Hybrid, Hexagonal & Energy Efficient (H2E2) WSN Platform for Precision Agriculture-Mapping with Standards and e-Governance

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***Abstract* — World is at challenge to double agricultural production in coming 40 years. To enhance productivity of farms there is need to follow mantra by Food and Agricultural Organization of the United Nations (FAO) i.e. "Save & Grow". Save and Grow directs towards Precision Agriculture (PA) for sustainable crop production intensification which can be well achieved with the help of Information and Communication Technology (ICT). There are challenges to establish ICT fields and remote areas. Proposed system is novel platform to establish wireless sensor network (WSN) to execute PA overcoming the challenge to set up wireless sensor and energy efficient network at farms. Hybrid network of free space optics (FSO) and radio frequency (RF) connectivity and use of solar at farms and base station/ control station makes it energy efficient. License free, high bandwidth FSO technology enables multimedia data exchange thus opening gate for many applications. Novel Hybrid Hexagonal Positioning (HHP) for sensor nodes has achieved energy efficiency and increased lifetime network. Requirement of hybrid network standardization is mentioned. Overall energy efficient, centralized, environment friendly system allows cost effective solution to farmers. E-governance and Village Level Entrepreneur can play big role in achieving socio-economic development through this system**

***Keywords* — Wireless Sensor Network, Free Space Optics, Precision Agriculture, Hybrid Network, Village Level Entrepreneur.**

I. Introduction

Food and Agricultural Organizations of the United Nations (FAO) recently gave the mantra 'Save and Grow' which directs to achieve sustainable crop production intensification. Precision Agriculture (PA) is best technique to achieve it. ICT plays crucial role in PA and this will enhance productivity, conserve resources, reduce negative impacts on environment and improve socio economic condition of farmers [1]. WSN catalyze the agricultural productivity with the help of sensors. Sensors record the data on field and reports to control station with the help of connecting network. Electricity or energy is the major barrier for sensor and network lifetime. Energy consumption is the major consideration in designing WSN due to limited and irreplaceable power source for an individual sensor node [2]. Node's power source dictates the lifetime of network. Currently most of the WSN use RF channel for connectivity which consumes the maximum energy of the individual node [3].

Challenge is to overcome the energy demands at sensor node and communication transmission. Unavailability of electricity at base station, control station may lead to failure of system thus WSN and PA practices in developing countries. To overcome the challenges and taking advantage of open space and ample light at farm fields this study proposes use of FSO-RF hybrid connectivity with novel sensor nodes positioning system and solar energy harvesting supported by technology from [4] for control station and base station. FSO uses reflectors to avoid retransmission energy requirement [5]. Printable solar cells can be used for RF nodes mentioned in the system from [6] which are DSSC modules with highest power density energy conservation. Further to cover maximum area with minimum sensors and energy novel positioning system called Hybrid Hexagonal Positioning (HHP) is proposed. Following village centric or big farm centric model is presented to show applicability of the proposed system.

