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Smart Plant Automation via Smart Mesh Wireless Hart Technology

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Abstract. The search for modern and extensive technology has been a major push for the industries today especially the EPC business segment. This Technical Paper investigates the usage of Wireless HART technology for the overall control and automation for large complex projects in Oil & Gas and/or Power Business segment wherein this technology is generally preferred for monitoring purposes in open loop systems rather than for functioning in closed loop systems citing questions on its reliability. Wireless HART in collaboration with other technologies like TDMA, 128 AES encryption and multi-hopping techniques can possibly result in a fruitful combination enhanced with Reliability, Security and Durability apart from other technical parameters. The discussion herein focuses on exploring Wireless HART based on IEEE 802.15.4 standard so as to optimize the budget and efficiency to the positive side with much better results compared to current levels with available technologies. This type of wireless sensor network can be applied for controlling the instruments and rotating equipments as well rather than operating the system with typical wires and cables. This renders the plant with reduced installation and material cost, self-organizing and self-healing capabilities along with security and adaptability.

Keywords: EPC- Engineering, Procurement and Construction, HART- Highway Addressable Remote Transducer, TDMA- Time division multiple access, AES- Advanced Encryption standard, IEEE-Institute of Electrical and Electronics Engineers.

1. Introduction

"Engineering" refers to development of technology and also innovations. Various improvements are already done from time to time regarding plant run and its processing. Presently, the plant is trapped in the wired and cabled networks. Implementing the wireless HART network[1] in place of the wired one and securing the network through Advanced Encryption Standard (128AES) and TrueTime simulation[2,5] will be a great development towards the existing technology. The latest specification, wireless HART, is a part of HART 7 communication protocol and the same will be used for this particular implementation. A plant, in its processing needs simple, reliable, secure, flexible and robust technology[3]. Wireless HART technology is simple to implement and is perhaps appropriate for process automation applications. Wireless HART can also be applied to a wide range of applications from adding measurements where they were previously out of physical or economic reach to enabling plant-wide functions such as asset and people tracking, security, and worker productivity [4].

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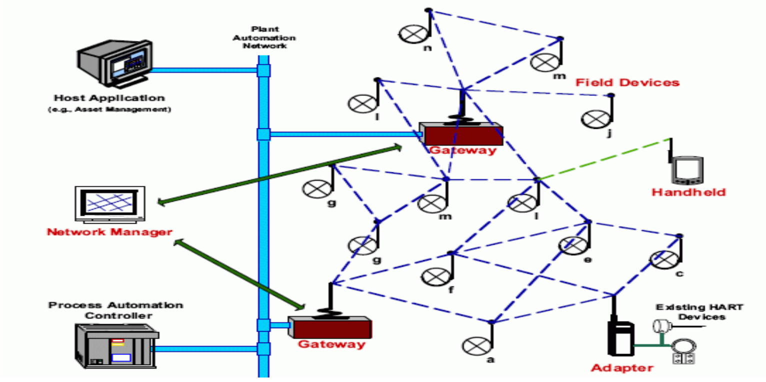

Fig. 1: Structure of a Wireless HART plant

2. Wireless HART Technology

2.1 Overview

This technology is sole extension to the wired HART platform providing additional benefits as compared to the latter one. It can be implemented for real time industrial plants of different variants i.e. Oil and Gas, Power etc. at an optimal cost and enhanced reliability. It has a physical layer based on IEEE 802. 15.4 standard and adopts an operating frequency of 2.4 Ghz in ISM radio band utilising 15 different channels. The device to device communication is enabled using TDMA with each slot of 10 ms. A superframe is formed from combination of multiple time slots. Wireless HART provides hopping capability and also reduces the possibility of multipath fading to a significant extent. The time slots can also accommodate multiple device communication or single source to multiple field device communication which can be accomplished through CSMA MAC protocol. A network manager is present as a supervisor functioning on SNMP which is responsible for creating an initial superframe and configuring the gateway in order to initiate the communication process with the field instruments and other devices such as compressors, pumps etc.

2.2 APPLICATIONS

Among many applications possible via Wireless HART network usage of Pump in Rotating equipments category is one amongst them. Let us take a simple example of incorporating the Wireless network in the circulating tank-valve pump control system where a pump is used to push the fluid into/out of the tank and the valve (On/Off control type) is to keep a check on the level of tank. For controlling the system a wireless gateway is connected to a control system which controls the working of the pump-valve system. A typical schematic of the pump-valve system is shown in the below Fig 2. The On/Off status of the pump-valve is sent to the wireless position monitor via wireless Gateway, which further connects to the control system. The open/close valve status is also reported to the control system. The wireless position network can initiate the actuation of the valve depending upon the level of liquid in the tank. The valve gets open/close accordingly as the liquid level is low/up to the mark, in order to prevent an overfill condition.

