Implementation Strategy for Optical Fiber Modbus-TCP Based Nuclear Radiation Detection Instrument for Nuclear Emergency

Shripad Shyam Vaijapurkar [1], S.M. Kate [2]

[1] *Pursuing P.G. Program in VLSI and Embedded systems, Sinhgad Institute of Technology, Lonavala, India*

[2] *Department of Electronics and Communication, Sinhgad Institute of Technology, Lonavala, India*

***Abstract*— Any detection of Nuclear emergency is prone to the EMP generated by the blast. Hence use of conventional wireless & wired sensor networks in such scenarios becomes very difficult. Thus an effective sensor network scheme is needed which effectively senses and communicates in such scenarios over an existing protocol. The proposed system offers such a scheme where Optical fiber based communication is used for immunity against EMP, while MODBUS-TCP protocol is used for faster communication over existing network protocol**

***Keywords*— EMP, Nuclear, MODBUS, Fiber Optic LM3S6965, Ethernet, TCP/IP, uIP**

I. Introduction

Any kind of nuclear detonation poses a serious risk of EMP based electronic failure. The harmful effects of such an EMP become more prominent when the nuclear detonation takes place at high altitudes. A classic example of this is the blast conducted by the Soviet Union in the ariel space of Kazakhstan in the year 1962, which resulted the failure of a 500Km long ariel communication line [1]

The types of EMP generated in such scenario is also called High Altitude EMP (HEMP) and can have different components depending upon the altitude of detonation and the interaction with the geomagnetic field and the electrons in the atmosphere. Thus they may be early-time HEMP (fast), intermediate-time HEMP (medium), and late time HEMP (slow) [1].

Since EMP is primarily a high energy Electromagnetic signal, it always induces high currents into the metallic obstructions it encounters. Thus, any wired sensor network without proper shielding will become useless in such a scenario. The same holds true for the Wireless sensor networks. Shielding may be too expensive incase of the wired sensor network, while in case of the Wireless Sensor Network the data signal itself will become distorted.

One of the most common protocol for Wired Sensors Communication is MODBUS, where data is usually sent over a serial line from the sensors (Slave) to the control unit (Master). To make the existing setup compatible with the TCP/IP, usually a Serial-Ethernet bridge is introduced between the sensor's serial link and the control unit. Bu this approach underutilizes the capacity of TCP/IP as the data speed is influenced by the speed of the serial link at the bridge. Also it adds to the cost of the sensor network and makes it more complicated.

In this paper, a novel idea is suggested where the Sensor Network is realized over a Optical Fiber Channel, thereby eliminating the EMI pickups resulting from the EMP's without adding much to the complexity of the system. The communication network will be realized over the MODBUS-TCP protocol where a developed MODBUS-TCP stack code will be mounted in the sensor thereby eliminating the need of the Serial-Ethernet bridge and thus making the network less complicated and more efficient.

II. Background

One of the major effects produced by atmospheric Nuclear blast is the ionization of the atmospheric air due to the radiation. The intensity of the blast wave coupled with the effects of the earth's geomagnetic forces would result in the production of a massive EMP called HEMP.

The magnitude and coverage of such an EMP is vast and its effects on the electronics is devastating. The generation and coverage of such an EMP with respect to the height of the blast can be explained in detail in Reference no. [2]

Thus detection of a nuclear emergency is rendered impossible by the EMP of the Nuclear blast as conventional Sensor electronics will be damaged by it. Therefore, a wired sensor network for detection of radiation fallout will be much suitable than a wireless one, as better shielding can be achieved by drawing underground cables. But even this method may not always shield it from the EMP effects [3]. Thus the optical fiber based communication becomes the most suitable choice.

The industrial sensor networks are usually realized using serial communication link derived out of RS-485 based channel. The communication protocol usually used is

MODBUS-serial which is a de-facto communication standard for PLC communication. Because of serial channel (RS-232/RS-485), the speed of communication is the limiting factor, which is of prime importance in a nuclear detection scenario. Ethernet is the most ideal choice for such a scene and hence an Optical fiber based sensor network would be the most suitable choice.

III. MODBUS-TCP PROTOCOL IMPLEMENTATION

.MODBUS is a standard Master-Slave based protocol used in industrial automation where one Master will control various slave devices identified by the address configured on them [4]. Due to its simplicity and wide availability of support tools, it is also used for implementation in the industrial wired sensors network. Depending on the type of data transfer, serial MODBUS can be classified into MODBUS-ASCII (for ASCII data) and MODBUS-RTU (for Hex data). For sensor based applications, MODBUS-RTU is a better choice for its small frame size and CRC error correction.