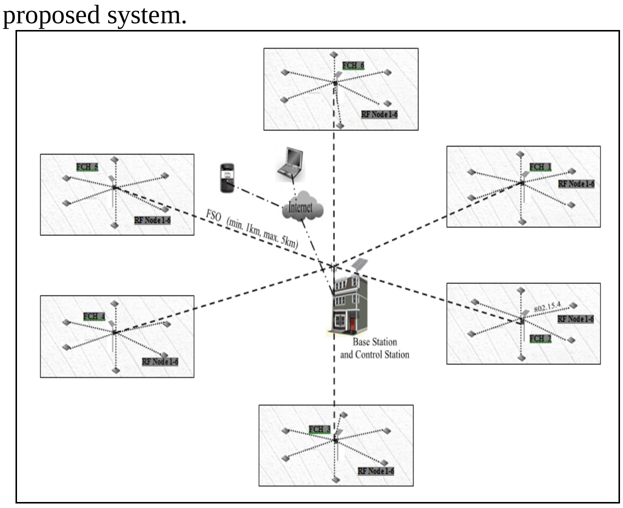

Fig.1. HHP Architecture Model for a village

HHP Architecture shown in figure uses hexagonal shape similar to cellular cell with the logic of covering maximum area. FCH1 to FCH6 (FSO cluster heads) are cluster heads with FSO links and retro-reflectometers to reflect the laser beam back to receiver at direction of incidence, RF1 to RF6 nodes in each of six farms are connected with 802.15.4 ZigBee connectivity to the related cluster head. RF nodes are supported can be given solar cell support for energy [6]. FCHs can be given solar support as per [4]. At centre base station/control station for a village is shown. All the data is sent to base station from sensor nodes as per defined flow. Base station is connected with FSO link with line of sight (LoS) on FCH in field. Base stations are also solar powered as major source. Control Station for a village maintains network and provide services of sensor deployment, network connectivity and user end services for software application, mobile application, revenue generation etc. which will enable centralized farm monitoring, data analysis, regulations, and precision agriculture practices to implement. With the help of internet connectivity users can manage their farms from internet. RF communication is kept for shorter distance communication and FSO for longer distance communication.

Section II describes FSO-RF Hybrid link and benefits, section III is Hybrid Hexagonal Positioning (HHP) for agricultural fields, section IV presents simulation and results of proposed system , section V maps the model with National e-Governance plan of India (NeGP) and opprtunity for Village Level Enterprenure (VLE) to facilitate the service and section VI shows the standardization requirement for hybrid network technologies and section VII concludes the paper with application, delivery model, challenges and future scope of project.

II. FSO-RF Hybrid Link and Benefits

A. *Free space optics for H2E2*

Free space optics has outstanding advantages compared to to point-to-point radio systems in terms of higher bandwidth, license free spectrum, better security and no electromagnetic pollution [7]. It has challenges of rain, snow, fog and direct sun beam. These challenges are not permanent thus data acquisition per day or some hours is not the issue. Base station is connected by FSO link to cluster heads. Beam is targeted from elevated base station. The power requirements will be fulfilled by solar as major source. The laser beam is reflected back by node to base station after modulation at sensor node in field. Each node on field is equipped with modulating retroreflectometer (MRR) [8]. The MRR has an optical retroreflectometer- a passive device which reflects the beam incident on it back to the direction of incidence targeted to receiver [9]. MRR uses On Off Keying (OOK) which is again energy efficient modulation technique. For the modulation device C being capacitance and V being voltage, energy required for switching voltage. Energy required for modulation is related to CV2. Atmospheric Turbulence becomes issue for FSO link with laser beam for than 1km range. For villages this is sufficient range with availability of LoS. Equipment with following status are available in market which suits to requirement mentioned in table 1.

Table 1: FSO Outdoor Equipment performance

Bit Rate	**Rain Level (Coverage)**		
	Light Rain	**Heavy Rain**	**Monsoon**
1.25 Gbps	2km	1.1km	600m
1.5 to 54 Mbps	5.2km	2.3km	1km
Attenuation /Loss	-3db	-10db	-30db

B. *Radio Frequency link for H2E2*

RF nodes RF 1 to 6 are connected by 802.15.4 ISM 2.4GHz band which is again license free and suits to the coverage requirement of 500 to 800 meters for the proposed model. These nodes are arranged in specific hexagonal positions to cover maximum area in minimum sensors. Optimized distance between sensor nodes and fixed positions i.e. known positions helps to save energy and thus increase life time of sensor nodes.

