

**Studies on Sensor Networks with
Fiber Optics for Agricultural
Environment Monitoring**

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Chapter 1

Introduction

1.1 Background

Agriculture has been facing many challenges, including climate change, limited water resources, environmental pollution, aging and shortages of farm workers, and increase of greenhouse gas emissions. Climate change is likely to add uncertainty to projections of agricultural output, highlighting the importance of monitoring and research to refine those predictions (Nature, 2010). Massive climate change also affects the global hydrological cycle in many ways, such as timing and distribution of rainfall, and sea level rise (Rosegrant et al., 2009). Environmental pollution by anthropogenic or natural sources constrains agricultural activities.

Aging and shortages of farm workers is also a concern. A survey by Japan's Ministry of Agriculture, Forestry, and Fisheries (MAFF) examined concerns of the rural elderly, mostly farm workers aged 65 to 75, about participation in farming and other activities in their communities (Japan MAFF, 2009). Due to aging of the workforce and lack of replacement human resources in a rural community, one of the requirements to maintain agricultural production and rural resources within communities is a securing IT and other information infrastructures.

There are research of wireless sensor networks which supporting the agriculture activities. The details of such related research are discussed later in section 3.2. Besides, Ruiz-Altisent et al. (2010) has reviewed various sensing technologies for agriculture support, such as wireless sensor networks and radio frequency identification sensors.

1.2 Sensor Networks and Optical Fiber Sensors

Recently, a number of wireless sensor networks (WSNs) have been widely developed and studied. Applications of wireless sensors are available in different monitoring areas (Rahman, (2010), Corker et al.,(2010), Hill and Culler, (2002), M. Ruiz-Altisent et al., 2010, Alemdar and Ersoy, (2010), Hadjidj, (2013), such as military, medical and health, industrial, nuclear plant maintenance, ocean, agriculture, airport, disaster management and home network. These sensor networks act as information infrastructure, helping to provide ubiquitous services by using information from daily life

Lately, optical fiber has been used not only for data communications but for sensor applications (Yin et al., 2008). Fiber sensors have been applied to measuring stress in bridges, measuring water quality, and predicting mudslides.

This study uses a hetero-core spliced optical fiber that has been developed and studied for various purposes. The fiber can be easily manufactured through simple cutting and fusion splicing processes, and has been used in a soil gravity water detection sensor (Kumekawa & Watanabe, 2011), a humidity sensor (Akita et al., 2010), a chemical sensor for measuring of the pH of liquids (Iga et al., 2003; Seki et al., 2003), a bending sensor for gauging pressure, a restraint-free wearable cloth sensor for measuring arm motion and walking action (Nishiyama et al., 2007a, 2007b), and a smart pressure-sensing mat for monitoring human activities (Nishiyama et al., 2010).

The study employs a hetero-core spliced optical fiber surface plasmon resonance (SPR) sensor (HC-SPR sensor) that detects soil gravity water. An HC-SPR sensor has functionality both as a sensor and as a medium for data communications. Kumekawa and Watanabe (2011) tested its sensing function and evaluated its sensitivity. To extend

the advantages of the sensor function, a fiber sensor system capable of simultaneously providing both data communications and sensing functions over the same optical fiber line is designed.

1.3 Overview of the Thesis

This thesis is divided into eight chapters. First chapter describes the overall background, sensor network and fiber optics sensor. In the second chapter, fiber optic sensors and its applications are discussed. Next, chapter three summarizes the current conditions and issues in regard to network sensors, including the requirements of sensor networks, a comparison of sensor networks, related work on natural environmental monitoring systems, and some issues not yet addressed by current research. The chapter four discusses research objectives and system requirements.

The next section- chapter five presents the details of Hetero-core SPR sensor, its related research and summarizes a performance experiment that verifies combined data communications and sensing for short and longer distance.

Chapter six proposes, evaluates and discusses the system design for the hetero-core fiber opticsl sensor system for soil gravity water monitoring. Chapter seven describes the detail of optical sensor network management using internet-standard protocol – SNMP and the verification test of the system configuration using different light source. Lastly, chapter eight provide a summary with discussion, conclusions and future works.

Chapter 2

Fiber Optic Sensors

2.1 Fiber Optics

Optical fiber systems have many advantages comparing to the metallic based communication systems. These advantages consist of attenuation, interference and bandwidth characteristics. To operate a fiber optic system properly, it is important to know what type of fiber is being used and why. There are two basic types of fiber which is Multimode Fiber (MMF) and Single mode Fiber (SMF).

MMF has a larger core diameter compared to SMF, therefore, it allow for the larger number of modes. On the other hands, SMF allow higher capacity to transmit information. It is because it can retain the fidelity of each light pulse over longer distances and it exhibits no dispersion cause by multiple mode. (Fiber Optic Info).

2.2 Fiber Optics Sensors

(a) Strain Dependency Types

I. Fiber Bragg Grating (FBGs) Sensors

The sensing mechanism of FBG is based on strain dependence of frequency of light reflected at grating. In FBGs the Bragg wavelength λ_B , or the wavelength of the light that is reflected, is given by

$$\lambda_B = 2n \Lambda \quad (1)$$

where the n is the effective refractive index of the fiber core and Λ is the grating period. Refer to Eq. (1), it can be seen that the Bragg wavelength is

changes with a changes in the grating period or effective refractive index. (Lee, B., 2002).

In another word, the grating period is the case for strain and the effective refractive index is for temperature variation. This means, FBGs, respond to both strain and temperature. Most of the FBG sensors are used in the applications in smart structure. There have been demonstrated on civil engineering structures such as bridges, dams; oils wells; also for composite material structures such as aircraft and spacecraft (Yin, S., et al. 2008).

II. Brillouin Optical Time-domain Reflectometer (BOTDR)

The Brillouin optical time-domain Reflectometer is a distributed optical fiber strain sensor whose operation is based on Brillouin scattering (Hiroshige et al., 2001.).

In the proposal by Kurashima et al. (1993), a technique employs Brillouin spectroscopy in optical fibers and is based on a time domain analysis of the signal. They name the technique Brillouin optical-fiber time domain analysis (BOTDA) which can be used to measure not only temperature distribution but also tensile strain distribution along optical fiber.

(b) Macrobending Types

Fiber macrobending is well developed as a technology. Macrobending of an optical fiber is the attenuation associated with bending or wrapping the fiber. Light can “leak out” from a fiber when it is bent. When the bend becomes more acute, more light leaks out. (J.A. Jay, 2010) In Macrobend sensors, the SMF is usually used and it is bend at

relatively large diameters. A specially bend sensitive SMF is used as regular telecommunication fiber is usually not sensitive enough to macrobending.

Watanabe et al. 2000 has investigated the macrobending characteristics of a newly developed hetero-core splicing for the practical use intended for relatively large distortion monitoring and for liquid adhesion detection. The results shown that the sensor with SMF of 9-5-9 structure detected large distortion and the sensor with SMF of 9-3-9 structure shown as a viable technology for liquid adhesion detection around the curved hetero-core portion.

(c) Surface Plasmon Resonance Types

SPR refers to the excitation of surface plasmon polaritons (SPPS), which are electromagnetic waves coupled with free electron density oscillations on the surface between a metal and a dielectric medium (or air) (Lee, B., et al. 2009)

In the study of SPR sensors based on MMF, the sensing element encompasses the fiber with an exposed core that coated with a thin metal layer supporting surface plasma waves (SPW). The propagation constant of the SPW is depends on the refractive index of the medium adjacent to the coated metal. (Slavik R., et al., 2001). Moreover, thickness of the metal is a crucial parameter in determining sensor characteristic.

According to the study by Lee, B., et al., diverse structures of SPR fiber sensors are available. The structures include D-shaped, cladding off, end-reflection, angled fiber tip and taper fiber structures.

2.3 Application of Fiber Optics Sensors (FOS)

The evolution of optical fiber sensor technology has expand its capability as a sensor.

It can measure nearly all of the physical measurands of interest such as bridge, building; large number of chemical or liquid such as acid, soil water and even gas such as hydrogen.

The optical fiber sensor measurands are listed in the table below.

Table 2.1 Optical fiber sensor measurands

Acceleration	Magnetic Field
Acoustic Fields	Pressure
Chemical	pH
Displacement (Position)	Strain
Electric Fields	Radiation
Flow	Rotation
Force	Temperature
Humidity	Velocity
Liquid level	Vibration

Some of FOSs are chemical sensors, temperatures sensors, strain sensors, biomedical sensors, electrical and magnetic sensors, rotation sensors, pressure sensors, displacement and position sensors, pH sensors, acoustic and vibration sensors.

In the next page, a table summarized the application of the different types of FOS and the related research of them. Different types of FOS has it unique function and application, therefore, it may only specific to certain application.

Table 2.2 Summary of Fiber Optic Sensors Application

Fiber Optic Sensors	Application	Reference
(a) Strain Dependency Types		
● FBGs	Measure temperature and strain	Du, W.C., et al., 1999 ; Kersey, A, et al., 1997
● BOTDR	Measure temperature and strain	Kurashima et al., 1993,
(b) Macro bending Types	Displacement and positions Liquid adhesion detection	Watanabe, K., et al., 2000, Nishiyama, M., et al., 2007
(c) Surface Plasmon Types	Chemical (liquid) pH Humidity Water level	Iga, M., et al., 2004; Seki, A., et al., 2007 Shiraishi, M., et al, 2011 Takagi, K. and Watanabe, K., 2012.

2.4 Fiber Optics Sensor Networks

Studies related to fiber optics sensor networks has become more common in recently years. The most suitable transmission medium for signals that generated by the fiber sensors is optical fiber, therefore, fiber-based networks has the advantages to accommodate the fiber optic sensors.

In the review of fiber optic sensor networks by Perez-Herrera and Lopex-Amo (2013), they classify the fiber optic sensor network into four subdivisions. The first subdivisions between them are

- Hybrid networks
- Simple networks

Further subdivisions that based on the type of sensors used are

- Reflective networks
- Transmissive networks

Moreover, they also discussed diverse of topologies for making sensors available in a network which are divided into four fundamental configuration. The topologies are (i) serial bus / dual bus or ladder, (ii) star, (iii) tree and (iv) mesh.

Chapter 3 Sensor Networks

3.1 Current Status of Sensor Networks

Although, many such wireless sensor networks (WSNs) seem to be successfully deployed and have evolved in many aspects, they continue to be networks with constrained resources in terms of limited in power, memory, and computational capacities (Liao and Yang (2012), Sahoo et al., (2009). Power efficiency is the main concern in sensor networks; however, the QoS (Quality of Service), requirements also need to be satisfied (Tadayon, et al., 2013). In the study by Zhu et. al. (2012), they mentioned that coverage is one of the measurements of WSNs QoS and it is closely related with energy consumption. In addition, nodes have limited communications capabilities, due to which a source node can cover only within its maximum transmission range (Rizvi, et al., (2012).

The fiber optic sensor network (FOSN) is fully wired in entire system or network, so there is no major concern to the limited power resource which will later cause the low quality of data communications or failure.

However, the cost of the fiber optic sensor network with only a single channel of fiber optic sensor is relatively high. Opportunely, if the system or networks would be possible to share either the source of light, system of detection or preferably, both; the aggregation of the sensors could results in their cost reduction (Perez-Herrera and Lopez-Amo, 2013).

3.1.1 Sensor Network Requirements

In comparison, the devices on an optical fiber sensor network differ from those on a WSN; however, it is reasonable to suppose that the general requirements of both sensor networks are basically the same. Therefore, from the requirement of WSNs, general requirements of a sensor network can be considered as following.

- (1) Installation: it should be easy to install sensor devices and to deploy communications and power cables.
- (2) Power supply: electric power required for communications and sensing should be able to be stably supplied over a long period of time.
- (3) Network capacity: even if the volume of sensor data increases owing to an increase in the frequency of measurements, the network should have sufficient capacity to accommodate the increased volume of data.
- (4) Device cost: sensor network components such as sensor devices or elements, and communications devices should be inexpensive.

3.1.2 Comparison of Sensor Networks

In this section, the advantages and disadvantages of the wireless sensor network and fiber optics sensor network is discussed. The comparison is based on the general requirements discussed in section 3.1.1.

(i) Installation

A wireless Sensor device is feasibility of installment because there is no need to lay cables (Ruiz-Altisent, et al., 2010) and wireless sensor devices are very small, as in the case of MICA-mote (Hill and Culler, 2002), and smart-its (Beigl and Gellersen, 2003).

On the other hand, the implementation and configuration of a satellite sensor network could be a hassle which involved many man power and time consuming.

Comparing to the WSN, the installation of a fiber optics sensor network is more complex due to the need to lay optical fibers.

(ii) Power Supply

Limited battery life is recognized as being a serious problem with WSNs. Therefore, various kind of energy saving techniques which include energy-efficient routing protocol, medium access control schemes, special operating systems and system-on-chip technology has been studied. Although this techniques seems to be useful to extend the battery life time of the WSN nodes, but none of them offers an indispensable solution to the battery replacement issues. It is difficult and troublesome to replace dead batteries of a large number of sensor devices (Minami et al., 2005). Refer to this issue; research on the power supply by solar power has been carried on. However, the energy or power supply could be affected by changes of weather or level of illumination in the environment. Therefore, attempts to prolong battery life impose limitations on the operations of sensor devices has become an issue.

As for optical fiber network systems, fiber sensor elements use light propagating along optical fibers to take measurements. Therefore, fiber optics sensor elements do not need to be supplied with power although communications and measurement apparatuses do. Furthermore, connecting a number of fiber optics sensor elements in series over a fiber line enables reduction of the number of communications and measurement apparatuses. In this case, the complexity of the power supply cable that connects to the system could be avoided.

(iii) Network Capacity

In wireless sensor network, since the radio communications dominates the power of the sensor node, severe constraints on the wireless communications protocol and transceiver is present. Wireless technology such Bluetooth and ZigBee which assumed a variety of application, therefore, its complex features and the high power consumption are not suitable for wireless sensor network (Shih et al., 2001). Wireless sensor devices mainly employ low-power and low-speed radio transceivers due to the problem of battery life (Shih et al., 2001, Rhee et al., 2003). In the case of an increase in traffic, such as by the occurrence of an abnormal event, challenges remain network congestion is likely to occur. In addition, in order to prolong battery life, sensor devices or nodes usually communicate only intermittently (Akyildiz, et al., 2008). In such situation, sensor nodes might appear in an inactive condition, so data receiving operation could not be performed. This increased the distance between nodes which cause the nodes reception is at the impossible state. Then, error rate increases and the data communications quality are degraded.

Fiber optics sensor networks are expected to offer high-speed communications.

By utilizing inherent features of the optical fiber as a transmission medium, high-speed large-capacity communications can be achieved. Therefore, even if the sensing information generated in large quantities, the network congestion occurrence is very minimal. In addition, it is not only functioning as the propagation of sensing information, but it provides a function as a normal LAN.

(iv) Economy Efficiency / Device Cost

Advances in hardware and engineering design have led to a reduction in the cost of sensor devices (Pottie and Kaiser, 2000). However, WSNs require a large number of closely arranged sensor devices because of the constraints imposed by the propagation range of radio waves. Therefore, it is not always true that the cost of the entire system is low.

In terms of fiber optics sensor networks, the sensor elements, light sources, and measuring equipment are more expensive than wireless sensor devices.

3.2 Related Research: Natural Environment Monitoring System

A number of natural environment monitoring systems which especially focus on agriculture have been researched and studied. A regional and on-farm wireless sensor networks is implemented in the eastern Washington, (Pierce, et al., 2008), NAV system is designed for remote real-time monitoring of a vineyard in Italy (Matese, et al., 2009).

In Japan, Geographic Information System by Fujitsu (Hori et al., 2010, Fujitsu Hokkaido System, 2011) introduces the latest technology such as sensors, wireless networks and cloud computing into agriculture practices. Fujitsu revises approaches and conducts business feasibility studies to establish a hypothetical model of cloud services that make genuine contribution to agriculture.

GeoMation Farm by Hitachi (Hitachi, 2011a and 2001b) utilizes a satellite service to provide the image for analysis and a visual indication on the best time to harvest crops. The system regulates the quantity, frequency and timing of agricultural chemicals.

NEC provides agriculture ICT Solution by collecting sensing data such as farm temperature and humidity or cultivation work history and then centralizing data in the cloud for management and agricultural production support purpose. The services also include statistical data analysis, application development and network setup at the farm (NEC, 2012).

FieldServer by Elab Experience (2010), a sensor network environmental monitoring device is designed with a camera and sensor communications. FieldServer applications include a web marketing service to view scenery of a coffee farm, next generation of agricultural education based on ICT in Shizuoka Prefectural Agriculture and Forestry College and Himalaya Lake Inja monitoring project. Sensor Service Grid (SSG) by Geomove (2011), provides a cloud service for constructing field sensor network system.

The alternative technology such as satellite remote sensing already exists and uses for agricultural meteorology or agrometeorology remote monitoring (Minami et al., 2005).

Faruolo, M, et al., 2013 discussed a sensor-independent approach (RST, Robust Satellites Techniques-FLOOD) is presented and applied to data acquired by two different satellite systems (Advanced Very High Resolution Radiometer (AVHRR) onboard National Oceanic and Atmospheric Administration platforms and Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Earth Observing System satellites) at different spatial resolutions (from 1 km to 250 m) in the case of Elbe flood event occurred in Germany on August 2002.

In study by Mello, M.P., et al., 2013; a new image processing method: Spectral–Temporal Analysis by Response Surface (STARS), which synthesizes the full information content of a multitemporal–multispectral remote sensing image data set to represent the spectral variation over time of features on the Earth's surface.

However, such systems involved country level or high level of research works in order to implement and provide the satellite remote sensing system. Therefore, cost of implementation is very high and it could not be user friendly due to complexity of the system.

3.3 Current Agriculture Monitoring Activities

In recent years, a revolution toward the environmental sensors network (Hart et al., 2006) has results in many studies that focusing on the sensing technologies for crop production (Lee et al., 2010) and agriculture activities monitoring (Zhang et al., 2011).

According to the summary by Hart et al. (2006), the example of different environment sensor networks has shown that soil moisture, air temperature and humidity, water and light level are important factors for agricultural environments monitoring.

On the other hand, because water makes major contribution to the crop production and majority of crops are produced from rain-water (Mark, et al., 2009), therefore, it is very essential to monitoring soil gravity water or soil moisture in agriculture activities.

Related research of recent environment sensor monitoring and its monitored items have been summarized in the next table.

Table 3.2 Current Agriculture Monitoring: Related Research Summary Table

	Environment Sensor Network	Monitoring items	Research by
1	Sensor networks for pasture assessment	Soil moisture	Wark, et al., 2007
2	An agricultural weather network and an on-farm frost monitoring network	Micro-meteorological parameters	Pierce, et al., 2008
3	WSN sensor network of remote real-time monitoring and collecting of micro-meteorological parameters in a vineyard	Irrigation and soil moisture	Matlese, et al., 2009
4	An ethnographic study of the denizens of vineyards	Temperature	BeckWith, et al., 2009
5	Deployment of sensor network to provide reliable, long-term monitoring of rainforest ecosystems.	Rain forest- restoration of biodiversity	Corke, et al., 2010
6	Using the fieldserver to provide an outdoor solution for monitoring environmental parameters in real-time.	Water, soil, air , sunlight	Honda, et al., 2009 Field Server, 2010
7	A remote monitoring system using cloud service to provide real-time data from sensors	Temperature, air moisture, soil, soil temperature, soil gravity water	Fujitsu, 2013
8	A system to manage and utilize information for each piece of field, including crops, staff, the record of fertilizer and other agricultural chemical usage, and yield and quality	Soil type management, soil usage management, soil fertilizing management	Hitachi, 2011
9	Smart monitoring solutions for crop and water management	Air temperature and humidity, soil temperature and soil moisture	Sensor Ware Systems, 2013
10	Design and implementation of a reactive, event driven network for environmental monitoring of soil moisture and evaluates the effectiveness of this solution	Soil moisture, soil temperature	Cardell-Oliver, et al., 2004

3.4 Remaining Issues of Previous Research

Based on the comparison of the sensor network and the natural environmental monitoring system in section 2.2 and 2.3, the remaining issues of existing research are summarized as below.

(i) Larger, complex system configuration and function

Wireless sensor network and existing commercial system is very complex and involve large system configuration. Furthermore, an alternative of satellite remote sensing involved country level or high level or research work (Faruolo, et al., 2013; Mello, et al., 2013).

(ii) Limited sensor's power or battery supply

Power management is one of the major concerns in the sensor network systems intended to operate wirelessly (Burrell et al., 2004). If electricity supply is unavailable, sensors are required to have a battery. Limited battery life time may cause direct operation interruption during the data communications (Tanenbaum et al., 2006).

(iii) Low reliability on data communications

A wired network is not present, thus this requires a sensor to communicate using an ad hoc wireless network (Tanenbaum et al., 2006) which unable to produce high connectivity networks. Assurance the delivery of data over multiple node hops is extremely difficult, because low data throughputs expected to go through long hops count before reaching the sink.

Moreover, the microwave radio communications cannot permeate through obstacles such as forests, building and metallic walls and dominates energy consumption (Gracia-Hernandez et al., 2007, Hu et al., 2010, Lee et al., 2010).

(iv) Higher production cost

A cost of a single sensor node could justify overall cost of a sensor network. In order to provide a low cost sensor network, manufacturing cost of a sensor is required to be low (Tanenbaum et al., 2006).

Table 3.1 Summary of the requirements, existing research and the remaining issues.

No	Requirements	Existing Research	Remaining Issues
1.	Installation	<p>Satellite based remote sensing : Faruolo, et al., 2013, Mello, et al., 2013;</p> <p>Commercial system: By Fujitsu, NEC, Hitachi.</p>	<p>Larger, Complex System Configuration and Function</p> <p>Faruolo and Mello are both research using the satellite-based remote sensing system. Although the system cover a huge monitoring area, however, it involved a complex installation and years of research works.</p> <p>The commercial system is mainly target for huge production farm which equipment with complete infrastructure. Installation of the system is difficult when the farmer do not have further knowledge regards to the system infrastructure.</p>
2.	Power Supply	<p>Environmental WSN : Minami, et al., 2005; Puccinelli and Haenggi, 2005; Piece, et al. 2008; Matese, et al., 2009; Corke, et al., 2010; Liao and Yang, 2012;</p>	<p>Limited Battery or Power Supply</p> <p>Corke, et al., 2010: radio clearly dominates the energy consumption; the energy state of a node places a constraint on the performance that a node can deliver.</p> <p>Minami, et al., 2005 Battery replacement problem could not be solved with various energy saving techniques.</p>
3.	Network Capacity	<p>Sensing Technology : Lee, et al., 2010;</p> <p>Outdoor Sensornet : Hu, et al., 2012;</p> <p>Environmental WSN : Corke, et al., 2010;</p>	<p>Low Reliability on Data Communications</p> <p>According to Corke et al., numbers of their deployments showed, the variability in conditions in many environmental area (e.g. Foliage, rain, humidity) means that communication LQ between nodes is highly dynamic and unpredictable.</p> <p>In evaluation study by Hu, et al. they observed a highly dynamic environment between the sensors nodes cause by a combination of many environmental parameters.</p>
4.	Device Cost	<p>Commercial system: By Fujitsu, NEC, Hitachi.</p> <p>Satellite-based remote sensing : GeoMation farm by Hitachi, Faruolo, M, et al., 2013, Mello, M.P., et al., 2013;</p>	<p>Higher Production Cost</p> <p>Commercial sensing system which provides many monitoring features and management system is always consume huge cost during implementation. Those systems is also mainly target to larger commercial farm not suitable for small-size farm.</p> <p>Satellite-based remote sensing involved high end research by the government and research institute, furthermore, it is not a low-cost technology which also take years to complete the research. Comparing the WSN or OFSN, such system definitely far more expensive in cost.</p>

Chapter 4

Research Objective and System Requirements

4.1 Research Overview and Concept

The overall concept of our research laboratory is to construct a sensor network which could be utilized in the wide area of environmental monitoring with fiber optic sensor. The natural environment could be a forest, a farm or a natural park. Figure 4.1 shows the overall concept of our study. In order to operate such a system, the fiber sensors are installed in a target sensing point in the local sensor network and link up with fiber optic line. The local sensor network will then send the required data from a measuring local station to the monitoring center remotely. The connection from the local sensor network to the monitoring center using wireless, public network or fiber optic is possible to be included in the existing sensor networks.

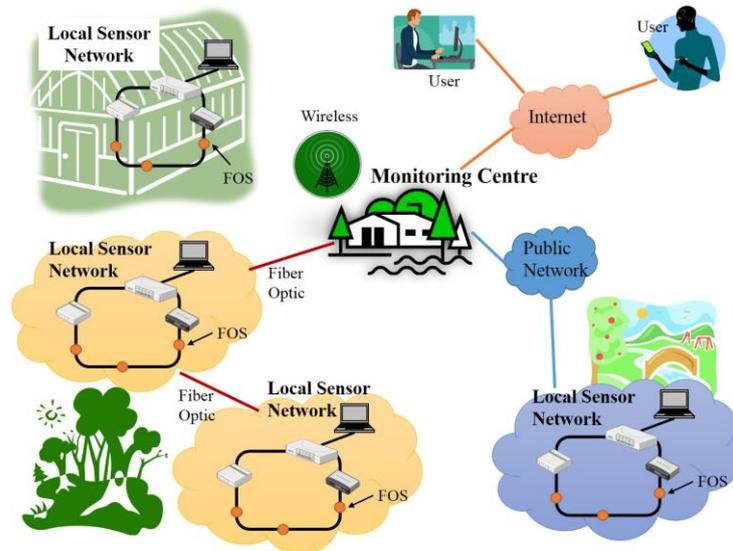


Figure 4.1 Overview Concept of Sensor Network for Natural Environment Remote Monitoring

4.2 Research Objective

Based on the overall concept, this research topic focuses on the realization of a fiber optic sensor system for agricultural environments such as a farm. Therefore, this research objective is to propose and construct a remotely monitor fiber optic sensor system for soil gravity water monitoring in agricultural environments.

The system is capable of adaptation to larger areas with real-time measurement and data transmission. In order to remote monitor a sensor networks, we study the optical sensor networks remote management using the internet-standard protocol. The study involves the installation of multipoint sensors into the same fiber line and differentiates the response from each sensor by using the internet-standard protocol – Simple Network Management Protocol (SNMP).

4.3 Significance of Study

Natural environmental monitoring involved in many aspects, such as ground water monitoring, rain forest micro-climate monitoring, lake water quality monitoring and environmental impacts monitoring (Corke, et al., 2010). The target of those monitoring items could be different from each monitoring systems depend on their purposes.

In order to achieve the overall concept of our laboratory study, we start with a focus on agricultural environment monitoring with fiber optics sensor.

However, before we could realize the entire sensor networks, many challenges such as the usability of the fiber optic sensors, the balance between the sensing and data communications, simplicity of the measurement devices, and others remaining issues of the related research need to be studied.

By conducting the research over some related research based on agriculture, the current agriculture monitoring activities have been summarized in sections 3.4. We could see that most of the target monitoring items are soil, soil moisture, soil gravity water and soil temperature. Therefore we start from the soil gravity water monitoring.

Next, we need to find an appropriate fiber optic sensor which can detect soil gravity water. According to the study by Lee, B., et al. (2009), one of the important advantages of fiber-optic SPR sensing configurations are the simplified optical design and the capability for remote sensing. In our study, we choose a hetero-core spliced optical fiber surface plasmon resonance (SPR) sensor (HC-SPR sensor) that detects soil gravity water. The sensitivity of HC-SPR sensor to detect the soil gravity water has been studied. (Kumekawa and Watanebe, 2011). However, the agriculture remote monitoring (soil gravity water in this research) which involves the installation of the HC-SPR sensor within the communication line, and retrieving data for both sensing and data communications simultaneously have not been studied yet.

There is a trade-off relationship between communications quality and measuring accuracy when the sensors is installed in the same line with the communication signal. Hence, this research has a challenge to study on how to balance data communications and measurement sensitivity features requiring proper devices and their consistent integration. Furthermore, a remote monitoring technique which could handle such system need to be studied.

The main contributions of this study are system integration that meets the requirements for soil gravity water monitoring in agricultural environment and to realize the remote management of fiber optic sensor networks. Throughout this study, we focusing on two main parts of which this doctoral dissertation consists.

- (i) A study on a system integration of Sensor system for soil gravity water monitoring in agricultural environments with HC-SPR sensor
- (ii) A study of a remote management of multipoint sensing systems using HC-SPR sensors

The system requirements and the proposed methods are discussed in the next section. Based on those requirements, a proposed system is configured, tested via experiments to verify its feasibility. The experiments and results will be discussed in chapter five.

4.4 System Requirements

The systems requirements of our proposed system are define based on the user needs and refer to remaining issue discussed in previous section. By consulting the local farmers near to our university, we found their needs are, broad area monitoring, real-time status monitoring of farm environment and a low cost with easy to install system. Therefore, we aim to construct a simpler configuration, higher quality communications optical fiber sensor system which provide a real-time measurement and adaptable to broad area. The system requirements are describes as below.

- (i) Simpler configuration sensing system and network management: the number of system components such as communications and measurement devices are minimized in order to facilitate simple installation of the system. A simple

network management method is required to manage the sensor network.

- (ii) Continuous power supply: Being different from wireless sensors, the FOSs do not need power supply for operation, while other measuring devices are connected to the power directly. Therefore, the installation of FOSs can solve the power or battery supply issues for the sensors.
- (iii) Data communications reliability and real-time measurement: the system is wired connect with continuous power supply which ensured the data communications reliability. To send real-time measured data to users is one of the crucial features of our monitoring system. It is to provide users a real-time measured and processed data which collected from the sensor located at farm.
- (iv) Adaptable to larger area of environment: In most countries in Southeast Asia, the average farm size is less than 2 hectares (Eastwood et al., 2010). However, to accommodate the expansion of the farm size or monitoring area which includes two or three farms, a longer distance monitoring system need to be constructed. Thus, a system which is able to offer a soil water monitoring service in a broad area needs to be studied.
- (v) Multi-point sensing: Sensors are tandem install in the same fiber line in order to collect data in a few areas.

4.5 System Requirements and Proposed Methods

Based on the defined system requirements, some methods are proposed. The main proposed methods to meet the system requirements are, the use of Fiber Optic Sensor (in this study, the HC-SPR sensor is utilized) and SNMP as network management approach. Table 4.1 describes the detailed of the proposed methods.

Table 4.1 System requirements and proposed methods.

No	Requirements	Proposed Methods
1.	Simpler configuration sensing system and network management	<p><i>Avoid complex measurement devices</i> In order to measure the output from the network, the FOS measuring devices such as Optical Time-Domain Reflectometer (OTDR), Optical Spectrum Analyzer (OSA) are replaced by the measurement devices such as combination of Photodiode with power meter.</p> <p><i>SNMP as a remote network management</i> To remote monitor the network status, SNMP agent and software which is simple to be configured are integrated into the system.</p>
2.	Continuous Power Supply	<p><i>Fiber optics sensors</i> Being different from wireless sensors, the FOSs do not need power supply for operation, while other measuring devices are connected to the power directly. Therefore, the installation of FOSs can solve the power or battery supply issues for the sensors which is a major challenges in WSNs.</p> <p>With a continuous power supply to the system, the data communications is stable and the sensing data could be send to measuring device in a real-time. Other than that, fiber optics also provide a larger network capacity.</p>
3.	Data communications reliability and real-time measurement	
4.	Adaptable to larger area of environments	<p><i>Fiber optics sensors</i> The fiber optics sensor used in this study able to simultaneously provide data communications and sensing. It is the hetero-core spliced SPR sensor. To adapt the sensor to larger area of monitoring, the sensor coated with a metal film of 25nm of gold and 60nm of tantalum pentoxide. This sensor could perform the sensing approximately 2000m with the wavelength of 1310nm.</p>
5.	Multi-point Sensing	<p><i>SNMP to manage multi-point sensors</i> The SNMP trap PDU which can be used by the agent to alert the manager that a predefined event has occurred. By configure the settings of trap value enable the system to recognize the identity of the responded sensor (explain as a predefined event). Such technique do not required complex configuration and SNMP agents can be configure easily to the existing system.</p>

Chapter 5

Soil Gravity Water Monitoring using Hetero-core Fiber Optics Sensor

5.1 Hetero-core Fiber Optics Sensor and Verification Experiments

5.1.1 Hetero-core Fiber Optics Sensor

The structure of the fiber consists of a multimode transmission fiber and a single-mode fiber segment inserted in the transmission line, where the core of the multimode fiber is 50 μm and the core of the single mode fiber is 3 μm . Figure 5.1 shows the hetero-core structured optical fiber SPR sensor. The sensor is fabricated with a graded index multimode fiber with core and cladding diameters of 50 μm and 125 μm , respectively, and an inserted 10 mm long step index single-mode fiber with a core diameter of 3 μm and cladding diameter of 125 μm . The core diameter of the inserted fiber, which is smaller than the transmission fiber, works as a sensor portion. Since the core diameter of the inserted fiber for the sensor portion is much smaller than the transmission line, most of the light wave would leak into the cladding layer at the interface of the transmission line and the hetero-core. Next, the hetero-core portion is fabricated by cylindrically coating the bare fiber surface with metal using an RF sputtering machine (CFS-4DS-231, Shibaura Mechatronics Corp).

In this research, the coating on the cylindrical surface of the hetero-core portion with metal material allows the formation of a surface plasmon wave when the evanescent wave reflects on the metal surface. The light leakage generates an evanescent wave in the course of the cladding mode development when reflecting at the boundary surface

between the cladding and the surrounding medium.

The SPR resonance wavelength varies, depending on the refractive index and absorbance of the metal surface. Thus, this device can be used as a sensor for measuring refractive index by measuring the resonance wavelength.

In previous work by Takagi & Watanabe (2012), the Au/ Ta₂O₅ coating combination was properly selected to give a sufficient SPR dip according to a series of experiments. By increasing the Ta₂O₅ thickness coating to 60nm, the experiment shows that the resonance wavelength is largely shifted. Figure 5.2 shows the spectrum of an HC-SPR sensor with 10 mm insertion length coated with 25nm Gold (Au) and 60nm Tantalum Pentoxide (Ta₂O₅).

This sensor's SPR dip occurred at the wavelength 1310nm which is the resonance wavelength. It is depicted by the arrow in figure 5.2. According to the graph*, the maximum sensitivity or power loss of this HC-SPR sensor with a 1310 nm wavelength in water is approximately 2 dB.

*(*The sensor's spectrum graph is drawn by using value measured in air minus value measured in water – In this case – AIR is used as the base)*

The study applies the HC-SPR sensor to the communications line, where it simultaneously acts as a sensor and serves as a medium for data communications. In such a situation, light leakage, which is caused by SPR resonance in the HC-SPR sensor, is measured as the light loss. This system therefore measures changes in the signal intensity.