The MODBUS-TCP is further advancement in MODBUS-RTU, with the channel here being a TCP/IP network instead of a serial network. A typical standard frame for a MODBUS-TCP and its stack organization is as shown below:

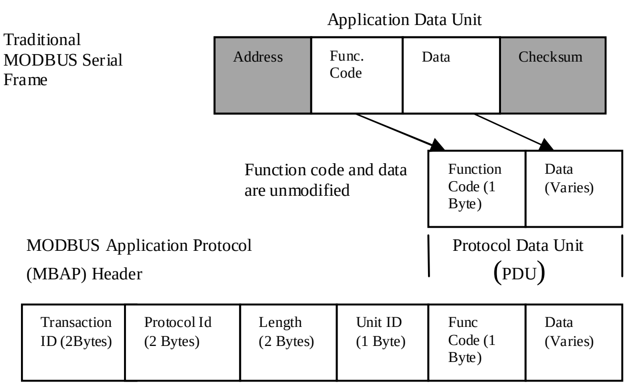

Figure1. MODBUS-TCP data packet[4]

TABLE I
MODBUS-TCP COMMUNICATION STACK ORGANIZATION [5]

MODBUS TCP-IP Communication stack			
#	**Models**	**Imp. Protocols**	**Reference**
7	Application	MODBUS	
6	Presentation		
5	Session		
4	Transport	TCP	
3	Network	IP,ARP,RARP	
2	Data link	Ethernet, CSMA/CD,MAC	IEEE 802.3 Ethernet
1	Physical	Ethernet Physical Layer	

To use MODBUS over TCP/IP, a serial to Ethernet bridge is usually employed, which limits the actual speed of data transfer and leaves the TCP/IP channel underutilized. The conventional MODBUS-TCP stacks available are usually rigidly PLC oriented, thus making it difficult to use them in embedded applications.

The system proposed here uses a MODBUS-TCP stack developed on an open source uIP (micro-ip) embedded TCP/IP stack [6], which is light weight TCP/IP stack and can be easily ported on Microcontrollers having required Ethernet supporting features. There are other TCP/IP stacks available, but uIP was chosen for its open source features [7] and its small memory footprint with respect to the code as well as data. The comparison of common TCP/IP stacks and uIP is as shown below for details:

TABLE II
MEMORY REQUIREMENTS OF VARIOUS AVAILABLE TCP/IP STACKS[7]

Memory Region	Memory Requirement [KB]			
	uIP	eCos	KwikNet	NicheStack
Code	17.2	79.7	69.9	44.9
Data	2.4	5.4	5.4	4.9
Total	19.6	85.1	75.3	49.8

The current stack has been ported on an Ethernet evaluation board having the Texas instruments LM3S6965 Microcontroller (Figure below).

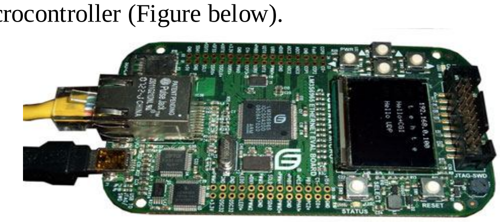

Figure 4: Stellaris TI- EKLM3S6965 Ethernet eval. Board[8]

The chosen controller supports 10/100 Mbps Ethernet and has inbuilt Ethernet PHY+MAC. Hence there is no need to connect an external PHY thereby giving a compact TCP/IP based embedded solution.

The uIP and the peripherals available with the LM3S6965 provides an ideal platform for the MODBUS-TCP implementation. The block diagram for the MODBUS-TCP implementation in the controller is as shown below:

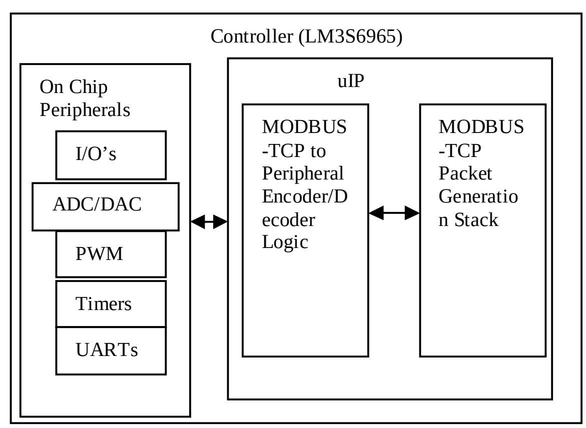

Figure 5: Block Diagram for MODBUS-TCP stack implementation in the LM3S6965 Controller

Here, the uIP's TCP/IP stack will act as a wrapper to the MODBUS-TCP packet. The IP address and the subnet mask for the device can be provided either in the code itself or a provision can be made to provide it over a User interface (keypad) or a Serial Interface (UART). The flow chart of the operation of the stack is as shown below:

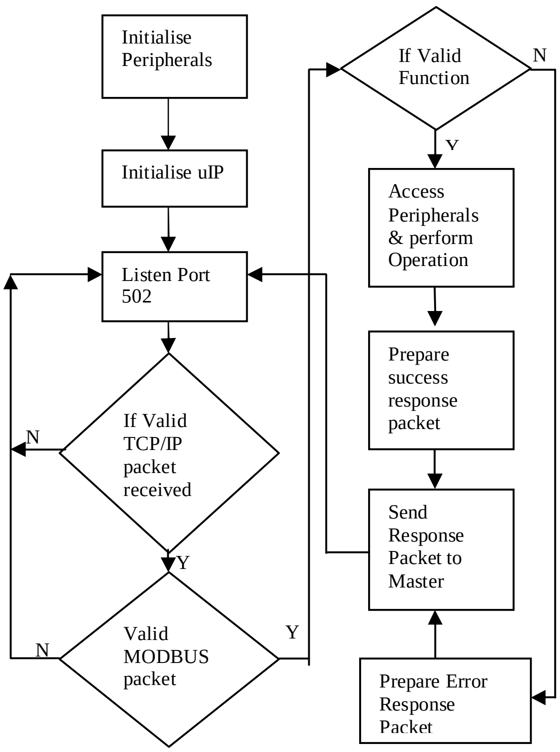

Figure 6: Flow Chart for MODBUS-TCP stack implementation

The user I/O's of the controller can be configured on the various Nuclear detection sensors such as Photo Multiplier Tube, Geiger Mueller tube or other semiconductor based Nuclear detection sensors and associated signal conditioning circuitry. The Ethernet section of the controller is configured for the RX- Interrupt. If a packet has been received, this interrupt will indicate its presence, which is later used by the uIP stack to probe and identify the type of packet received.

Once the valid TCP/IP packet is received, the uIP will call the MODBUS-TCP process functions. These function will locate the useful byte from the entire TCP-IP packet and check for the authenticity of the packet, i.e., if the received TCP/IP packet is a valid MODBUS packet or not.

After the packet is validated, the operation with respect to the function code is performed. This operation may pertain to Read/Write of Single bit values (commonly called coils in regular MODBUS) or Read/Write of 8 bit data (commonly called Register in regular MODBUS). The on-chip and off-chip peripherals connected to the device can be configured as either one of the two value types depending upon the requirement. Fore.g., the GPIO's can be configured as either Read/Write coils or registers, while the Comparator status can be configured as a Read-Only coil. Further details about the protocol organization and the associated data types can be found in reference no. [5].

After the function code is identified, the control is transferred to the peripheral Encoder-Decoder logic. This block will determine the peripherals to be accessed for intended operation. If a read operation is performed, then the data from the particular peripheral will be fetched and a read packed will be created in the MODBUS-TCP stack, which will be later transmitted to the MODBUS-MASTER from which the request had been generated. If a write operation is performed, then the response will be the echoing of the request packet minus the data information written. Further details about the response packets for various queries can be found in reference no. [5].

IV. DISCUSSION

The MODBUS-TCP stack was developed and implemented on the EK-LM3S6965 Ethernet development board. The Read write and read only functionalities of the stack were verified using the standard industrial tool MODPOLL. Also a separate application for verification was developed using VB6 interface and the read/write functionality of the stack was tested and verified on both of them.

The intended wired sensor network thus developed using the presented stack, will have its detection application ported onto the controller itself. The MODBUS-TCP stack will be used for configuring the sensor instrument as slave and allowing the master i.e. a PC based application to send and receive data. Since the instrument is intended to be used for detection of the Nuclear radiation in an Nuclear emergency scenario, the primary requirements for the detection will be:

- Detection of the level of Contamination
- Detection of the dose rate and the total dosage of radiation taken
- Detection of the real time environment conditions i.e., temperature, humidity, wind speed etc.
- A user interface for manual entry of data and showing the current status.

The proposed wired sensor network organization is as shown below:

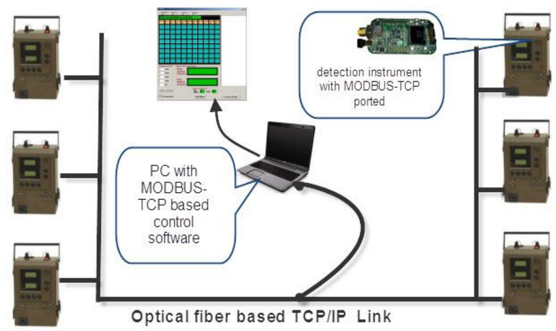

Figure 7: Sensor network organization for Optical fiber based Nuclear detection sensor network using MODBUS-TCP

The Sensor equipment used here can be an array of Nuclear detectors such as Geiger Mueller tubes, which will determine the contamination level in the surrounding in the terms of Counts per second (CPS). For determining not only the contamination level, but the type of contamination level as well, the Photo Multiplier Tube (PMT) will be used along with the associated signal conditioning circuitry interfaced to the MODBUS-TCP Stack loaded controller. Along with these, semiconductor sensors such as MOSFET and PIN diodes can also be used for radiation detection. As MODBUS-TCP supports both single and multiple bit address values, these peripherals and their responses can be tied to these addresses which will be later accessed by the MODBUS-TCP Master.