For RF link the signal power at the receiver Pr(d) is a function of the transmitter and receiver separation distance, *d*, and given as

$$P_r(d) = P_t / P_L(d) \tag{1}$$

where P_L is power loss and P_t is transmitted power. The free space reference distance d_0, is determined from measurements close to the receiver [10]. Assuming average path losses the path loss can be written as [10]:

$$P_L(d) = P_L(do).\left(\frac{d}{d_0}\right)^n \tag{2}$$

The path loss exponent, n, depends upon propagation environment. Free Space Propagation Path Loss, P_{LF} is given as [9]:

$$P_{LF}(d) = \frac{(4\Pi)^2 d^2 L}{GtGr\ \lambda^2} \tag{3}$$

where Gt is transmitter antenna gain, Gr, is the receiver antenna gain, λ is the wavelength and L is the system loss factor. The value $P_L(do)$ in equation 2 can be determined using equation 3. For microcontroller systems, a suitable value of d_0 is 1m [10]. Assuming L, G_t and G_r are 1, Equation 2 can be written as

$$P_L(d) = \left(\frac{4\Pi}{\lambda}\right)^2 .d^n \ , d > d_0 \tag{4}$$

Most of the energy dissipated by sensor node is due to RF transmission and reception [11]. Here RF transmission and reception is made for small distance. Further they are

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connected with FSO link from cluster heads. Even positions of sensors are almost fix which do not consume more energy in routing. Sensor nodes used in agriculture are well tabulated in [12].For reference (1500 m x 1500 m) ZigBee network which suits best and covers 500-800 meters.

Table 2: ZigBee for Proposed Model

	Specifications	
ZigBee	Frequency Band	2.4Ghz
	Range	30m-1.6km
	Data Rate	250Kbps
	Power Consumption and Cost	-3dBm or 0.5mW
	Modulation/Protocol	DSSS,CSMA/CA
	Security	128 bit

C. Introduction to OFC-FSO System

Proposed system can also take the advantage of Optical Fiber Network if provided as backbone network. As OFC network is speedily spreading across country use of it for the proposed system can be considered in future. OFC-FSO model are tried and are used as redundant model in optical network breakdown. [13] has achieved more than 1 Gbps for 120 meters of FSO link.

III. HYBRID HEXAGONAL POSITIONING (HHP) FOR AGRICULTURE FIELD

Random deployment of sensor in the network environment and need for determining sensor location has made the location problem as critical challenge. Importance of organized sensors and use of FSO/RF is tabulated from study of [9] [14][16].

Table 3: Value of Organized Sensor Positioning

Sensor Positioning	Effects on Network	
	Random	**Organized**
Traffic Distribution	Non uniform and leads to blocking and extra energy utilization	Uniform and hence optimized energy utilization
Lifetime	RF only has less lifetime	RF/FSO has 2-3 times higher lifetime
Area Covered	Non uniform area is covered so it's waste of resources	Uniform area is covered and exact information is obtained

Figure 2 presents the grid model for sensor positioning in agricultural fields. Sensor positions are marked in hexagon edges and for the present model cluster heads FCH 1 to 6 are linked with FSO to solar powered base station of figure1. Putting up the geographic two dimensional position of sensors generalized scale up model for multiple and different size of farms can be achieved. Conditions of atmospheric turbulence need to apply depending upon region of implementation. As per figure 2 Position (P) for FSO nodes from 'a' to 'h' expressed as

PNode = {(X1, Y2), (X3,Y1/2), (X5,Y1/2), (X7, Y1/2), (X9,Y2), (X7,3Y3/2), (X5, 3Y3/2), (X3, 3Y3/2)} (5)

The base station position

PBS = (X5, Y2) (6)

Now using trigonometric properties and basic geometry positions of sensor nodes are known. So there will be no need of GPS for position tracking thus part of this energy will not be consumed at sensor nodes. Also distance between each node can be known which also allow planning the link budget for RF nodes.