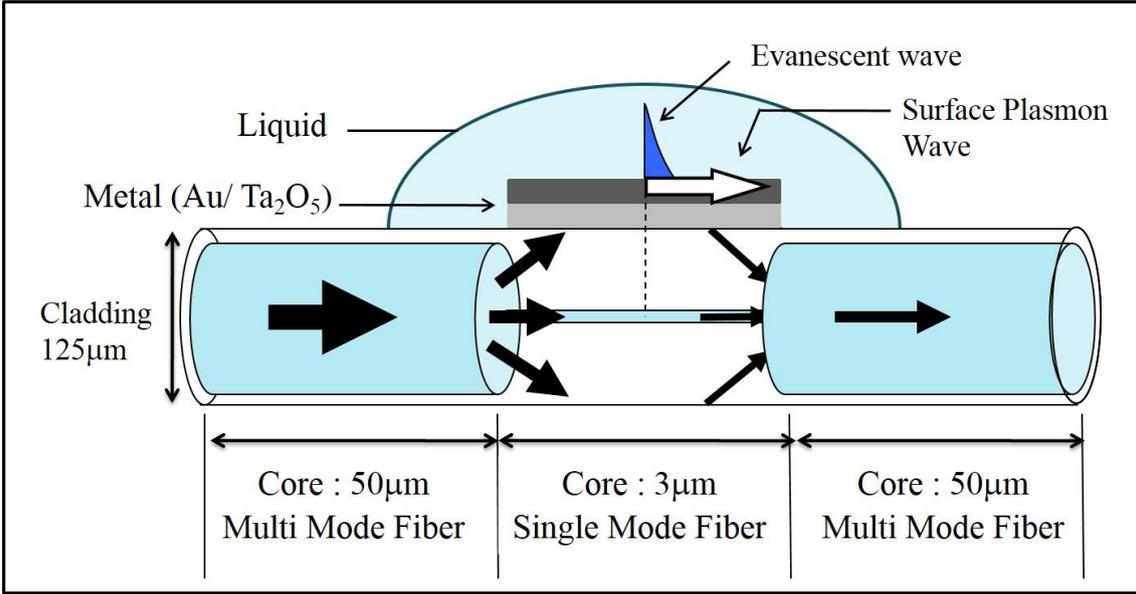


Figure 5.1 Structure of hetero-core structured optical fiber SPR sensor

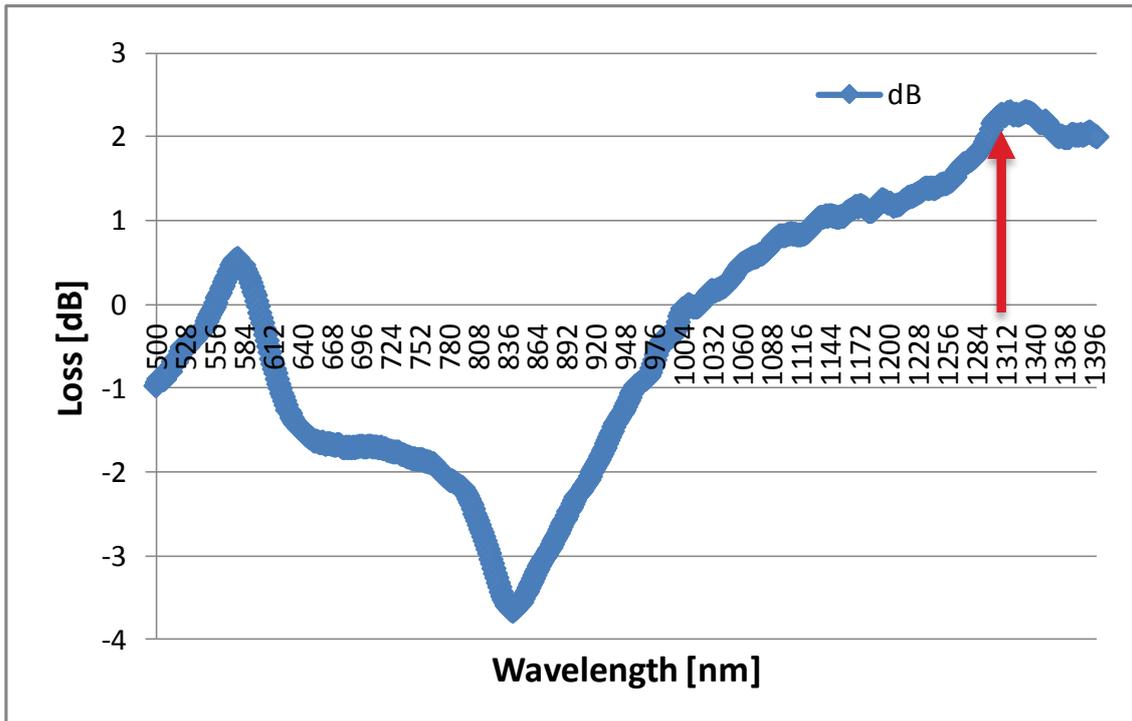


Figure 5.2 Spectrum of an HC-SPR sensor with 10 mm insertion length

5.1.2 Related Research

One of the fiber optic based sensors – FBG (Fiber Bragg Grating) sensor which serves as a communications network and as health monitoring system has been studied (Golt, et al 2004). The sensor can serve a dual role through wavelength division multiplexing, which allows multiplexing of multiple wavelengths into a single fiber. For example, the sensor uses 1310nm wavelength for data communications and 1550nm for strain sensing.

With this method, the data communications reliability requirement can be achieved.

However, the manufacturing process of FBG sensor is highly to be complicated which lead to high manufacturing cost. Furthermore, measurement devices required for a FBG sensor network such as OSA (Optical Spectrum Analyzer) and OTDR (Optical Time Domain Reflectometry) are known to be expensive.

5.2 Wide-area monitoring using Tantalum Pentoxide (Ta_2O_5)-coated HC-SPR Sensor

5.2.1 Tantalum Pentoxide (Ta_2O_5)-coated HC-SPR Sensor

A Ta_2O_5 coating over part of the metallic lamina on the surface of an SPR sensor makes it possible to shift the resonant wavelength of SPR to a longer wavelength, due to the higher dielectric constant of Ta_2O_5 (Slavík et al., 2001). The SPR resonance wavelength is largely shifted to a region over 1000 nm by thickening the Ta_2O_5 coating to 60 nm (Takagi & Watanabe, 2012). Therefore, proper adjustment of the Ta_2O_5 coating thickness can be expected to induce the SPR phenomenon even at the 1310 nm wavelength used for long-distance data communications.

This section describes an experiment for verification of short- and long-distance data communications and sensing using a Ta_2O_5 -coated HC-SPR sensor, and the results of

each experiments.

5.2.2 Short-distance Data Communications and Sensing Verification Experiment

Figure 5.3 shows an overview of the experiment. An HC-SPR sensor coated with 25 nm of gold (Au) and 60 nm of Ta₂O₅ was prepared. A NextStream (Fujitsu Network Technologies) network-testing unit was used to measure data throughput and frame check sequence (FCS) errors using an optical communications signal with 1310 nm wavelength.

First, the data flow of the experiment started with generating a data communications signal (1310 nm) from the NextStream. Next, the signal was passed through a media converter and an HC-SPR sensor, and then separated by an optical fiber coupler. Lastly, a power meter measured the transmitted light and measurement data was sent to a PC. Pure water was used as the test sample in this study.

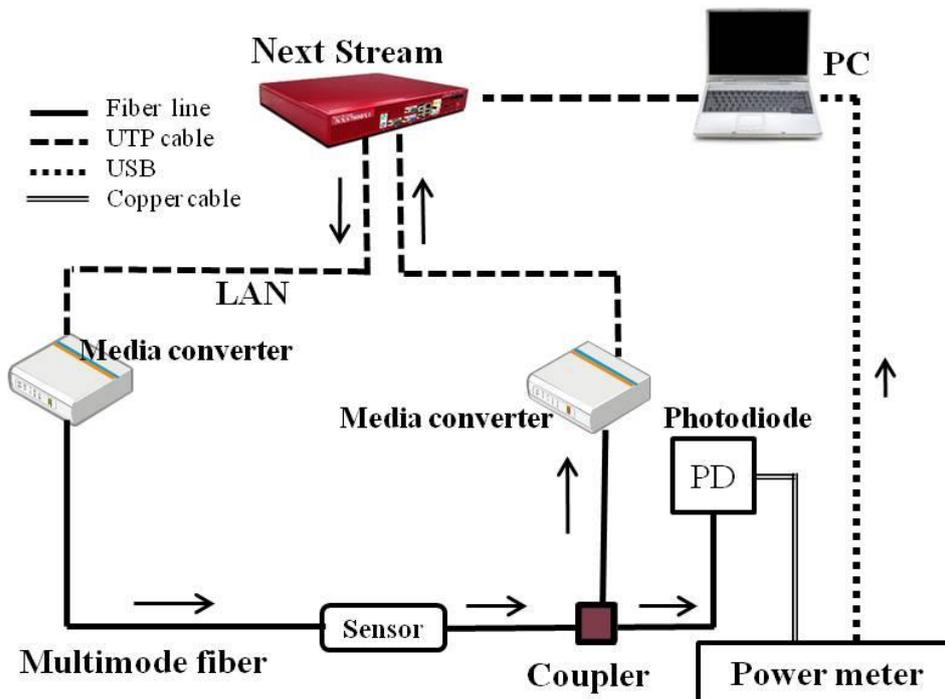


Figure 5.3 Structure of the verification experiment for data communications and sensing

Figure 5.4 shows the experimental results. The experiment was carried out in two cycles of immersing the HC-SPR sensor in pure water within 150 s. The experiment was carried out in two cycles to identify the pattern of light loss when the sensor was immersed and removed from the water.

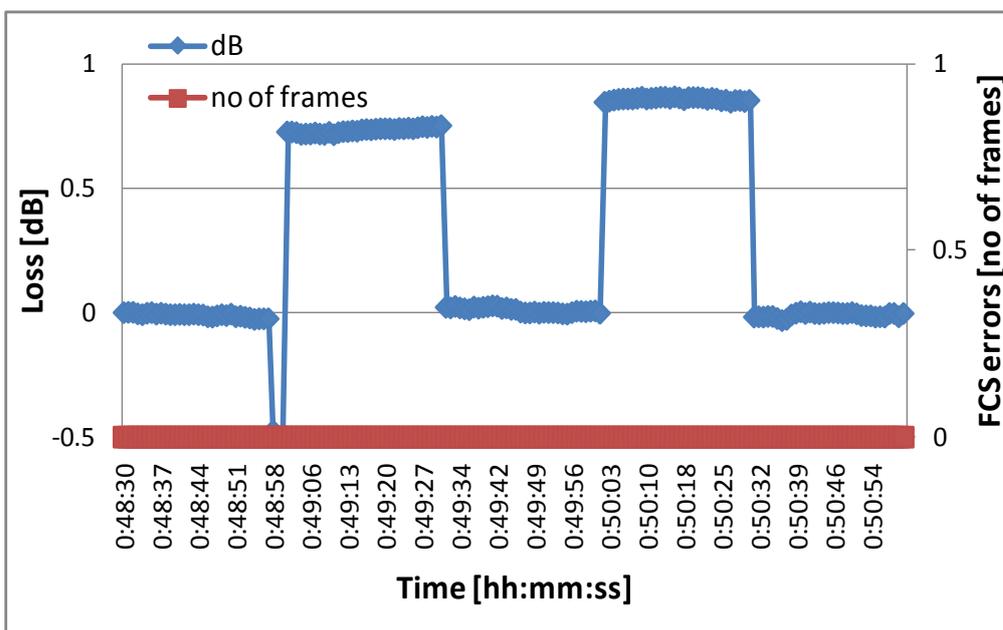


Figure 5.4 Experimental result of verification of the sensing characteristic for a tantalum pentoxide (Ta_2O_5) coated HC-SPR sensor

During the first 30 s the sensor was dry, and from 31 to 60 s the sensor was immersed in water. This was then repeated for another cycle. The results in Figure 5.4 show that the power loss of the HC-SPR sensor increased when it was immersed in water in the first and second cycles, from 31 to 60 s and 90 to 120 s. When the sensor was immersed in the first cycle, the movement caused the sensor to touch the surface of the water, which caused a power increase. This occurrence was due to the bending or position of the

HC-SPR sensor, and is a normal phenomenon.

Both cycles show that the power decreased when the sensor detected water, with an average power loss of 0.8 dB. The NextStream did not detect any FCS errors during this experiment.

These results demonstrate that the proposed system can perform data communications without interruption while measuring variations in power loss.

5.2.3 Long-distance Data Communications and Sensing Verification Experiment

In order to provide a data communications and sensing service to farm in a longer distance, a few experiments are conducted in order to evaluate the feasibility of the HC-SPR sensor under our proposed system. Those experiments are conducted to verify the data communications and sensing characteristics of an HC-SPR sensor coated with 25 nm of Au and 60 nm of Ta₂O₅ in a longer-distance of 1000 m. The pattern of the experiment A, B and C is described in Table 5.1.

Table 5.1

Experiment description for long-distance data communications and sensing verification.

No	Experiment	Description
1	A	Verification experiment with two 500 meter long of 50 μm core multimode fibers install <u>before and after</u> the SPR sensor position
2	B	Verification experiment with a 1000 meter long of 50 μm core multimode fiber install <u>before</u> the SPR sensor position
3	C	Verification experiment with a 1000 meter long of 50 μm core multimode fiber install <u>after</u> the SPR sensor position

5.2.3.1 Experiment A

Figure 5.5 shows the experimental setup for experiment A. The experimental environment was constructed using two 500 m rolls of 50 μm core multimode fiber. A multimode optical coupler was used as a signal splitter. A power meter was used to measure the light loss. In this study, pure water was used as the test liquid.

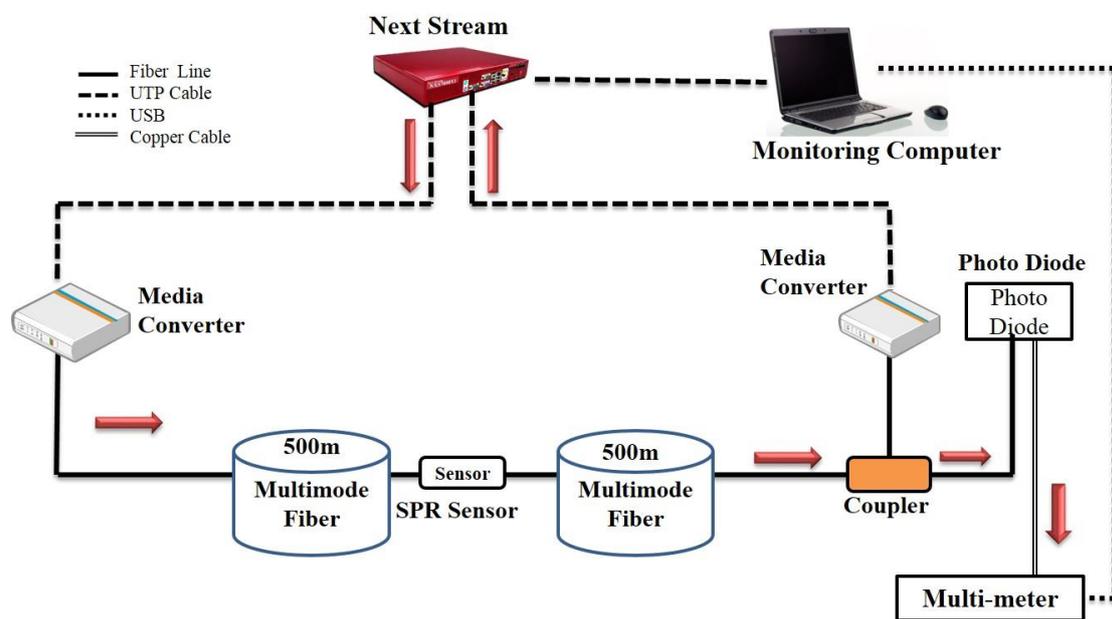


Figure 5.5 Experimental setup A - to verify the data communications and sensing of an Au and Ta_2O_5 HC-SPR sensor over a long distance

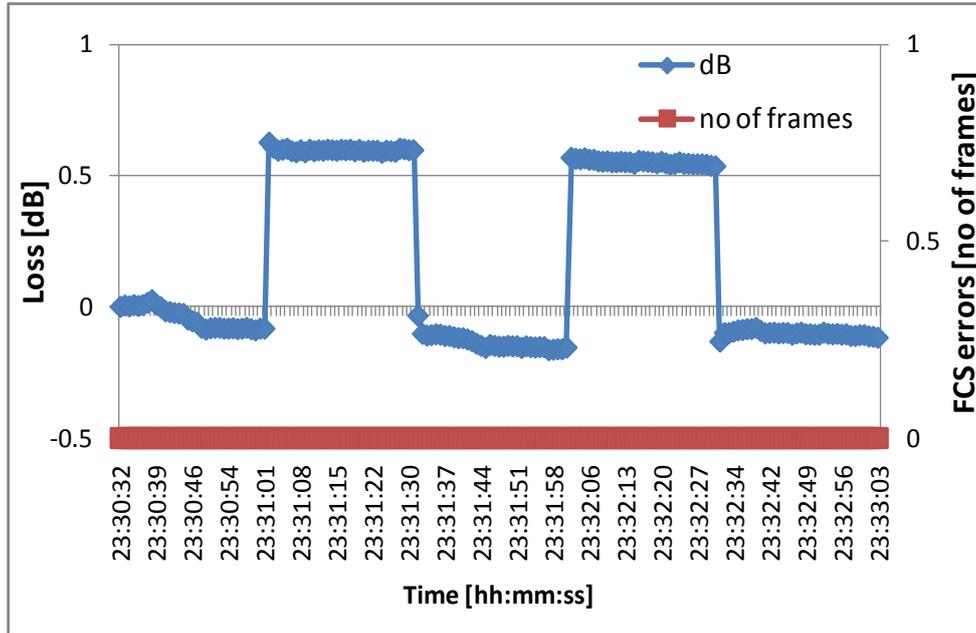


Figure 5.6 Results for experiment A

Figure 5.6 shows the experimental results for experiment A. In the first 30 s, the light loss was zero while the sensor was in air. From 23:31:01 to 23:31:30 and from 23:32:06 to 23:32:27 the sensor was immersed in water. The average power loss when the sensor was immersed in water was 0.6 dB. The NextStream detected no FCS errors, and then data communications were not interrupted, either. The result of experiment A demonstrates that the proposed system can perform sensing and data communications without interruption while successfully measuring power loss.

5.2.3.2 Experiment B

The experimental environment is almost the same as experiment A, and water was used as the test liquid. However, the two 500 m rolls of 50 μm core multimode fiber are installed before the HC-SPR sensors as shown in figure 5.7.

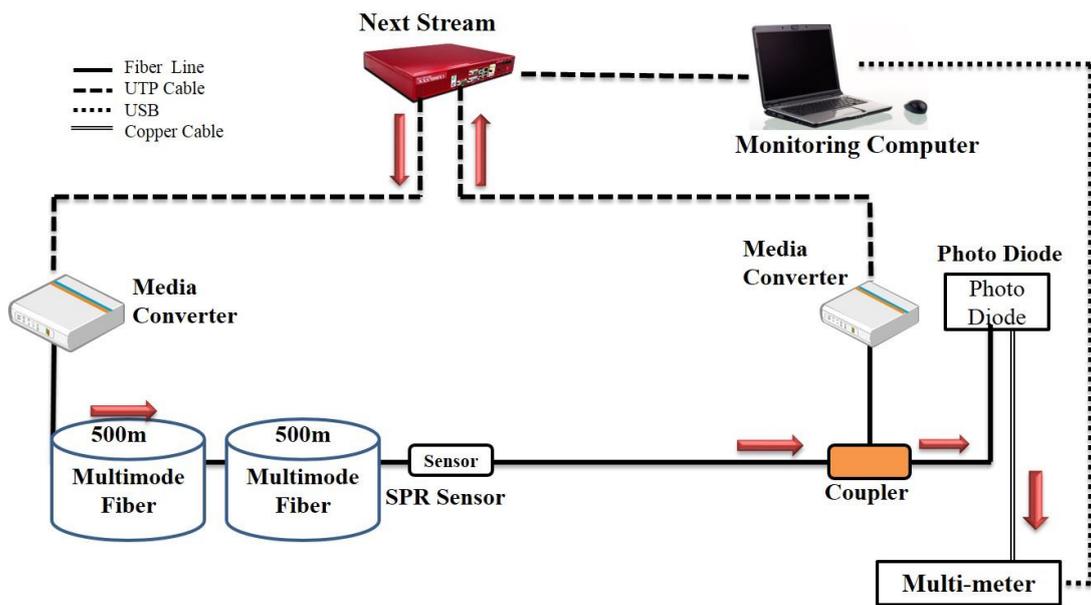


Figure 5.7 Experimental setup B - to verify the data communications and sensing of an Au and Ta₂O₅ HC-SPR sensor over a long distance

Figure 5.8 shows the experimental results for experiment B. In the first 30 s, the light loss was zero while the sensor was in air. From 15:32:00 to 15:32:30 and from 15:33:00 to 15:33:30 the sensor was immersed in water. The average power loss when the sensor was immersed in water was 1.0 dB. The data communications were not interrupted and the NextStream detected no FCS errors. The result demonstrates that experiment B can perform sensing and data communications without interruption while successfully measuring power loss, even with 1000 meters fiber optic is installed before the sensor.

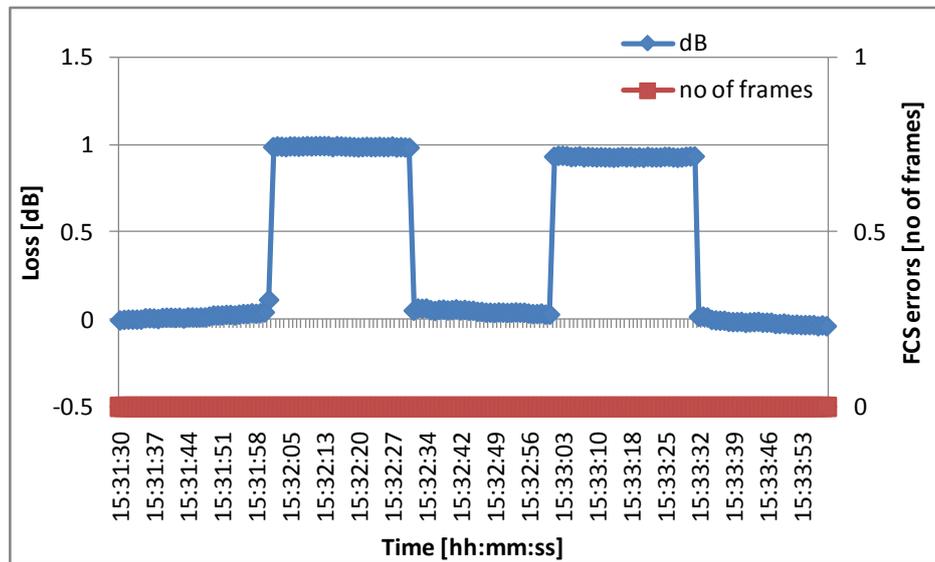


Figure 5.8 Results for experiment B

5.2.3.3 Experiment C

The experiment C's setup is similar to experiment A and B. The two 500 m rolls of 50 μm core multimode fiber are installed after the HC-SPR sensors as shown in figure 5.9.

Figure 5.10 shows the experimental results for experiment C. In the first one minutes, sensor was in the air therefore, the light loss was zero. From 15:42:00 to 15:42:30 and from 15:43:00 to 15:43:30 the sensor was immersed in water.

The average power loss when the sensor was immersed in water was 0.4 dB. The NextStream detected no FCS errors and data communications has no interruption. The experiment C result also shows that this configuration can perform sensing and data communications successfully, even with 1000 meters fiber optic is installed after the sensor.

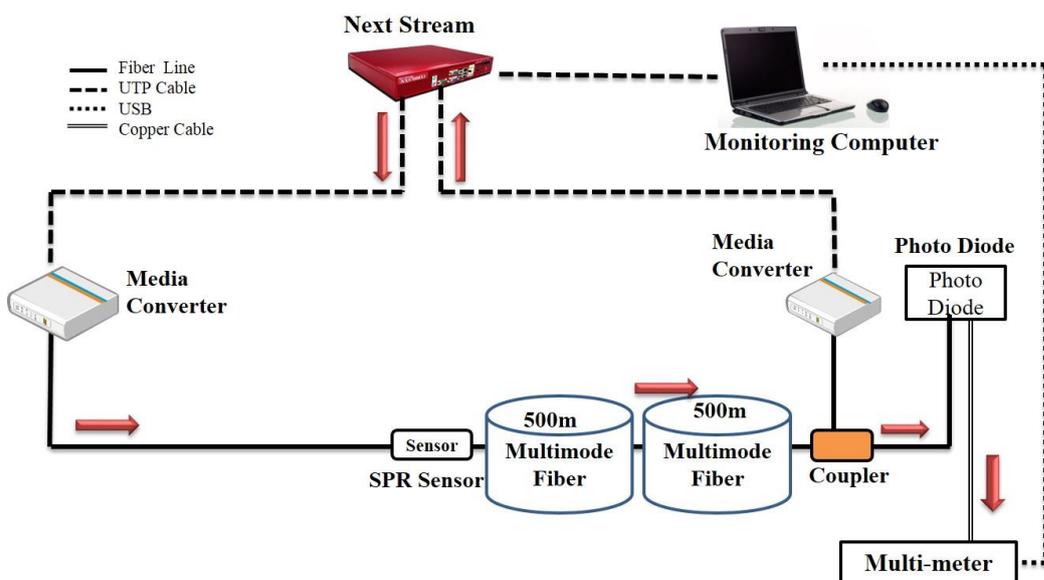


Figure 5.9 Experimental setup C - to verify the data communications and sensing of an Au and Ta₂O₅ HC-SPR sensor over a long distance

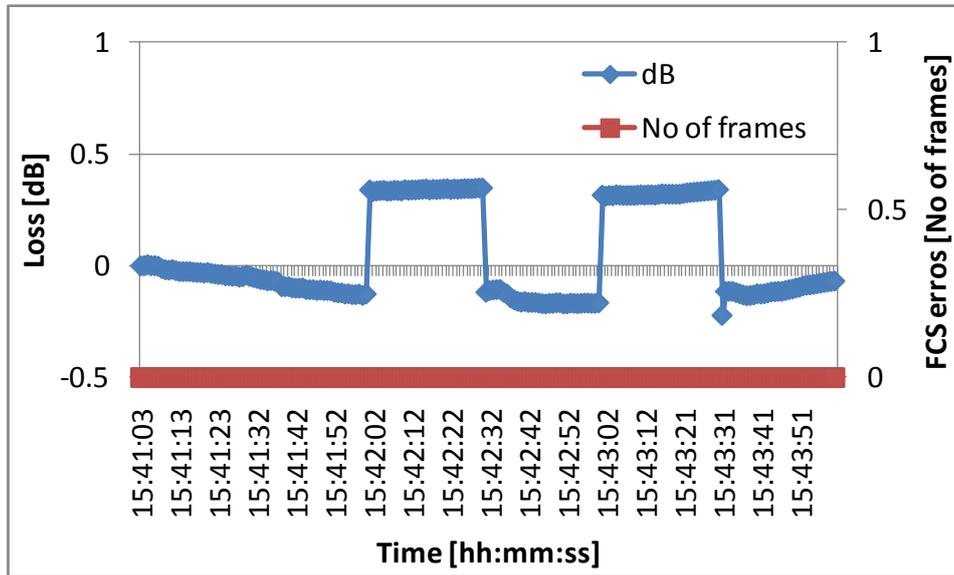


Figure 5.10 Results for experiment C

Chapter 6

Soil Gravity Water Monitor Sensing System using Hetero-core Fiber Optics Sensor

6.1 Conceptual System Configuration of Hetero-core Fiber Optics Sensor System

Figure 6.1 shows the construction of the proposed conceptual system. The system hardware configuration consists of a hetero-core spliced SPR sensor, media converter (Core System Japan Co., Ltd.), switching hub, power meter, USB device server and a notebook PC.

To meet the system requirements of (i) simpler configuration sensing system and network management, those complex and expensive measuring devices such as open system adapters and optical time-domain reflectometers are not used in this system configuration.

The sensor system is wired connected to the system, so (iii) continuous power is supplied to the system therefore (iii) data communications reliability is guaranteed. Moreover, (vi) adaptation to a wide-area environment can be accomplished by introducing a hetero-core spliced fiber sensor coated with 25 nm of Au and 60 nm of Ta₂O₅.

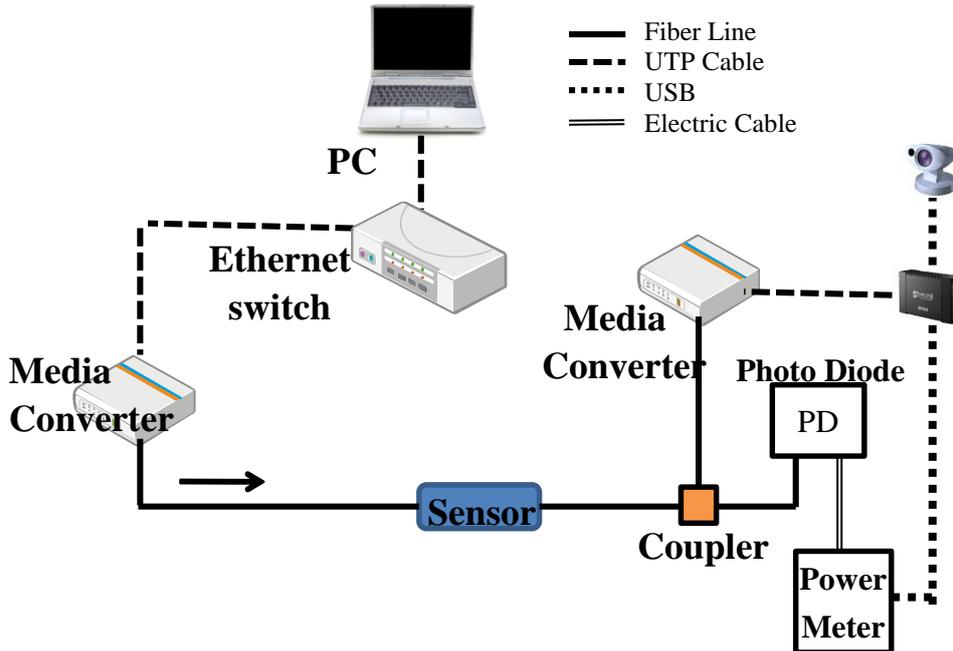


Figure 6.1 Proposed conceptual system configuration of HC-SPR sensor system for agricultural environment monitoring

6.1.1 Verification experiment of the hardware configuration of hetero-core optical fiber sensor system

The configured system shown in figure 6.1 is tested for its function. The web camera is connected via the USB device server to the sensor system, which it is control by its own software at the monitoring PC. The data from the monitoring PC to the camera and vice versa is send through the sensor.

After confirming the web camera connection and the real-time camera data is sending back to the monitoring PC, the sensor is immersed into the water for 30 seconds for two cycles. The test results are shown in figure 6.2 and table 6.1.

The HC-SPR sensor could detect the water when immersed to the water at 20:41:00 to 20:42:00 and 20:43:00 to 20:44:00 as shown in the graph (figure 5.2). Besides, the

camera data transmission is not interrupted when the sensor is immersed into the water.

The real-time data is viewed clearly and video data is captured.

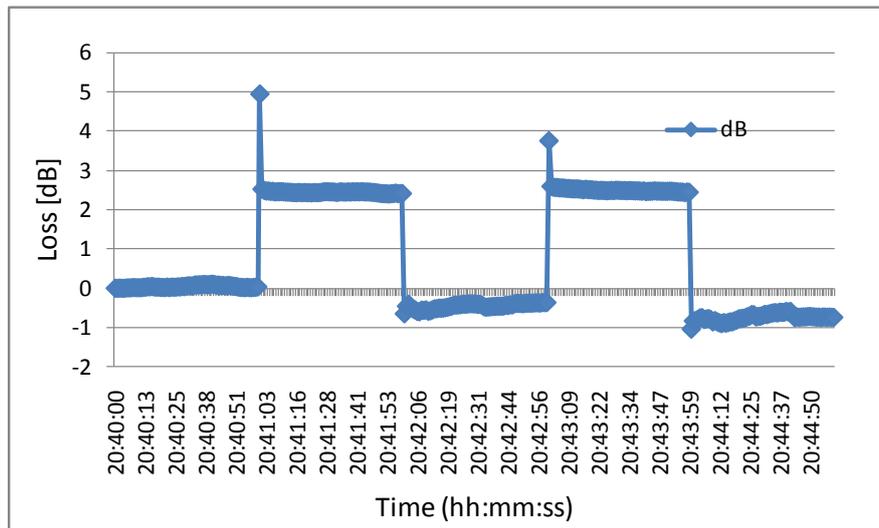


Figure 6.2 Test result of HC-SPR sensor with proposed hardware configuration

Table 6.1

Captured video file details for experiment conducted based on figure 6.1

Captured video file details	
File Type	WMV format
Video size	12.8 MB
Length of the video	5minutes 02seconds

6.2 Software Architecture Design of Hetero-core Fiber Optics Sensor System

The system architecture for an HC-SPR sensor system for agricultural monitoring is designed and shown in Figure 6.3. An HC-SPR sensor, media converter, power meter, and on-site PC are situated on the farm. The SPR sensor pushes the data via the media converter to the power meter for measurement, then to the on-site PC for temporary storage. The on-site system is connected to the Internet to allow data synchronization with a public cloud storage service. Next, the server will request the data from the public cloud storage to analyze and process the sensor data. The web and database server is a server-class computer located in the lab at a university with Internet connectivity. Finally, the data is displayed on the web, and can be viewed via PC or smart device. This architecture design achieves the system requirement of (iii) real-time measurement.

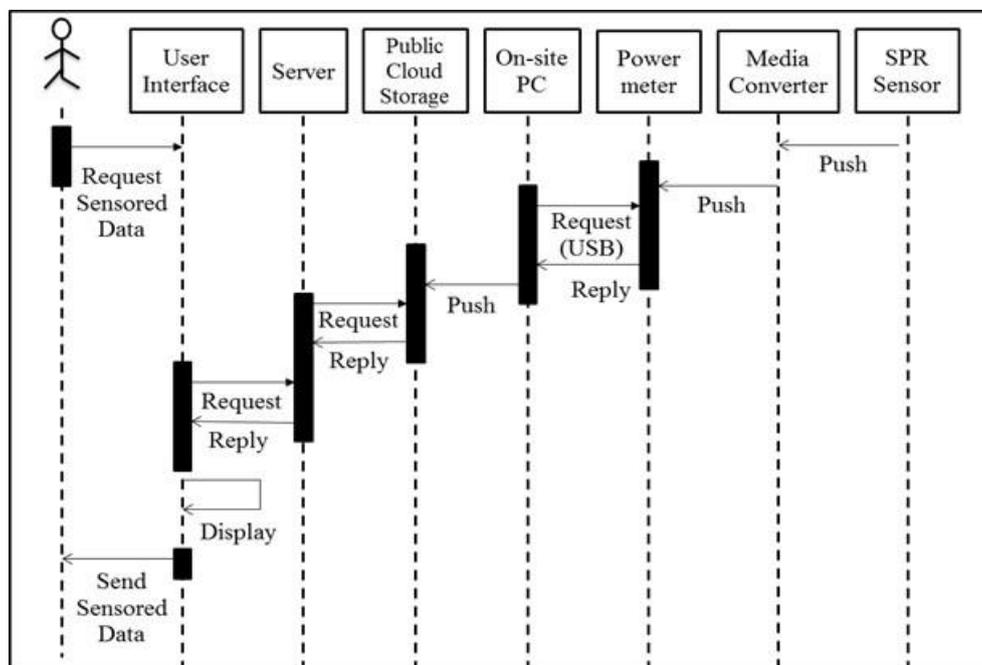


Figure 6.3 sensor system software architecture design

6.3 Field trial Verification Experiments and Results under the Andosol

Based on the conceptual system configuration show in Figure 6.1, an HC-SPR sensor system for soil gravity water monitoring in agricultural environments is constructed. The diagram is shown in Figure 6.4. An experiment to evaluate performance of the system is conducted. This experiment uses an HC-SPR sensor coated with 25 nm of Au and 60 nm of Ta₂O₅ with insertion length of 10mm.

Andosol was used after drying to 15–20% water content over about 24 h in a dryer. Next, the sensor was installed in a plastic chassis sensor unit (W: 55 mm × H: 28 mm × D: 95 mm) (Figure 6.5). The top of the case was covered with an urethane mesh to prevent soil from dropping directly into the sensor case. Next, the sensor unit was set 5 cm below the top of the Andosol (Figure 6.6).

The experiment started by spraying 1000 ml water via a sprinkler as uniformly as possible on the surface of the Andosol within 60 s. The on-site PC captured sensor data, and a web camera connected to the system recorded video.

The data and video captured and stored by the on-site monitoring PC were pushed to public cloud storage. The server requested the data from the public cloud storage and processed the data for real-time display. Users could request sensor data via a remote monitoring PC or other smart device such as a smart phone or tablet computer.

