH such as the extra overhead for cluster head changing [46] and the delay due to the in-networking process such as aggregation and encryption.

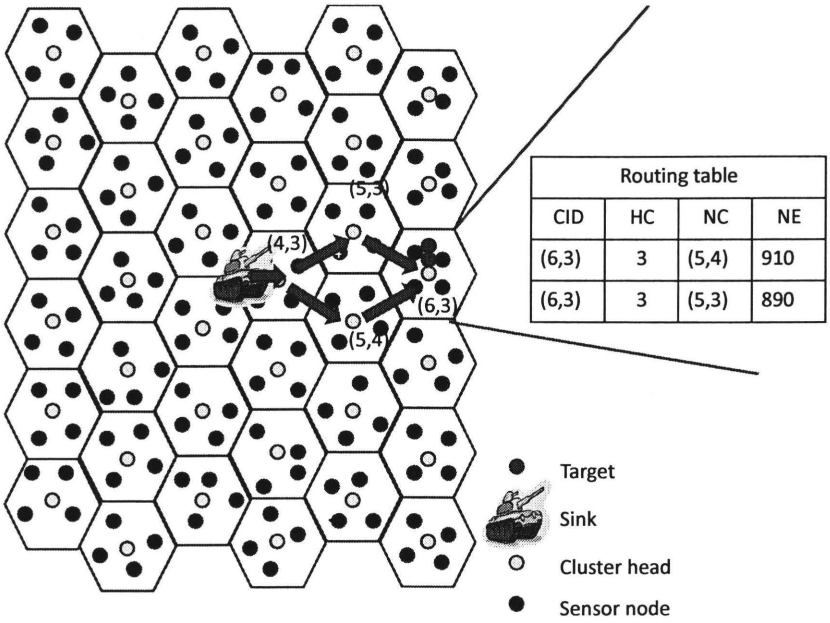
Another category is deployed mobile sink into WSN. In [46], the mobility of data collection points (sinks) are deployed into WSN. The simulation results are shown that energy consumption varies with the current sink location. In [47], authors proposed a scheme which adopts a mobile sink for target tracking applications to maximize the network lifetime. [50] suggests to use a mobile robot as a sink to collect information in single tracking applications. In [51], four characteristic mobility patterns for the sink along with different data collection strategies are proposed. The results shows that by taking advantage of the sink's mobility, the energy spent in relaying traffic significantly reduce and thus greatly extend the lifetime of the network.

The mobile can be classified into two types of movement: random mobility and predictable mobility. The simplest of all possible mobility patterns is the random walk, where the targets can move chaotically towards all directions at constant speeds. In [52], random walk model is given. At each invocation M selects a random uniform angle in $[-\pi, \pi]$ radians. This angle defines the deviation from the target's current direction. Predictable mobility, on the other hand, is a good model for public transportation vehicles (buses, shuttles and trains), which can act as mobile observers in wide area sensor networks [55].

In [53], alternative tracking error metric Q, the expected distance between the estimated and actual positions of the target is defined in equation (1):

$$Q = E[\sum_i q_i(t)] = E\left[\sum_i \sqrt{(X_e(t) - x_i(t))^2 + (Y_e(t) - y_i(t))^2}\right], \tag{1}$$

where $q(t)$ is a instantaneous tracking error which is represented by the distance between the estimated and actual locations of the target,($X_e(t), Y_e(t)$) is the estimated location of the target, ($x_i(t)$, $y_i(t)$ is the actual position of the target at time t. For multiple-targets situation, Q represents the sum of distances between the sink to each target.



Routing table			
CID	HC	NC	NE
(6,3)	3	(5,4)	910
(6,3)	3	(5,3)	890

Fig 3.1 Routing schemes

3.2.2 Routing Scheme

In figure 3.1 shows the routing scheme. For each cluster head, we pre-deploy it into the center of cluster area. The cluster head will have better energy capacity comparing with sensor nodes. The key features of deploying cluster head in WVSN are localized coordination and control. Based on [49], the Sensor nodes only store the routing information to its belonging cluster head. In addition, the routing table of cluster heads can be reduced in terms of memory all the routing information and reduce the bandwidth consumption. At first, the sink will broadcast an ANNOUCENMENT messages

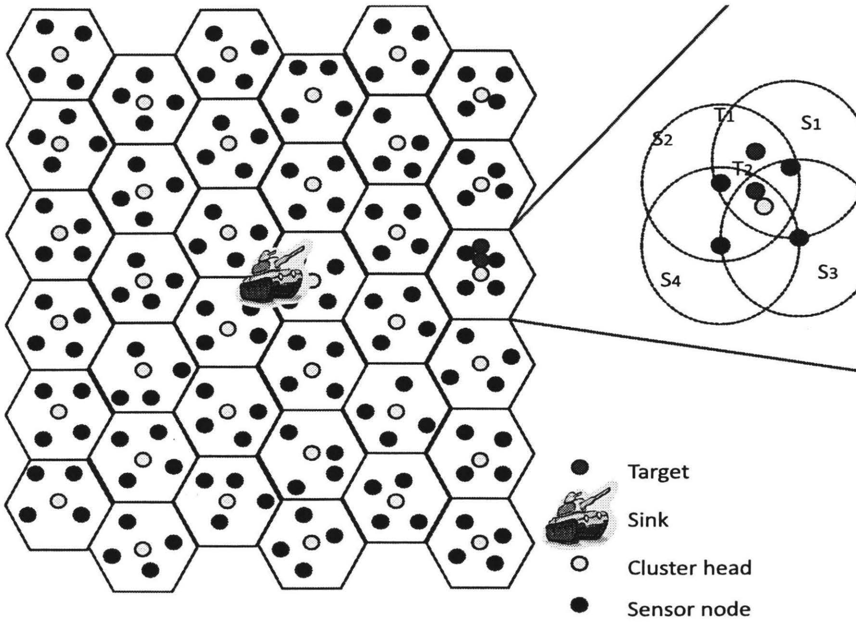


Fig .3.2 The deployment of a WVSN

containing the Hop_Count (HC) field, Next_hop (NH), and the remaining energy of next hop (NE) to the neighbour cluster heads. The HC will be used to denote the hop distance to the sink. The energy consumption will based on the distance and calculate the energy. While the cluster head received this ANNOUCENMENT originated from sink, it will increase the HC by 1 and forward this message to its neighbor cluster heads. If the cluster head received more than one message, it will select the route with lowest HC. If the HC is the same, it chooses the one which has higher remaining energy of next hop. This process will last until all the cluster heads decide the shortest path to the sink. Finally, the sink will store the locations and ID of the cluster head in its routing table.

Since the sink will move and the routing table will be changed depending on the position of the sink. In order to get the better lifetime, when the sink still in the same cluster, the routing table will not be changed (reduce the routing overhead).

3.2.2 Scheduling mechanism

As we mention in section 3.1, scheduling the wireless nodes to alternate between active and sleep mode can save the energy consumption of sensor nodes. In addition, due to the randomly deployment of sensor nodes, the coverage of sensor nodes has certain overlap. The advantage of this coverage overlapping provides redundant data and solves the fault tolerant problem. However, the redundant data will consume more energy and bandwidth in WSN. For scheduling mechanism, cluster head can send a message to control the active or inactive of sensor node. When the tracking target moves to the monitoring area that only one sensor can detect, the cluster can reactive the inactive nodes.