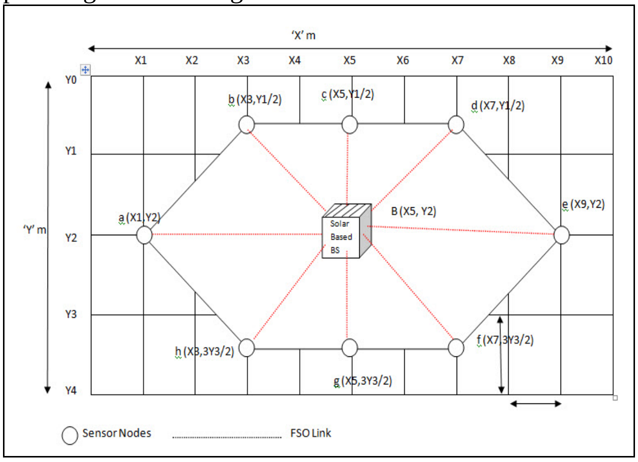

Fig.2. Hexagonal Positioning Grid Model

D. Architecture framework for HHP

To set the grid model to proposed village centric or big farm centric system in figure 1, double hexagonal shield is prepared. First covers for FSO link connecting cluster heads at farm. Second covers individual RF connectivity at each cluster in fields. Thus overall model is replicated with basic grid model

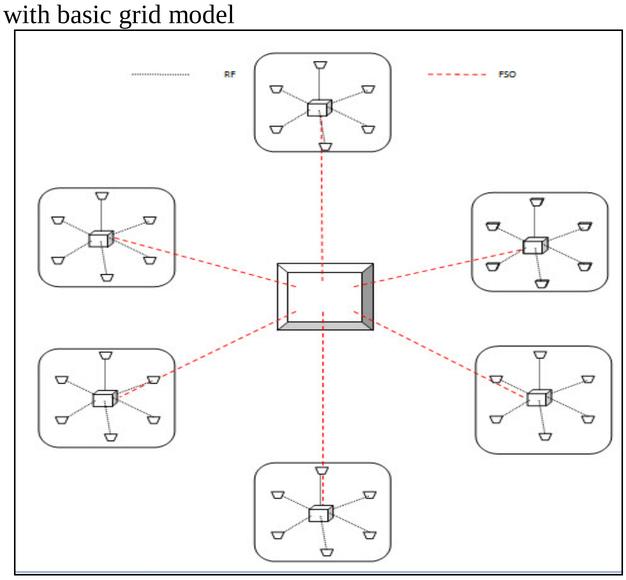

Fig.3. Scale up model to fit in complete framework

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IV. SIMULATION AND RESULTS

Simulations for the proposed system are performed at different levels. First the hexagonal framework is compared with other topologies in wireless network. Separate FSO model is simulated for the range of 500 meters from optical simulator. Hybrid network model as per proposed system is simulated and results are obtained which makes the system reliable. Separate simulations are run with some common parameters set as combining optical and RF simulation was not achievable. Authors will try to cover the combined simulation and results with proper simulator meeting the requirements in future study.

E. Topology Comparison

Simulations are performed with 'Qualnet' comparing Grid, Tree and Proposed HHP topology. Wireless test bed is set. Routing protocol is Bellmen Ford for all. Link bandwidth is 10Mbps with header size of 224 Bytes. [15]

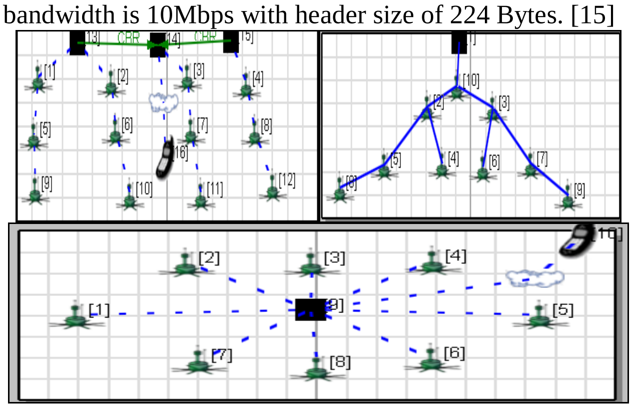

Fig.4. Grid, Tree and Proposed Architecture

The results obtained shows clearly that organized sensor positioning gives better performance. Link Utilization by proposed structure is uniform than Grid and Tree structures. Thus as per the study by [9][14]energy utilization and lifetime proposed architecture will be higher.