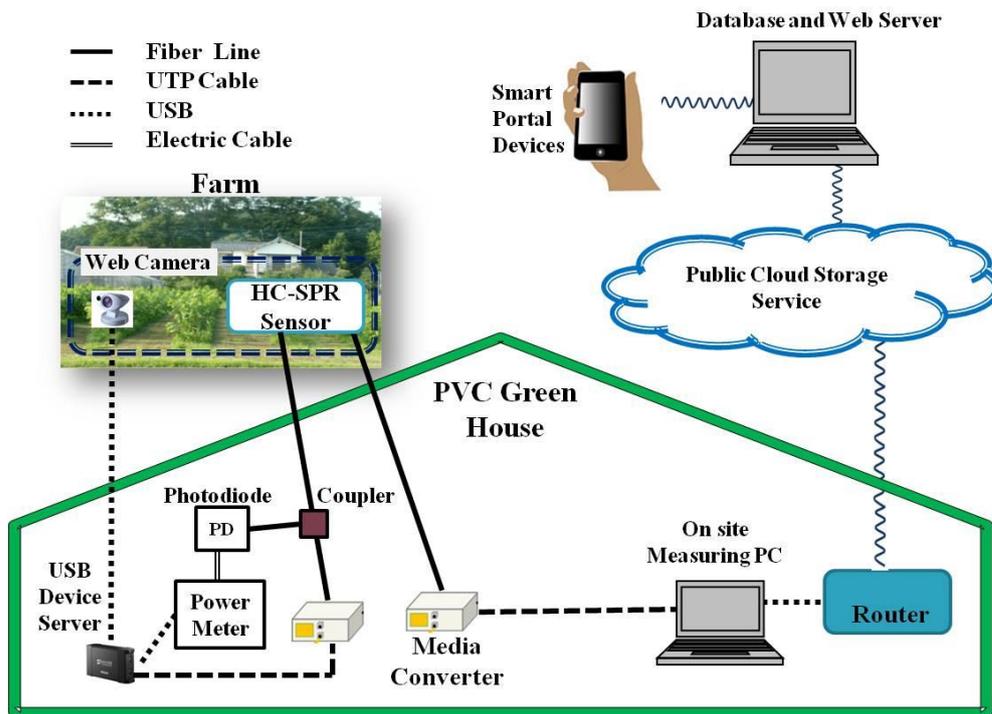


Figure 6.4 HC-SPR sensor system for soil gravity water monitoring of agricultural environments

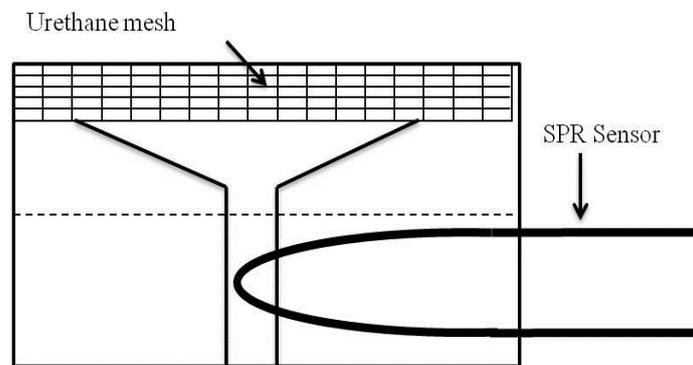


Figure 6.5 Side view of the sensor units

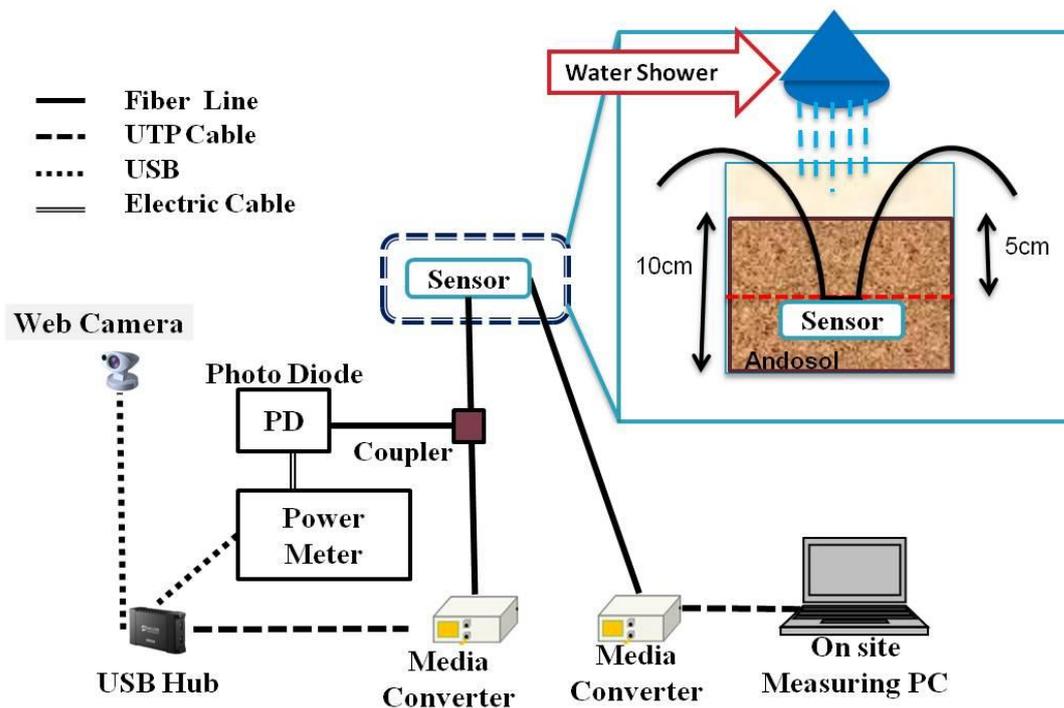


Figure 6.6 Image of the system performance evaluation with HC-SPR sensor under the Andosol

Figure 6.7 shows the results of this experiment. The watering process started at 13:10:00, and took about 60 s to complete. A power meter was used to measure the sensing data, and the baseline of light loss for this experiment was zero.

Initially, the Andosol moisture level was less than 20%. The dry soil absorbed the sprayed water instantly, and thus the sensor could not detect the water immediately after the watering process started. Detection started after about 30s of watering. The power loss gradually increased to 1.5 dB. After the watering process stopped, the power loss from the sensor maintained at 1.5 dB as long the soil was kept moist. In addition, during the experiment, video data were seamlessly captured. The experimental result shows that data communications and sensing was successfully carried out with an HC-SPR sensor set in Andosol.

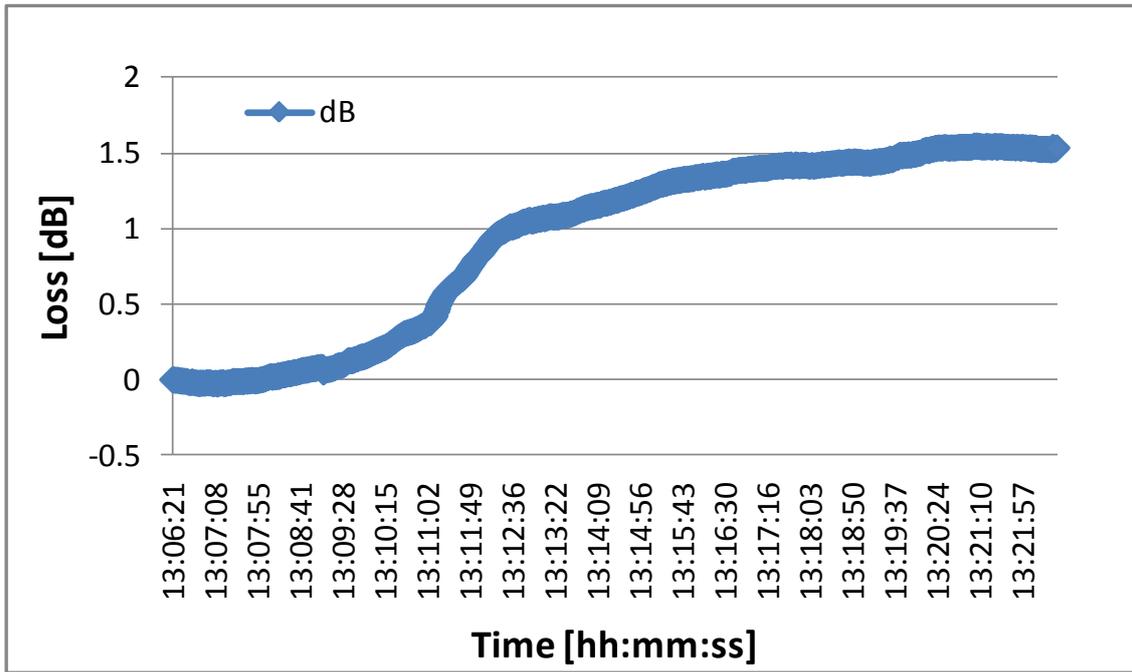


Figure 6.7 Experimental results for an HC-SPR sensor set in Andosol.

Chapter 7

Optical Sensor Network Management using Internet-standard Protocol – SNMP

7.1 Overview

In the review by Rathnayaka and Potdar (2013), transport protocols for WSNs are discussed. Due to the numerous requirements and constraints on WSNs, many standard network transport protocols such as User Datagram Protocol (UDP) and Transmission Control Protocol are not appropriate.

In our study of monitoring sensor conditions in the network, an existing Internet-standard protocol which works in the application layer of the Open Systems Interconnection (OSI) model –SNMP is used. The OSI management environments includes five categories of network management, which are called the OSI specific management functional areas (SMFAs). They includes fault management, accounting management, configuration management, performance management and security management (Mark A. Miller, P.E 1997). Based on the management functions categories defined in the OSI standards by Raman, L. (1998), these characteristics have a significant impact on configuration, performance, and fault management. They need to be considered from the view of network management.

SNMP which introduce to this study is referred to as “simple” because the agent requires minimal software. Furthermore, most of the processing power and data storage resides on the management system. Besides that, one of the most useful aspects of

SNMP trap is their ability to communicate significant event such as a threshold that exceeds a predetermined value to a remote network manager. (Mark A. Miller, P.E 1997).

7.2 Multi-Point Sensor Networks and System Configuration

7.2.1 Multi point Sensor Networks Requirements

In order to manage a multi-point fiber optics sensor network remotely the following functions are required. Such as (i) real-time measurement and data transmission and (ii) the ability to distinguish the identity of responding sensors, a sensor network management method is required.

Vancea and Dobrota (2007) discussed a related topic, sensor network management of WSN devices by SNMP with IEEE 802.15.4. However, their work is intended to provide a system that can be used for management of low-rate wireless personal area network equipment.

This study is considering both the attenuation of light by HC optical fiber sensors as an element to measure the sensing performance and the value of the light intensity as a performance indicator for the communication signal among the resources to be monitored in an OSN. Besides, the system also needs to identify the response from multiple sensors installed into the same fiber line. This proposed system use the attenuation of light intensity in the data communications signal to measure the sensing performance; therefore, it makes sense to consider failures in data communications as arising from attenuation of the light. To manage this, a method that relies on SNMP is used.

7.3 SNMP Agent and Its functions

SNMP can detect changes in the network environment by means of a threshold value and using trap functions. To identify the operational status of multiple sensors, a unique management information base (MIB) must be defined for use by the SNMP agent (ASABi301TM (IP2AGP-301)) and SNMP manager (TWSNMP Manager). SNMP agent device used in this study can act as measuring devices for sensor data and also as an SNMP agent.

This device has total of 10pins, whereby (i) pin no 1 to 4 and pin no 6 to 9 belong to four different channels with one signal pin and one ground pin for each channel; while (ii) pin no 5 and no 10 for the 5V output. The agent is connected to an Ethernet interface, and four-channel analog input to this device can be used to measure electric voltage which converted from the light intensity responded from the sensor. The USB connection is to supply the power to the device.

The SNMP agent requires a script to function. Before writing the script into the SNMP agent, the output value of the sensors which are tandem connected in fiber line in a few combinations are measured. After identifying the different output values from the sensors (by conduct the test with different combination patterns), the trap numbers are assigned to each value in the script (for SNMP agent). The script will be updated to the SNMP agent via the script transmission program that is shows in figure 7.1. Then, the SNMP manager will refer to the trap numbers to identify the source of the response from the tandem connected sensors and display it on the manager interface.

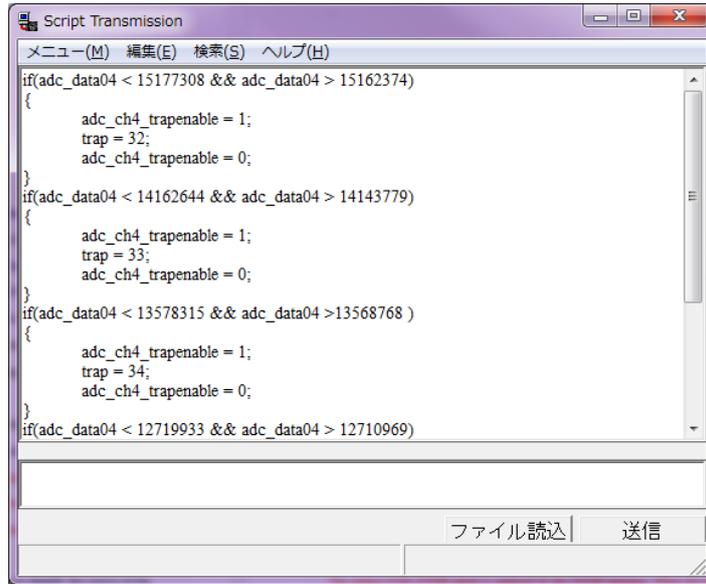


Figure 7.1 The interface of script transmission program which use to connect and update the script for trap setting to the SNMP agent

7.4 Remote Management of Multi-point HC-SPR Sensors with LED Light Source

7.4.1 System Configuration for Multiple HC-SPR Sensors

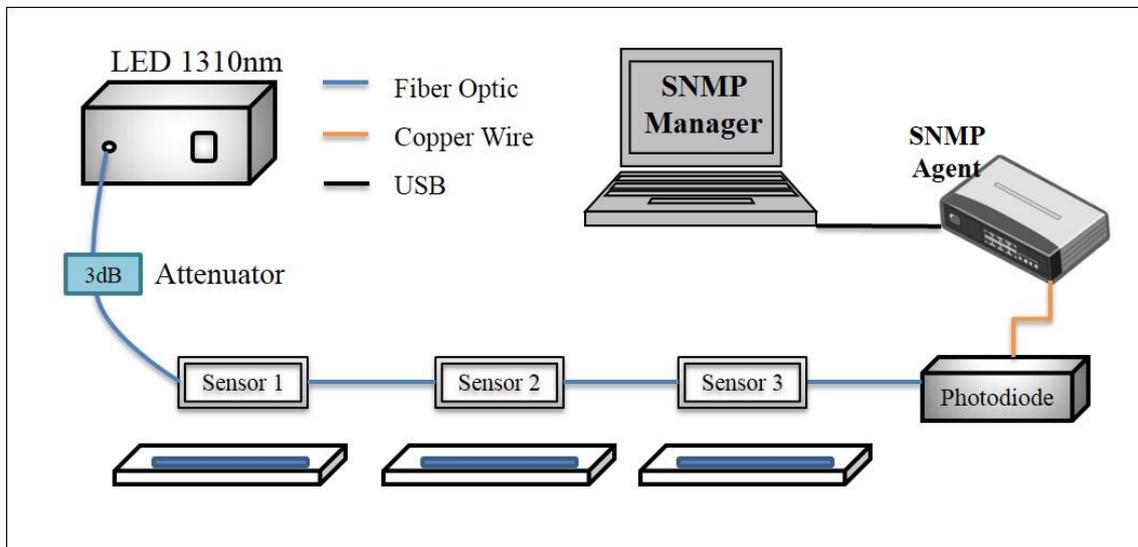


Figure 7.2 System configuration of OSN management using the SNMP for SPR sensors

Takagi and Watanabe (2012) studied water multi-point detection using HC-SPR sensors. Their detection scheme employed a combination of an LED light source and a

photodiode. The experiment result shown that the study was successful. However, the remote management of the sensors was not implemented in that study. In our study, we extends the application of the above previous work and the proposed system configuration is shown in Figure 7.2.

Three HC-SPR sensors with different insertion lengths are used. The insertion lengths of the sensors are 2 mm, 5 mm, and 15 mm for sensors 1, 2, and 3, respectively. The system devices are an LED light source, a 3dB attenuator, a photodiode, SPR sensors, an SNMP agent, and an SNMP manager. The connection from LED light source to photodiode is using the multi-mode fiber optic, while the connection from the photodiode to SNMP agent is using a copper wire. SNMP agent is connected to the manager through a USB cable.

In this study, the copper wire which transmit the sensing signal from the sensors is connect to the channel no 4: pin no 8 for signal line (+) and the channel 4: pin no 9 for the ground line (-). Further details about the SNMP agent: ASABi301TM (IP2AGP-301) could be found at http://www.ip-square.com/sensor_stationASABi.html.

The output of the SNMP agent is captured by the SNMP manager. When the threshold settings in the SNMP agent match the sensor output value a trap message will be sent to the SNMP manager to identify the ID of the responding sensors.

7.4.2 System Verification and Results

The experiment was conducted with the test patterns listed in Table 7.1. An ‘ON’ signal means that the sensor is immersed in water. The loss value of sensors immersed in water is captured using the SNMP agent, and the value is calculated. Table 7.2 show the responded value from the sensor with different combination pattern.

The loss value of each combination pattern is covert using the formula

$$“-10*\text{LOG}(\text{current value}/\text{absolute of base value})”$$

and the graph results of the loss value are shown in Figure 7.3.

Table 7.1

Trap number assignment for the SPR sensors and detection results

No	Test Pattern Description	Assigned Trap Number	Result
1	Sensor 1 ON	Trap No 32	Detected
2	Sensor 2 ON	Trap No 33	Detected
3	Sensor 1,2 ON	Trap No 34	Detected
4	Sensor 3 ON	Trap No 35	Detected
5	Sensor 1,3 ON	Trap No 36	Detected
6	Sensor 2,3 ON	Trap No 37	Detected
7	Sensor 1,2,3 ON	Trap No 38	Detected

Table 7.2

Each combination pattern responded value captured by SNMP Agent (Asabi)

	All OFF	Sensor 1 ON	Sensor 2 ON	Sensor 1, 2 ON
Maximum Value	15177308	14162644	13578315	12719933
Average Value	15170991	14152294	13575398	12718236
Minimum Value	15162374	14143779	13568768	12710969
	Sensor 3 ON	Sensor 1,3 ON	Sensor 2,3 ON	All ON
Maximum Value	11302458	10654391	10307336	9769148
Average Value	11293269	10646267	10302599	9756926
Minimum Value	11285632	10637841	10299186	9710233

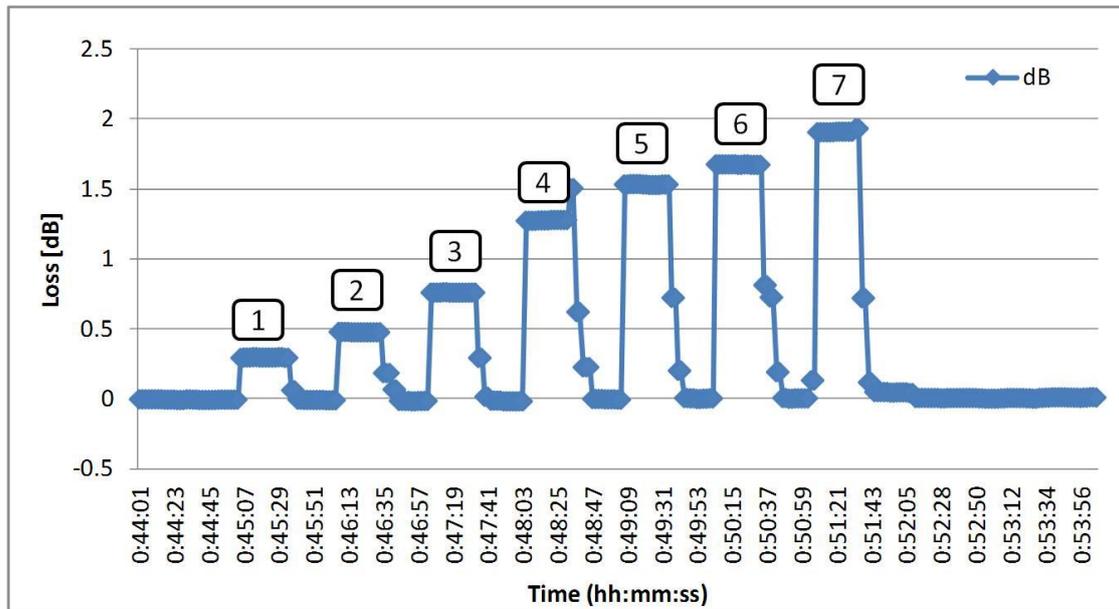


Figure 7.3 The loss value of sensors measured using SNMP

The results showed that each combination pattern could detect a different loss value. Therefore, this value is use to set the threshold value in the SNMP agent and configure the MIB settings. Each combination pattern is assigned to a trap number in the SNMP agent by writing a simple script. This script which written for the SNMP agent to detect the respond from the sensors are update to the agent via script transmission program is shows in Table 7.3.

When a sensor is immersed into water, the trap will be send from the SNMP agent and then the trap numbers will be shown in SNMP manager according to the response by the sensors. Table 7.1 shows the results of this experiment. All test patterns were successfully detected by the SNMP agent and display at the SNMP manager.

Table 7.3 Script for SNMP agent to detect respond from the sensors

```
if(adc_data04 < 15177308 && adc_data04 > 15162374)
{
    adc_ch4_trapenable = 1;
    trap = 32;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 14162644 && adc_data04 > 14143779)
{
    adc_ch4_trapenable = 1;
    trap = 33;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 13578315 && adc_data04 >13568768 )
{
    adc_ch4_trapenable = 1;
    trap = 34;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 12719933 && adc_data04 > 12710969)
{
    adc_ch4_trapenable = 1;
    trap = 35;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 11302458 && adc_data04 >11285632 )
{
    adc_ch4_trapenable = 1;
    trap = 36;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 10654391 && adc_data04 > 10637841 )
{
    adc_ch4_trapenable = 1;
    trap = 37;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 10307336 && adc_data04 > 10299186)
{
    adc_ch4_trapenable = 1;
    trap = 38;
    adc_ch4_trapenable = 0;
}
if(adc_data04 < 9769148 && adc_data04 > 9710233)
{
    adc_ch4_trapenable = 1;
    trap = 39;
    adc_ch4_trapenable = 0;
}
}
```

7.5 Remote Management of TIP-type HC-SPR sensor with LD Light Source

The multi-point detection using HC-SPR sensors with LED light source has been successfully carried on as described in section 7.4. Next, the study could challenge the multi-point sensing with HC-SPR sensor by combining the data communications and sensing using with the LD light source which is generated by the media converter.

Our study has conducted experiments based on the concept in section 7.4 (figure 7.2) by including the data communications devices and its measuring devices such as media converter, Ethernet switch and NextStream into the test. The HC-SPR sensors are use in the test; both sensing data and data communications is measured to identify the feasibility of such system. The experiment is conducted in seven different pattern as same to test pattern described in table 7.1. The system configuration and the results of those experiments are summarized in appendix C.

After conducted the experiment, the results are converted into graph for analysis purpose. From the experiment results, below two points can be concluded:

- (i) the sensors could not provide a stable data measurement
- (ii) those data could not clearly differentiate the responding sensors, this is because the different test patterns have similar output data (although it supposed to give a different output data)

By analyzing the experiment results, the identification of the sensors status is difficult when three HC-SPR sensors are inserted into same line for the sensing and data communications purpose. Thus, the multi-point HC-SPR experiments with the LD light source (from media converter) are considered difficult and have many challenges.

Consequently, we look into another option and possibility to implement the multi-point HC-SPR system with the integration of sensing and data communications by using the TIP-type HC-SPR sensor.

In the next section, the spectrum of TIP-Type HC-SPR sensor and the details of the experiment are describe.

7.5.1 TIP-Type HC-SPR Sensor

The structure of the TIP-type HC-SPR sensor is shows in figure 7.4.

The sensor is fabricated with a graded index multimode fiber with core diameters of 50 μm , respectively, and an inserted 2~10 mm long step index single-mode fiber with a core diameter of 3.1 μm . Then, the hetero-core portion is fabricated by cylindrically coating the fiber surface with metal using an RF sputtering machine. In this study, the metal film uses in this sensor are Gold and Tantalum Pentoxide (Au & Ta₂O₅) coating combination with the thickness or 25nm and 60nm respectively.

When this sensor is immersed in the test liquid, a surface plasmon wave is generates. The wave is then reflects on the mirror portion of the sensor which is also coated by the Au/ Ta₂O₅, and then the reflected signal is send to the measuring devices via the transmission portion of the sensor (which is the multi-mode fibers). The amount of change from the reflected sensing signal can be used to measure as the light loss of the sensor.

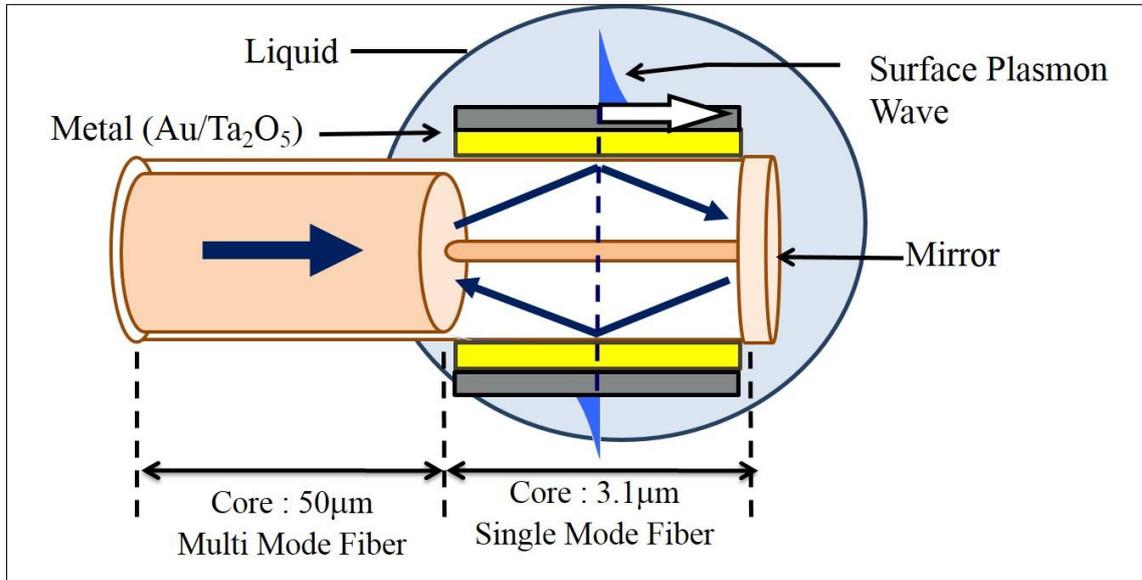


Figure 7.4 Structure of the TIP-type HC-SPR Sensor

Spectrum of TIP-type HC-SPR sensor for insertion length of 2mm, 5mm and 10mm are shown in this section. In order to view the spectrum of the TIP-type HC-SPR sensors, both measurement in air and in water is measured. Then, the spectrum graph for each insertion length are drawn by using air as the base (*The value measured in air minus value measured in water, which is same with HC-SPR sensor spectrum graph preparation*).

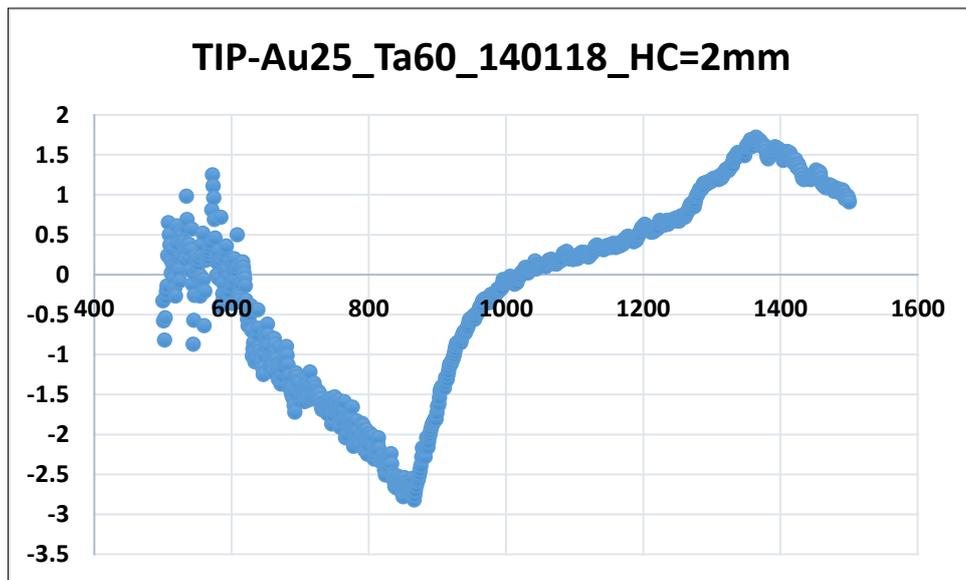


Figure 7.5 Spectrum of TIP-type HC-SPR sensor for 2mm

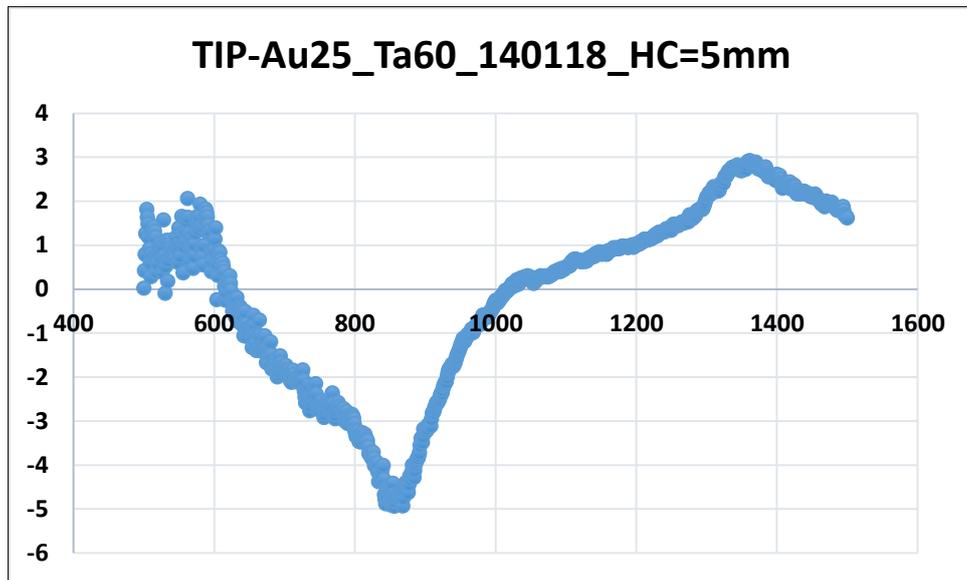


Figure 7.6 Spectrum of TIP-type HC-SPR sensor for 5mm

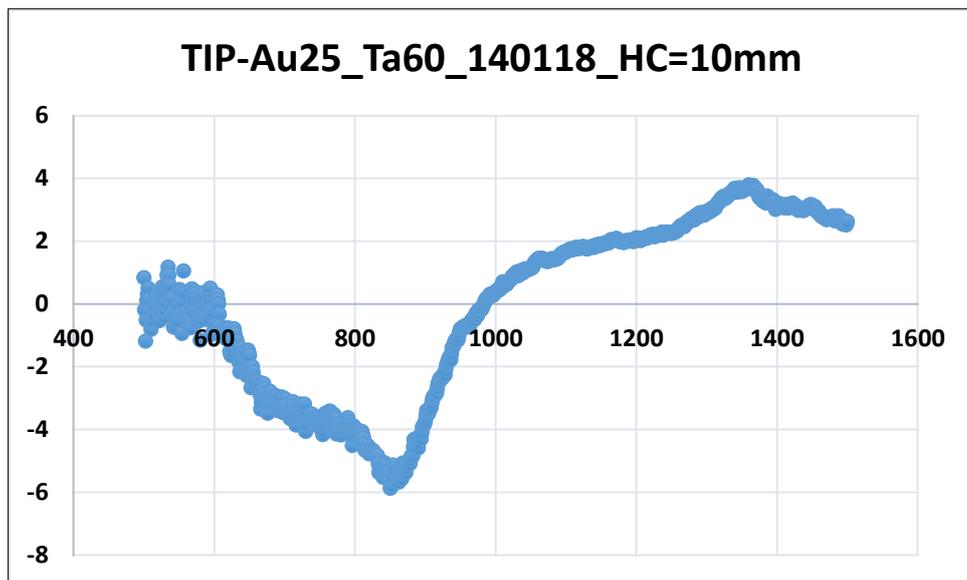


Figure 7.7 Spectrum of TIP-type HC-SPR sensor for 10mm

7.5.2 System Configuration for TIP-type HC-SPR sensor

A new system configuration is proposed for the TIP-type HC-SPR sensor. The design is shown in figure 7.8.

As a first step, the experiment is conducted with only one point of the TIP-type HC-SPR sensor to identify the feasibility of the system for both sensing and data communications.

The test starts with the TIP-type HC-SPR sensor with 10mm insertion length.

Before conducting this test, some verification tests have been conducted to verify the response of the TIP-type HC-SPR sensor. The details are summarized in appendix D.

The communication packet (data) is generated by NextStream and sent via the Ethernet switch, media converter and coupler to the sensor. The reflected signal will be sent back to NextStream and measured by the monitoring PC which is connected to NextStream.

The LD light generated by the media converter is sent to the sensor through the coupler.

When the sensor is immersed into the test liquid, the signal is reflected and sent to the measuring devices. However, in this setup, the sensing signal is saturated, therefore a 6dB attenuator is positioned before the measuring devices (the photodiode and SNMP agent). In other words, the sensing signal will pass through a 6dB attenuator before it is sent to the photodiode and SNMP agent for measurement.

The photodiode is connected to the measuring PC via USB and the sensing signal is measured by the photodiode software. On the other hand, the SNMP agent is connected to the photodiode using a copper wire and the sensing signal is sent to the measuring PC through the Ethernet switch via RJ45 (LAN) cable. The power of the sensing signal which is received by the SNMP agent is measured using the SNMP manager software called TWSNMP.

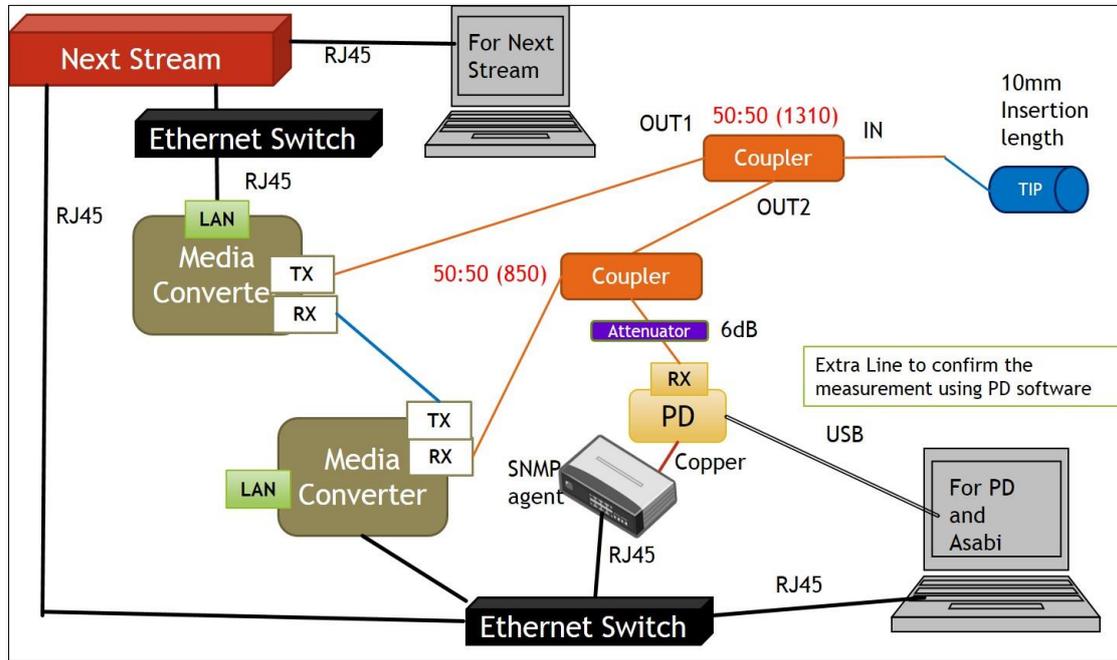


Figure 7.8 System configuration for the TIP-type HC-SPR sensor (10mm)

7.5.3 System Verification and Results

The experiment results for the TIP-type HC-SPR sensor which describes in section 7.5.2 are shown in figure 7.9, figure 7.10 and figure 7.11.

In figure 7.9 the data shows the power value measured by using the SNMP agent. The graph shows that sensor responded because the power is decreased when it was immersed into the water.

The sensing signal from the sensor is also measured using the photodiode. Figure 7.10 shows the value measured by photodiode software. The graph shows that the sensor responded due to the power decrease of sensing signal when it was immersed into the water. Then, the loss value measured by photodiode is calculates and shows in figure 7.11 in the graph format. This graph shows that the sensor generates about 2.2 dB of loss value when immersed into the water.