In each cluster, node selection is determined based on the coverage. The sensing range of each sensor is predefined and each sensor is equipped with global position system (GPS) to locate its position. In addition, we can assume that n sensors, denoted as S_1, S_2, ..., S_n, are randomly deployed in a cluster and k tracking objects, denoted as R_1, R_2, …, R_k, are located in a cluster. The coverage relationship between sensors and targets can be illustrated in Fig. 3.2. T_1 can be detected by {S_1, S_2, S_3 S_4}. T_2 can be detected by {S_1, S_2}. To remove the duplicate information and reduce the bandwidth usage, only S_1 or S_2 needs to send the data to the cluster head (depending on the remaining energy). For example, the remaining energy of S_1=910 unit and the remaining energy of S_2=810 unit. The cluster head asks only S_1 to forward the sensed data; other sensors are off-duty. In Fig. 3.2, 4 sensors are triggered by T_2 and forward the data to the cluster head; however, with the node scheduling method, only one of sensors will be asked to forward the sensed data.

We also define the cluster heads' power consumption in (2), where P_t is the power consumption on wireless transmission, and P_v is the power consumption on the data processing such as source coding and data aggregation. By using the scheduling method we reduce P_v on data aggregation.

$$P_{ch} = P_t + P_v, \tag{2}$$

Since the node scheduling reduces the number of on-duty nodes, the number of packet sent to the cluster head is reduced. For example, in Fig. 3.2, four sensor nodes are triggered by the target at time *t*. If all sensor nodes send the sensed data to the cluster head and assume the power consumption on sending and receiving is the same, 4 units of energy in cluster head is used for receiving packets. However, by using the node scheduling, only 1 unit energy in cluster head is used. Therefore, the energy consumption of transmission is reduced. In addition, by applying the Power-Rate-Distortion model (P-R-D) [51][55], the relationship between the distortion and network lifetime is investigated. The source coding distortion D_s is given in [55].

$$D_s = \sigma^2 \, e^{-\gamma \, R_s \cdot g(P_v)}, \; P_v \epsilon \, [0,1], \quad (3)$$

where D_s is the encoding distortion caused by lossy video compression, σ^2 is input variance, γ is a model parameter related to encoding efficiency. $g(\cdot)$ is the inverse function of the power consumption model of the microprocessor. In (3), the reception energy of cluster head (P_{rec}) is given [56].

$$P_{rec} = h \times d^{-n} \times E_t^b \, , \quad (4)$$

where d is the distance between the visual sensor and the cluster head, n is the path-loss exponent (which is typically $n \, \epsilon \, [2,5]$), and is a parameter depending on the transmitter, the wireless channel, and receiver. E_t^b is the transmission energy per bit at the visual sensor node. We simulated D_s from 50 to 275 and analyzed the relationship between the network lifetime and the encoding distortion. Since P_v is fixed in our model, a larger D_s leads to a smaller source rate R_s. Because the source data rate is reduced, the reception energy of cluster head P_{rec} is also decreased.

3.2.3 Multiple Targets Scheme

In single target situation, the prime goal is to capture the tracking object by mobile sink. In addition, the moving direction is simple following the target or estimated position. The simple method to define the moving direction of sink is to use the information of cluster head. By using the time interval between two consecutive target locations, the sink can estimates the location of the target and move forward to the target.

In multiple targets situation, capturing the tracking objects by mobile sink is difficult. To capture one of the tracking objects can increase the energy consumption of tracking other targets. Therefore, the prime goal of multiple targets is to balance the energy consumption during the transmission. The simple way to solve this problem is to find the shortest distances from sink to each target. As equation (4) shows, Pt is proportional to the n-th power of the distance between the visual nodes and their cluster heads. If the sink moves to the position which are relative shortest to each target, the lifetime can be increased.

To find the solution of multiple targets, we can define the next position of sink ($T_{Track\ t}$) in the following equation.

$$T_{Track\ t} = \frac{\sum_{i=1}^{n} W_i * T_{track\ t-1\ i}}{n}, \qquad (5)$$

where $\mathrm{T_{Track\ t-1}}$ is the previous position of target *i*. n is the number of tracking objects. $\mathrm{W_i}$ is the weight of data rate created by target *i*. Apart from the single target, the best speed of multiple-targets occurs at 3m/s in our current model (This is a value we pick up in the simulation and may not represent a general situation). The reason is because mobile sink moves to the point which has average shortest distance to targets instead of moving toward the targets.

To measure the performance of network, the lifetime is defined as the time (measure by the round number of events) when the first cluster head exhausts its energy.

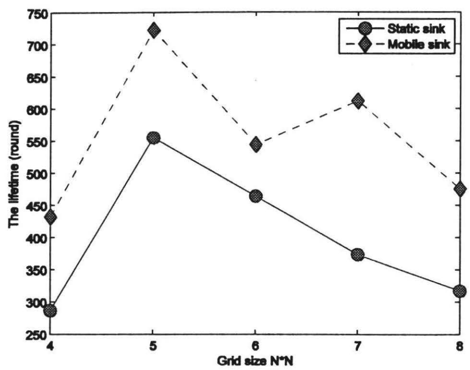


Fig. 3.3. Lifetime comparison between mobile sink and static sink

3.3 Simulation Result

To evaluate our scheme, we consider three different scenarios in our model. In the first scenario "static sink", the sink is static and is located at the center of the covered area. In the second scenario "mobile sink", the sink moves based on $T_{Track\ t-1}P$ in four target objects. In the third scenario "mobile sink with record", the sink moves based on $T_{Track\ t-1}P$ with the previous records. The previous location method is used for determine the starting point of sink. In traditional method, after all the targets disappear in the monitoring area, the sink will be back to the center point. For some open area which has certain obstacles and targets may come in certain direction. To use the previous position to help determine the next time starting point can achieve the better lifetime. We have simulated this model in Matlab. In the simulation we initially use 1000 nodes deployed in the 200m × 200m monitored area. Each cluster has the same amount number of sensor nodes. In addition, the number of clusters will be divided into N×N fields. The speed of the target is 15 m/s, and the speed of the sink is 3m/s by default. In this proposed model, target follows the simplest of all possible mobility patterns, where the targets move randomly towards all directions at constant speed. In [53], a random walk model is given. At each time slot selects a random uniform angle in [−π, π] radians. This angle defines the deviation from the target's current direction. Each cluster head node is loaded with 1000 units of energy and we assume that the cost of sending or receiving a packet is 1 unit. The routing protocol algorithm is shortest-path routing.

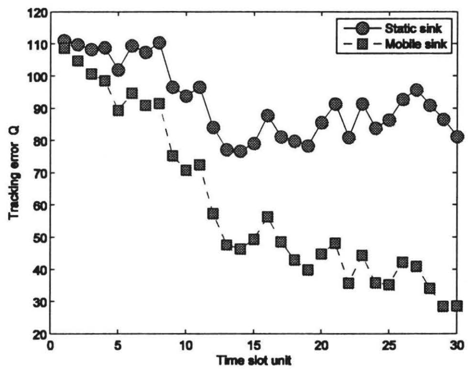


Fig. 3.4a. The Tracking error comparison in single target

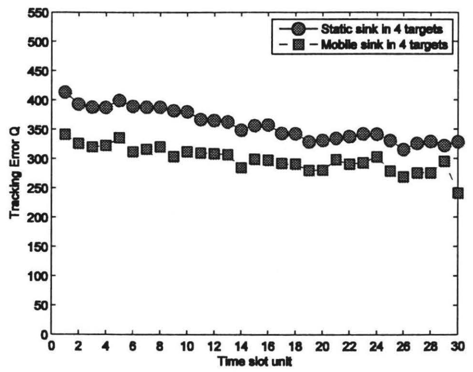


Fig. 3.4b. The tracking error comparison in multiple targets

In Fig. 3.3, we simulate the lifetime results in mobile sink and static sink in single target situation in our proposed model. As the result shown, the mobile sink method solved the problem that the cluster head close to sink deplete the energy first. The mobile sink prolonged the system lifetime compared to the static sink. In addition, the expected tracking error Q between the estimated and actual positions is simulated in Fig. 3.4. We assume that the target is only alive in the monitoring area every 30 unit time slots and the simulation results shows 30 unit time slots. In Fig.3.4a, the expected tracking error in single target is shown. Fig.3.4b shows the expected tracking error in multiple targets. As the results show, the mobile sink obtains a smaller Q in 30 unit time slots. The reason is that transmission power is proportional to the n-th power of the distance between two nodes in wireless network [51]. The parameter n is the path loss exponent. Therefore, mobile sink can consume less transmission power compared to the static sink.