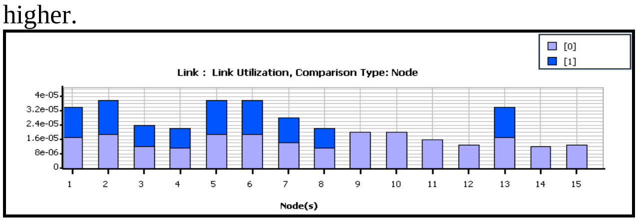

Fig.5. Link Utilization by Grid topology

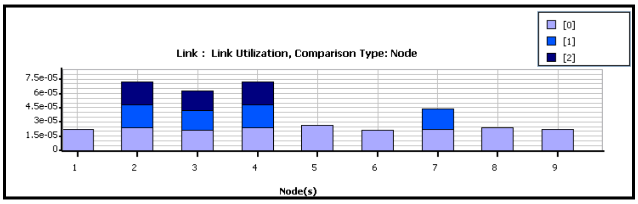

Fig.6. Link Utilization by Tree topology

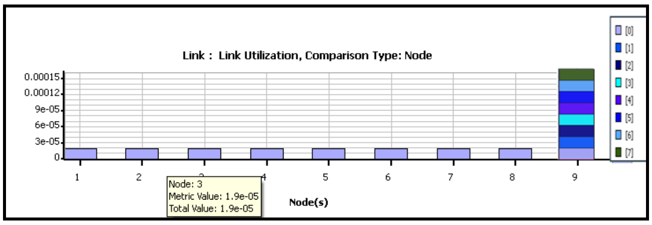

Fig.7. Link utilization for proposed structure

Following observations were made from the results

Table 4: Observation for topology comparison

Parameter	Topology		
	Grid	**Tree**	***P***
Link Utilization/ Traffic Distribution	Non uniform leading to high energy utilization and low lifetime	Non uniform leading to high energy utilization and low lifetime	Uniform and as per studied will utilize low energy and will have 2-3 times more lifetime
Packet Queue	More queue on node in field	More queue on node in field	Que only at substation or base station
Frame Loss	No frame loss	Observed	No Frame Loss

F. FSO Link as Reflected Beam

As mentioned earlier FSO link is targeted by laser beam and the same beam is retroreflected by a passive optical device. No such passive optical device is available to show reflected beam in simulator. This study opens the opportunity for simulators to build a patch for retroreflectometer. FSO communication link is built using optical simulator [17]. It is shown in figure 8.

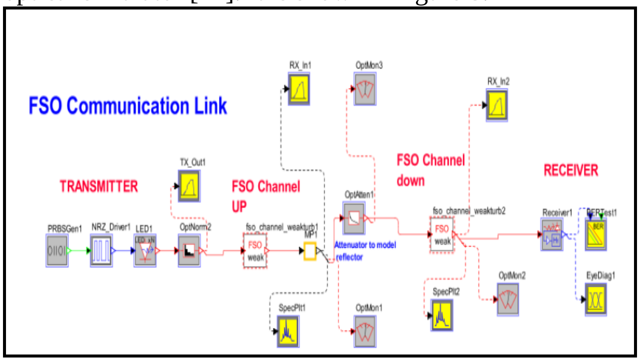

Fig.8. FSO Reflected Link Model

This figure demonstrates a simple FSO link design. Transmitter consists of NRZ-modulated LED a bit rate1.25Gbps, wavelength 1550nm and power 1.3dBm. Receiver is PIN/TIA with an aperture area 180 sq.cm. The link range is 500meters.The beam divergence angle is 3mrad. Additional environmental attenuation of FSO channel in weak turbulence approximation is represented as Gaussian distributed variable with mean value -4.98dB and standard deviation 1.9dB.

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The reflected beam is achieved after transmission and after FSO channel model an attenuator is connected to model reflected light which can be passed through another FSO channel (reflected light towards origin).Link Parameters set for the simulation are mentioned in table V.