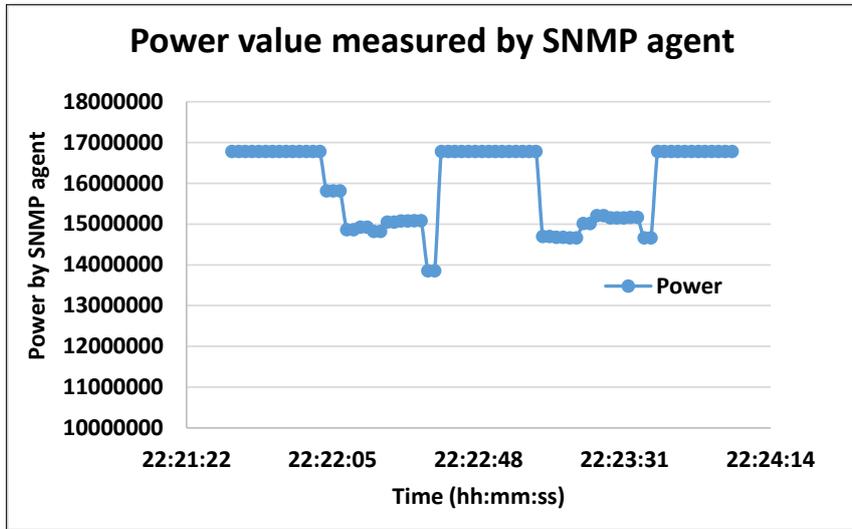


Figure 7.9 Graph for the power value measured by SNMP agent

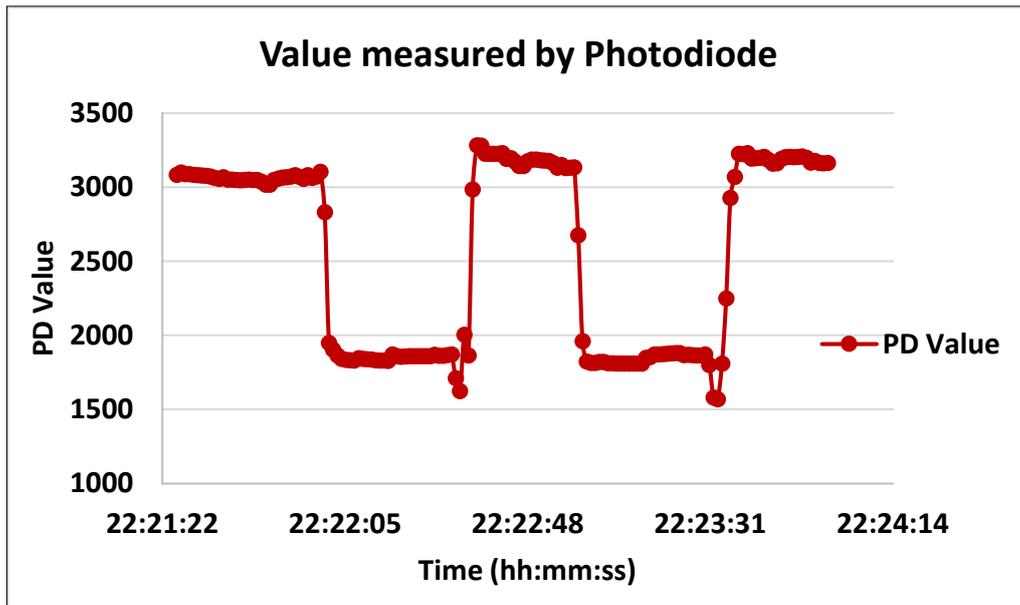


Figure 7.10 Graph for the value measured by photodiode

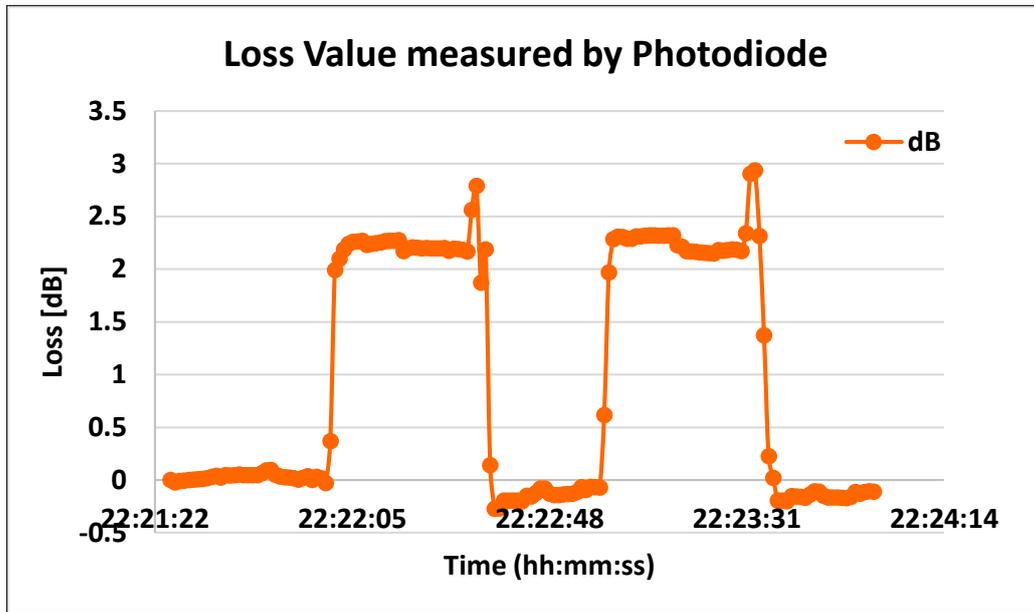


Figure 7.10 Graph for the loss value calculate from the value measured by photodiode

7.5.4 System Configuration of Multi-point Sensors and Experiment Results

An experiment based on the design concept in figure 7.8 to test the feasibility for two-points of TIP-type HC-SPR sensors has been carried on. The sensors with insertion length of 2mm and 10mm is used in the experiments. However due to a large amount power loss after the light is separated by the coupler, the communications is down. The simple summary of this experiment (test 10) is described in appendix D page 127 while the diagram (slide 26) is shown in page 130.

Chapter 8

Discussion, Conclusion and Future Works

8.1 Discussion

This paper presents studies of sensor system with hetero-core spliced optical fiber sensor which developed for soil monitoring in agricultural environments based on the requirements of (i) simpler configuration sensing system and network management, (ii) continuous power supply, (iii) data communications reliability and real-time measurement capability, (iv) adaptable to larger area of environments and (v) multi-point sensing.

During the system construction, we designed and tested many system configurations to obtain results that match our system requirements. The system was constructed using an HC-SPR sensor, power meter, media converter, USB device server, and notebook PC. The HC-SPR sensor is simple to manufacture, and can serve a dual role as data communications transmitter and sensor, so data communications devices and sensors do not need to be set up separately. Besides, the complicated and expensive measuring devices for fiber optic sensor such as Optical Time-Domain Reflectometer (OTDR), Optical Spectrum Analyzer (OSA) are replaced by the measurement devices such as combination of photodiode with power meter. The requirement of (i) simpler configuration sensing system is thus met.

In chapter 7, the Internet-standard protocol – SNMP is described. SNMP is referred to as “simple” because the agent requires minimal software. Utilizing the SNMP method to

manage the sensor network, the system can avoid the complication of setting up the communications protocol or finding a suitable protocol for it. The FOS network has the advantage to use this existing standard protocol when compare to WSNs which has numbers of requirements and constrains in selecting the proper network communications protocol.

Unlike wireless sensor networks the entire fiber sensor network is wire-connected, so the system is able to (ii) continuous supply power to data communications devices and measuring devices, which means that data communications reliability is ensured.

FOS do not has power supply or battery life time issues because FOS operate using the light propagation. The experiment results indicate no interruptions in the data communications, as no FCS errors were detected while the SPR sensor was functioning as a sensor. The data communications quality of our proposed system is more reliable than that of wireless sensor networks. Because of the data communications reliability of our system, it has the ability to provide real-time measurement and offer users real-time information from the sensor. The requirement (iii) reliable data communications and real-time measurement capability is achieved.

Next, to achieve (iv) adaptability to larger environments, a hetero-core spliced fiber sensor coated with 25 nm of Au and 60 nm of Ta₂O₅ was utilized in the system. This sensor can serve as a data communicator and sensor at distances up to 1000 m. This feature overcomes the data communications issues that challenge wireless sensor networks, such as difficulty transferring data through larger areas and limited network capacity. As discussed in section 4.4, the average farm size in most countries in Southeast Asia, is less than 2 hectares. Our system can provide the sensing and data

communications up to 1000 m based on the verification test. Therefore, the system consider to have the ability to accommodate the average farm size in South East Asia even if the monitoring area includes two or three farms.; however, it is also depends on the layout or topology of the sensor network configuration and design.

There are many network patterns or combinations of devices that can realize such a system, but it is not easy to select devices that meet our system requirements in agricultural environments. Selection of the proper devices for our proposed system that balance the requirements of data communications and sensing is non-trivial, because both functions have a trade-off relationship. Specifically, from a communications standpoint, this might lead to optical signal degradation and increase FCS errors.

For the requirement of (v) multi-points sensing, the sensors are tandem installed in the same fiber line and then the feasibility of multi-point sensing for HC optical fiber sensor networks by SNMP is evaluated. The experiment was carried on with the light source from LED as described in section 7.4. To distinguish the status of fiber optic sensors and to construct remote data acquisition sensor networks, a method that uses SNMP is introduced. The responses from HC-SPR sensors were successfully detected using the proposed method.

Next the multi-point of HC-SPR sensors experiment is carried on with the LD light source which is generated by the media converter. The system configuration of the experiment is redesigned and both sensing data and communications data are measured to identify the feasibility of such system. However, the experiment results show that the

identification of the sensors status is difficult when three HC-SPR sensors are inserted into same line for the sensing and data communications purpose. Therefore, a sensor network with the integration of sensing and data communications by using the TIP-type HC-SPR sensor is studied. A new system configuration is proposed and verification is conducted. The experiment result shows that the possibility of using the TIP-type HC-SPR sensor in the new proposed system, but further study to overcome the challenge to construct a multi-points sensing system with LD light source (by media converter) need to be carried on.

On the other hands, the measuring devices that were used in our system are more affordable devices, as compared to other optical fiber sensor networks (Golt et al., 2004) , commercial sensor networks (Fujitsu Hokkaido System, 2011; Geomove 2011; Hitachi, 2011a and 2001b; Hori et al., 2010; NEC, 2012) and satellite-based remote sensing (Faruolo, M, et al., 2013; Mello, M.P., et al., 2013). Therefore, our system cost might be lower when comparing to those system mentioned above; however, further study need to be carried on to evaluate the system cost efficiency with WSNs.

Table 8.1 Summary of requirements, proposed methods, implementation and verification test

No	Requirements	Proposed Methods	Implementation and Verification Test
1.	Simpler configuration sensing system and network management	<ul style="list-style-type: none"> ● Avoid complex measurement devices In order to measure the output from the network, the FOS measuring devices such as Optical time-domain reflectometer (ODTR), Optical Specturm Analyzer (OSA) are replaced by the measurement devices such as combination of Photodiode with power meter. ● SNMP as a remote network management To remote monitor the network status, SNMP agent and software which is simple to be configured are integrated into the system. 	The proposed system utilized the power meter as measurement devices. The data can be easily stored and use for analysis later. The system integration has been verified in section 6.3 for soil water monitoring.
2.	Continuously Power Supply	<ul style="list-style-type: none"> ● Fiber Optics Sensor FOSs do not need power supply or depend on battery to operate. While the other devices in the system are always supplied with power. Without the power supply issue, the data communications is stable. Moreover, the fiber line could provide larger network capacity and the sensing data could be send to measuring device in a real-time. 	Data communications reliability and real-time measure has been verified in section 5.2.2 and 6.1.1, 6.3. The fiber optic wired system ensure the power continuously supplied. Furthermore, by integrating FOS– HC-SPR which utilized in the system did not affected the data communications.
3.	Data communications reliability and real-time measurement		
4.	Adaptable to larger area of environments	<ul style="list-style-type: none"> ● Fiber Optics Sensor To adapt the sensor to larger area of monitoring, the HC-SPR sensor coated with a metal film of 25nm of gold and 60nm of tantalum pentoxide. 	In section 5.2.3.1 the experiments result shown that the HC-SPR sensor with 25nm Au 60nm Ta ₂ O ₅) successfully detected water in the distance more than 1000m. In another word, the system could be implemented in a larger monitoring area.
5.	Multi-point Sensing	<ul style="list-style-type: none"> ● SNMP to manage multi-point sensors By configure the settings of SNMP trap value enable the system to recognize the identity of the responded sensor. Such technique do not required complex configuration and SNMP agents can be configure easily to the existing system. 	The multi-point sensors management using SNMP has been verified in section 7.4. The experiment results shown that the proposed SNMP method to manage and identify the respond of multi-points sensors successfully.

8.2 Conclusion

This study described and analyzed a hetero-core spliced optical fiber SPR sensor system for soil monitoring of agricultural environments. The goal is to design and construct a remotely monitor fiber optic sensor system for soil gravity monitoring in agricultural environments. Many related research has been studied in order to identify the remaining issues of the current research. Based on those data, this study define the requirements to construct the remote FOS system for soil gravity monitoring which target to be used in agricultural area.

First part of the study is to construct a sensor network with fiber optics sensor. In order to extend the distance of data transmission for large-area monitoring, the study used an HC-SPR sensor coated with Ta_2O_5 and adopted a wavelength of 1310 nm. The HC-SPR sensor network system has been constructed, and experiments succeeded in gathering real-time sensor data from the system.

Next, the second part of the study proposes and evaluates the feasibility of multi-point sensing for HC optical fiber sensor networks with LED light source using the SNMP method. To distinguish the status of fiber optic sensors and to construct remote data acquisition sensor networks, a method that uses SNMP is introduced. The responses from HC-SPR sensors were successfully detected using the proposed method.

In a nutshell, the objectives of the study has been achieved and all defined requirements has been met with the proposed method.

8.3 Future Works

Future work could include developing integrated simultaneous data communication and sensing functions for multiple sensing points on a multimode fiber line. A further study is needed to find out the possibility usage of multi-points TIP-type HC-SPR sensors in proposed system. The study could be focus on the system design or improvement of the specification of TIP-type HC-SPR sensor in order to accommodate to the current design.

This study also can further investigate the “multiplicity boundary” to identify the limit on how many HC-SPR sensors can be connected in series under no degradation in communication quality. To expand the usefulness of this type of sensor network, combinations of different types of HC sensors and testing the feasibility of these mixed systems could also be examined.

After investigate the above issues, the on-field experiment need to be conducted in order to identify others issues of such system when it is implemented in a real outdoor environment or farm. The collaboration with local farmer and researcher from environmental engineering might be needed.

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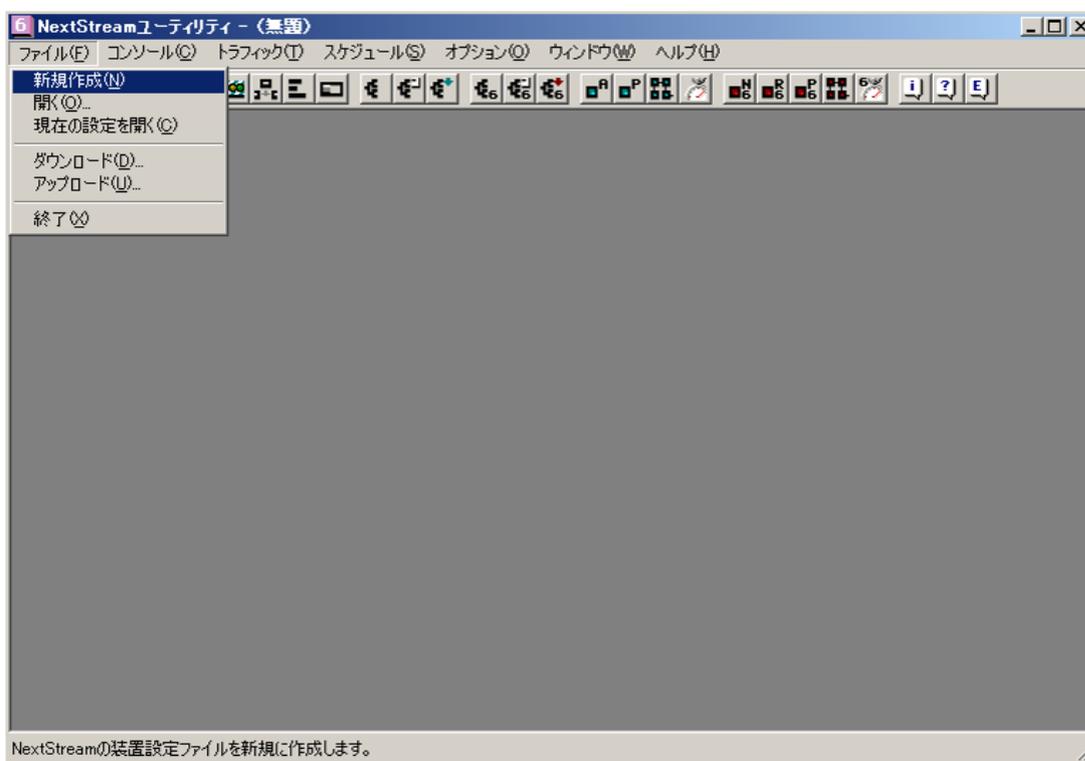
Appendix A

NextStream Menu Settings Reference and Media Converter Diagram

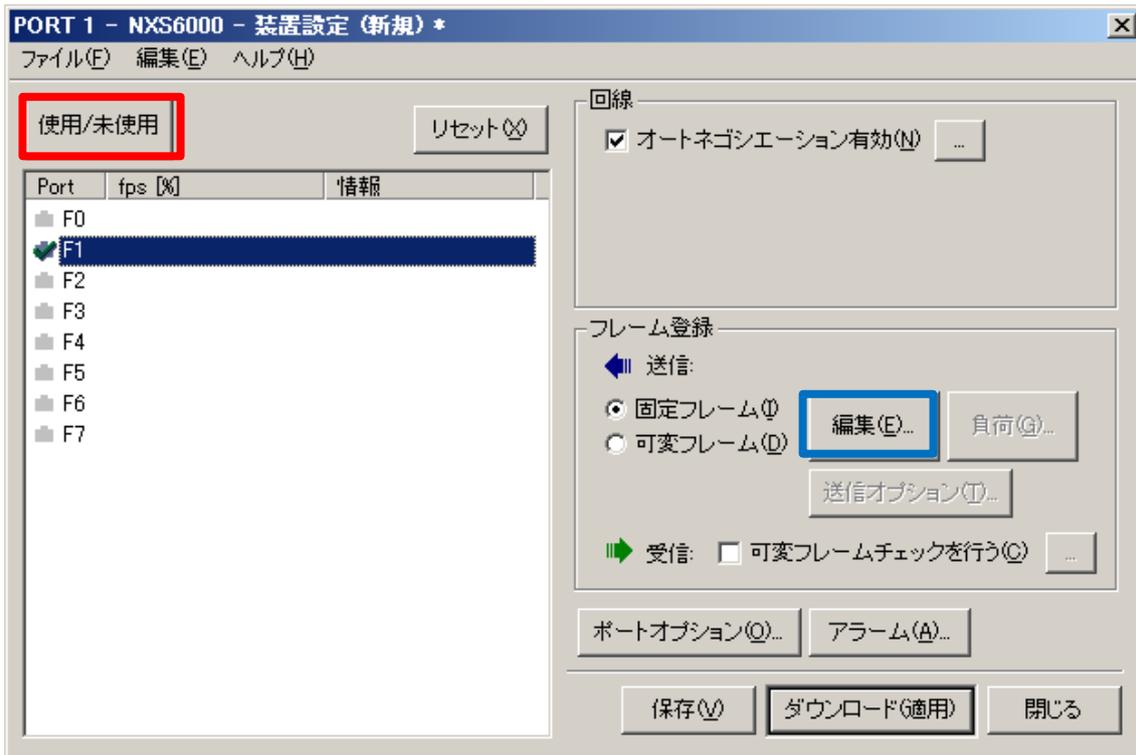
Appendix A.1 NextStream NX 6000 F

This section described the steps for (i) New frame settings (ii) Using traffic monitor function and (iii) saving log data into CSV format

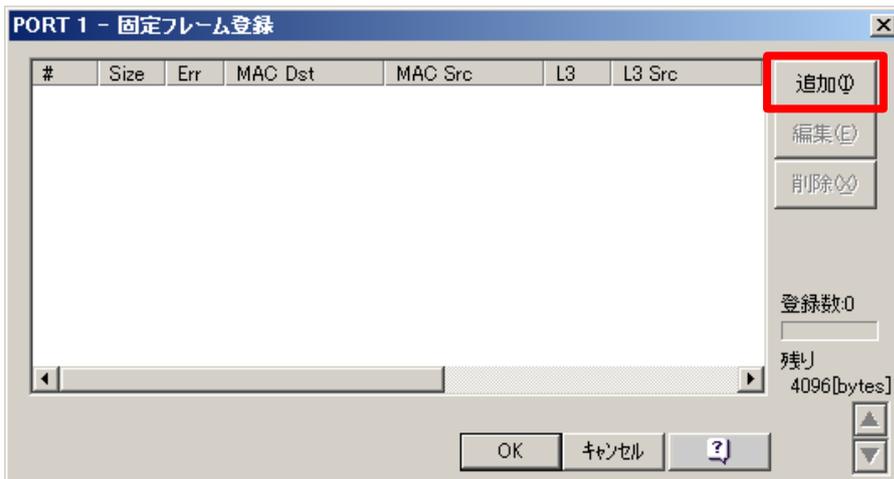
(i) New frame settings



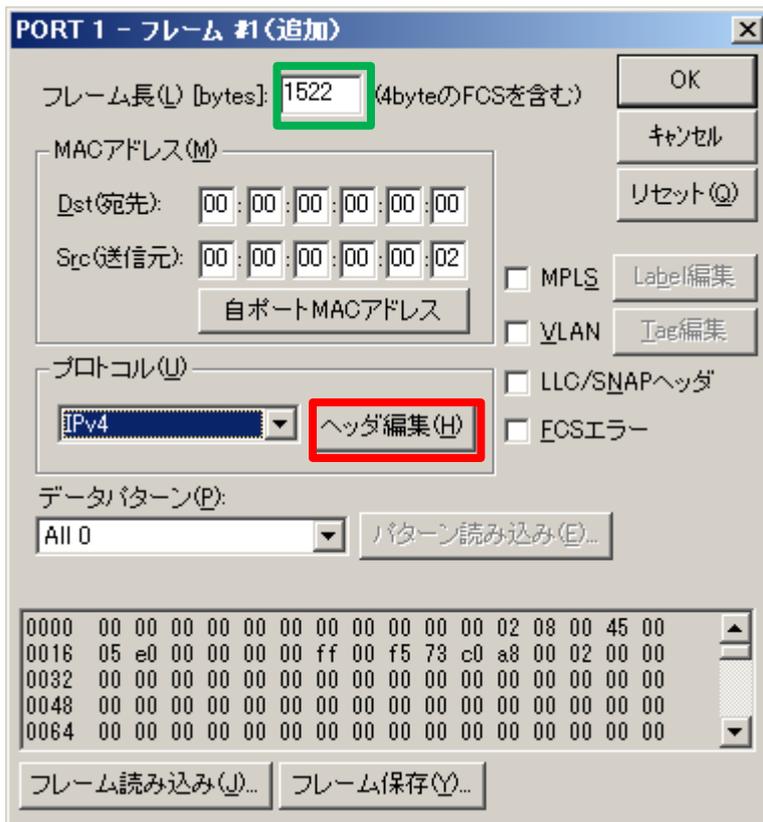
Go to [File] <ファイル> and select [New] <新規作成>



- Select the port to be used (for TX) and click on the <使用・未使用> to choose the port
- Next click on <編集> to make configuration , below screen will appear



- Click on the <追加> to register the frame and next screen will appear

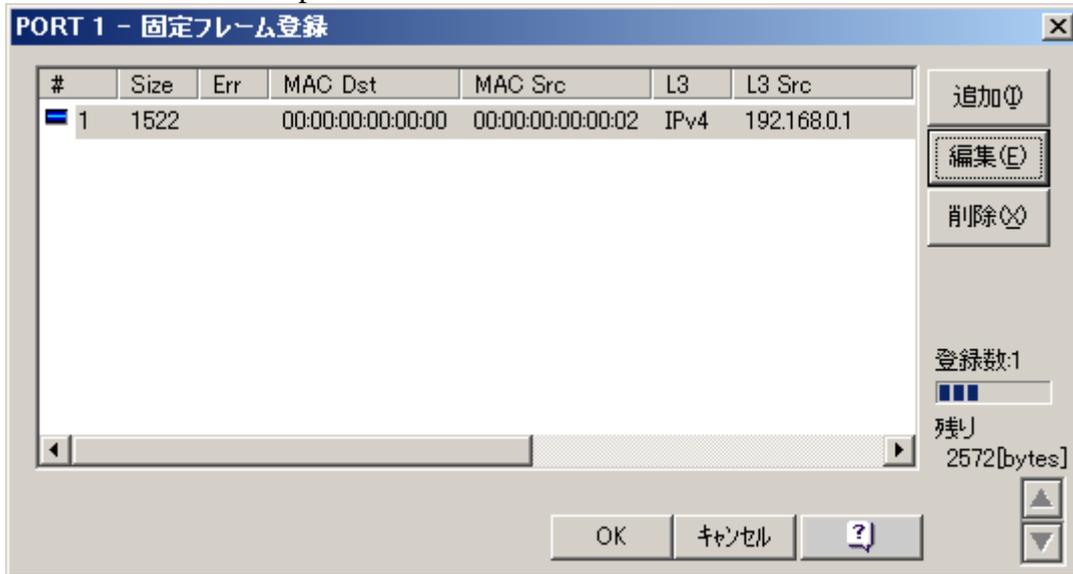


- For frame length [bytes] <フレーム長> change settings to 1522.
- At the <プロトコル> select IPv4 and click on the <ヘッダ編集> to go for next settings

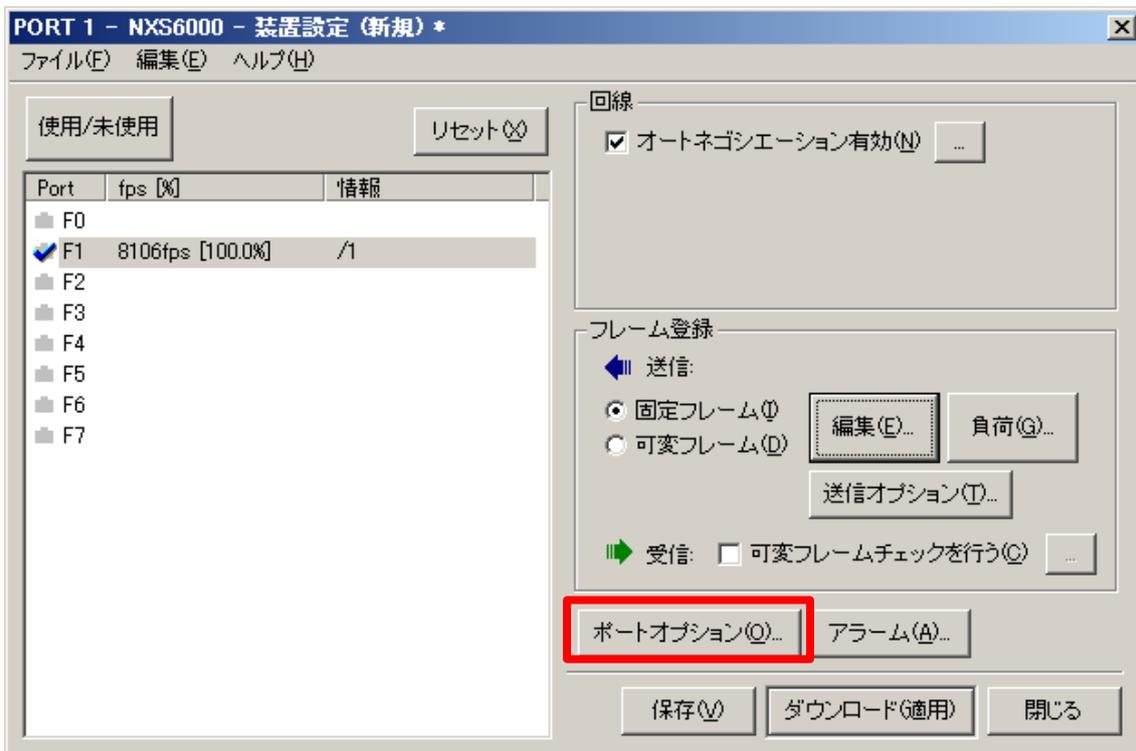


- In this menu, key-in the Src address to 192.168.0.1 and the Dst address to 192.168.0.2
- Keep the rest of the settings as original

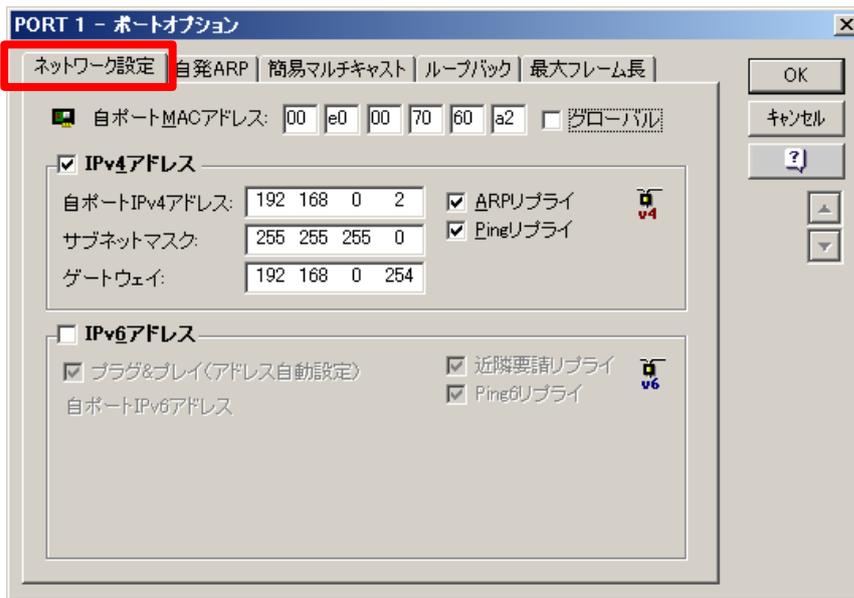
- Click ok to exit to previous screen



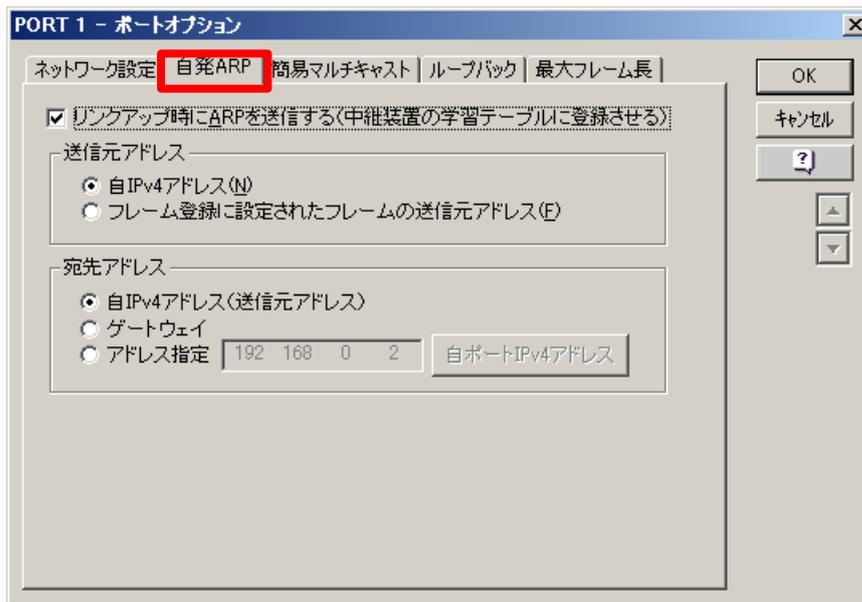
- This screen shows that the frame settings has been done, exit to go back to main menu



- Next from this menu, select the <ポートオプション> to make settings
- *These settings are the same for RX port which will be configured later

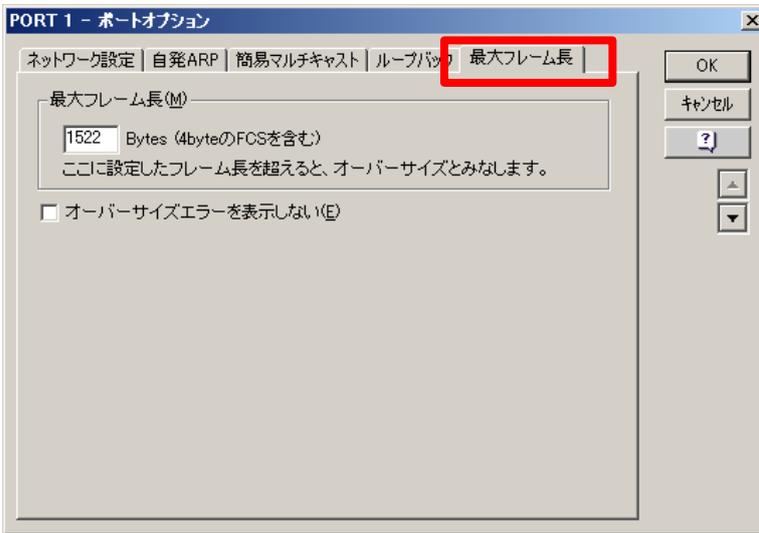


- *At the <ネットワーク設定>
 - uncheck the <グローバル> and check on the IPv4 アドレス

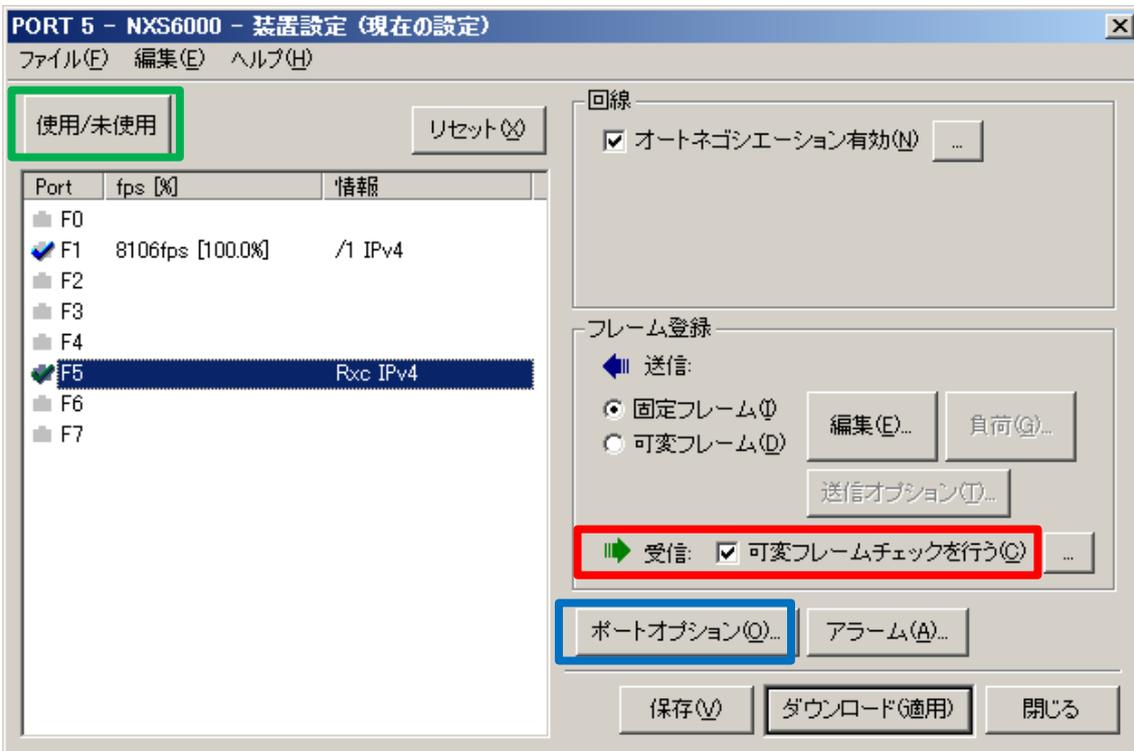


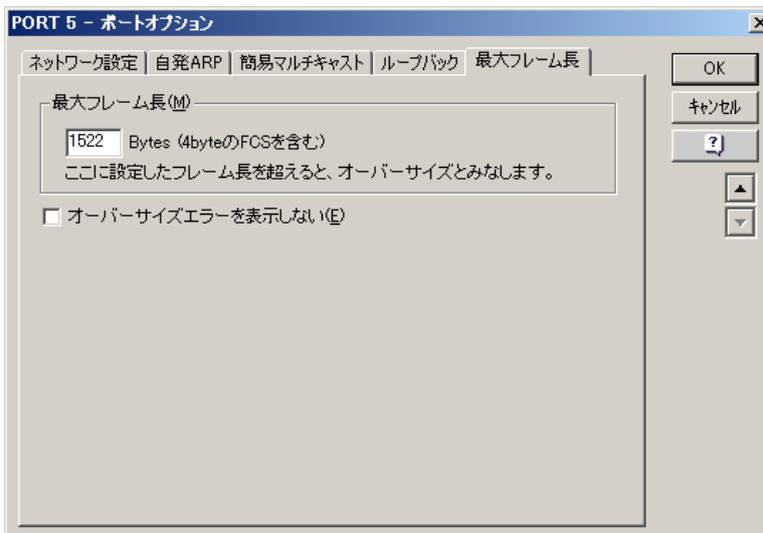
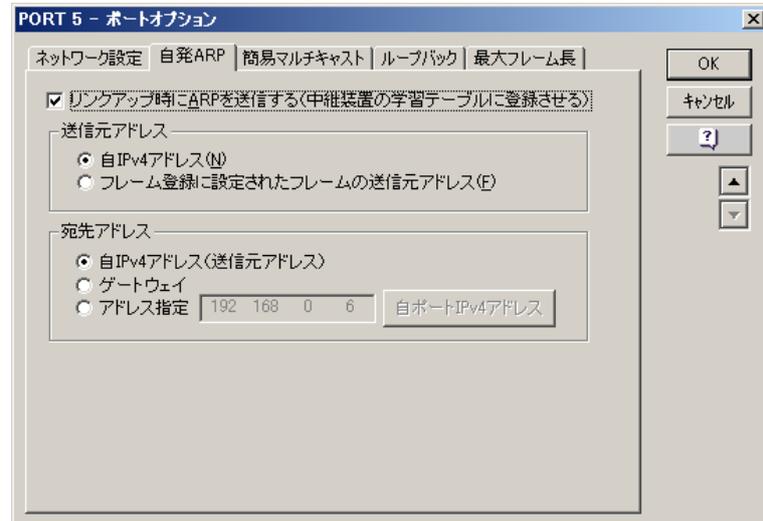
- *At <自発 ARP> follow above screen shot to do the setting.