Fig 3.5 shows that scheduling mechanism increases the lifetime of cluster head in single cluster without communicating with other networks. We assume the coverage of each sensor node is 10m in radius and when transmitting data each time each on-duty sensor node consumes 1 unit of energy in cluster head. In addition, we also simulate different number of sensor nodes in each cluster. As the figure shown, when the number of nodes increases, the lifetime will decrease. The reason is that the same event will trigger more sensor nodes at the same time, create more data traffic, and thus depleting the energy of

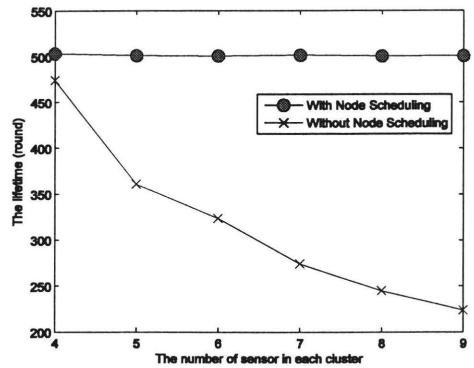


Fig.3.5. Comparison of node scheduling mechanisms

cluster head quickly in cluster head without node scheduling. The result also shows that the node scheduling method improve the system lifetime when the number of sensors is large.

In Fig. 3.6, we simulate the different speeds of mobile sink in 6×6 grids in single and multiple targets situations. We assume the target speed is 15 m/s and the speed of mobile sink will not vary with time. In single target situation, the system performance increase with the speed in Fig.3.6a. When the speed exceeds 20 m/s, the rate of system performance increased slowly. In multiple targets situation, the simulation result is shown that the best lifetime situation occurs in 3m/s in multiple targets situation. The reason is that most next position of sink is based on the center of multiple targets. In most situations, $T_{\text{Track}\ t-1}$ is not too far from the starting point. Mobile sink with a higher speed can arrive the point which has small checking error quickly. However, due to the speed of sink is constant in our proposed model, if the sink still keeps high speed, the distance between sink and $T_{\text{Track}\ t}$ is increased and the performance decreases.

Based on P-R-D model for wireless video transmission, the distortion and lifetime analysis is given in Fig. 3.7. As the results shown, with the distortion increased, the system lifetime increased. The reason is that the bit rate of transmission from visual sensor node to cluster head decreased when the distortion caused by lossy video compression increased. Therefore, the reception power of cluster head in (3) decreased.

Fig. 3.8 shows the four targets scenario with static sink, mobile sink, and mobile sink with history record. In mobile sink with history record situation, sink stores the previous 30 reports of position to determine the starting position of sink at next time. When all the targets leave the monitored area, the sink returns to the center point. In the final method, we use the previous 30 records to determine the starting point because the average system lifetime is around 160 rounds. As the result shows, both mobile sink and mobile sink with history record can retrieve the better system lifetime in compare with the static sink in multiple targets situation.

3.4 Chapter summary

Wireless sensor networks are battery powered, therefore prolonging the network lifetime is highly desirable. In most literature, researchers deploy the static sink in the center of WSN. However, the lifetime of system is determined by the cluster heads close to the sink. In this paper, firstly, we use node scheduling to prolong the lifetime and remove the duplicate information. The simulation results show that as the number of nodes increase, the node scheduling retrieve longer lifetime. Secondly, the expected tracking error result also shows that the mobile sink retrieved better value in compare with static sink. Thirdly, we also investigate the different speed in mobile sink and retrieved the best lifetime occurs at 3 m/s. Finally, the multiple-targets situation result in three different methods is given. The result shows our proposed scheme prolonged the system lifetime in comparison with static sink.

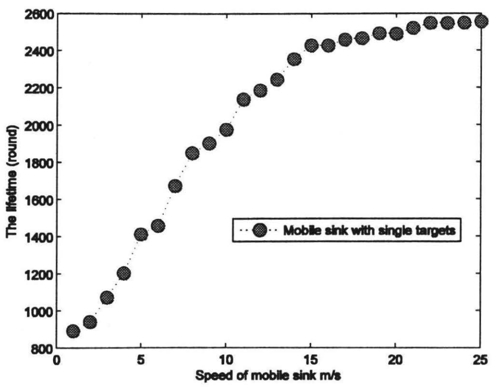


Fig.3.6a Different Speed in single targets

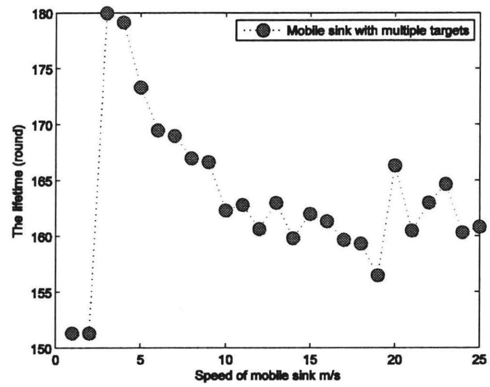


Fig.3.6b. Different speeds in multiple targets

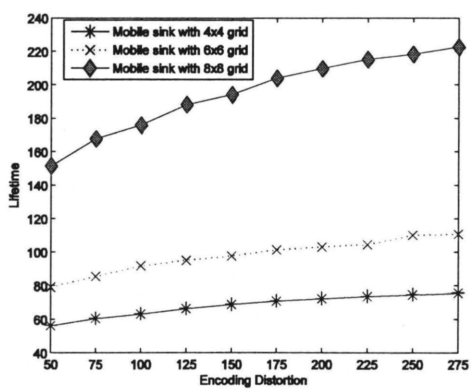


Fig.3.7 Lifetime and distortion analysis

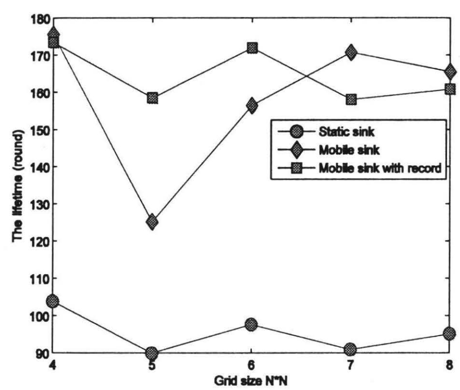


Fig 3.8 Multiple Targets Comparison

CHAPTER 4

LAYERED CLUSTERING FOR SOLAR POWERED WIRELESS VISUAL SENSOR NETWORKS

This chapter first introduces the background knowledge of WVSN. Then, layered clustering model and its experiment are illustrated respectively. The remainder of this chapter is arranged as follows,

Section 4.1 introduces the background knowledge of WVSN.

Section 4.2 presents the system model, which is composed of five units, solar cell unit, event trigger unit, energy consumption unit, layered clustering unit, and video distortion unit.

Section 4.3 shows the experiments of the layered clustering model under the considerations of visual quality and solar cell recharging.

Section 4.4 summarizes the layered clustering model for the solar-powered WVSN.