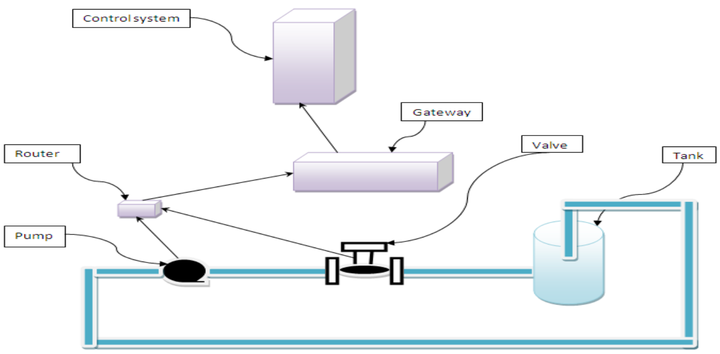

Fig 2- Schematic of a Pump-Valve system

2.3 The Mac Protocol

The MAC protocol indicates whether the device is ready to transmit a message or not. The main operations that are carried out by this protocol are-

•Synchronization of time slot information and identification of devices in Wireless HART medium.

•Delivering of message packets and receiving acknowledgement for the same.

The MAC sublayer comprises of the following components-

•Tables of neighbours, superframes, links, and graphs that configure the communication between the device and its neighbours.

•A link scheduler that evaluates the device tables and chooses the next slot to be serviced by listening for a packet or by sending a packet.

2.4 TDMA in Wirelesshart

The WirelessHART technology makes the use of TDMA and hopping concept in order to have a stabilized and a substantial network formation. The purpose of TDMA in this technology is to ensure a collision free and deterministic wireless communication. A series of time slots form a superframe and the devices generally used in the field support multiple superframes. Slot sizes and the superframe lengths are fixed at the beginning and the superframes are also repeated continuously until the network cycle terminates. The time synchronization between the field devices and control system is very crucial so that the plant can function in continuation with the desired efficiency that is near to 100% only. As soon as the slot is initiated the transfer of data packets is initiated. A short time delay is incorporated in order to adjust the same frequency levels both at source and destination. Precautions are observed in form of clock tolerances, The receiver must start the listening process even before the transmission starts and it should go on till the entire process is completed. The end of this process is marked with the reception of "ACK" i.e. Acknowledgement signal which can indicate whether the process in closed loop is error free or reliable. Following the results the action course is taken to make the entire process more reliable and efficient

2.5 The Concept of Shared Slot

In an industrial plant it is essential that multiple field devices should communicate simultaneously as the network has to be established over a large scale area. If multiple devices are using the same time slot then chances of multiple collisions may arise causing loss of vital information in the plant. This may lead to improper transfer and inturn improper Acknowledgement(ACK) signal as a result. To reduce such probability of repeated collisions source devices should use random back-off delay when their source devices are not substantially acknowledged. A device maintains two variables for each neighbour which are Back-Off Exponent(BOExp) and Back-Off Counter(BoCntr). These two variables are initialised to zero at first and the back-off period is calculated based on the value of BOExp. Each unsuccesful transmission of data packet results in the increment of BOExp by one. The set of numbers incremented are whole numbers and is given as

$$\mathbf{L = (2BOExp - 1)}$$

2.6 Communication Tables

The devices are responsible for maintaining a table referred to as the communication table through which the properties related to transmission and reception are determined. It is also in the case of WirelessHART, A sample arrangement of such tables is depicted in the diagram below-

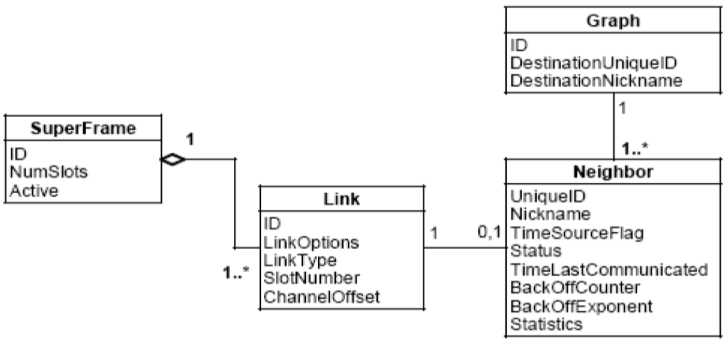

Fig 3- Communication Tables

3. Mathematical Modeling

3.1 The Concept of Truetime

Truetime is basically a simulation tool for network and embedded systems and the relevance of this tool lies in effective scheduling and overall communication between the control system and the field devices. Now to start up with the description of this tool we would like to first give an overview about its library and the functions included in them. TrueTime comprises of a six block library with a collection of C++ functions and the corresponding MATLAB MEX interfaces. For the sake of clarity the functions are divided into two different groups out of which one permits to configure the simulation by creation of tasks, interrupt handlers, monitors, timers etc and the other one deals with real time primitives that are called up from the task code during execution and provides for AD-DA conversion, Changing task attributes, Entering and leaving monitors, Sending and receiving network messages etc.