- *Lastly at <最大フレーム長>, set the value to 1522 and then click [OK].

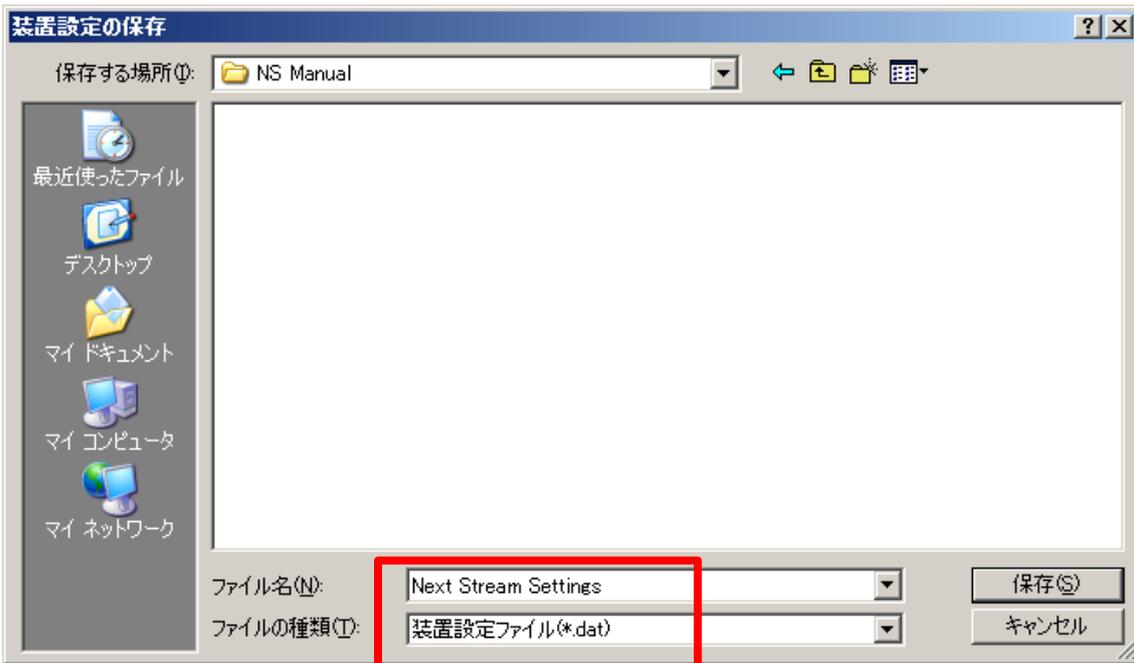
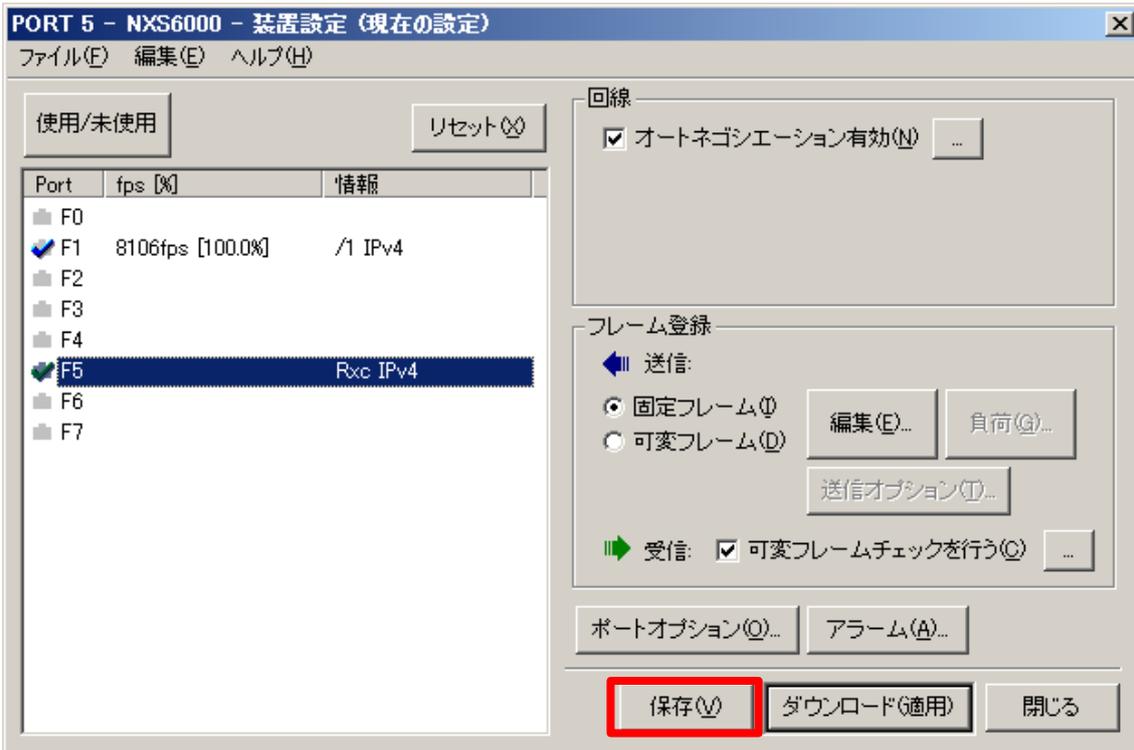


- To set up the RX (receive port), select one of the port from the list and click on the <使用・未使用> to choose the port
- At the <受信> check the <可変フレームチェックを行う>
- Next click on the <ポートオプション> to make the same settings as TX port





- After all the settings has completed, this setting can be saved by select the <保存> button as shown below.
- Name the file accordingly, so it can be retrieved when NextStream is used in similar experiment.

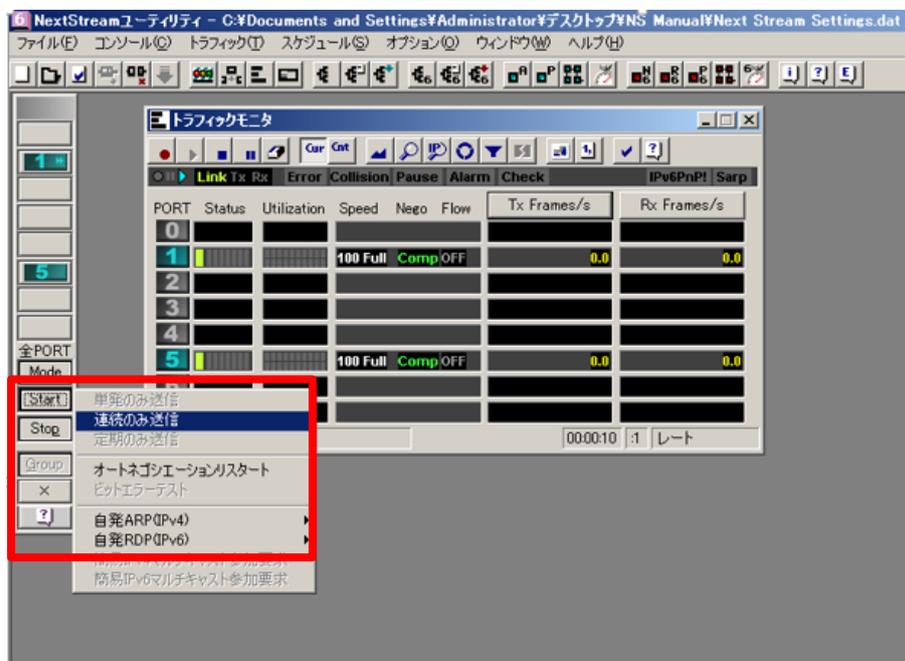


(ii) Using the traffic monitor function

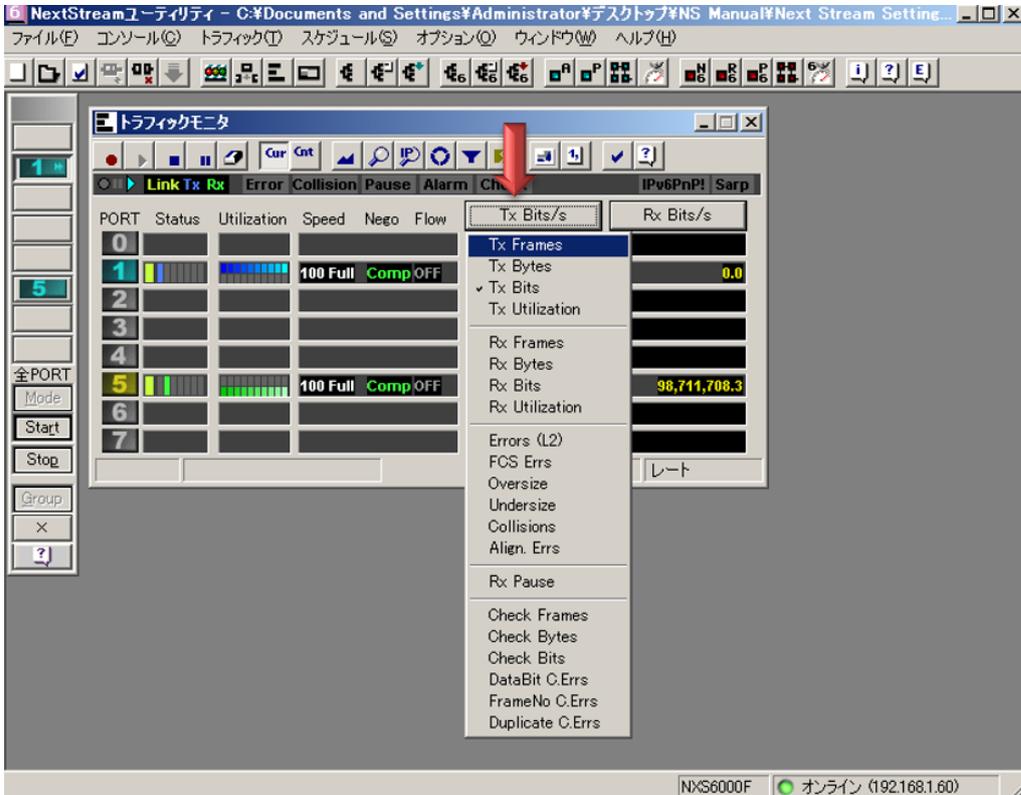
- Next to view the traffic condition using the traffic monitor, follow the steps below
- Go to <トラフィック> and select <トラフィックモニタ>



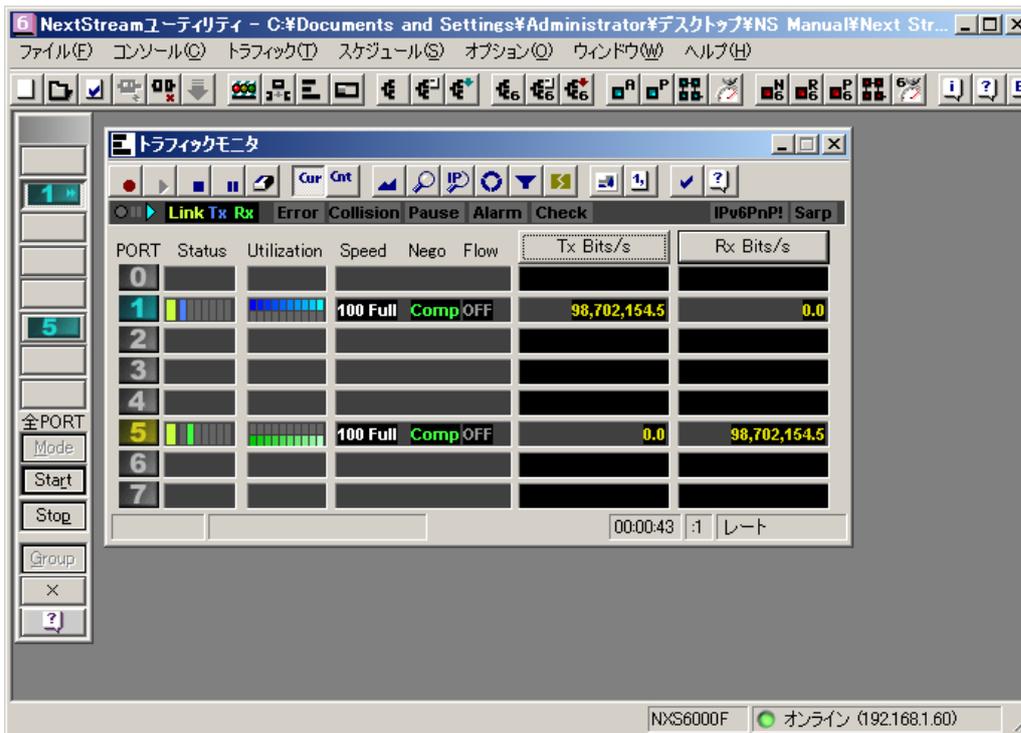
- Below screen will appear
- Next, go to the side menu and select the <Start> then choose <連続のみ送信> from the menu



- Tx and Rx value can be view in variety of measurement. Click on the top menu of each column to change the measurement value.

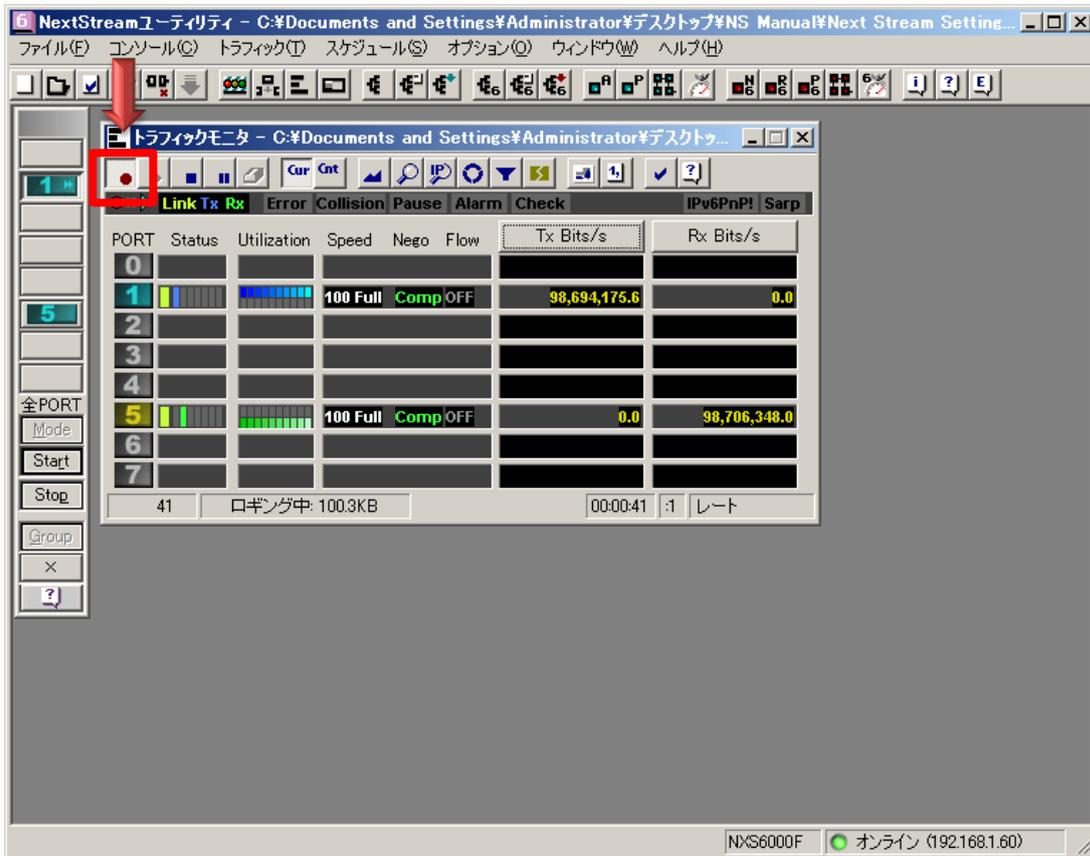


- Now the traffic condition of the network can be viewed (in this case Bits/s)

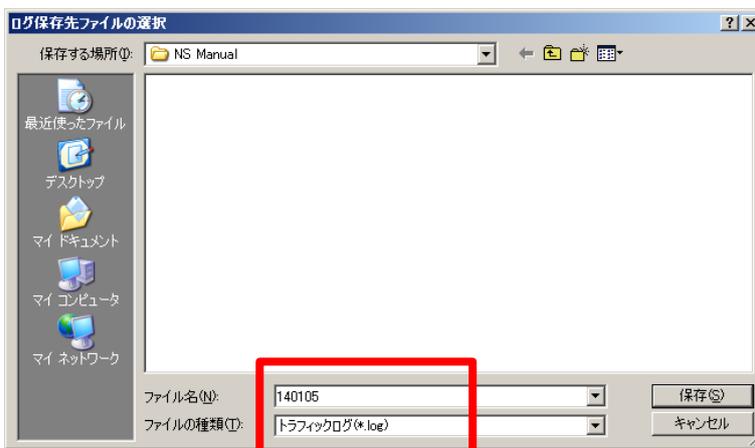


(iii) To save the traffic monitor log data into CSV format

- Click on the record button at the traffic monitor menu



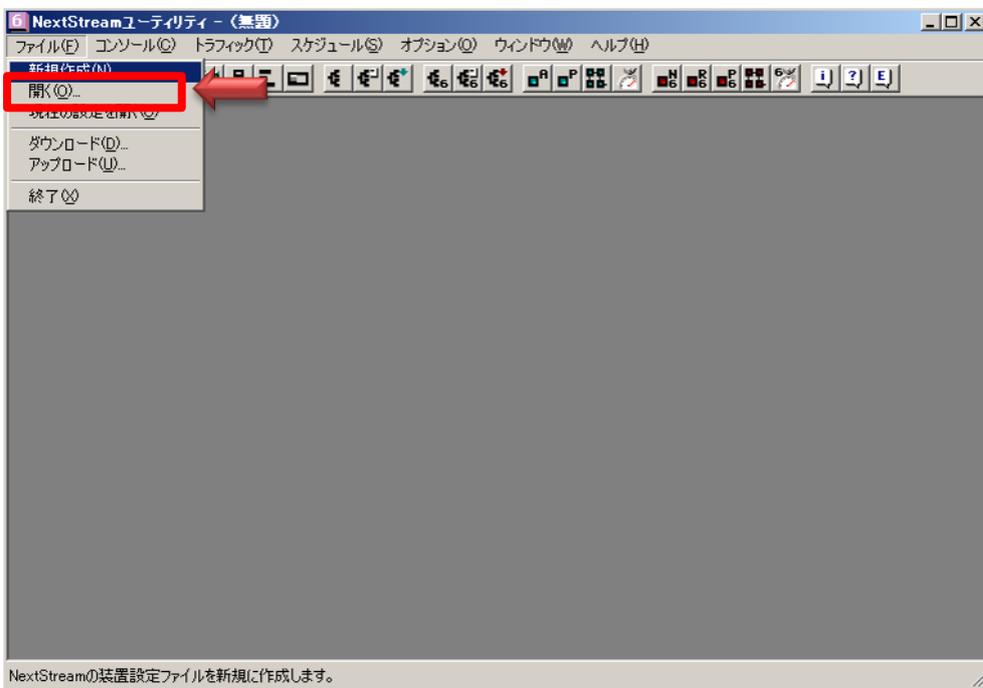
- A pop-up windows will appear and select a location and insert file name before save the log file



- After the location and file name is defined, click on save button and below message will appear to inform where the file is saved.



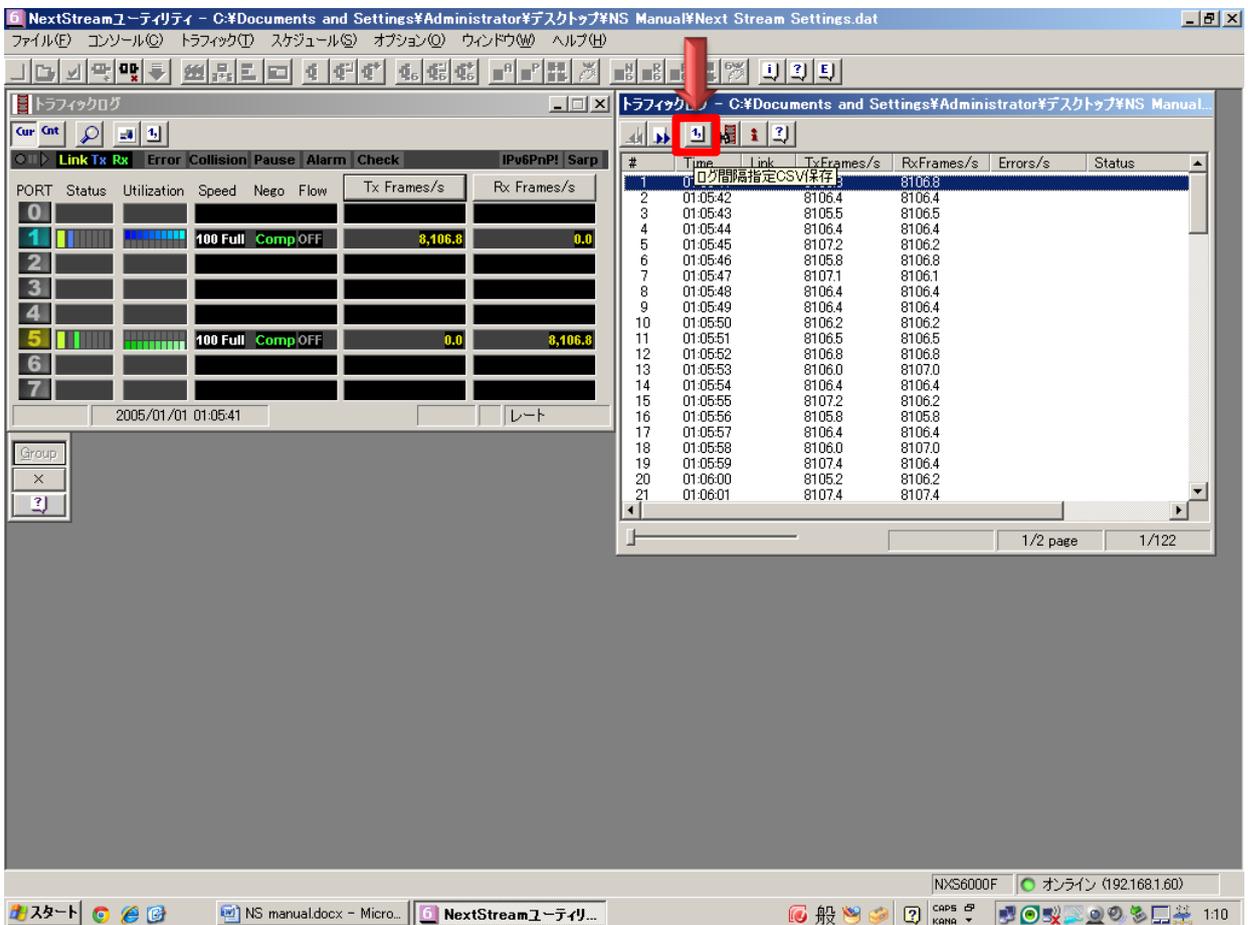
- The log will continue to save automatically to the designated file until the STOP button at the traffic monitor menu is click
- To open the saved log file, go to FILE in the main menu of NextStream and select open (O)



- In the open file pop-up windows box, select the saved log file



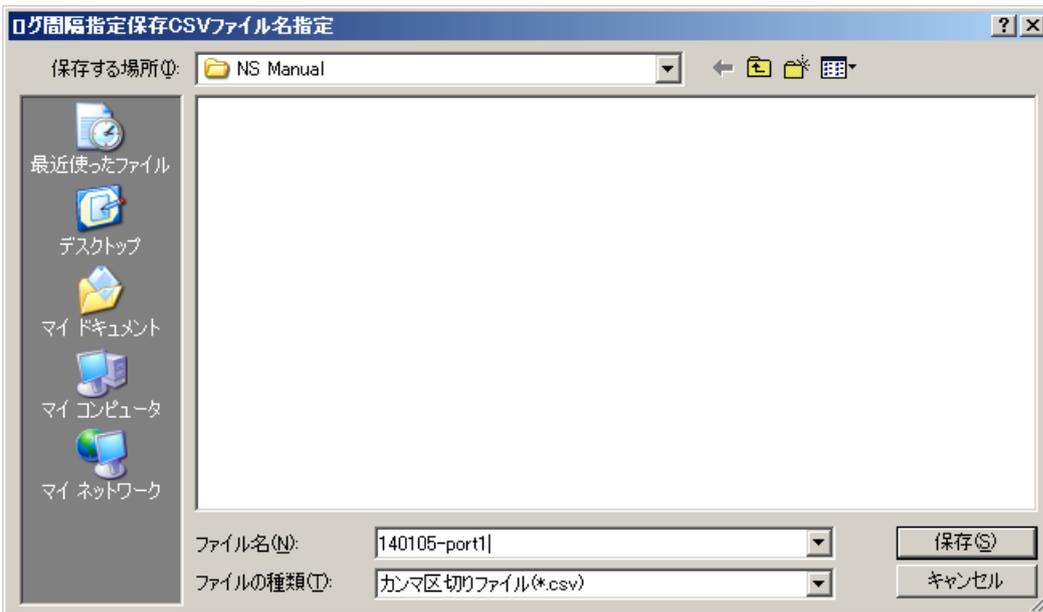
- The log file will be displayed and click on the [save the log file into CSV format] to save the file into the CSV format for further analysis



- Select the port (in this example is port 1) in order to save the log data and defined the period of the log (No) that want to be saved into CSV format, then click start button.
- Repeated the same steps for second port (in this example is port 5)



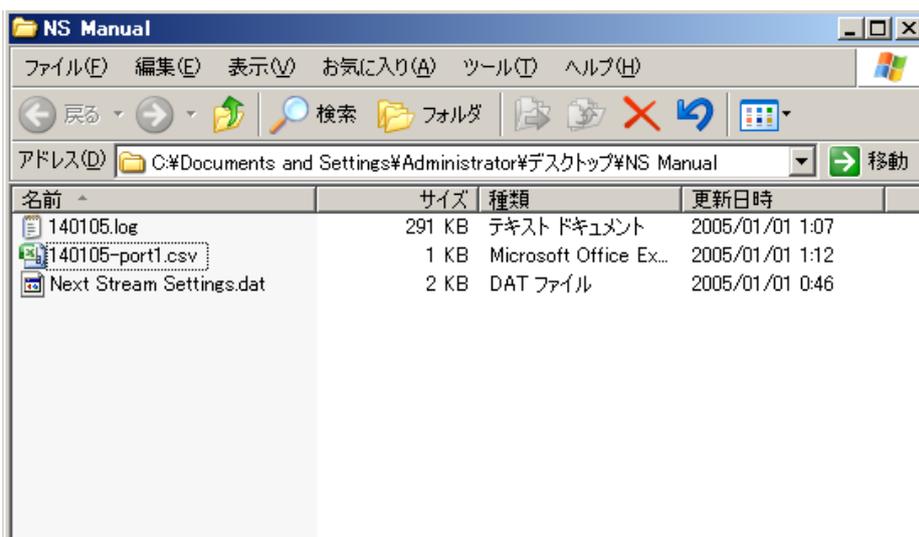
- After clicked on start button, below windows will appear. Define the location to save the file and insert a file name.



- Below screen shows that the log file has been saved into the CSV format



- Go to the saved file location to open the file

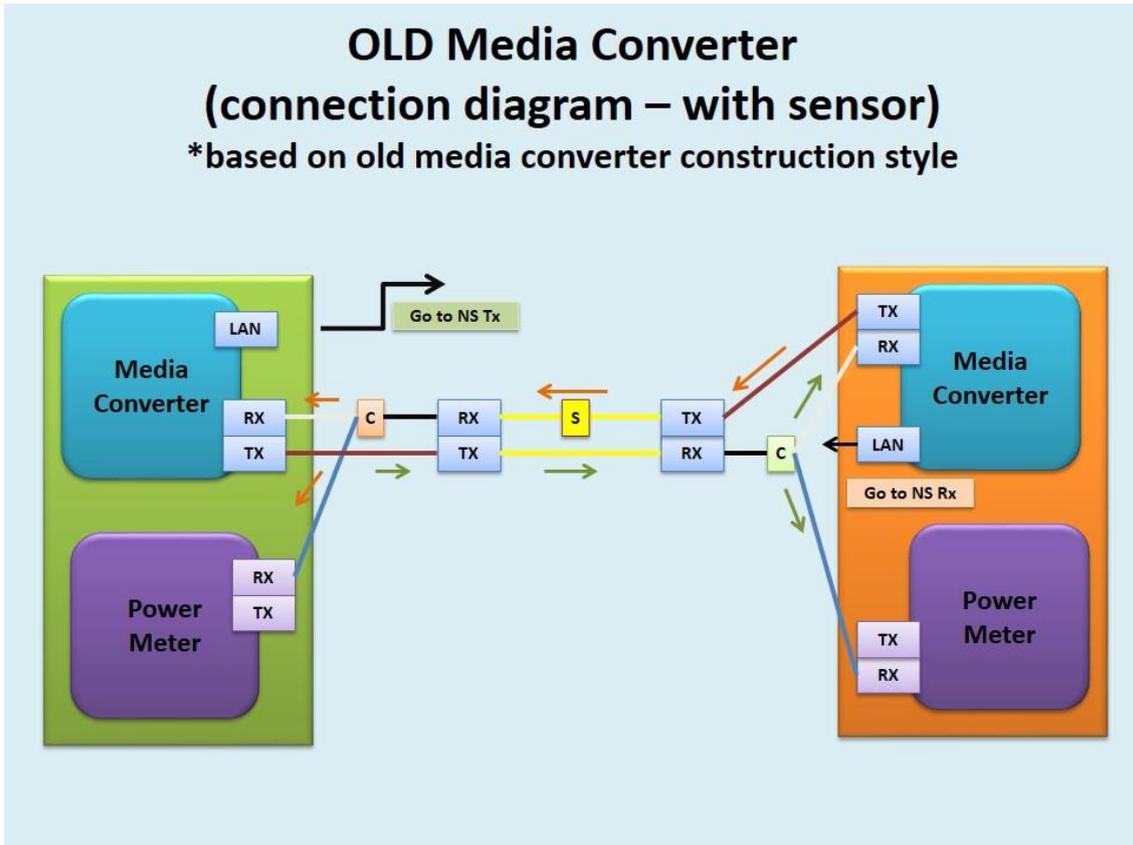


- The log file saved in CSV format is shown as below. The data can be used to draw graph for visual purpose.
- The file can also be saved in the xls or xlsx format by choosing the [Save As] from the Menu

Time	LINK	回線速度	全/半二重	フロー制御	オートネゴ	Tx Frames	Rx Frames	Tx Bytes	Rx Bytes	Tx Bits	Rx Bits
2005/1/1 1:05						9,125	0	13,888,250	0	111,106,000	0
2005/1/1 1:05						17,233	0	26,228,626	0	209,829,008	0
2005/1/1 1:05						25,340	0	38,567,480	0	308,539,840	0
2005/1/1 1:05						33,448	0	50,907,856	0	407,262,848	0
2005/1/1 1:05						41,556	0	63,248,232	0	505,985,856	0
2005/1/1 1:05						49,656	0	75,576,432	0	604,611,456	0
2005/1/1 1:05						57,764	0	87,916,808	0	703,334,464	0
2005/1/1 1:05						65,872	0	100,257,184	0	802,057,472	0
2005/1/1 1:05						73,980	0	112,597,560	0	900,780,480	0
2005/1/1 1:05						82,087	0	124,936,414	0	999,491,312	0
2005/1/1 1:05						90,187	0	137,264,614	0	1,098,116,912	0
2005/1/1 1:05						98,296	0	149,606,512	0	1,196,852,096	0
2005/1/1 1:05						106,403	0	161,945,366	0	1,295,562,928	0
2005/1/1 1:05						114,511	0	174,285,742	0	1,394,285,936	0
2005/1/1 1:05						122,619	0	186,626,118	0	1,493,008,944	0
2005/1/1 1:05						130,719	0	198,954,318	0	1,591,634,544	0
2005/1/1 1:05						138,827	0	211,294,694	0	1,690,357,552	0
2005/1/1 1:05						146,934	0	223,633,548	0	1,789,068,384	0
2005/1/1 1:05						155,043	0	235,975,446	0	1,887,803,568	0
2005/1/1 1:06						163,149	0	248,312,778	0	1,986,502,224	0
2005/1/1 1:06						171,258	1	260,654,676	64	2,085,237,408	512
2005/1/1 1:06						179,358	1	272,982,876	64	2,183,863,008	512
2005/1/1 1:06						187,466	1	285,323,252	64	2,282,586,016	512
2005/1/1 1:06						195,574	1	297,663,628	64	2,381,309,024	512