4.1. Wireless multimedia sensor network

With dynamic enhancement and development of wireless communication and miniaturization of hardware in last decade, wireless sensor network (WSN) has been identified as one of the most important technologies for 21^{st} century. These characteristics form the profile for small-unit, low-power, low cost, and multifunctional sensor nodes. These tiny sensor nodes offer a higher capacity for sensing, processing, storing, and communication data [58]. Limited by their size and power, how to maximizing the lifetime of the whole network becomes an ultimate challenge to researchers. The optimized MAC protocols for energy efficiency are discussed in [59]-[61]; [62]-[64] try to provide the efficient power utilization and error control system by designing the routing protocols; saving the energy and maximizing the system's operational lifetime in the wireless sensor network are also discussed in [65]-[68]. It is envisioned that the applications of WSN will be deployed in our daily lives.

Unlike the traditional WSN merely capturing temperature and pressure and generating the text data, wireless visual sensor network (WVSN) is equipped with the camera and is capable of capturing the image. With the additional transformation power consumption on video generation and multiple data formats codec, power management and bandwidth usage in WVSN become more critical than that in WSN. The difference between the video-based sensor network and traditional wireless sensor network by discussing the coverage preservation problem is introduced in [69]. [57] outlines the main research challenges in wireless multimedia sensor network (WMSN). The most influencing factor of wireless multimedia sensors networks is the power consumption. Most of visual sensor nodes are supplied by battery and with low power capacity. [71] presents the unequal clustering size (UCS) to prolong the lifetime of wireless sensor networks. By grouping the sensors into clusters, data are collected and processed locally at the cluster head before they are transmitted to the base station. [72] discusses the consideration for solar energy wireless embedded systems. By using solar cell, the battery can be contiguously recharged during the daytime and enhance the utilization of the sensor network.

A wireless visual sensor network is composed of three components: visual sensor nodes, cluster heads (CHs), and a base station (Sink). Fig.4.1 gives the system structure. A visual sensor node acts like a surveillance camera. It captures the image signal, encodes and transmits to the cluster head in its cluster. Because cluster head aggregates its received video raw data, the total number of packets that transmitted by cluster head decreases. It means power consumption and data collision in wireless transmission can be reduced and the distortion of video data can be decreased. The cluster head nodes usually hold several functions: capturing the video data, processing the data received from the visual sensor nodes or outer cluster head nodes, and then forwarding it to the base station. Due to the vital role of the cluster head in WVSN, the performance of WVSN is related to the lifetime and capacity of their cluster heads.

The energy capacity of sensors diverges with the resource it possesses. The base station powered by wall outlet usually has endless lifetime; the cluster heads and visual sensor nodes powered by battery have limited lifetime. Due to the much heavier load of multiple functions comparing with the normal senor nodes, the power utilization of cluster heads becomes more restrictive. In this chapter, we apply the solar cell recharging model in the visual nodes and cluster heads. The solar cell recharging algorithm used in microcontroller is given in [72]-[74]. [72] presents the algorithm to detect the solar cell overcharging. In [73], the charging power rate is considered in the conditions of outdoor bright sunlight and indoor illumination. [74] describes a prototype of solar-powered wireless embedded system and presents some key issues and tradeoffs arise in the system design.

By organizing the sensors into several different layered clusters, [71] gives the energy function of heterogeneous clustering sensor network. The radiuses of layers are acquired by the energy functions of cluster heads in different layers. We extended its energy function by considering the video processing power and the recharged solar cell power. By using this new power consumption model, we can enhance the performance and prolong the lifetime of WVSN. In [75], independent packet generation rate of visual sensor nodes with Poisson distribution in the clustering sensor network is given. According to probability theory, the expectation values of total packets arriving rate of cluster head nodes are introduced into the equation.

In [76]-[78], the Power-Rate-Distortion (P-R-D) model is proposed. Based on the P-R-D model, the power allocation between wireless transmission and video encoding can be optimized. The achievable minimum distortion (AMD) is also introduced to quantify the video quality in the WVSN. The potential applications of WVSNs include enemy tracking, battlefield surveillance, robotic research, and environment monitoring [70].

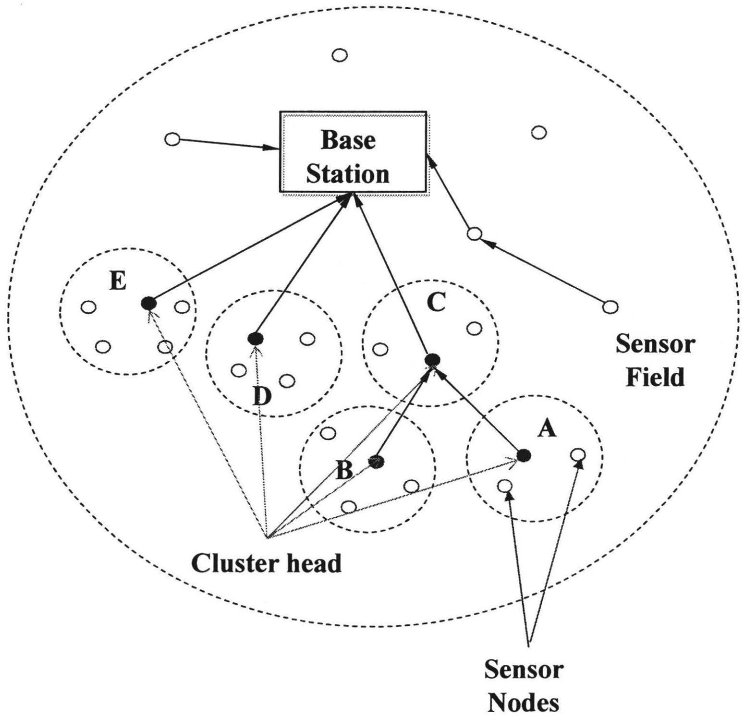


Fig.4.1 The architecture of WVSN

The rest of chapter is organized as follows. In section 2, we introduce the detail of three models: solar power consumption model, layered clustering model and video distortion model. Based on these models, section 3 simulates the solar powered WVSN in a two-layer circle area and analyzes the experiment results.

4.2. System Models

In solar-powered wireless visual sensor network (SPWVSN) system, we assume the visual sensor nodes are grouped into the clusters and are one hop away from the cluster head with error-free transmission. By deploying these models into the SPWVSN, we can formulate the system and evaluate the utilization improvement in the following sections. In the wireless communication, the energy consumption on wireless transmission between two nodes is exponentially proportional to their distance [81]. By using the clustering algorithm for wireless sensor networks, it can save the energy [81][82]. In the cluster architecture, a cluster head node acts as not only a data collection center but also a visual node. Thus, additional power is required for cluster head node. If cluster heads break down, the data received by cluster heads cannot be forwarded and the whole network becomes out of order.

In this section, we introduce three models that applied in SPWVSN system. These models are solar power consumption model, layered clustering model, and video distortion model. The definition of network performance is also illustrated in this section.

4.2.1. Solar cell model

Solar power consumption model is made up with analysis of solar cell, event trigger and power consumption models. To prolong the lifetime of WVSN, the solar cell model is applied into the system. We assume the recharging process only occurring under the direct daytime light. With this assumption, we can eliminate other charging possibility when the time is before sunrise and after sunset such as moonlight. In this paper, we apply the daytime schedule of Toronto area in the experiment. The daytime length varies from 11 hours to 15 hours depending on the season [79]. Table 1 lists the daytime schedules of several main cities.