The sensor network itself will be organized upon a fiber optic link to nullify the effects of the EMP generated during the Nuclear emergency. The detected quantities will be communicated to a remote server through MODBUS-TCP protocol. The remote server will act as a master and will periodically issue commands and capture the response from the slave devices i.e. the instruments. This MODBUS-TCP communication will be carried out by mounting the detection application on the developed MODBUS-TCP stack. This detection application as well as the MODBUS-TCP stack can be ported entirely to the controller or else, the detector section can be connected to the MODBUS-TCP controller through a high speed serial protocol, such as SPI, thereby achieving the high speed data transfer without compromising the speed.

For obtaining the data from the instruments and for sending them the control instructions, the Master will be connected to the network. The Mater will consist of a PC with an MODBUS-The CP based control application installed over the PC.As MODBUS-TCP is a Query-Response based protocol, the query will be initiated by MASTER in the form of a request, while an appropriate response will be generated by the slave with respect to the validity and type of the request.

V. Conclusion and Future Applications

In this paper, a novel application of MODBUS-TCP coupled with Optical fiber communication is proposed for a real time scenario of Nuclear Emergency. The idea is compiled to make the optimum use of both the Optical fiber channel's EMP resistive properties as well as effective high speed sensor data communication using MODBUS-TCP. The conclusion for the above paper can be summarized as below:

- EMP is one of the major factors hampering in rapid detection of Nuclear emergency
- Optical fiber, being naturally resistant to the effects of EMP, is the ideal choice of communication channel in Nuclear Emergency scenario
- MODBUS is widely used communication protocol for wired sensor networks and MODBUS-TCP will be the suitable choice of protocol to use a Optical fiber Ethernet channel for fast, efficient and reliable data transmission in Nuclear emergency scenario.
- The developed MODBUS-TCP stack can be used for designing reliable Wired Nuclear sensor network over a Optical Fiber based TCP-IP network.

The above sensor network scheme has been proposed for a situation specific wired network. With little modifications, the same idea can be utilized in various other sensor network scenarios (Wired as well as Wireless) where rapid detection is the primary concern. Some of the application scenarios are as listed below:

- Wired/ Wireless chemical sensor network for use in Industries or Chemical and Biological attack emergency
- Industrial sensor network and parameter monitoring
- Military applications such as Sensor network for monitoring various important parameters on a Naval ship etc.
- Natural and manmade disaster management which employs both Wired and Wireless sensor networks

References

[1] Vasily N.Greetsai, Andrey H. Kozlovsky, Vadim M. Kuvshinnikov, Vladimir M. Loborev, Yuri V. Parfenov, Oleg A. Tarasov, and Leonid N. Zdoukhov, *Response of Long Lines to Nuclear High-Altitude Electromagnetic Pulse (HEMP)*, IEEE Transactions on Electromagnetic Compatibility, Vol.40, No. 4, November 1998, pp. 348-354

[2] Lieutenant Colonel Thomas C. Riddle, United States Army, *Nuclear High Altitude Electromagnetic Pulse-Implication s for Homeland security and Homeland defences*, pp. 1-7

.[3] Jim Jachetta, Edmund A Williams, *National Association of Broadcasters Engineering Handbook, 10th Edition, Chapter 6.10 –Fiber Optic Transmission Systems*, pp.208-211

[4] ACROMAG Incorporated, Wixom, Minnesota-USA, BUSWORKS 900EN Series, Technical Reference – MODBUS TCP/IP, "*Introduction to MODBUS TCP/IP*",pp. 1-42

[5] Modbus Messaging on TCP/IP Implementation Guide V1.0b, s3.1.3, pp 1-35

[6] Adam Dunkels, Swedish Institute of Computer Science, *The uIP Embedded TCP/IP Stack, The uIP 1.0 Reference Manual, June 2006*. Pp 1-23

[7] Pedro Sampaio, Tiago Dias, Centro de Cálculo do ISEL, Lisbon, Portugal, *TCP/IP stack optimized for standalone applications running on ARM7 processors*. pp 1-6

[8] Description for TI's Stellaris series LM3S6965 Ethernet Evaluation Board. (http://www.ti.com/tool/ek-lm3s6965#descriptionArea.)