Appendix A.2 Media Converter Connection Diagram

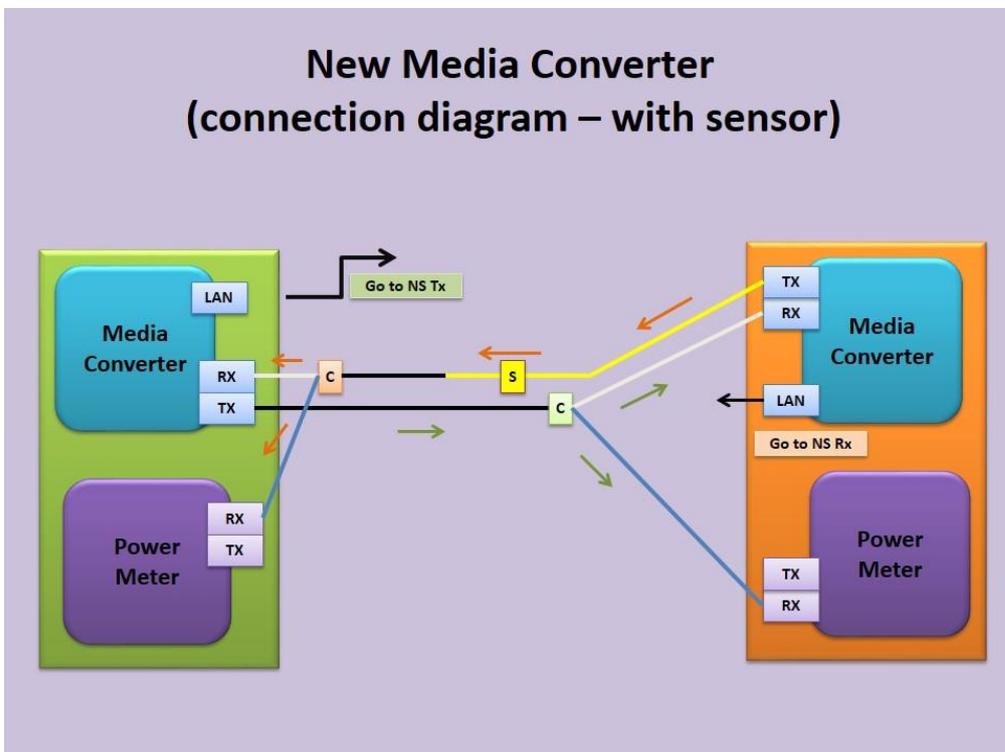
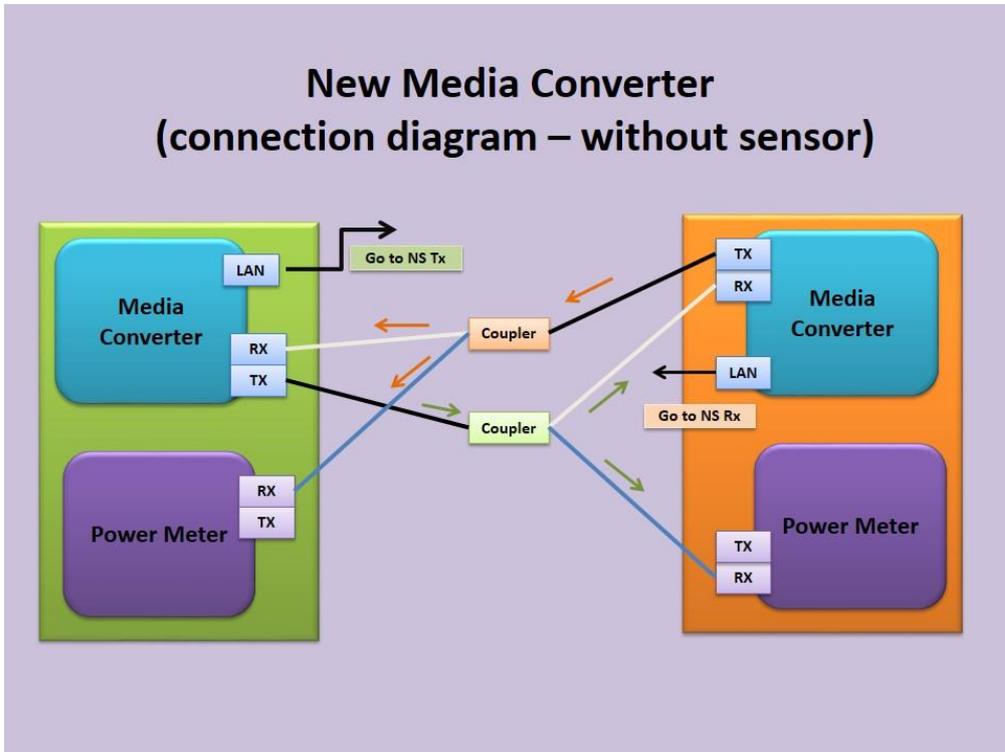
(i) Old Type Media Converter Layout



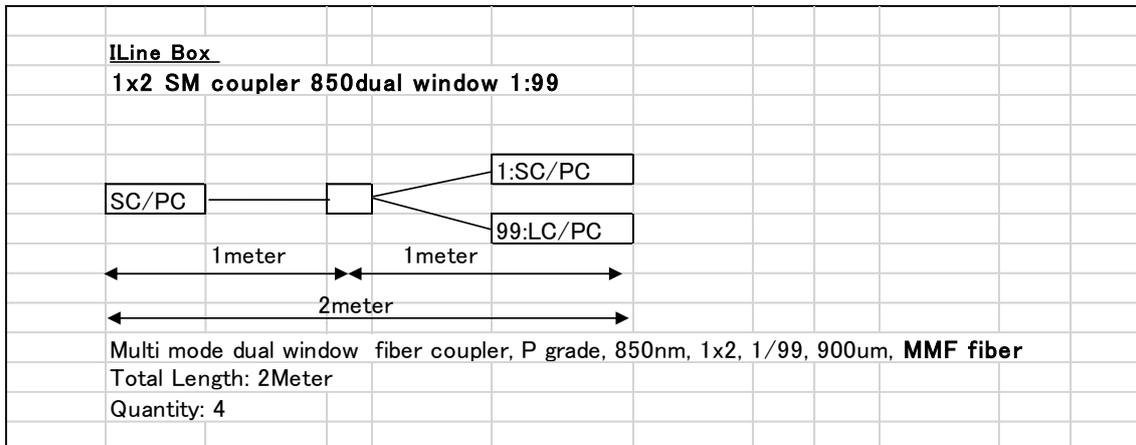
Coupler specification for Old Type Media Converter

Old Type Media Converter									
1x2 SM coupler 1310 dual window 1:99									
Single mode dual window fiber coupler, P grade, 1310nm, 1x2, 1/99, 900um, SMF fiber									
Total Length: 2Meter									
Quantity: 4									

(i) iLineBox(New Media Converter) Layout



Coupler specification for iLineBox



Appendix B

Troubleshooting the Experiments and the Best Know Method

Troubleshooting Case (I)

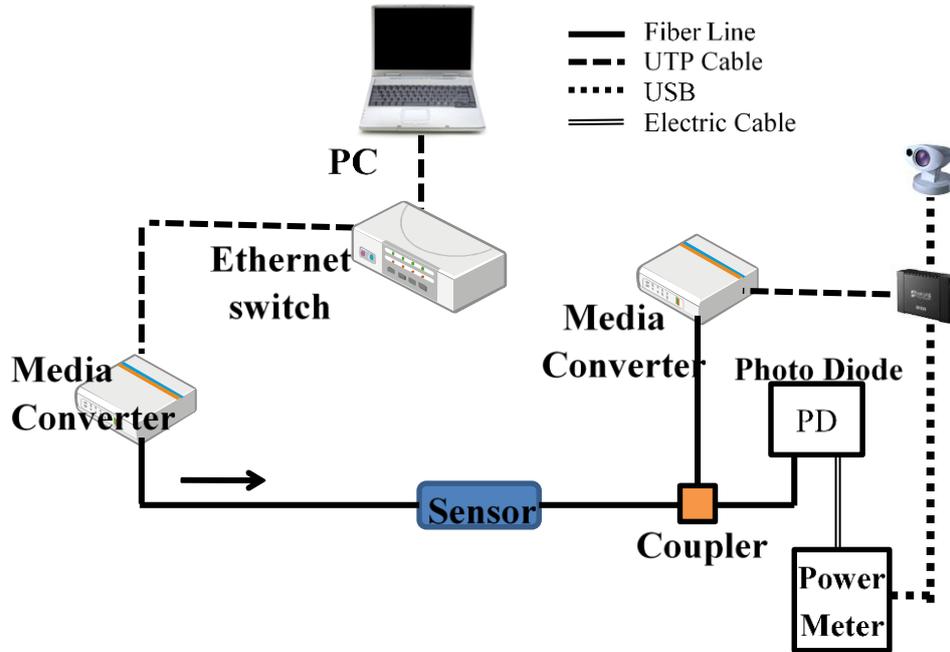


Figure appendix B.1 proposed conceptual system configuration of HC-SPR sensor system for agricultural environment monitoring

In order test the system configuration, the experiment has been carried on based on the diagram above (Figure appendix B.1). The details of the experiments has been explained in section 6.1.1.

In the early stage of the experiment, two issues occurred.

- (i) The USB connection is frequently disconnected or the measuring PC system is restarted.
- (ii) The web camera data could not be viewed clearly or when web camera try to capture a video, the connection will be disconnected.

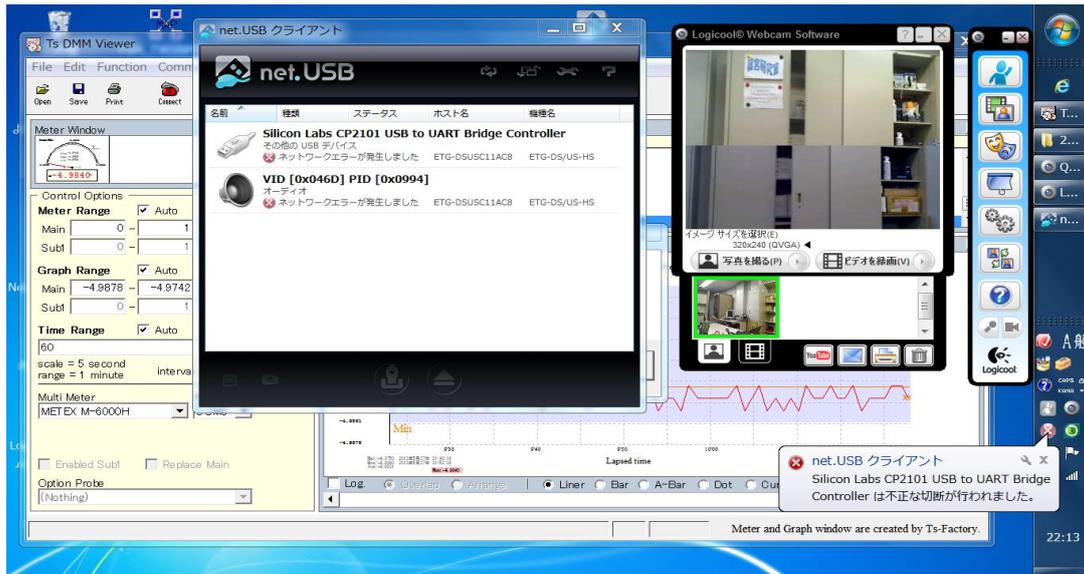


Figure appendix B.2 screen captured when issues occurred during the experiment.

The figure appendix B.2 shown the disconnection of the USB server device and the unclear display of image from the web camera.

The troubleshooting is carried on based on the two different tests.

At first, the media converter II is replaced by the new media converter. The TX output from the media converter I (MC I) is measured. The results should that the TX loss output from MC I is -8.73dB .

Then, the MC I is replaced by MC II in order to do the same measurement, and the result from MC II TX port is -10.20dB .

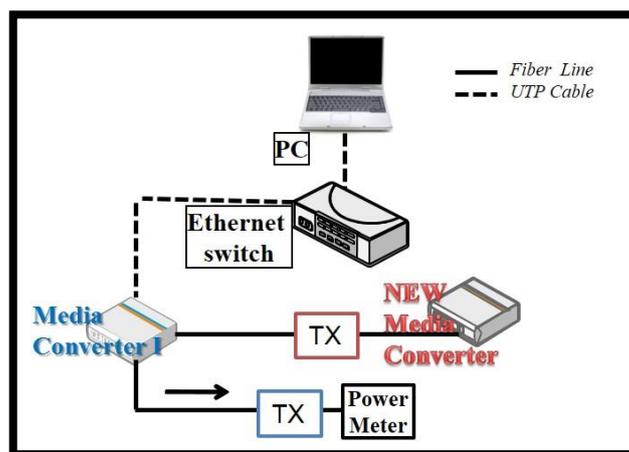


Figure appendix B.3 measuring the output from MC I and MC II in the same system configuration.

Next, in the same configuration the position of the MC I (shown in figure appendix B.3) is replaced by new media converter to measure its TX port loss output. The results is -10.30dB, which is almost similar to MC II. This means that the light intensity of MC I is higher compare to other Media converter TX output. So, the uneven of the light intensity of the TX port of the MC I is the root cause of the unstable connection. Therefore, the MC I is replaced with the new media converter (figure appendix B.4) in this configuration and the experiments managed to get the successful result.

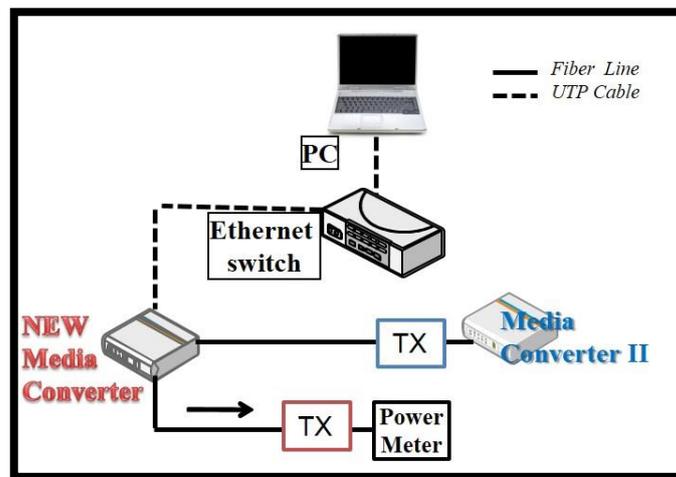


Figure appendix B.4 measuring the output new media converter in the same system configuration.

Data Collection Challenges

Troubleshooting Case (II)

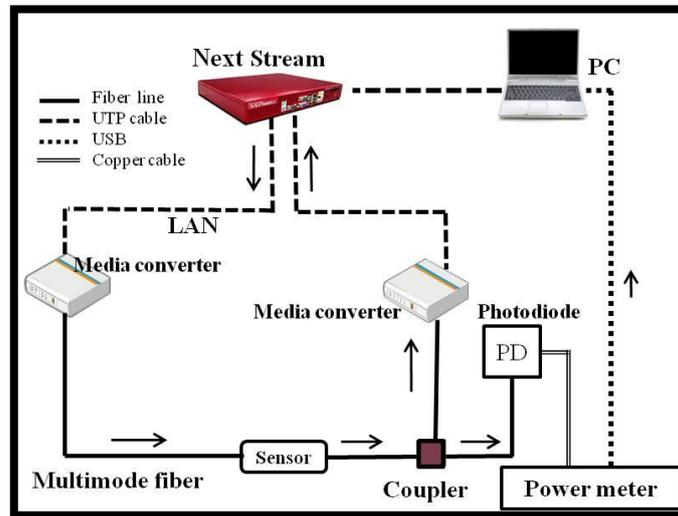


Figure appendix B.5 verification experiment for data communications and sensing using the HC-SPR sensors

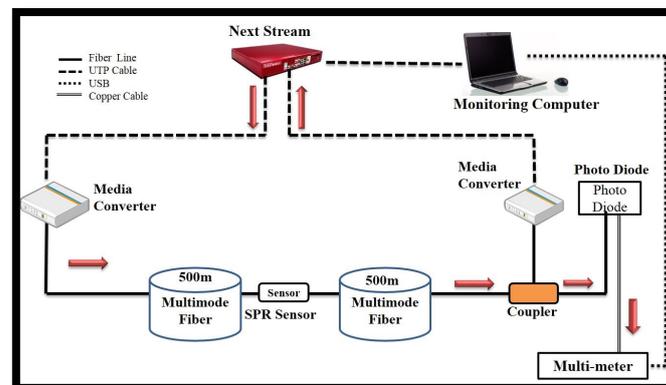


Figure appendix B.6 verification experiment for data communications and sensing using the HC-SPR sensors over longer distance

The detail of experiments show in Figure appendix B.5 and B.6 has been explained in section 5.2.2 and section 5.2.3. At the early stage of the experiment, the stable sensing data could not be retrieved.

The results for short distance test (figure appendix B.5) of SPR sensor I and II is shown in figure appendix B.7. While figure appendix B.8 shows the results for longer distance test for SPR sensor I, II and III. All results show unstable output from the sensors.

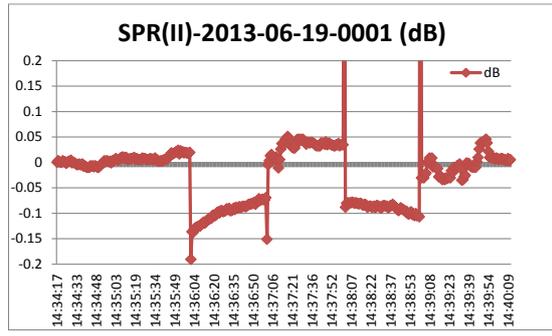
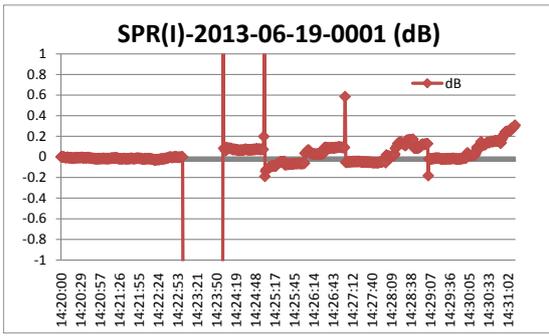


Figure appendix B.7 Experiment results for SPR Sensor I and II for experiments in figure appendix B.5.

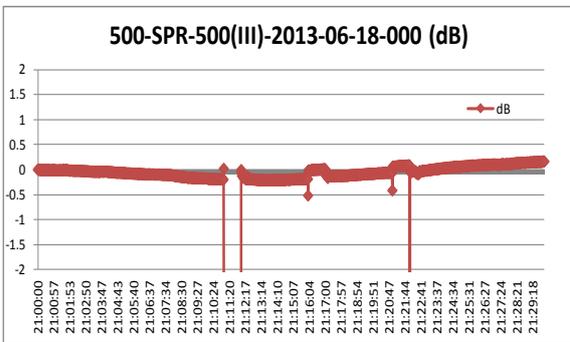
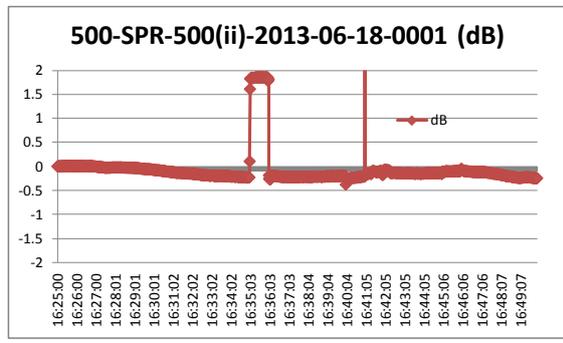
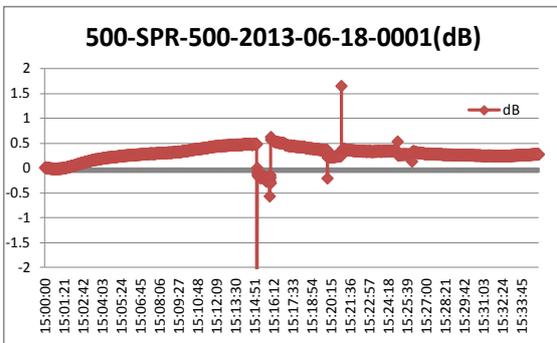


Figure appendix B.8 Experiment results for SPR Sensor I, II and III for experiments in figure appendix B.6.

Solution:

The media converter and photodiode always adjusted their own base line value each time the electric power is supplied to them (in an experiment set up).

If a new experiment or configuration is set up and the power of the media converter and photodiode is not reset, then the old base value will be use. Each experiment has different base line value even though the configuration could be considered the same.

Therefore, each time before the next experiment, the power of the media converter and photodiode need to be restarted in order to retrieve a new base line value. By performing this steps each time before a new experiment ensure a stable sensor results as described in section 5.2.2 and section 5.2.3.

Appendix C

Summary of Multi-points HC-SPR Sensors Experiment using LD light

This section summarized the experiment the multi-point detection using HC-SPR sensors with LD light source from media converter. The data communications devices and its measuring devices such as media converter, Ethernet switch and NextStream into the test.

There is about 14 different test has been conducted with different configuration in order to identify the feasibility of the sensors or the system configuration.

Although the experiment results show that the system could not provide a stable result for measuring purpose, this steps is important in the study. The result from the experiments are essential to detect and analyze the existing issues; or to assist on making further improvement to the current system.

List for Experiment conducted for HC SPR Sensor

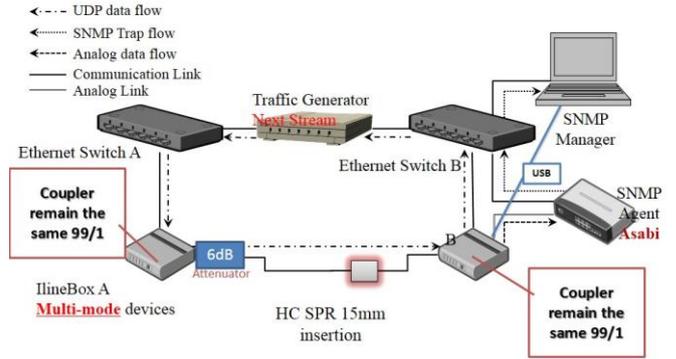
Test	Description	Slide	Result
A- 15mm SPR test	Test with 6dBATT - 15mmSPR	Slide 1-4	Sensor responded, base line is considerable stable
B - 2mm SPR test	Test with 9dBATT -2mmSPR	Slide 5-9	Sensor responded, base line is considerable stable
C - 5mm SPR test	Test with 6dBATT -5mmSPR	Slide 10-15	Sensor responded, result is not expected or not stable
Test 1, 2, 3	Test with SPR15-5-2	Slide 16-27	Sensors responded; but the first test for 15mm seems to be weird. The respond for 2mm seem to be larger than 15mm. All 2mm involved result seem to be larger. <i>*Why 2mm responded larger compare to 5mm or 15mm?</i>
Test 4	Test with SPR15-5-2 on different day	Slide 28-34	Same test as above. All sensors responded accordingly. Stable graph result. But the 2mm sensor show better responded than other. Refer to slide 34 for clearer picture, however the dB is high for 2mm too (-5dB?)
Test 5, 6	Test with 3dB ATT -SPR 2-5-15	Slide 35-44	Try the connection different from test 1-4 but the graph shown the results is unstable. Not sure if need a longer timing to get a stable baseline before start testing??
Test 7	Test with SPR 2-5-15	Slide 45-50	Repeat test 6 without Attenuator. The result is not positive too.
Test 8	Test with SPR 2-2-2	Slide 52-57	2mm seem to be responded very well in Test 1-4 therefore try combination of 2mm-2mm-2mm SPR without attenuator. The result is not responded well for Asabi (slide55). But Iline box seem to have little respond (slide56)
Test 9	Test with 3dB ATT- SPR 2-2-2	Slide 59-63	Test with Attenuator, but result is not stable too. Before the test, the base line is not stable as well (slide 60)
Test 10	Test with 3dB ATT- SPR 2-15	Slide 65-69	Results seem to be stable (slide67) except 2mm was not responded at first test. But cannot differentiate the sensor as the result is almost the same line for 15, 2&15.
Test 11	Test with 3dB ATT- SPR 15-2	Slide 71-73	All sensors responded but I think the result is not very positive as the graph go descending.

15mm SPR test

NS-ES-IlineBox-6dBATT- 15mmSPR-iLineBox-Asabi-PC-ES~

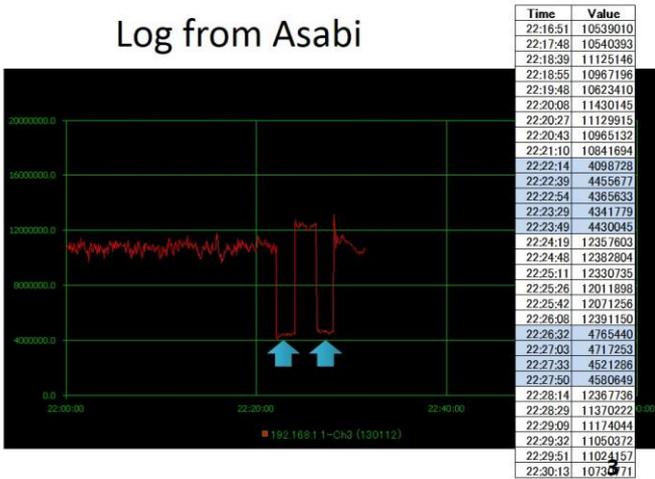
1

Experiment Diagram

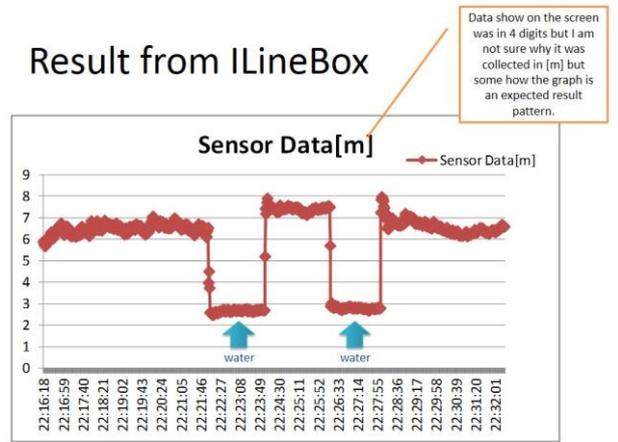


2

Log from Asabi



Result from ILineBox



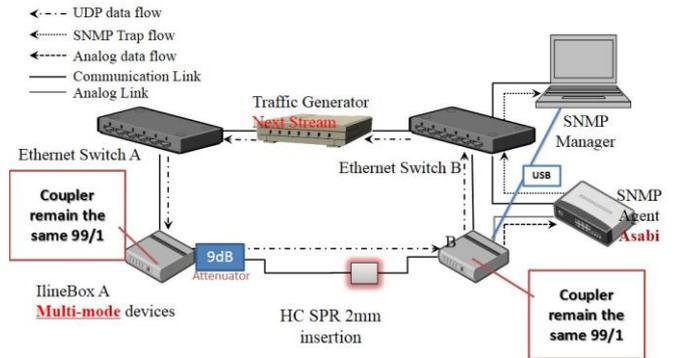
4

2mm SPR test

NS-ES-IlineBox-9dBATT-2mmSPR-iLineBox-Asabi-PC-ES~

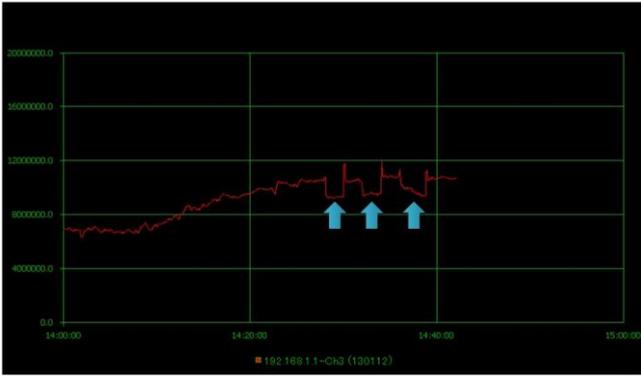
5

Experiment Diagram

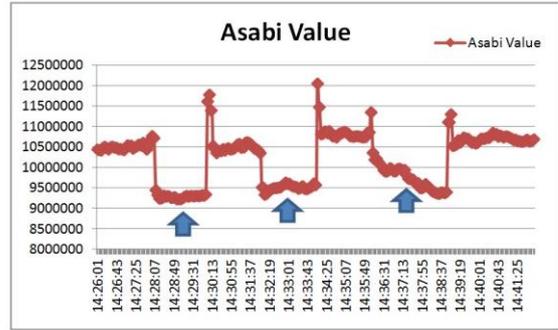


6

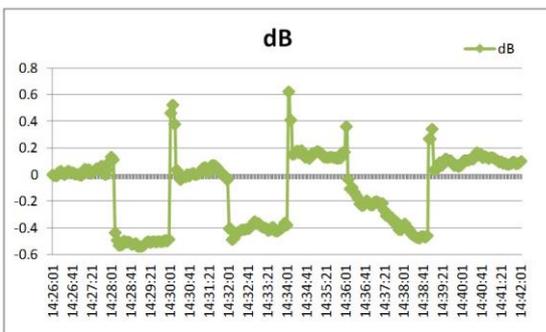
Log from Asabi



7



8



9

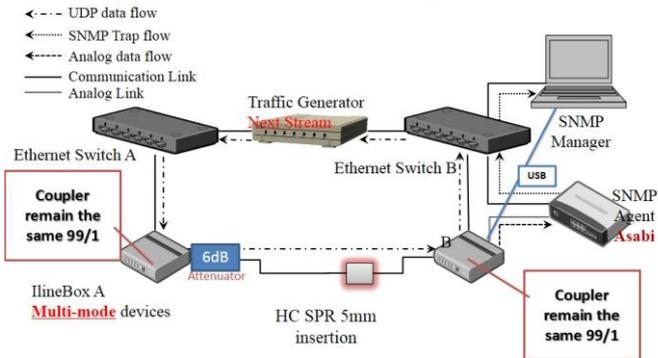
5mm SPR test

NS-ES-ilineBox-6dBATT-5mmSPR-ilineBox-Asabi-PC-ES~

10

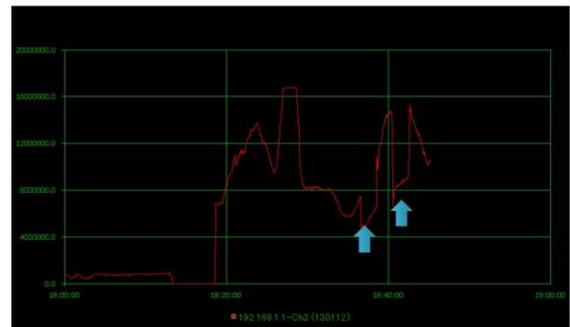
NS-ES-iline-6dBATT-5mmSPR-iline-Asabi

Experiment Diagram



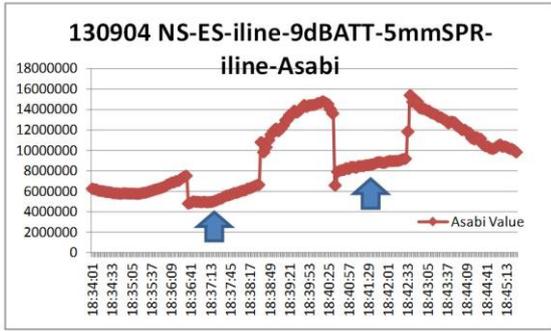
11

Log from Asabi

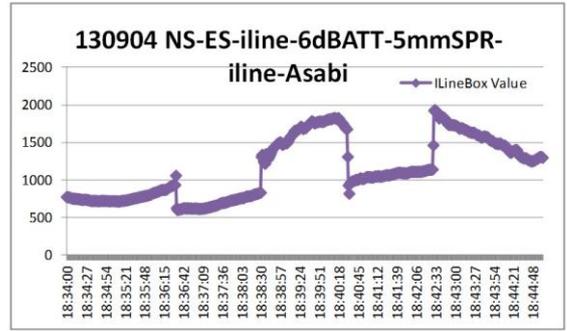


12

130904 NS-ES-iline-9dBATT-5mmSPR-iline-Asabi

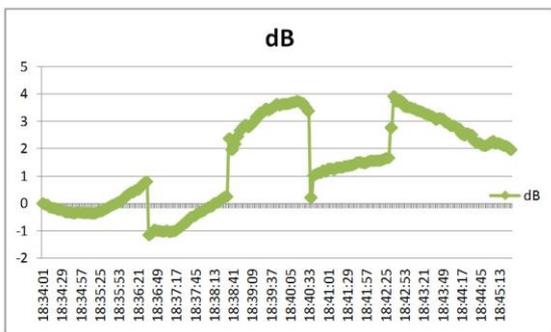


13



14

dB Value is converted from Asabi value



15

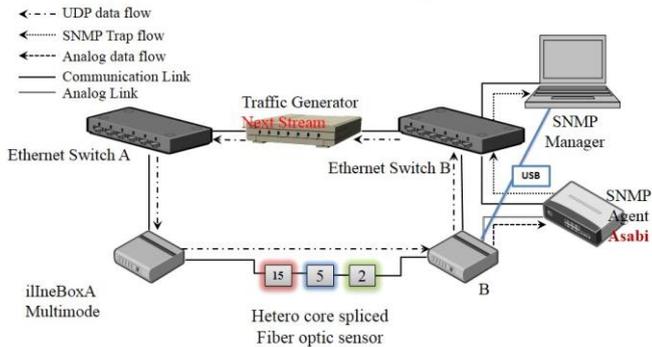
Tandem connection test 2nd Sept

Test 1,2,3

NS-ES-iLineBox-SPR15-5-2-iLineBox-Asabi-PC-ES~

16

Experiment Diagram



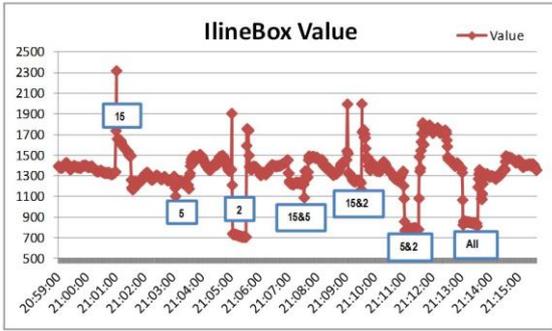
17

In-House Experiment Pattern

Experiment with 3 sensors	Sensor 1	Sensor 2	Sensor 3
Test0	OFF	OFF	OFF
Test 1	○		
Test 2		○	
Test 3			○
Test 4	○	○	
Test 5	○		○
Test 6		○	○
Test 7	○	○	○

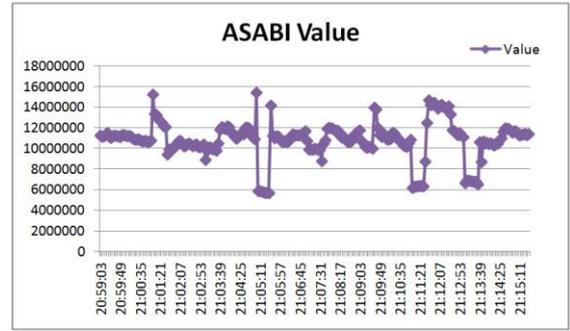
18

Test 1
immersed in water for 30seconds



19

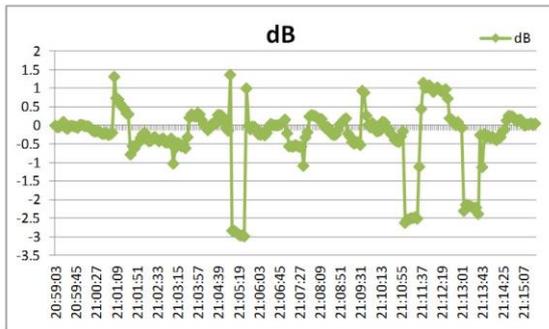
Test 1
immersed in water for 30seconds



20

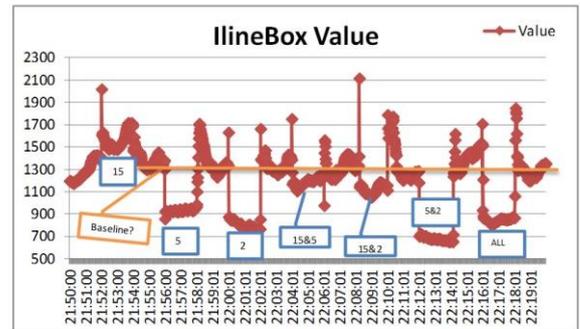
Test 1
immersed in water for 30seconds

dB calculation based on Asabi Value



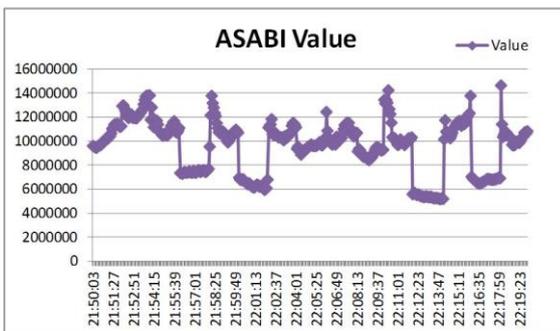
21

Test 2- air 2 minutes & water 2 minutes then repeat



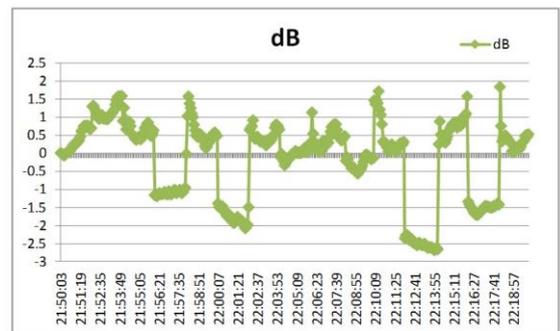
22

Test 2- air 2 minutes & water 2 minutes then repeat



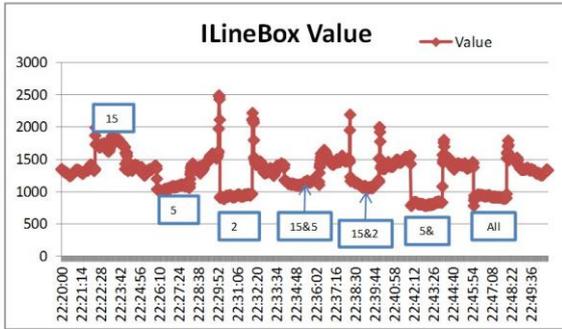
23

Test 2- air 2 minutes & water 2 minutes then repeat



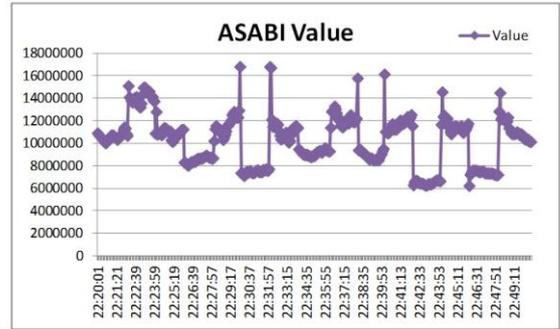
24

Test 3
continue after test 2, same as test 2



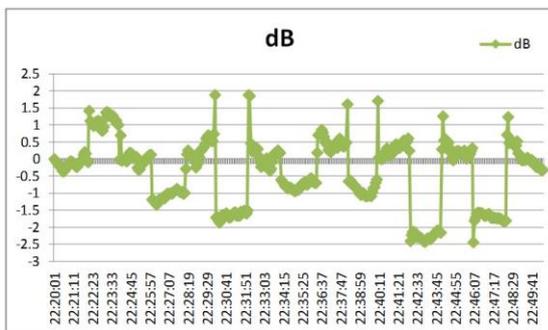
25

Test 3
continue after test 2, same as test 2



26

Test 3
continue after test 2, same as test 2



27

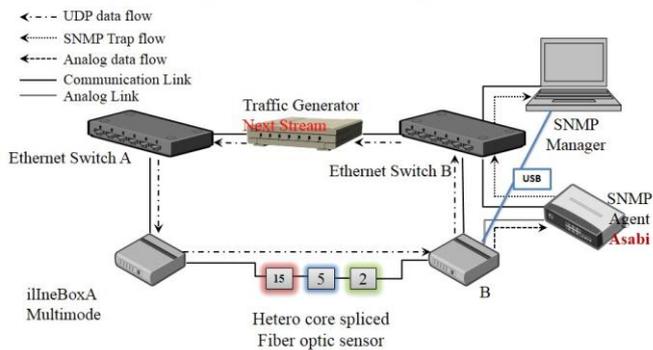
Tandem connection test
3rd Sept

Test 4

NS-ES-IlineBox-SPR15-5-2-iLineBox-Asabi-PC-ES~

28

Experiment Diagram



29

In-House Experiment Pattern

Experiment	with 3 sensors	Sensor 1	Sensor 2	Sensor 3
Test0		OFF	OFF	OFF
Test 1		○		
Test 2			○	
Test 3				○
Test 4		○	○	
Test 5		○		○
Test 6		○	○	○
Test 7		○	○	○

30

12hours data without water test (SPR 15-5-2mm)



31

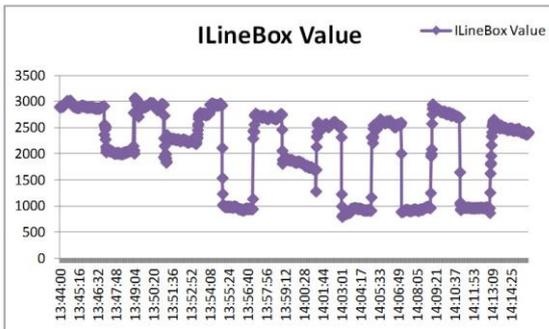
Test 4- air 2 minutes & water 2 minutes then repeat



Sorry Asabi Value is a bit weird as the log might not be correctly captured.