In this chapter, we assume that all visual sensors have the same specification and are randomly deployed in the same environment. [73] shows that solar illumination yields around $1 mW/mm^2$ ($1 J/day/mm^2$) under full sunlight. In the SPWVSNs system, when the sensor power (P) is not at fully power level (P_{max}), the total power of solar recharged power (P_s) can be represented in equation (1). ρ_d is the solar illumination in sunlight; S is the size of solar panel, T_s is daytime length, τ is the solar cell efficiency and Δt is the recharging time slot.

$$P_s = \begin{cases} \tau \cdot \rho_d \cdot S \cdot \Delta t, & \forall P < P_{max}, \quad \forall \Delta t \in T_s \\ 0, & others \end{cases} \tag{1}$$

4.2.2. Event generation

In our experiment, a cluster head is the centroid of the cluster. The clusters surround the base station as a multiple layers concentric circle in Fig. 4.2. All visual sensor nodes in the cluster only directly communicate with the cluster head node in their cluster. All clusters in one layer have the same amount of visual sensor nodes and there is no multi-path from the cluster head node to base station. With this assumption, the total number of senor nodes (N_s) can be figured out by the equation (2). L is the number of layers, C_i is the number of clusters in layer i, N_i is the number of normal visual sensor nodes in a layer i cluster, N_{chi} is the number of the cluster head node in one cluster, and the B_s is the number of base station.

$$N_s = \sum_{i=1}^{L} C_i \cdot (N_i + N_{chi}) + B_s \quad . \tag{2}$$

In this model, only one cluster head node in each cluster and one base station in system model. Since all the visual sensors in a cluster have identical independent packet generation rate with Poisson distribution [75], the video packet arriving rates for cluster head nodes are also Poisson distribution. Denote λ_j as the packets generation rate of visual node and λ_{ch} as the packets generation rate of cluster head. The video packet arriving rate of a cluster head shows in equation (3).

$$\begin{aligned} \lambda_i &= \lambda_{ch} + \sum_{j=1}^{N_v} \lambda_j \\ &= \sum_{j=1}^{N_v+1} \lambda_j = (N_s + 1)\lambda, \quad \forall \lambda_j = \lambda_{ch} = \lambda \end{aligned} \tag{3}$$

Since the video packet generation distributions of all sensors are identical, according to the probability theory, the total packets expectation value of a cluster head, $\overline{Z_i(t)}$, satisfies

$$\overline{Z_i(t)} = (Ns+1)\lambda t, \quad \forall \lambda_j = \lambda_{ch} = \lambda \tag{4}$$

4.2.3. Power consumption

In this system, the power utilization can be formulated by the three main parameters: coding power, transmission power, and solar power. Equation (5) is the power function P_n of a solar-powered cluster head in SPWVSNs.

$$P_n = \begin{cases} P_{\max}, & \forall t \in T_s, \forall P_{n-1} \geq P_{\max} \\ P_{n-1} - P_t - P_v + P_s, & \forall t \in T_s, \forall 0 < P_{n-1} < P_{\max} \\ P_{n-1} - P_t - P_v, & \forall t \notin T_s \ \forall 0 < P_{n-1} < P_{\max} \\ 0, & \forall t \notin T_s, \forall P_{n-1} \leq 0 \end{cases} \tag{5}$$

In equation (5), P_{max} is the maximum power capacity of the sensor node, P_{n-1} is the power recharged by solar panel, P_v is the power spent on coding and capturing the video, P_t is the transmission power consumption and T_s is daytime length. In our simulation, the transmission P_t is proportional to the second power of the distance between the two nodes. If t is sufficiently large, the number of packets transmitted will be close to its expectation value. We can obtain the total transmission power equation of a cluster head from equation (6). P_t is proportional to the n-th power of the distance between the visual nodes and their cluster heads [76]. The parameter n is the path loss exponent.

$$P_t = (\beta + \mu d^n) \cdot (Ns+1)\lambda t, \quad \forall \lambda_j = \lambda_{ch} = \lambda, \forall n \in \{2,3,4,5\} \tag{6}$$

The lifetime of a cluster head (T_i) can be defined in equation (7)

$$T_i = \frac{E_i}{P_t + P_v} = \frac{E_i}{\left(\beta + \mu d^2\right) \cdot \left(\lambda_{ch} + \sum_{j=1}^{N_v} \lambda_j\right) \cdot t + P_v} \tag{7}$$

The lifetime of SPWVSNs (T) is defined as the time when the first cluster head exhausts its energy. E_i is the energy capacity of cluster head. It can be described as follows.

$$T = \min\{T_i\}, \quad i \in C_i \tag{8}$$

In equation (8), T is the system lifetime and T_i is the lifetime of cluster heads. With the same packet arriving rate λ_j in the sensor nodes, $\forall j \in [1,2,\ldots,N_v]$ and $\forall \lambda_j = \lambda_{ch} = \lambda$, we can modify the equation (7) into (9).

$$T_i = \frac{E_i}{\left(\beta + \mu d^2\right)\left(Ns + 1\right) \cdot \lambda t + P_v}, \quad \forall \lambda_j = \lambda_{ch} = \lambda \tag{9}$$

4.2.4 Layered clustering model

There are two layer clustering model in the current literature: Equal clustering and unequal clustering. Equal clustering is the network is divided into clusters of approximately the same size. Unequal clustering, on the other head, is based on the amount of energy every cluster head spends during one round of communication, how many nodes each cluster should contain so that the total amount of energy spent by all cluster head nodes is balanced. Based on the unequal clustering model [71], all the cluster heads in the system are uniform. Consequently, the power consumption of the cluster head nodes in layer 1 should be equal to that of the cluster head nodes in the other layers. As we mentioned in previous section, cluster head nodes can encode, aggregate, and trans-code the received video data. In this chapter, we can easily define the cluster heads' energy equation in a layers clustering WVSN in equation (10). P_{ti} is the power consumption on wireless transmission, and P_{vi} is the power consumption on the video processing. W is the number of layer in this system.

$$P_{chi} = P_{ti} + P_{vi}, \quad 1 \le i \le W \tag{10}$$

In this model, due to the overlapping coverage, some of the duplicated video data can be aggregated. We also define the aggregation rate (α) in (11). TP_r is the number of packets received from the visual node and TP_s is the number of packet sending out after aggregation.

$$\alpha = \frac{TP_s}{TP_r} \tag{11}$$

For example, when α = 0.1, the cluster head receives 10 packets from the visual sensor nodes and only sends out 1 packet. By video data aggregation, SPWVSNs can enhance the utilization of bandwidth and reduce the collision probability on wireless transmission. In the table 1, layered clustering equations in ith layer are summarized.

4.2.5 Video distortion model

In this chapter, by applying the Power-Rate-Distortion model [76][77], we analyze the performance of solar-powered WVSN when the video distortion at Achieve Minimum

ith Layer

$$E_{chi} = E_{ti} + E_{vi} = E_{tsi} + E_{tri} + E_{vi}$$

$$E_{tsi} = \alpha \cdot (\beta + \mu {d_i}^2) \cdot (\sum_{w=i}^{W} N_w + 1) \cdot \lambda t$$

$$E_{tri} = E_{tr} \cdot (N_{vi} + \alpha \cdot \sum_{w=i+1}^{W} (N_{vw} + 1)) \cdot \lambda t$$

$$E_{vi} = (E_{vc} \cdot (N_{vi} + 1) + E_{vc}) \cdot \lambda t$$

$$N_{vi} = R_i^2 \cdot N_v \cdot \frac{1}{C_i * R_a^2}$$

$$d_i = (\int_{R_{i-1}}^{R_i} r \cdot 2 \cdot r \cdot \sin(\beta_i)\, dr \cdot) \frac{1}{(R_i^2 - R_{i-1}^2) \cdot \beta_i}$$

Table 4.1 Summary of Equations in SPWVSN

Distortion (AMD). The equation of the distortion is given in (12). g(P_v) is the power consumption model, P_v is the energy of video compression, R_s is the transmission bit rate, γ is the parameter for encoding, and σ^2 is the variance of input.