Table 5: FSO Link Parameters for simulation

	Link Parameters	
FSO	Wavelentgh	1.55E-6
	Bitrate	1.25E9
	TX_Power	20
	Distance	500m
	Divergence_rad	0.003
	Atten_add	-4.92 dB
	Sigma_add	1.9dB

Thus the expected results are obtained with the simulation. BER at the receiver is at acceptance level. BER obtained at the receiver is acceptable looking at the application targeted and comparing the RF network for the same conditions of FSO.

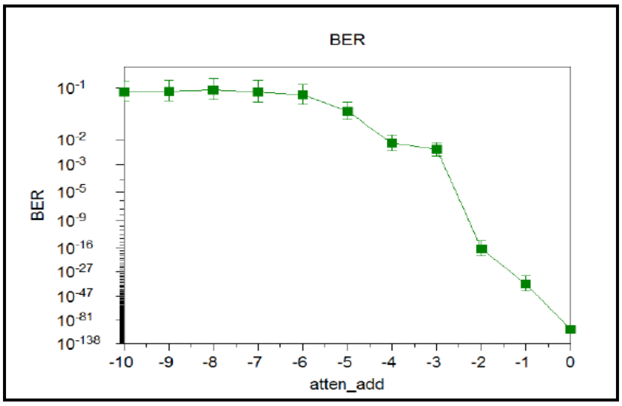

Fig.9. BER at receiver after beam travels twice in FSO channel

G. *Complete System Model Simulation*

Complete system model represents H2E2 platform. The complete system is placed or covers 4000mx6000m area. Qualnet is used for complete simulation. RF sub nodes are given bandwidth of 256Kbps to match with 802.15.4 Routing algorithm is kept common to complete system i.e. Bellman Ford. The FSO link which is achieved by wired link of bandwidth 1.25Gbps, link propagation delay 1ms is presented. Even same link is replaced by wireless link in simulator with bandwidth of 1.25Gbps. For the given distance and application no variations are obtained in results. H2E2 simulation model is shown in figure 10.

Transport layer covers packets through and from application layer, Network layer covers queue length and packet drops, MAC layer shows no. of frames sent and received and link utilization. Some of the results are mentioned here.

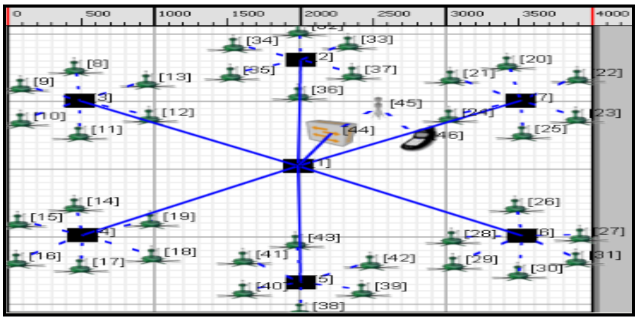

Fig.10. System simulation model to check performance

H. *MAC Layer Result*

At MAC layer number of frames sent and received is obtained. Here Link Utilization is presented as it reflects the energy utilization and lifetime of network. Node 2-6 which are cluster heads are equally utilized even RF sub nodes are equally utilized which reflects uniform distribution of load leading to healthy network.

I. *Network Layer Result*

Network layer defines peak queue length and packet drops observed. Queue length is in well control and uniform and 5 packet drops are observed on switch i.e. node 44 with the scale up network of system model. De-queuing is also observed in results of simulation performed.