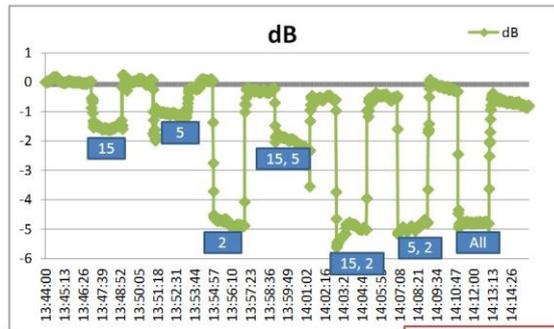
32

Test 4- air 2 minutes & water 2 minutes then repeat



33

Test 4- air 2 minutes & water 2 minutes then repeat



dB Value is converted from IlineBox value

34

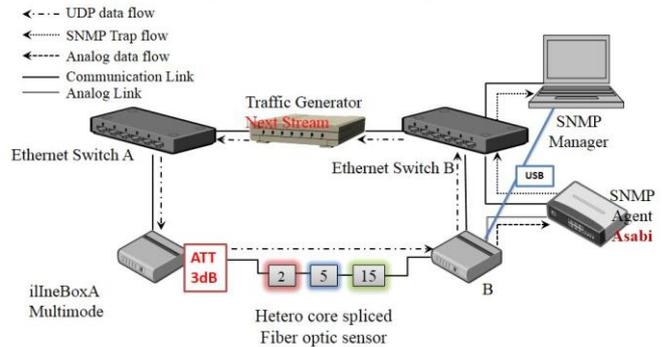
Tandem connection test 3rd Sept

Test 5 and 6

NS-ES-IlineBox-ATT3dB- SPR2-5-15-iLineBox-Asabi-PC-ES~

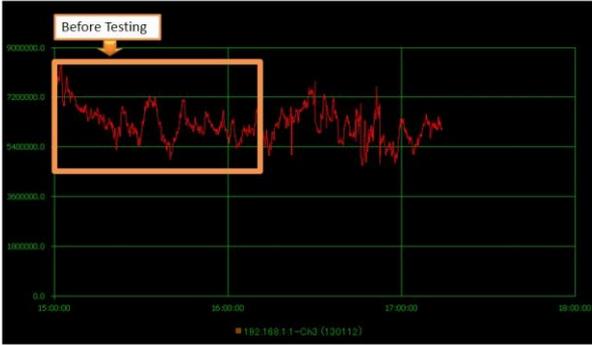
35

Experiment Diagram



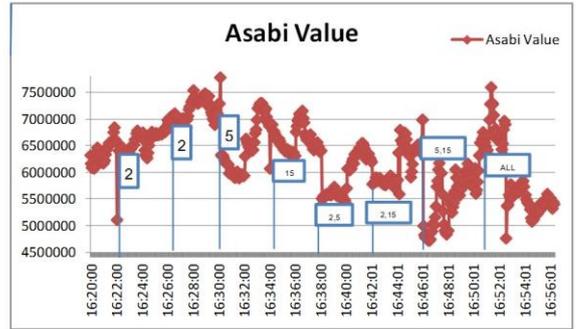
36

Graph from Asabi before testing



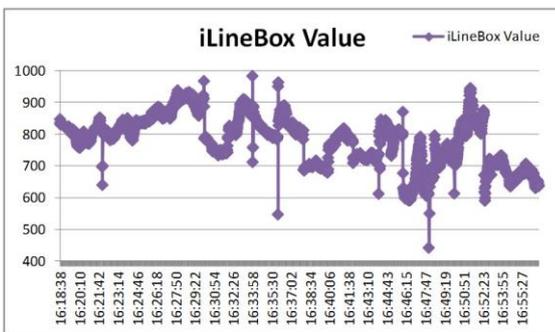
37

Test 5- air 2 minutes & water 2 minutes then repeat



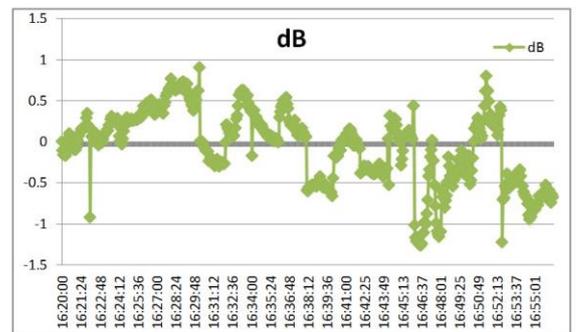
38

Test 5- air 2 minutes & water 2 minutes then repeat



39

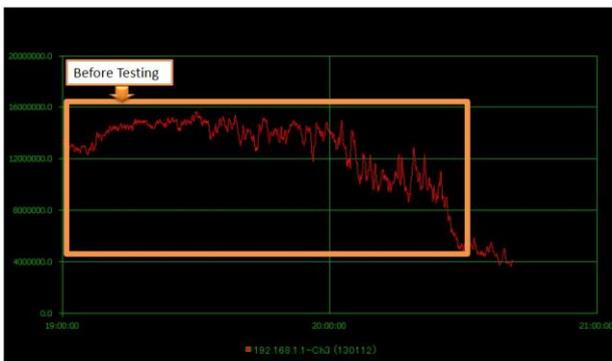
Test 5- air 2 minutes & water 2 minutes then repeat



40

Test 5 NS-ES-iLineBox-ATT3dB-SPR2-5-15-iLineBox-Asabi-PC-ES

Graph from Asabi before testing



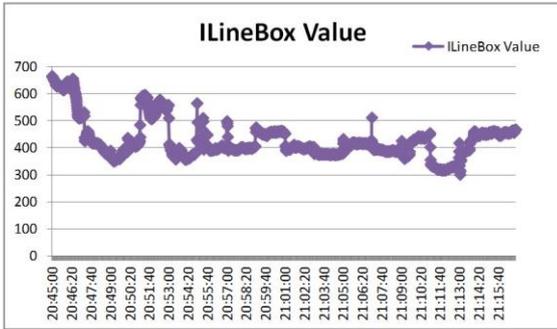
41

Test 6- air 2 minutes & water 2 minutes then repeat



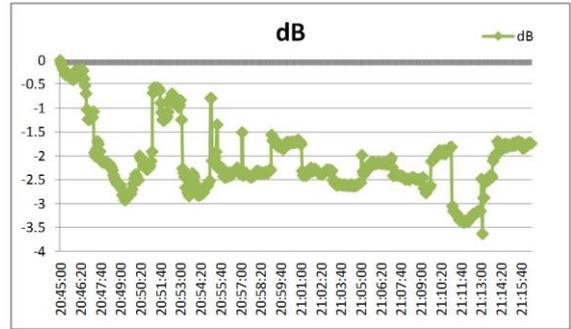
42

Test 6- air 2 minutes & water 2 minutes then repeat



43

Test 6- air 2 minutes & water 2 minutes then repeat



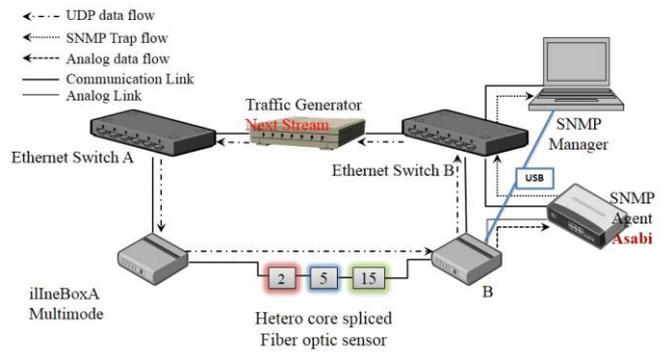
44

Tandem connection test
3rd Sept

3.NS-ES-iLineBox-SPR2-5-15-iLineBox-Asabi-PC-ES~
Without Attenuator

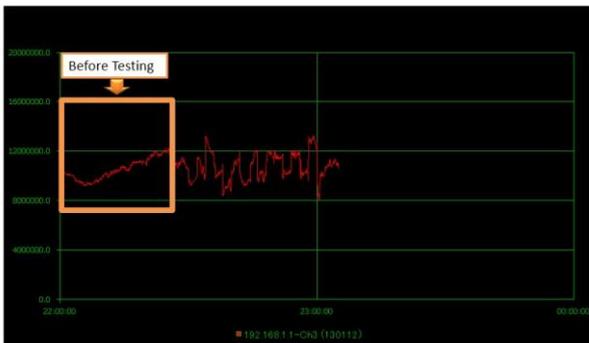
45

Experiment Diagram



46

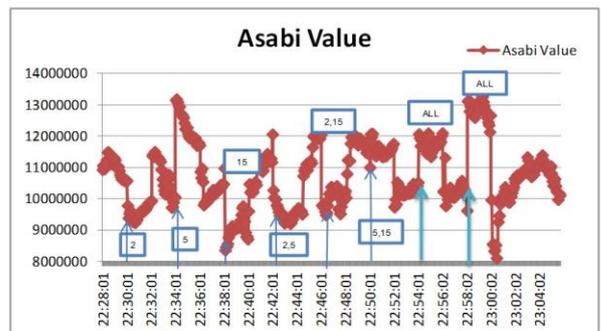
Graph from Asabi before testing



47

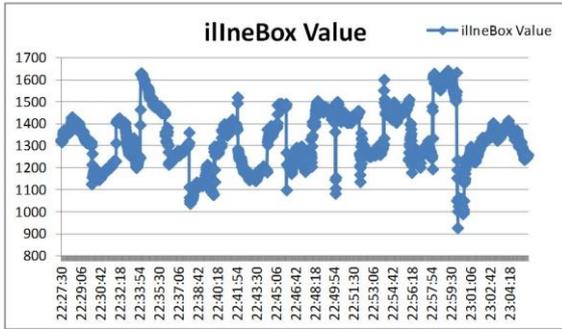
Test 7- air 2 minutes & water 2 minutes then repeat

Without ATT3dB



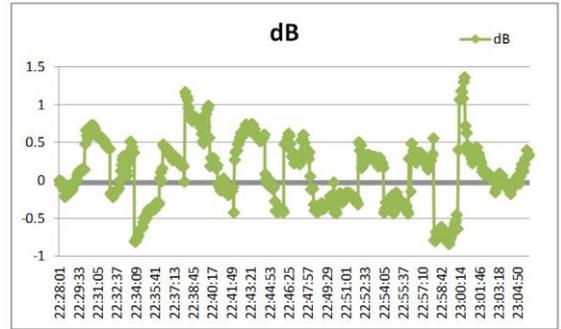
48

Test 7- air 2 minutes & water 2 minutes then repeat



49

Test 7- air 2 minutes & water 2 minutes then repeat



50

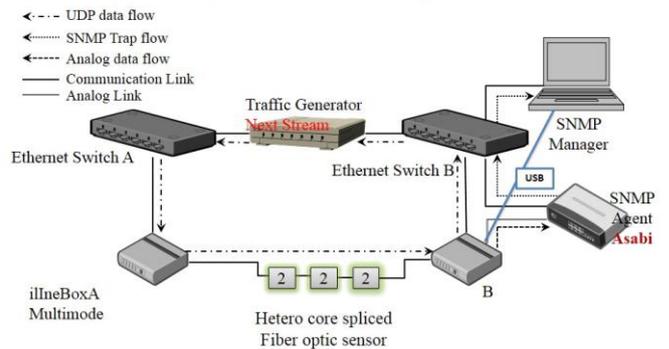
Tandem connection test
4th Sept

Test 8

NS-ES-IlineBox-SPR2-2-2-iLineBox-Asabi-PC-ES~

51

Experiment Diagram



1.NS-ES-IlineBox-SPR2-2-2-iLineBox-Asabi-PC-ES~

52

In-House Experiment Pattern

Experiment with 3 sensors	Sensor 1	Sensor 2	Sensor 3
Test0	OFF	OFF	OFF
Test 1	○		
Test 4	○	○	
Test 7	○	○	○

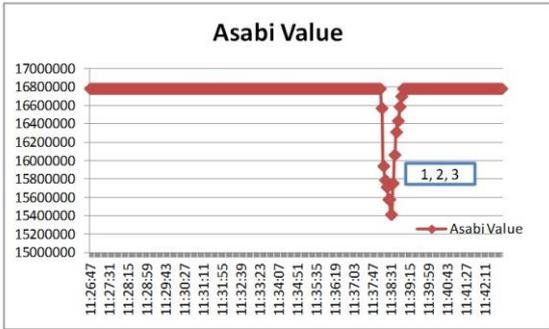
53

11hours data without water test
(SPR 2-2-2mm)



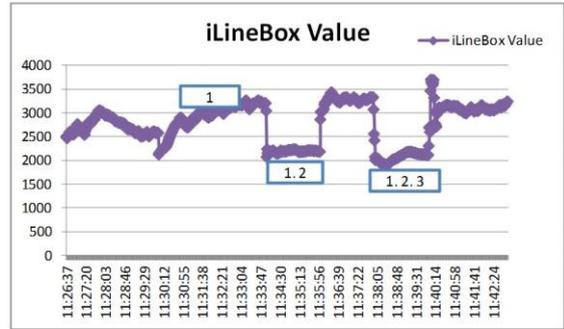
54

130904 2-2-2 tandem test8 (graph)



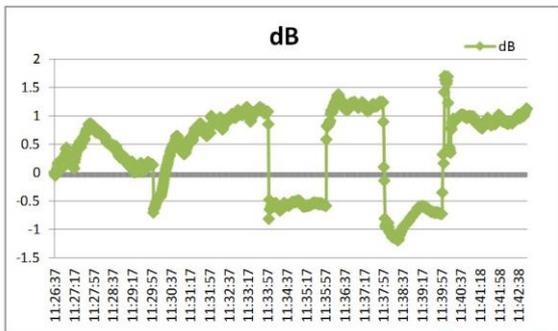
55

130904 2-2-2 tandem test8 (graph)



56

130904 2-2-2 tandem test8 (graph)



dB Value is converted from iLineBox val⁵⁷

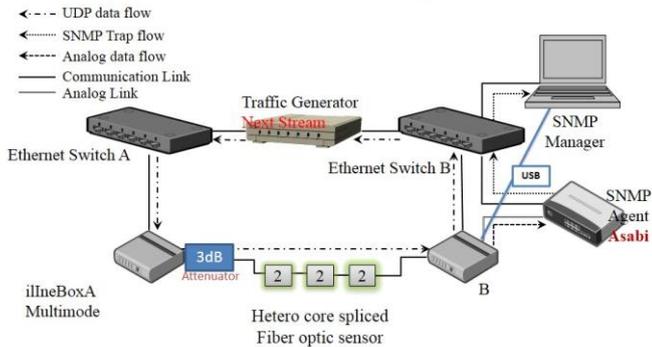
58

Tandem connection test 4th Sept

Test 9

NS-ES-IlineBox-ATT3dB-SPR2-2-2-iLineBox-Asabi-PC-ES~

Experiment Diagram



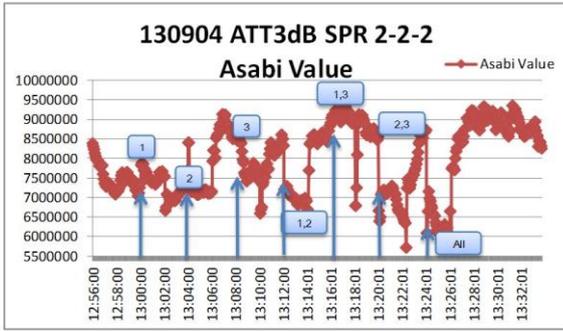
59

Before testing – an hour data



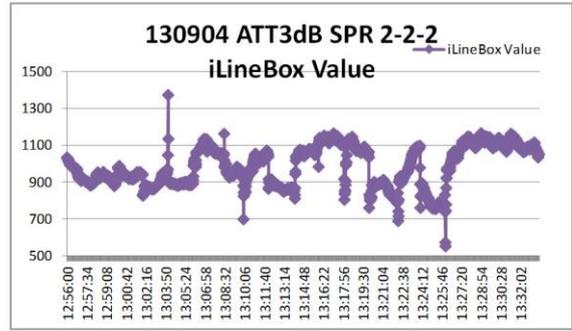
60

130904 ATT3dB 2-2-2 tandem test9



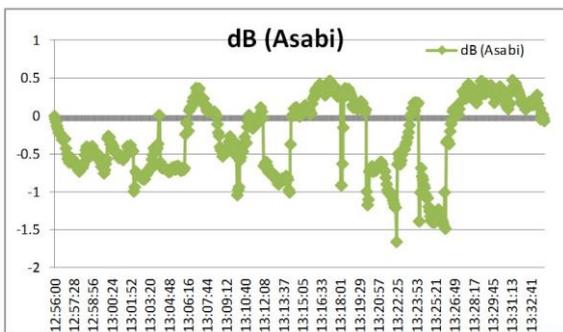
61

130904 ATT3dB 2-2-2 tandem test9



62

130904 ATT3dB 2-2-2 tandem test9



dB Value is converted from Asabi value **63**

64

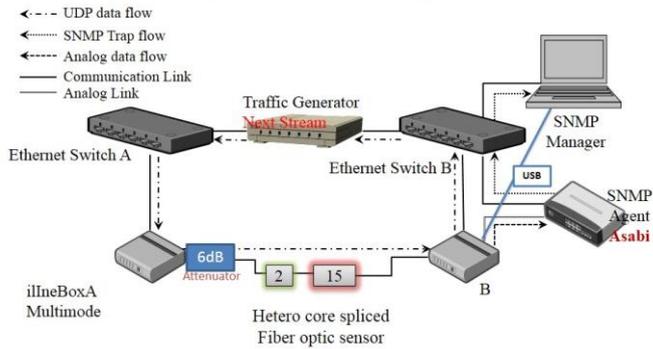
Tandem connection test 4th Sept

Test 10

NS-ES-iLineBox-ATT6dB-SPR2-15-iLineBox-Asabi-PC-ES~

3.NS-ES-iLineBox-ATT6dB-SPR2-15-iLineBox-Asabi-PC-ES~

Experiment Diagram



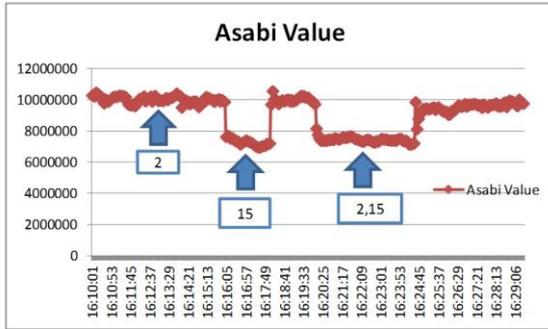
65

Before testing



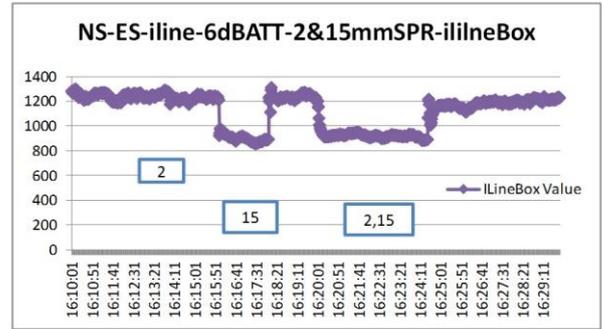
66

NS-ES-iline-6dBATT-2&15mmSPR-iline-
Asabi(graph)

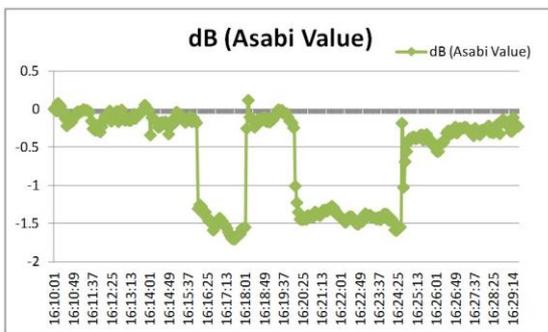


67

NS-ES-iline-6dBATT-2&15mmSPR-iline-
Asabi(graph)



68



69

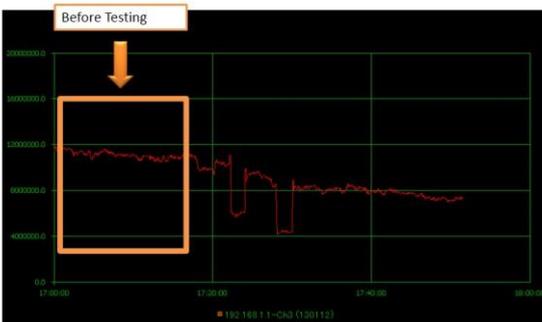
Tandem connection test
4th Sept

Test 11

NS-ES-ilineBox-ATT6dB-SPR15-2-iLineBox-Asabi-PC-ES~

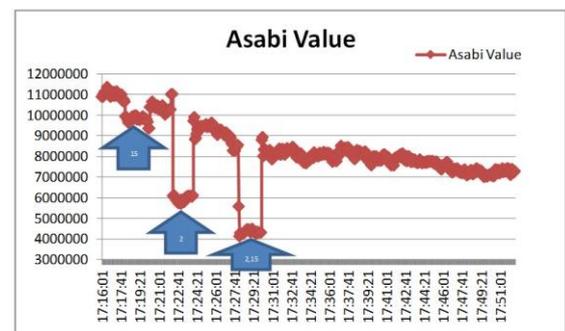
70

NS-ES-iline-6dBATT-15&2mmSPR-ilineBox



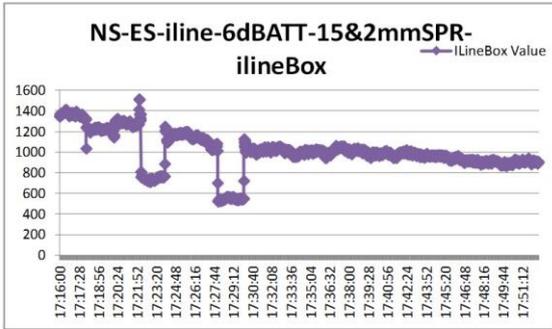
71

NS-ES-iline-6dBATT-15&2mmSPR-ilineBox



72

NS-ES-iline-6dBATT-15&2mmSPR-ilineBox



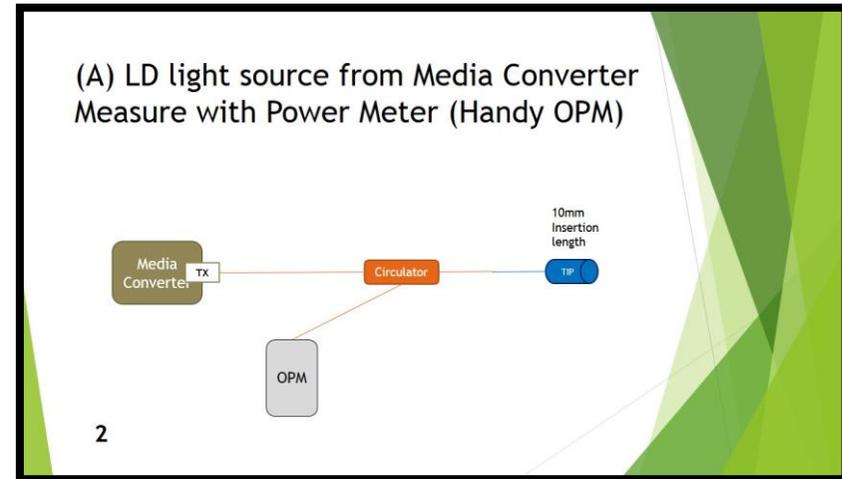
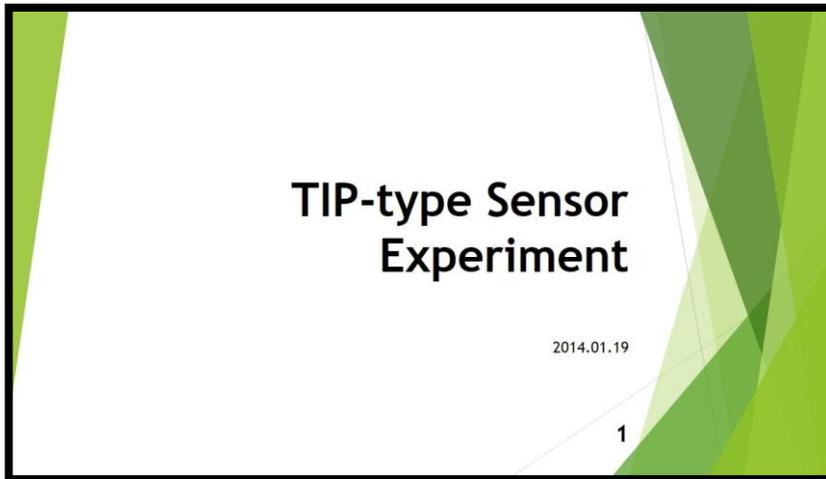
73

Appendix D

TIP-Type HC-SPR Sensor Verification Test

Summary of the conducted verification test

- (i) Test to verify the feasibility of TIP-type HC-SPR sensor

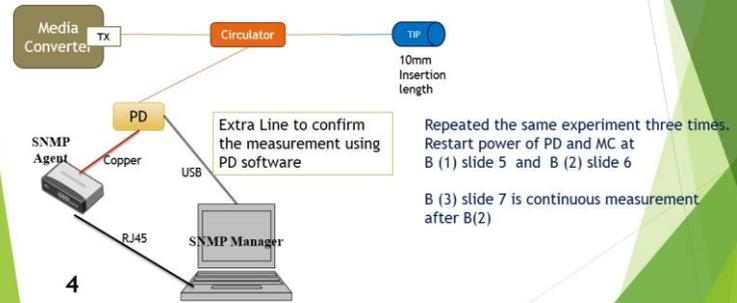


Results measured by OPM

Air	Water	Air	Water	Air
-29.28	-32.55	-29.90	-32.65	-29.50
-29.20	-32.59	-29.45	-32.48	-28.80
-29.03	-32.77	-29.65	-32.41	-28.86
-28.95	-33.15	-28.66	-32.41	-28.87
-28.83	-33.78	-28.55	-32.37	-28.90
-28.87	-33.81		-32.28	-29.15

3

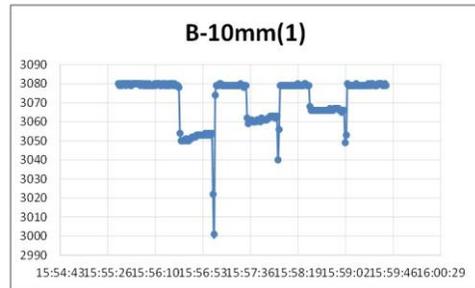
(B) LD light source by Media Converter Measure with Asabi (and PD software)



4

Restart power of PD and MC

Result Measured by Photodiode- B-10mm(1)



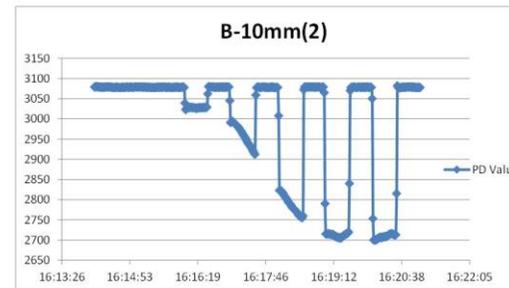
Measurement of Asabi did not change and remained at Peak

5

B-10mm(1) PD Value.xlsx

Restart power of PD and MC

Result Measured by Photodiode- B-10mm(2)

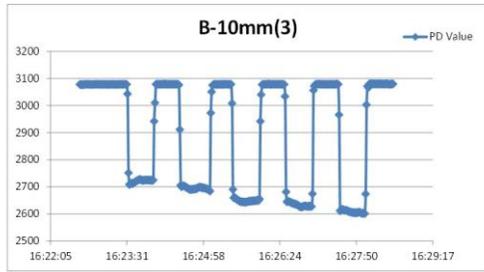


Measurement of Asabi did not change and remained at Peak

6

B-10mm(2).xlsx

Result Measured by Photodiode- B-10mm(3)

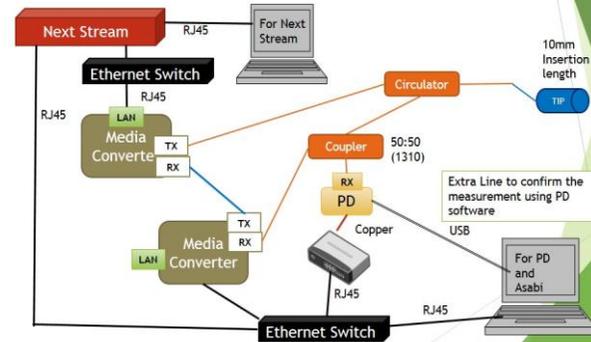


Measurement of Asabi did not change and remained at Peak

7

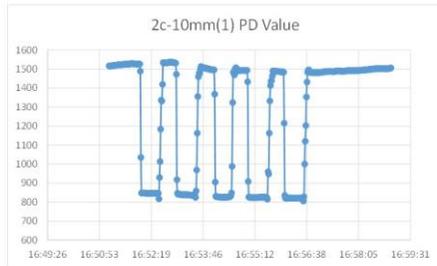
B-10mm(3).xlsx

C LD light source from Media Converter Measure with Asabi/PD/ Next Stream (communications)



8

Result measured using PD software (first round)



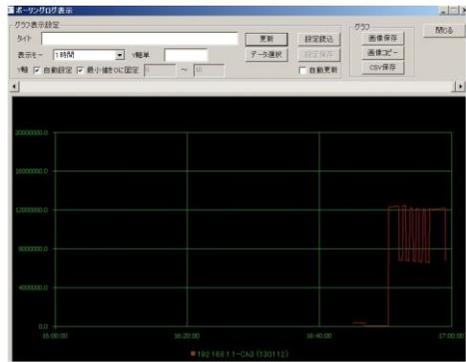
9

Result measured using PD software (first round) Value in dB



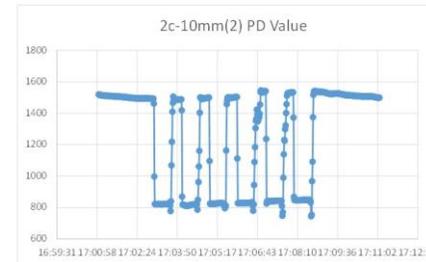
10

Result at Asabi First round



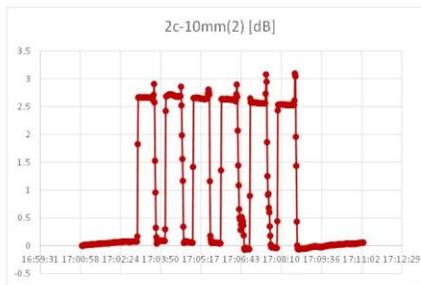
11

Result measured using PD software (Second round)



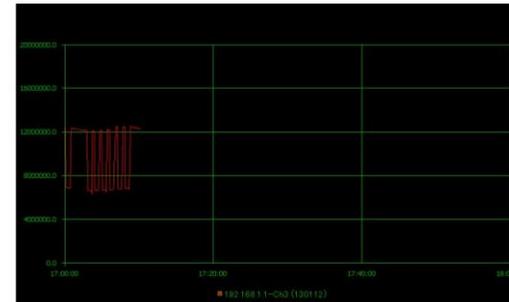
12

Result measured using PD software (second round) Value in dB



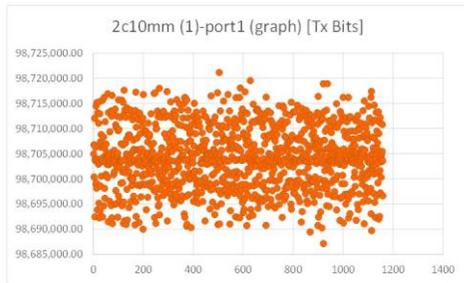
13

Result at Asabi second round



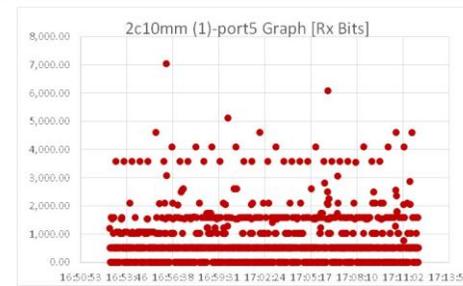
14

Result of Next stream in C test (for 1&2)
(TX port of NextStream)



15

Result of Next stream in C test (for 1&2)
(RX port of NextStream)



16

Summary for Experiment C

- ▶ The sensor is responded when it is immersed into water, and test has been repeated for two times.
- ▶ Both Asabi and PD is giving quite even respond, by looking at the result.
- ▶ **HOWEVER**, Data communications could not be carried on in this experiment.
- ▶ TX port of Next stream is at the average of 98.6Mbps but RX port is below 3000bps and mostly is at 0 meaning - link down. (slide 15 and slide 16)
- ▶ Next, the output from coupler (50:50) is measured using the OPM and the dB result is -52.58 on air and -55.22 in water.
This show that communication is not possible in such condition as the communications link will down when the dB value is over -24.** dB based on previous research.