$$D = D_s(R_s, P_v) = \sigma^2 e^{-\gamma R_s \bullet g(P_v)} \tag{12}$$

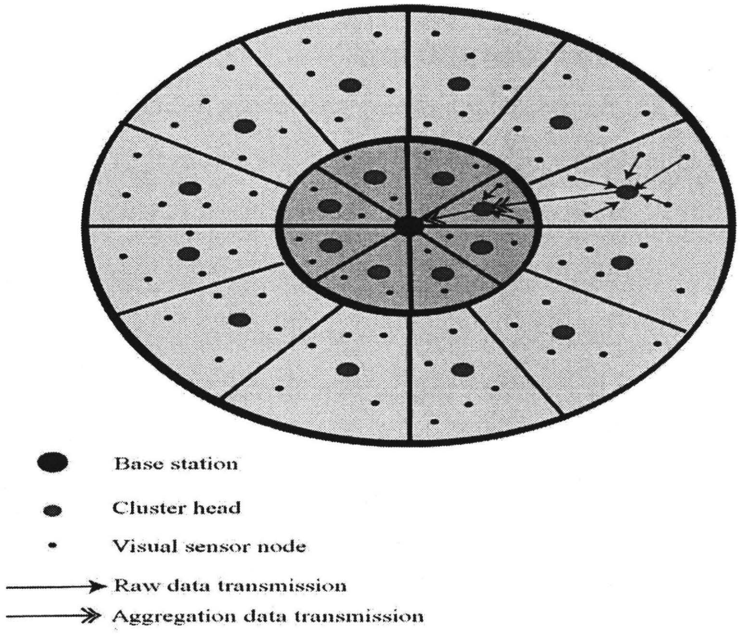


Fig.4.2 The architecture of SPWVSN with 2 layers

When the other parameters (σ^2, γ) are static, the distortion (D) varies with the video processing power consumption (P_v) and transmission bit rate (R_s).

4.3. Simulations

In this section, to validate the models presented in the previous section, the simulations are implemented in a network with 400 nodes that randomly distributed over a circular area whose radius is 400 meters. The radius of inner layer is derived from the cluster head power equation (10). The cluster number in layer 1 varies from 6 to 14, cluster number in layer 2 varies from 6 to 14, and cluster number in layer 2 varies from 6 to 14. It is also assumed there are no multi-paths to the sink. That means layer 2 cluster head nodes will not send duplicated information to cluster head nodes in layer 1.In addition, the 3 layers cluster model simulation are done in this section. Figure 4.2 shows our model setup in 2 layers model.

4.3.1 Layered clustering simulation

[71] proposes a unequal clustering size model (UCS) in a heterogeneous network by comparing with equal clustering size model (ECS). In this chapter, we also simulate these two clustering algorithms on the same test-bed to see which one can achieve a longer lifetime. With unequal layered clustering, the ratio of layer-1 nodes number and layer-2 nodes number at the condition of different aggregation rates are shown in the Fig.4.3. In this case, we can also conclude that with aggregation rate (α) increase, the nodes number ratio decreases and the ratio values are always less than 1. That is because layer-1 cluster head nodes have to relay the packets from not only visual nodes in their own clusters, but also layer 2 cluster head nodes. Thus, they have relatively lower energy to support sensor nodes in their clusters than layer-2 cluster heads. With the aggregation rate increase, the outer layer cluster heads aggregate less video data and forwarding more packets received from other nodes. The traffic in the whole network becomes more congested.

We also compare the total power consumption of two different layered clustering algorithms in Fig.4.4. The simulation is assumed that each node generates 1000 video packets in one day under the consideration of solar cell recharging and visual quality. The energy ratio of unequal cluster to equal cluster is always less than 1. That means the UCS consumes less power than ECS on our proposed model. Consequently, the system lifetime can be prolonged when total power consumption decreases.

4.3.2 Video distortion simulation

In [76], the distortion rate consists of two parts: the encoding distortion and the transmission distortion. The power consumption function can be written in equation (13).

$$P_{max} = P_v + P_t \tag{13}$$

When P_{max} is fixed, with video processing power increasing ($P_v \uparrow$), the transmission power consumption decreases ($P_t \downarrow$). It means the probability of data corruption in wireless transmission will increase. In the case when video processing power decreases ($P_v \downarrow$), the transmission power consumption increases ($P_t \uparrow$). It means the probability of data corruption during the encoding will increase. Fig. 4.6 shows that the achievable minimum distortion (AMD) of SPWVSN can be achieved when video processing power takes about 45% total power, ($P_v \approx 0.45\, P_{max}$). In Fig. 4.5, X-axis represents the number of clusters in layer 2 and Y-axis represents the total distortion. In Fig. 4.6, the distortion comparison in 2 layers and 3 layers model is given. Fig. 4.7 (a) shows the distortion in 2 layers model. Fig. 4.7 (b) shows the distortion in 3 layers model. Because the transmission range in 3 layers is reduced, the average distortion during the transmission is reduced.

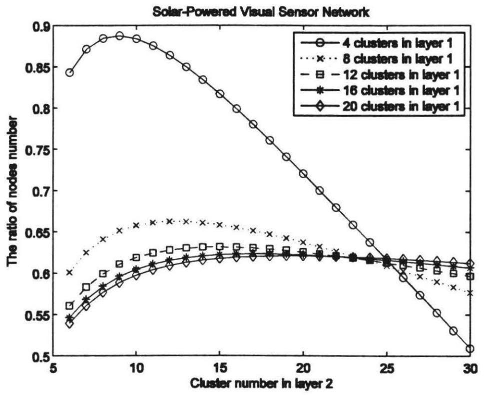
4.3.3 Power consumption simulation

In order to evaluate the node's lifetime and analyze system performance, we also apply different gate energy (GE) values on our proposed model. [80] GE ensures the system only starts to function when the nodes' energy level is higher than GE after the nodes exhausted their battery energy. Since visual nodes usually need more energy to start their visual functions. If the gate energy is not set properly, the visual nodes might turn off immediately after a short period of working time. We use the GE mechanism to achieve better performance and prolong the nodes' working time. Fig. 4.8 shows the number of total transmitted packets under the condition of different GE values. It is obvious that in the most cases, the number of total transmitted packets decreases when the GE value increases. That means in this model, if the system needs a smaller GE to keep visual facility alive, more packets can be sent out successfully. On the other hand, the total packet loss rate will go down.

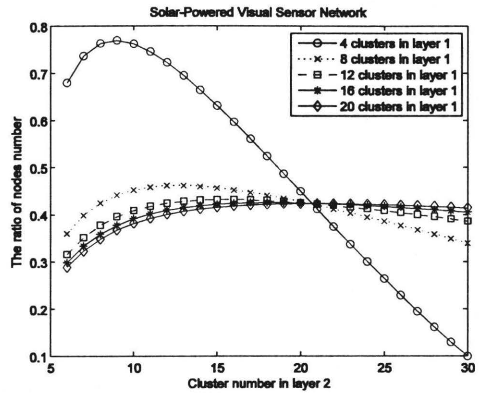
4.4. Chapter summary

In this chapter, we analyze the power consumption and video quality of wireless visual sensor network and simulate the system with three models, solar power consumption model, layered clustering model and video distortion model. By applying solar cell recharging algorithm, the visual sensor's lifetime can be prolonged when the visual quality is at achievable minimum video distortion. After comparing the simulations of different aggregation rates, it is easy to conclude that the cluster head in the inner layer can support more sensor nodes and reduce the bandwidth utilization when the aggregation rate is decreasing. Furthermore, by considering the video processing power consumption and recharged solar power into the layer clustering power equation, we evaluate the system performance with total transmitted packets with different GE values. The system can transmit more packets when the visual nodes need a less gate energy.