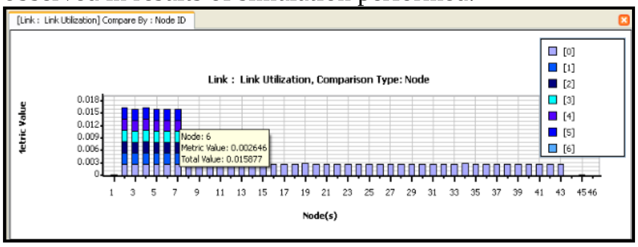

Fig.11. Link utilization for system model

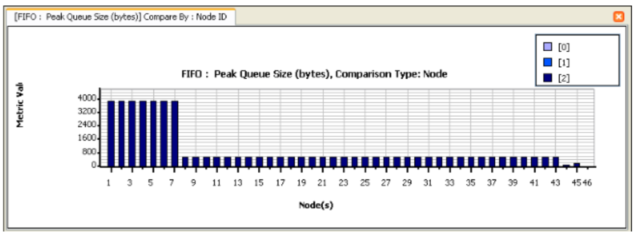

Fig.12. Peak Queue length

V. Mapping with NeGP and Village Level Enterprenure

The Government of India's National e-Governance (NeGP) Plan has a clear vision: to deliver, and make accessible al government, social and private sector services in the areas of agriculture, health, education, entertainment, FMCG products, banking and financial services, utility payments, etc. to the citizens at an affordable cost. With this intent, the Common Services Centers (CSCs) were conceptualized as the front end

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service delivery outlets enabling smooth and transparent governance at the village level. Under the scheme, over 100,000 internet enabled kiosks are being set up in the rural areas spread across more than 600,000 villages. One Kiosk is intended to serve a cluster of five to six villages. Village level entrepreneurs are encouraged to have ownership for the CSCs and more than 80,000 CSC are deployed and functioning. CSC can be mapped with control station of proposed system. And the required infrastructure can be set up for agriculture and environment services. At first the critical regions can be identified and tested for the service with the help of proposed hybrid link and wireless sensor network. With this facility farmers can get the service at home and experts view and local guidance at place. Information localization which is most important part will be covered and VLE will be able to provide services to the farmers.

J. Service at Developing and Developed world

Similar pattern to CSC and VLE can be applied to developing countries. For the developed country where farm size are very big independent set up can be created which will allow precision agriculture practices as per the requirement. Same platform can be used for recording environment data from various sources of pollution by deploying related sensors.

Socio-economic development can be achieved by promoting village level entrepreneur and public private partnership model.

VI. Standardization Requirement

With the help of this study author noticed hybrid networks can be effective solution for many applications. There can be combination of FSO-RF, OFC-FSO, RF-OFC etc for different applications. It may be internal hybrid utilization among standards under RF technology. In future Innovative hybrid network services, such as end-to-end services for scientific applications, hybrid network services for data centers, hybrid services for cloud computing, green hybrid networks, etc. Design of innovative service plane for hybrid network will emerge. Looking at this it is expected to have standards in place for hybrid network separately.

This will also enhance pricing and business analysis of hybrid networks and services. In this study we are considering combinations of three connectivity i.e. Free Space Optics (FSO), Optical Fiber Cable (OFC), Radio Frequency (RF). Wireless RF standards (IEEE 802.xx) and Optical standards (G.709) are defined. For FSO ITU –T G.709 was defined for two co-located FSO systems to avoid interference. The standards for hybrid interfaces will ensure interoperability and QoS. For proposed system the requirement flow of standard is shown in figure.

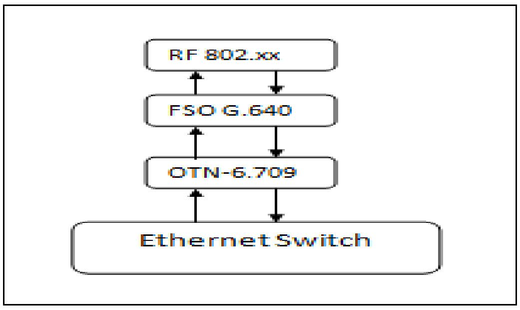

Fig.13. System flow for hybrid system understudy

FSO standard ITU-T G.640 does not full fill the requirements of the hybrid applications. Modifications or new standards are required from FSO end.

The expected OFC-RF/FSO or RF/FSO-OFC System or RF-FSO interface can be as shown.