17

(ii) Test to verify the feasibility of TIP-type HC-SPR sensor

Summary of the test result

Test Result based on Configuration C but measured using the OPM (handy)

Using 10mm insertion length TIP-type HC-SPR sensor

1. MC-Circulator - 50:50(1310) - diagram refer to slide 18
 - measured the coupler output with OPM - -33.56
 - no link down
 - PD software can measure some changes when sensor immersed into water, but not Asabi.

2. MC-50:50(1310) - 90:10(850)- diagram refer to slide 19
 - measured the coupler 90:10(850) output with OPM - -24.03
 - no link down but
 - sensor measurement could not be taken when sensor immersed into water

3. MC-50:50(1310) - 50:50(850)- diagram refer to slide 19
 - measured the coupler 50:50(850) output with OPM - -25.15
 - no link down but
 - sensor measurement could not be taken when sensor immersed into water

Test Result based on Configuration C ,

- Step 1 - measure using the PD and Asabi (SNMP Agent)
- Step 2 - then measure using the OPM (handy)

Using 10mm insertion length TIP-type HC-SPR sensor

4. MC-50:50(1310) - 50:50(850) - diagram refer to slide 20
 - measured the coupler 50:50(850) output with OPM - -27.03(air) -29.70(water)
 - no link down but
 - when sensor immersed into water PD and Asabi- NO reaction

5. MC-50:50(1310) - 90:10(850)- diagram refer to slide 21
 - measured the coupler 50:50 output with OPM - -25.67(air) -27.66(water)
 - no link down but
 - when sensor immersed into water PD and Asabi- NO reaction

Using 5mm insertion length TIP-type HC-SPR sensor

6. MC-50:50(1310) - 50:50(850)- diagram refer to slide 22

- measured the coupler 50:50(850) output with OPM - -27.87(air) -29.44(water)
- no link down but
- when sensor immersed into water PD and Asabi- NO reaction

7. MC-50:50(1310) - 90:10(850)- diagram refer to slide 23

- measured the coupler 50:50 output with OPM - -26.47(air) -27.49(water)
- no link down but
- when sensor immersed into water PD and Asabi- NO reaction

Test Result based on Configuration C, however Attenuator is inserted into the system

- Step 1 - measure using the PD and Asabi (SNMP Agent)
- Step 2 - then measure using the OPM (handy)

Using 10mm insertion length TIP-type HC-SPR sensor

8. MC-50:50(1310) - 90:10(850) -Attenuator(6dB)- diagram refer to slide 24

- no link down
- when sensor immersed into water PD and Asabi- has respond - graph quite stable

Using 2mm insertion length TIP-type HC-SPR sensor

9. MC-50:50(1310) - 90:10(850) -Attenuator(6dB)- diagram refer to slide 25

- no link down
- when sensor immersed into water PD and Asabi- has respond - graph quite stable

Two points of TIP-type HC-SPR sensor, using

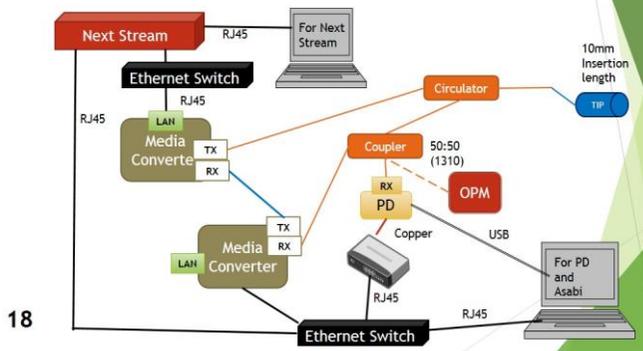
10. MC-50:50(1310) -50:50(1310)- 50:50(850) -Attenuator(6dB)- diagram refer to slide 26

(i) sensors with insertion length 2mm and 10mm

(ii) all 50:50 coupler (3 couplers)

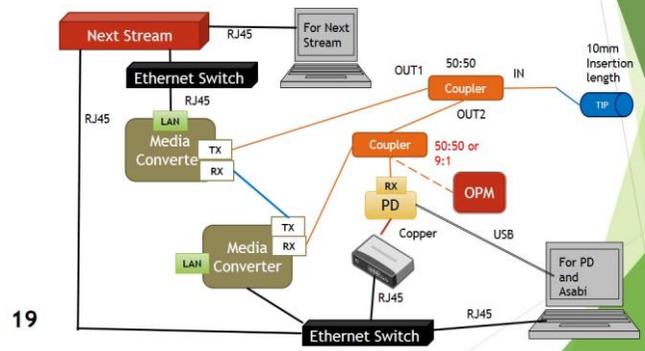
- link down as measured by NextStream
- measured the coupler 50:50(1310) output with OPM - -29.7(air)
- multiple-points could not be achieved, need further investigation

Test 1 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



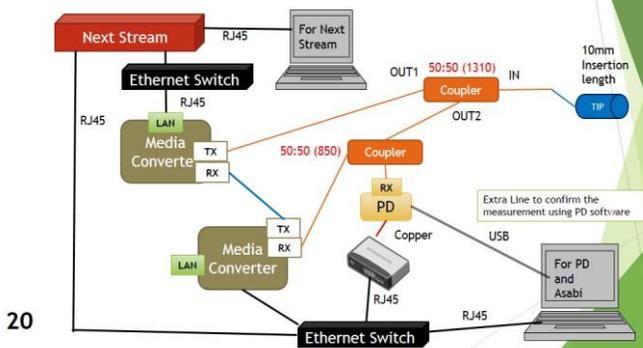
18

Test 2 & 3 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



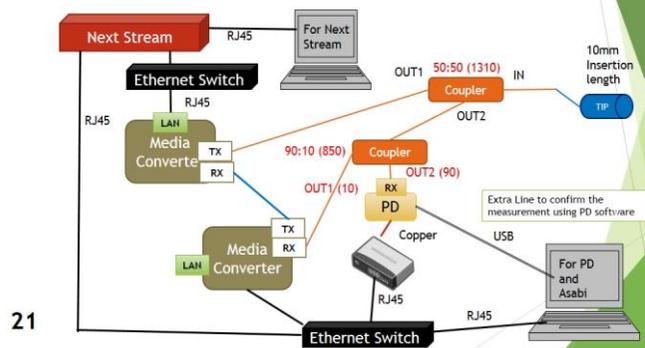
19

Test 4 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



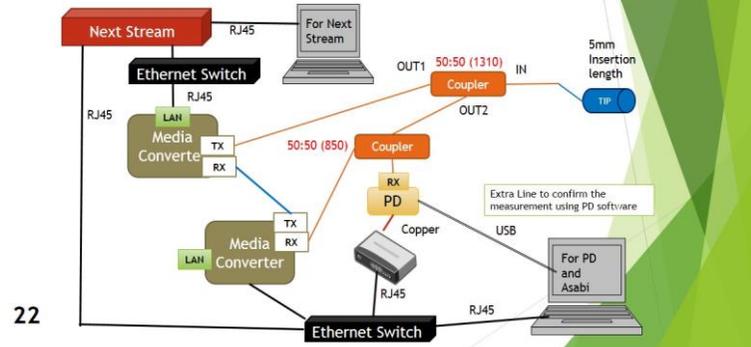
20

Test 5 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



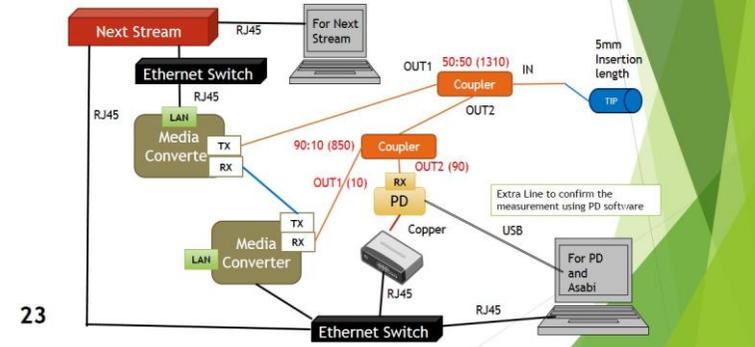
21

Test 6 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



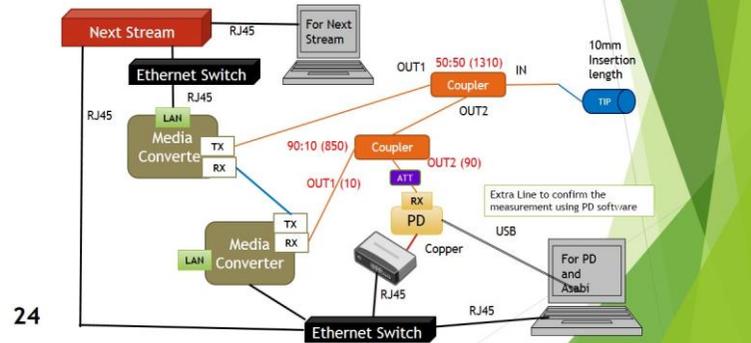
22

Test 7 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



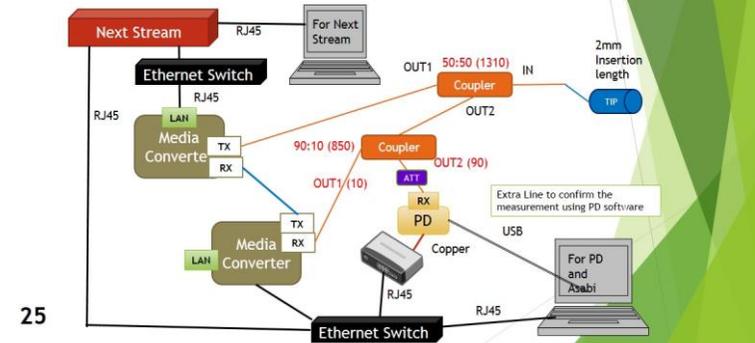
23

Test 8 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



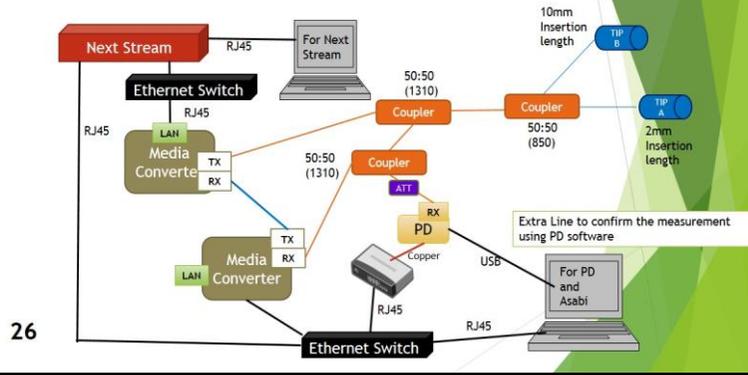
24

Test 9 LD light source from Media Converter
Measure with Asabi/PD/OPM / Next Stream (communications)



25

Test 10 LD light source from Media Converter
Measure with OPM / Next Stream (communications)



26

Appendix E

Verification Test of HC-SPR Sensor using different Light Source and Configuration

This section summarized the verification test of the HC-SPR Sensor by using different light source and system configuration. Before construct the system with the integration of sensing and data communications, some verification test need to be conducted.

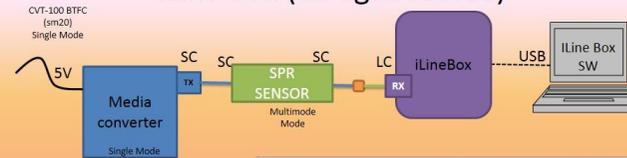
The purpose of the test is to find out the integration of the devices and their feasibility to obtain a stable sensing data. These verification tests is very important because the result able to show us which devices work best with sensor to provide a stable sensing result.

These result could be used to identify the appropriate devices that use in the system integration for our study,

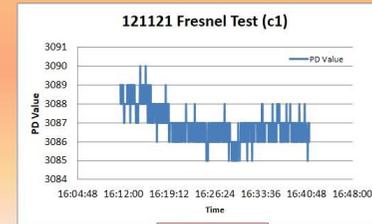
Summary of 2012 Experiments					
	Light source	Sensor	Coupler	Duration	comment
c1-SPR Sensor	LD	⊙		30mins	Data from the test is between 3085~3090
c2-SPR Sensor	LED	⊙		30mins	Data from the test is between 3085~3089
d1-Coupler	LD		99/1	40mins	Data from the test is between 2568~ 2579
d2-Coupler	LED		99/1	30mins	Data from the test is between 2568~ 2579
j1-SPR+Coupler	LD	⊙	99/1	30mins	Data from the test is between 3055~ 1749
j2-SPR+Coupler	LED	⊙	99/1	30mins	Data from the test is between 150~ 152
L-SPR+Coupler (matching oil)	LD	⊙	99/1	30mins	(I)Data from the test is between 2537~3192 (Differ 600) (Data from file 121121) (II)Data from the test is between 1517~1950 Differ 453 (Data from file 121121 – experiment on 22nd) (III)Data from the test is between 1081~1899 Differ 818 (Data from file 121121 – experiment on 22nd)
I-Circulator-SPR-Coupler	LD	⊙	99/1	30mins	Data from the test is between 815~2021, Data is not stable
II-SPR-Coupler 99% (OPM) 1%(iLineBox)	LD	⊙	99/1	10mins	Data from Power meter (1% output of coupler) is between 3212~ 4095 Data from the OPM (99% output of coupler) is between -9.95 ~ -9.97
III-SPR-Coupler 99% -ILineBox	LD	⊙	99/1	8hours	Data for about 8hours * Data from the test is between 3013~3019 Data is consider stable
IV-SPR-Coupler 50-50	LD	⊙	50-50	10mins	Data from Power meter is between 3162~ 3165 Data from the OPM is between -14.61 ~ -14.73 Both data is consider stable based on the result
II-SPR-500MMF-Coupler 99% (OPM) 1%(iLineBox)	LD	⊙	99/1	30mins	Data for about 30mins : Data is between 3500 ~ 1500, Data is not stable
III-SPR-500MMF-Coupler 99% -ILineBox	LD	⊙	99/1	30mins	Data for about 30mins : Data is between 3088~3084
V-SPR-Coupler 99% iLine-1%OPM	LD	⊙	99/1	30mins	Data from OPM - -52.80~-51.85 (dBm) Data from power meter – 3199~3204

Summary of experiment carried on November 2012

(c1) To check **SPR Sensor** stability with iLine box (LD light source)



- Data from the test is between 3085~3090

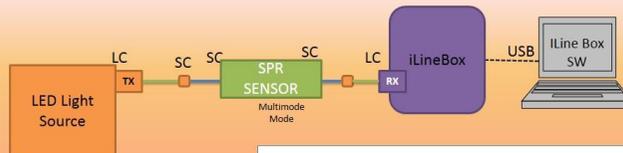


1

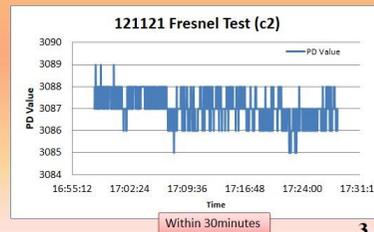
Data from file 121121

2

(c2) To check **SPR Sensor** stability with iLine box (LED light source)



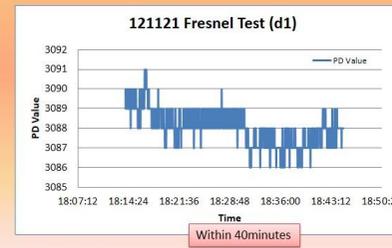
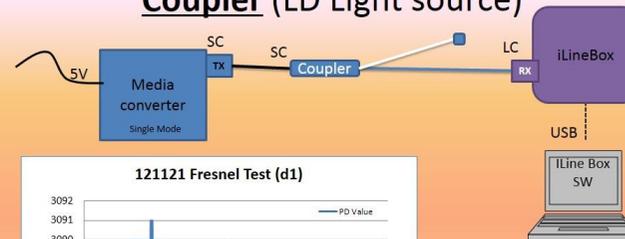
- Data from the test is between 3085~3089



3

Data from file 121121

(d1) To check iLine box stability with **Coupler** (LD Light source)

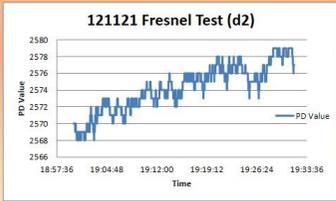
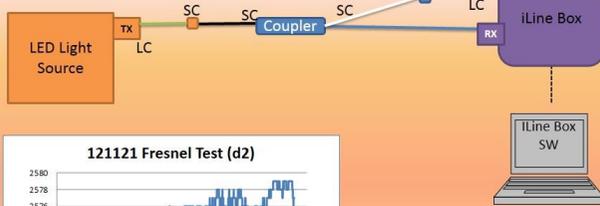


- Data from the test is between 3086~3091

4

Data from file 121121

(d2) To check iLine box stability with **Coupler** (LED Light source)

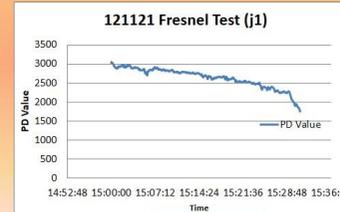
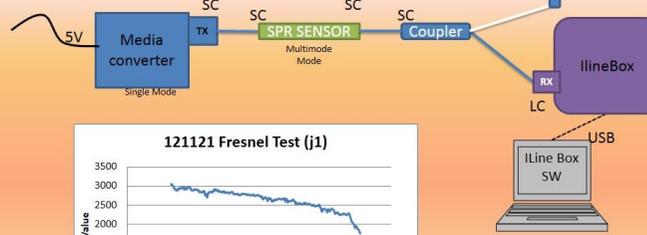


- Data from the test is between 2568~ 2579

Data from file 121121

5

(j1) To check iLine box stability with **SPR Sensor and Coupler** via LD Light source

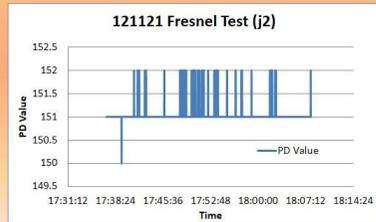
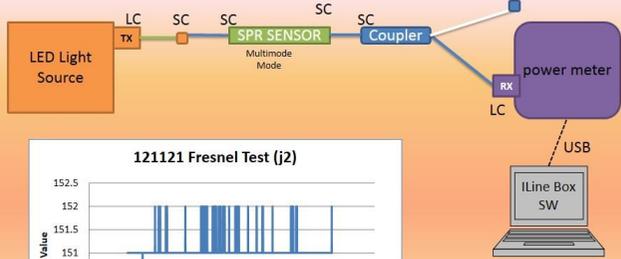


- Data from the test is between 3055~ 1749

Data from file 121121

6

(j2) To check iLine box stability with **SPR Sensor and Coupler** via LED Light source

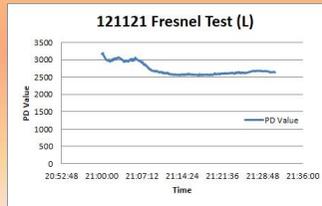
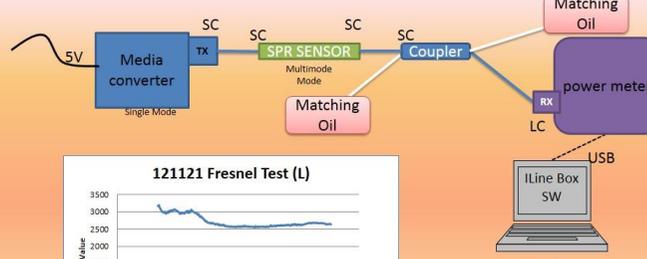


- Data from the test is between 150~ 152

Data from file 121121

7

(L) To check iLine box stability with **SPR Sensor and Coupler** (by immersed two end to matching oil)

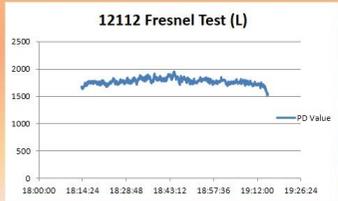
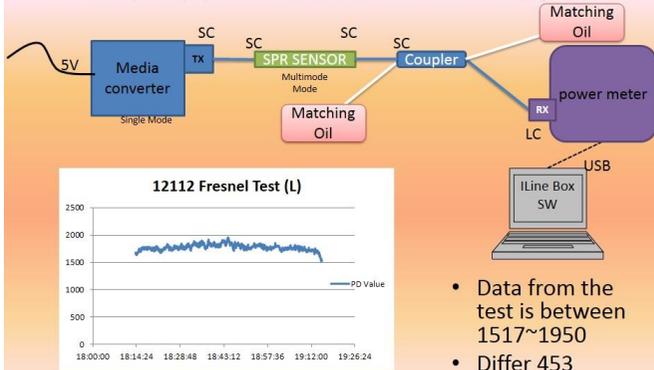


- Data from the test is between 2537~3192
- (Differ 600)

Data from file 121121

8

(L) To check iLine box stability with SPR Sensor and Coupler (by immersed two end to matching oil)



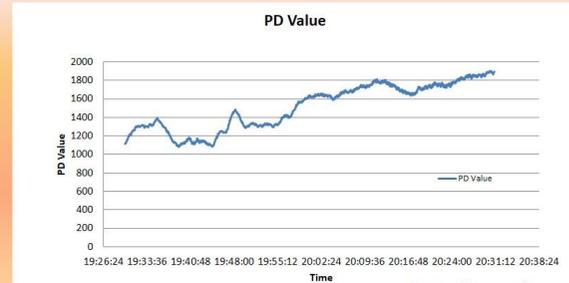
- Data from the test is between 1517~1950
- Differ 453

Data from file 121121 - experiment on 22nd

9

Experiment (L) No 2

(This experiment is repeated for second time)



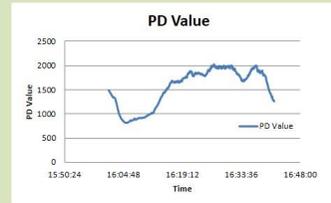
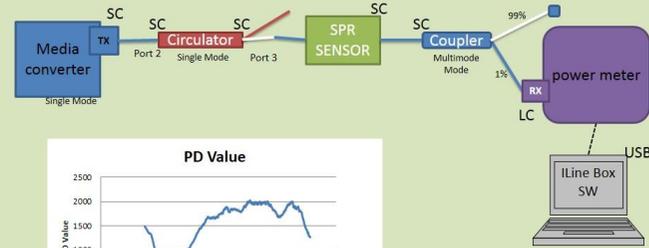
- Data from the test is between 1081~1089
- 818 differ

10

Experiment on 24th, 25th Nov

To test the data output by coupler in a few different test

(I) To check data stability with circulator, SPR Sensor and Coupler (LD Light source)



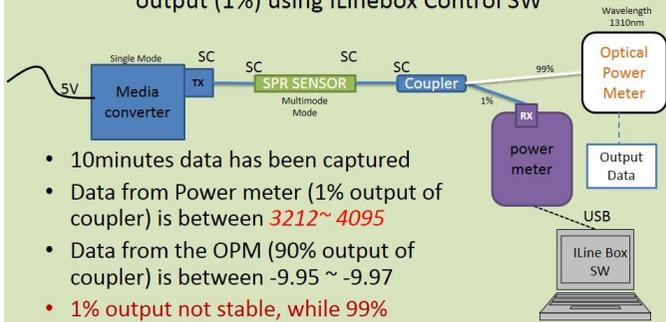
- 30minutes test
- Data from the test is between 815~2021
- Data is not stable

12

11

Data from file 121124 - experiment on 24th, 25th Nov

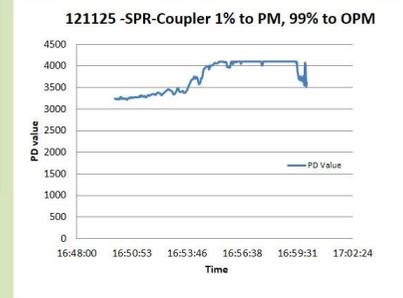
(II) To check coupler's data stability with SPR Sensor, coupler (with LD Light source) by measuring coupler data line output (99%) using OPM and sensing line output (1%) using ILinebox Control SW



- 10minutes data has been captured
- Data from Power meter (1% output of coupler) is between **3212~4095**
- Data from the OPM (90% output of coupler) is between -9.95 ~ -9.97
- **1% output not stable, while 99% output is stable**

Time	Power (dBm)
1650	-9.96
1651	-9.95
1652	-9.95
1653	-9.95
1654	-9.95
1655	-9.96
1656	-9.97
1657	-9.97
1658	-9.97
1659	-9.97
1660	-9.96

Result for -SPR-Coupler 1% to PM, 99% to OPM



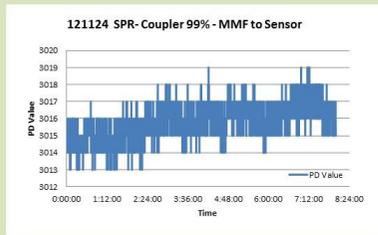
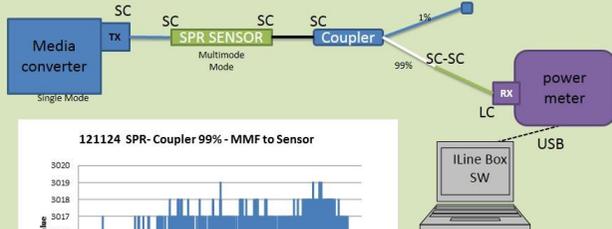
Data from file 121124 – experiment on 24th,25th Nov

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Data from file 121124 – experiment on 24th,25th Nov

14

(III) To check coupler data-line output (99%) stability with SPR Sensor and coupler by connect coupler data line (99%) to Power meter (with LD Light source)

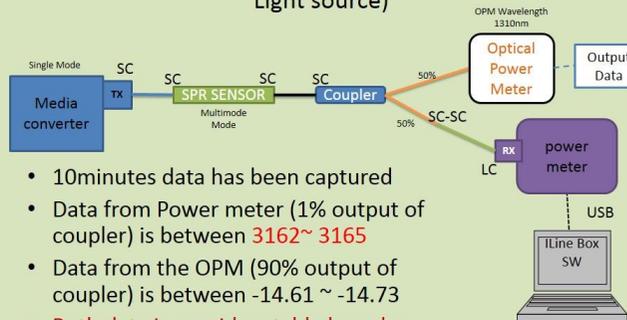


- Data for about 8hours
- Data from the test is between **3013~3019**
- **Data is consider stable**

Data from file 121124 – experiment on 24th,25th Nov

15

(IV) To check coupler (using 50%-50% multimode coupler) stability with SPR Sensor and Coupler (with LD Light source)



- 10minutes data has been captured
- Data from Power meter (1% output of coupler) is between **3162~3165**
- Data from the OPM (90% output of coupler) is between -14.61 ~ -14.73
- **Both data is consider stable based on the result**

Data from file 121124 – experiment on 24th,25th Nov

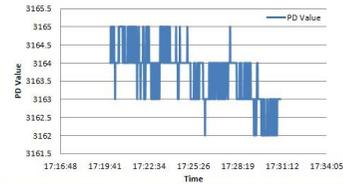
16

Result for 121125 with SPR-Coupler 50%-MMF to PW, 50% to OPM

Data captured using OPM

Time	Power (dBm)
1720	-14.61
1721	-14.61
1722	-14.62
1723	-14.62
1724	-14.62
1725	-14.63
1726	-14.63
1727	-14.66
1728	-14.69
1729	-14.71
1730	-14.73

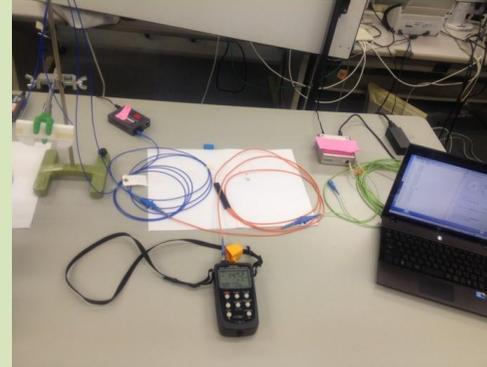
121125 with SPR-Coupler 50%-MMF to PW, 50% to OPM



Data from file 121124 – experiment on 24th,25th Nov

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Experiment view (SPR -> coupler50%-50% output)



Data from file 121124 – experiment on 24th,25th Nov

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Conclusion • discussion

- Problem with Coupler as it is at the coupling ratio of 98.4% to 1.6% (for operating wavelength of 1310)
- The coupler Fiber type is 62.5/125mm, this could also have effect for the measurement output
 - Current system use fiber type 50/125
- Summary by Nishiyama-san – coupler ratio for the sensing is only 1.6% thus, the signal is very weak and noise level is high and creating unstable data , it is called the Signal-to-noise ratio (often abbreviated SNR or S/N) scenario.
- To verify that coupler ratio effect the output data, a test has been conducted- test (IV) - using the multi-mode coupler of ratio 50/50 fiber type 50/125MM, the test show that both output data (measure using OPM or Ilinebox control software) is considerable stable.

Data from file 121124 – experiment on 24th,25th Nov

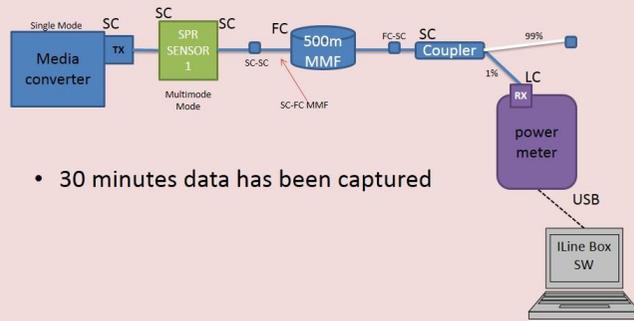
19

Experiment on 26th

Repeated test (II) and (III) by inserting 500meter roll fiber in between SPR Sensor and coupler

20

(II) To check coupler's data stability with SPR Sensor, coupler (with LD Light source) by inserting 500meter roll fiber in between sensor and coupler (sensing line output (1%) is measured using ILinebox Control SW)

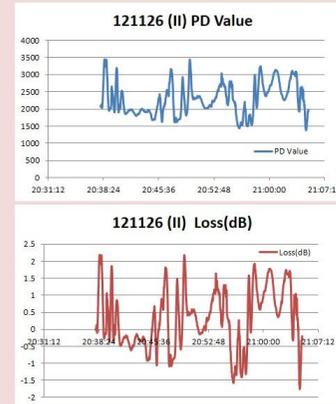


- 30 minutes data has been captured

Data from file 121126 – experiment on 26th Nov

21

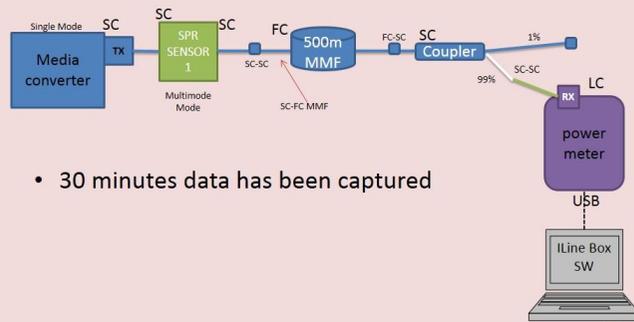
Result for experiment (II)



Data from file 121126 – experiment on 26th Nov

22

(III) To check coupler data-line output (99%) stability with SPR Sensor and coupler by connect coupler data line (99%) to Power meter (with LD Light source)



- 30 minutes data has been captured

Data from file 121126 – experiment on 26th Nov

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Result for experiment (V)



Data from file 121126 – experiment on 26th Nov

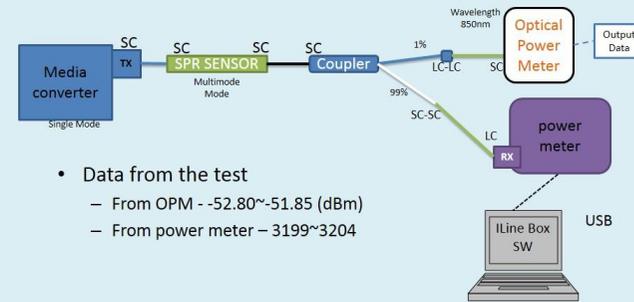
24

Experiment on 27th

Run a new test (V) to measure the output of coupler (1%) using OPM and (99%) using iLineBox Control SW
Same as test (III)

25

(V) To check coupler output stability with SPR Sensor and coupler by connect coupler data line (99%) to Power meter and (1%) OPM to (with LD Light source)

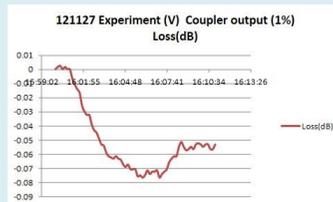
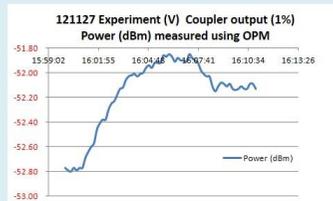


- Data from the test
 - From OPM - -52.80~-51.85 (dBm)
 - From power meter - 3199~3204

26

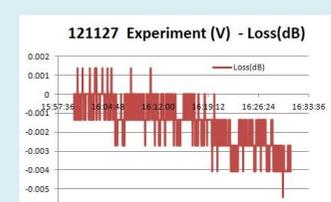
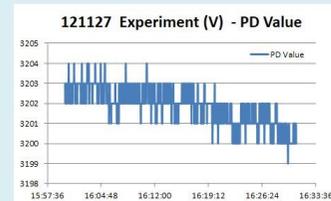
Data from file 121127 - experiment on 27th Nov

Data for 1% output measured using OPM



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Data for 99% output measured using iLineBox Control software



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Appendix F

Research Activities

<Journal Paper Publication>

1. Lee See GOH, Norikazu KUMEGAWA, Kazuhiro WATANABE, Norihiko SHINOMIYA
Hetero-core Spliced Optical Fiber SPR Sensor System for Soil Gravity Water Monitoring in Agricultural Environments
An International Journal of Computers and Electronics in Agriculture, ELSEVIER, Volume 101, February 2014, Pages 110-117, ISSN 0168-1699, DOI:10.1016/j.compag.2013.12.008, 2014.
2. Lee See GOH, Yuji ANODA, Kazuhiro WATANABE, Norihiko SHINOMIYA
Remote Management for Multipoint Sensing System using Hetero-core Spliced Optical Fiber Sensor
Sensors 2014, 14(1), Pages 468-477; doi:10.3390/s140100468.

<International Conference>

1. Lee See GOH, Koichi ONODERA, Mitsuhsa KANETSUNA, Kazuhiro WATANABE, Norihiko SHINOMIYA
Constructing an Optical Fiber Sensor Network for Natural Environment Remote Monitoring
Communications (APCC), 2011 17th Asia-Pacific Conference on, vol., no., pp.208-212, 2-5 Oct. 2011.
2. Lee See GOH, Takaaki ICHIMIYA, Kazuhiro WATANABE, Norihiko SHINOMIYA
A Hetero-Core Spliced Optical Fiber Sensor Network for Remote Monitoring of Agricultural Environment.
The 26th IEEE International Conference on Advanced Information Networking and Applications (AINA-2012), Proc. pp.418-422, Fukuoka, Japan, Mar.2012.

3. Lee See GOH, Kazuhiro WATANABE, Norihiko SHINOMIYA
A Hetero-Core Spliced Fiber Optic SPR Sensor Network for Extensive-area Natural Environment Monitoring
The 22nd International Conference on Optical Fiber Sensors, Proc. SPIE 8421,
OFS2012 22nd International Conference on Optical Fiber Sensors, 8421AR
(October 4, 2012)

4. Lee See GOH, Kazuhiro WATANABE, Norihiko SHINOMIYA
Feasibility Evaluation of Multi-point Sensing for Hetero-core Spliced Optical Fiber Sensor Using the Internet standard-standard Protocol
The 7th International Conference on Sensing Technology, To be published (Dec 3 to 5,2013)

<Award, Grants and Scholarship in various Academic Activities>

1. April 2011 to March 2012 - Makiguchi International Scholarship (Makiguchi Memorial Education Fund)

2. April 2012 to March 2013 - NEC C&C Foundation Grants for Non-Japanese Researchers

3. April 2013 - Soka University Da-Vinci Award

4. April 2013 to March 2014 - Makiguchi International Scholarship (Makiguchi Memorial Education Fund)

5. October 2013 - NEC C&C Foundation Grants for Researchers Attending International Conferences