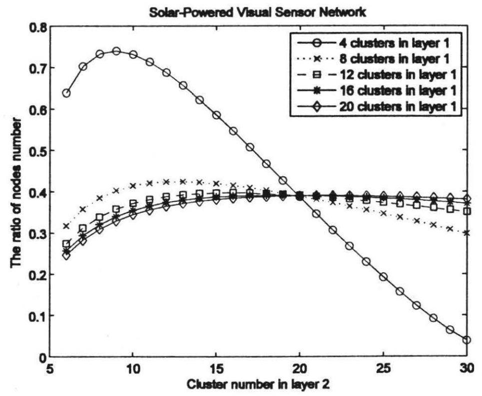
To conclude, under consideration of visual quality and gate energy, the layered clustering model can provide a valuable solution to prolong the lifetime of solar powered video-based wireless sensor networks.



(a) $\alpha = 0.1$

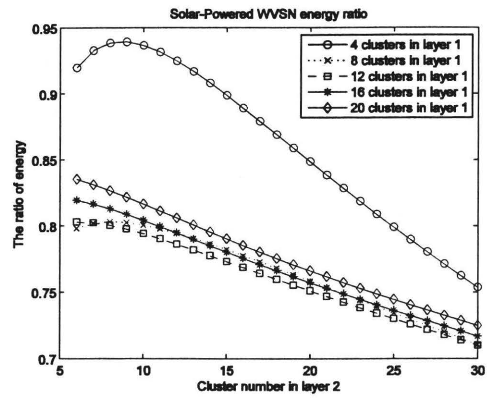


(b) $\alpha = 0.5$

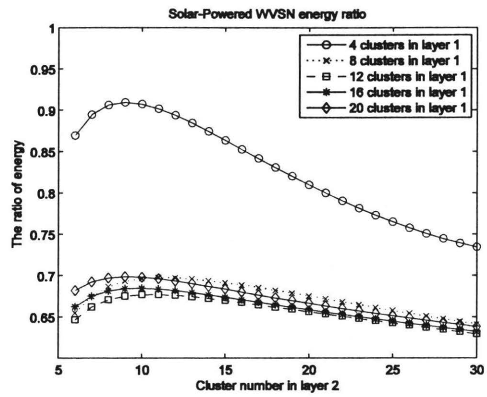


(c) $\alpha = 1$

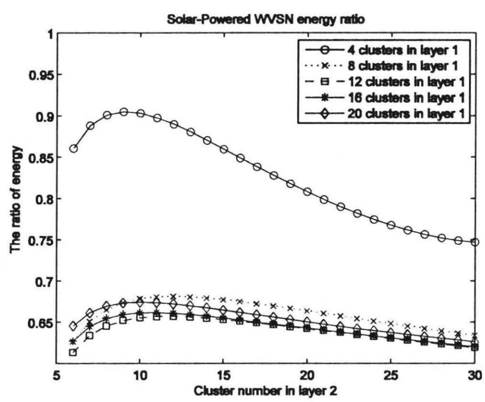
Fig.4.3 Nodes number ratio with aggregation rates



(a) α =0. 1

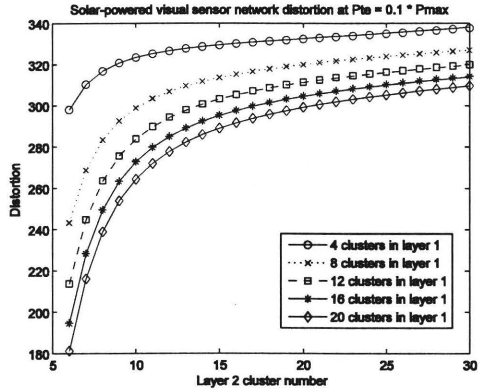


(b) α = 0.5

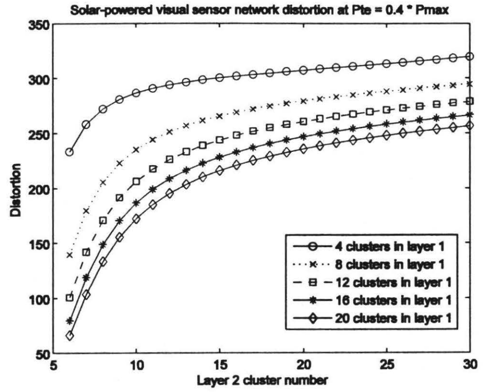


(c) α = 1

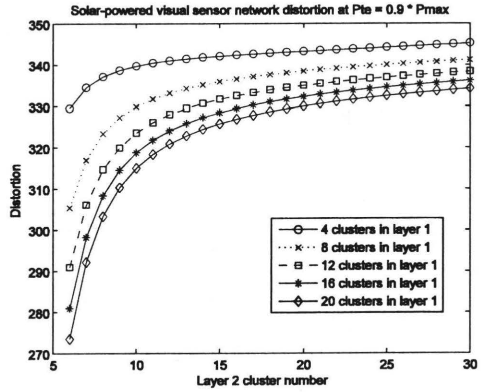
Fig. 4.4 Energy ratio with aggregation rates



(a) $P_v = 0.1\ P_{max}$



(b) $P_v = 0.4\ P_{max}$



(b) $P_v = 0.9\ P_{max}$

Fig. 4.5 Distortion analyses with different Pv

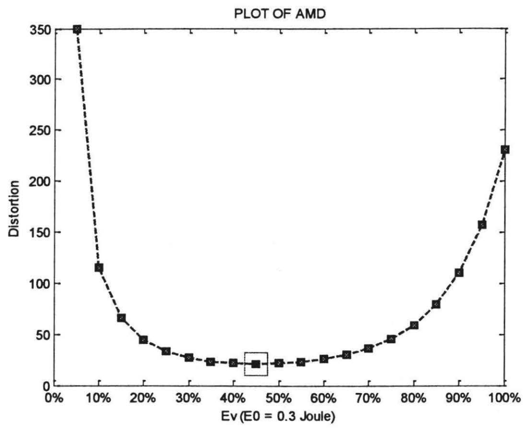


Fig 4.6. achievable minimum distortion

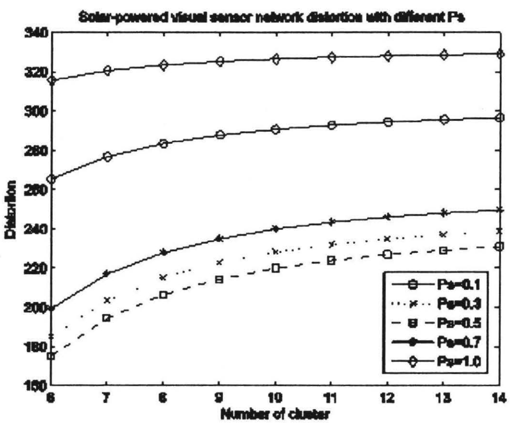


Fig. 4.7(a) 2 layers distortion

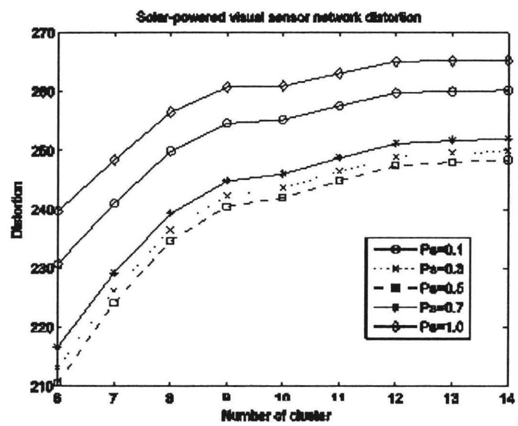
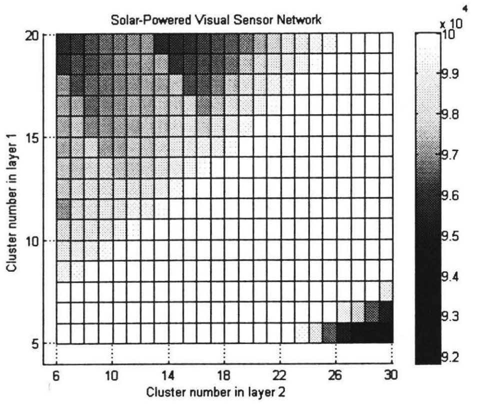
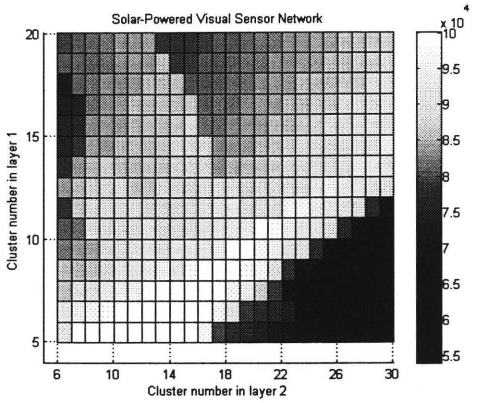