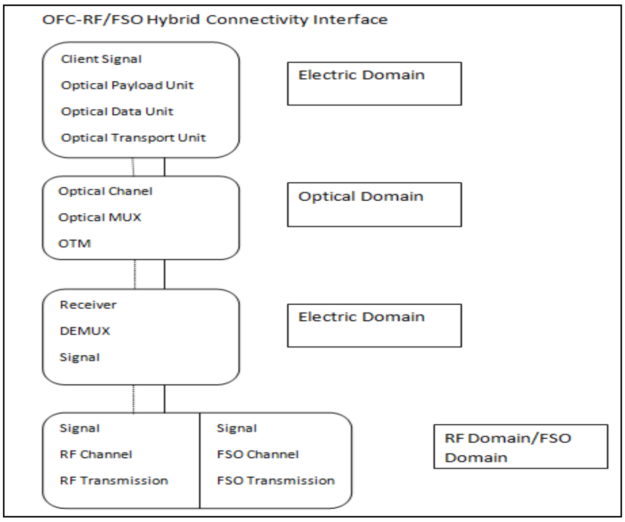

Fig.14. Hybrid Connectivity Flow and Interface

VII. Conclusion

Enabling precision agriculture with the support of WSN, HHP,entrepreneurship model and VLE is complete aim of this study. Technology in hands of people will bring changes and awareness of utilizing it for advanced farming systems. To bring it to real time, study proposed energy efficient and village centric or farm centric green H2E2 WSN platform. Use of long distance FSO link and short distance RF link, HHP, solar harvesting, introduction to OFC-FSO, results obtained for better link utilization and energy management makes this system green and locally fit. There are challenges of LoS, weather, awareness among people and cost of FSO devices.Technically hybrid network simulator, hybrid standards are some challeneges. Awareness for ICT is growing at very fast rate with cellular penetration. National e-Governance plan (NeGP) and establishment of CSCs maps best to deploy the proposed model. Similar patterns can be followed by developing countries to provide services at rural level. For

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big farms at developed countries farm centric model can provide required services. Study has created some opportunities for future work i.e. simulator patch for retroreflectometer, hybrid network simulators, low cost optical reflectors and modulators development, standards for hybrid networks, software application development for system and business model. As this is the platform and available smart systems with the help of data acquisition and processing further many things can be clubbed in near future. Similar model can be replicated for environment monitoring at reuired location. There is urgent need to declare standards for hybrid systems. Overall authors have tried to develop a deliverable green platform of hybrid network and create win- win situation for PA and sustainable communties.

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AUTHOR'S PROFILE

Dr. Milind Pande

Dr. Milind Pande is a dedicated Professional with 21 years of Academic Experience, is currently working as a Project Director, MIT Pune's MIT School of Telecom Management, India. He is highly qualified with Post Doctoral Research Fellowship by Ministry of HRD, Govt. of India on Telecom Technology Transfer, Ph. D. in Business Management (International Trades), Pursuing Ph.D. in E &TC Engineering, ME (Electronics), MBA (Marketing) and MPM. He has Published numerous Research Paper's in various Disciplines. He has extensively travelled abroad for Tie-ups and Collaboration, Faculty and Student Exchange program. He has done extensive research in the development, innovation & rural upliftment in telecommunication industry. Dr. Milind Pande got Awarded Post Doctoral General Fellowship-Funded by ICSSR, Ministry of HRD, Government of India; Research Pertaining to " Telecom Technology Options for Indian Rural Education".

Shantanu Pathak

Mr. Shantanu Pathak is researcher at MIT School of Telecom Management, Pune and working on wireless sensor networks in precision agriculture and health. With Industry experience of 2 years in telecom MNC, he is contributing to research for socially required technologies using ICT.
He has published research papers (IEEE and ACM, Scopus, DBLP) on Wireless Sensor Network in agriculture and energy efficient networks for wireless sensor networks with Dr. Milind Pande for the project of" "ICSSR, Ministry of HRD, Government of India.