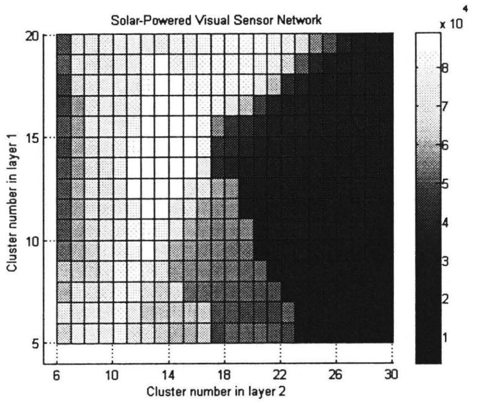
Fig. 4.7(b) 3 layers distortion



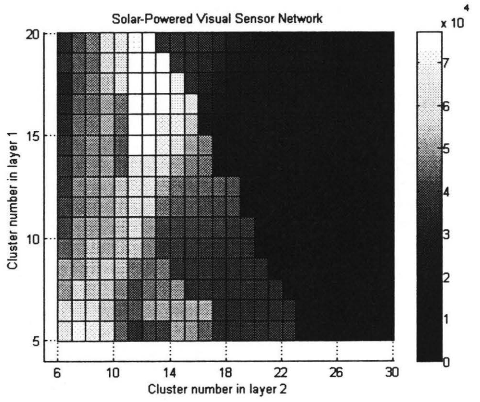
(a) GE = 0.1 P_{max}



(b) GE = 0.2 P_{max}



(c) GE = 0.3 P_{max}



(d) GE = 0.4 P_{max}

Fig 4.8. Total Transmitted Packets with Different GE Values

CHAPTER 5
CONCLUSIONS AND FUTURE WORK

This chapter summarizes the work addressed in this thesis, and introduces prospects for future work. We study a solar-powered WVSN and WVSN with mobile sink on multiple targets.

For target tracking applications, the robot can be used as a mobile sink in WVSN in Fig 5.1. We propose a node scheduling mechanism, mobile sink, and power-rate-distortion into the clustering model to deal with the restricted energy consumption. The system lifetime can be prolonged with our proposed scheme. In addition, we analyze the simulation results of different speeds of single and multiple targets scenarios and obtain the best speed in our proposed model. With the node scheduling mechanism, the simulation result shows a cluster head can support more events and reserve more bandwidth. The mobile sink with multiple targets can also yield better performance compared with the stationary sink. We focus on the performance of video quality and lifetime by using the P-R-D model.

In solar-powered WVSN, the limited energy capacity of normal visual sensors is limited. However, energy requirements of their communication and visual facility are much higher. Thus, the energy constraint is more critical in WVSN. By arranging sensors into different layers and clusters, the layered clustering model can dramatically shorten the communication distance. Instead of sending video packets to distant nodes, the layered clustering model lets the sensor nodes only send raw video data to the cluster heads. Then the cluster heads aggregate and relay the encoded visual data to the base station. The communication energy is thus saved by the shortened distance.

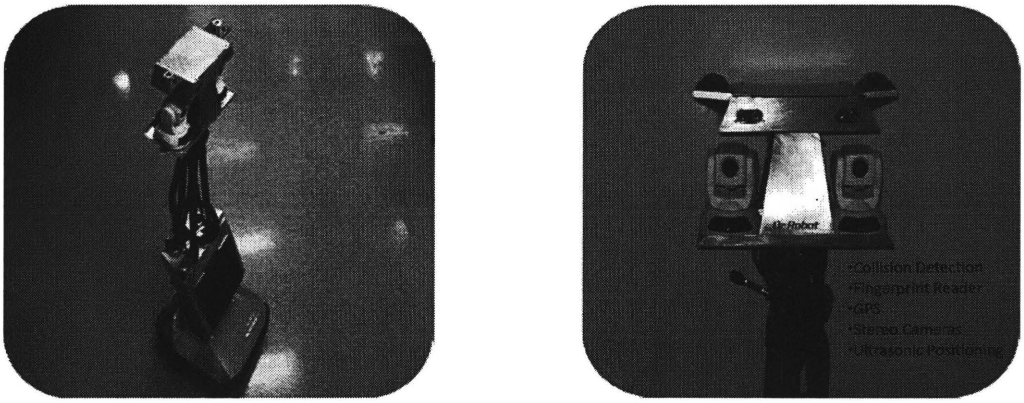


Fig. 5.1 Dr. Robot in Ryerson Multimedia Lab(put a period even if it is a phrase)

Although WSN can retrieve various contents such as video, audio and text, some aspects in WSN are worth further investigating, such as:

- Because of limited power and processing capability, there are three main challenges for video and audio transmitting in WSN First of all, the radio spectrum is a limited resource in wireless communication [84]. A solution for this challenge is to use an advanced source coding technique to drop the payload size, and hence reduce the bandwidth requirement. Secondly, the processing unit an33d the power unit are scarce resources for multimedia sensors. Therefore, a complex source coding technique can significantly increase the power consumption and delay. Lastly, unlike wired networks, wireless communication is subject to a high error rate due to channel interference, multi-path fading, and other loss mechanisms. Therefore, efficient and effective source and channel coding techniques are crucial to resolve the issues raised by the above mentioned challenges.

- Reducing power consumption is an important topic for ensuring an improved network lifetime. Aggregating the redundant video data captured by sensory devices helps eliminating excessive bandwidth usage and consequently reducing the transmission power. However, the complex aggregation algorithms processed by cluster head sensors take additional processing power and memory.

- WVSN in general is more vulnerable to malicious attacks in comparison with wired solutions due to the lack of physical medium protections [85][86]. For applications such as battlefield monitoring and surveillance, insecure communications may potentially be a catastrophic issue. Thus, delivery of sensitive multimedia data using an efficient and effective encryption technique while sustaining a low power consumption should be treated as a major design aspect for developing WVSN. With such design aspect, Conventional security mechanisms in 802.11 wireless LANs are not suitable for WVSN. Therefore, a lightweight security mechanism should be designed in WSN.

- Most routing protocols for WSN focus on energy saving rather than QoS. For applications such as remote medicine, high packet loss and delay can cause a catastrophic issue. Therefore, QoS-based routing is another important topic in WVSN. Conventional QoS routing protocols used in wireless ad hoc networks [87]-[89] may be inadequate for WSN due to its severe resource constraints.

- Unlike wired networks, packets in wireless networks are easily interfered by noise and lost during the transmission. In WSN, since the nodes may run out of the energy or might be damaged, it should provide certainly robustness mechanisms to guarantee that end users can still receive information. Therefore, a well-designed physical layer and MAC protocols are required.

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