3.2 Implementation

Any signal in a practical situation encounters some kind of loss to an extent. Obviously our aim is to build up a smart plant using WirelessHART with minimal errors but the avoidance of path loss can't be there. In true time the default path loss function is given as-

$$P_{receiver} = 1/d^a * P_{sender}$$

Where P is the power, d is the distance in meters and a is an unique parameter that can be chosen to model different environments. This is a default function which is readily available and a provision for user defined function is also there if the user wishes so in the MATLAB library.WirelessHART is implemented with some C++ functions and corresponding MEX-interfaces.The main function used is ttMAC.cpp that is entirely responsible for implementation of the algorithm which in turn permits the access to medium. As stated in section 2 WirelessHART uses TDMA and channel hopping to control medium access. Each device has a table in which all its communication specifications and process is listed. If a particular device or control system wants to transmit it must call the respective MAC function which inturn checks the table for the device and gives a green signal accordingly. If yes, the transmission is permitted otherwise it is blocked which also provides the basis for 128 AES encryption technique which is an effective security measure for the entire plant. In addition to this the purpose of channel hopping is to facilitate multiple devices using the same slot but different channels for communication. When a control system tries to transmit in a shared slot through gateway to multiple devices the MAC function verifies the status of the channel. If a channel is occupied a back-off is initiated as explained in 2.4. The working of MAC protocol is depicted via following algorithm-

- Read the actual simulation time and the device table.
- if device will communicate in this slot
- In case device has to receive
- set the state to reception
- if(slot=shared && BOcntr>0)
- BOcntr=BOcntr-1;
- in case device has to transmit
- if (slot=shared && BOcntr=0 && channel=occupied)
- set the state to COLLISION; \\ Includes Collision detection and handling
- BOexp=BOexp+1;
- BOcntr=random(0,(pow(2,BOexp) -1));
- else if(slot=shared && BOcntr>0)
- set the state to COLLISION
- BOcntr=BOcntr-1
- else if(slot=shared && channel!= occupied && BOcntr=0)
- set the state to transmission and set the channel to occupied.
- reset the BOexp (BOexp=0)
- else if(slot!=shared)
- set the state to transmission and set the channel to occupied.
- reset the BOexp (BOexp=0)

- if actual slot not reserved for this device and is not a shared slot
- reset Boexp and BOcntr (BOexp=0 & Bocntr=0)
- set the state to BLOCKED, this device cannot access medium in this time slot.

3.3 Task Synchronization

The device used in a TDMA scenario must know when the start of time slot occurs. For this very reason only the first and foremost duty of MAC function is to read the simulation time as mentioned in the preceding algorithm from the MATLAB environment. With this value the device is able to compute the actual slot time:-

$$ActualSlotNumber = (Actual\ Sim\ time+exectime /SlotSize \ \%SuperframeSize) + 1$$

Where the exectime is the execution time of the device task that has called the MAC function. The slot size is fixed to 10ms in WirelessHART and the Superframe size is the no of slots contained in a superframe. Clock drift is not taken into account and all the devices of the network are synchronized.

3.4 Simulation Example with Results

This section will show two simulations with different communication approaches namely WirelessHART and ZigBee. We should note that WiredHART and ZigBee provides similar simulation results. This is just a test case on TrueTime with a field device such as a DC Motor. Now the wireless PD control of two DC motors is given by- $G(s) = 50/s(25s + 1)$

The PD controllers are implemented in accordance to equations given as below-

$$P_k = K * (r_k - y_k)$$
$$D_k = a_d D_{k-1} + b_d\{(y_{k-1}) – (y_k)\}$$
$$u_k = P_k + D_k$$

where $a_d = T_d /NT_s+T_d$, $b_d = NKT_d /NT_s+T_d$, T_s is the sample time, T_d is the derivative constant, K is the gain of the controller and N is a factor for the filtering of the derivative part:

$$D(s) = -[\{sKT_d /1\} + \{sT_d/N \}]*Y (s)$$

In the case of WirelessHART, loop 1 uses multi-hop routing and loop 2 uses a single hop.

For ZigBee or WiredHART the communication is contention based and three retransmissions are allowed before dropping a packet. A comparison of the simulation results is shown in Fig. For this particular (random) pattern of packet loss WirelessHART with multi-hop gives a significantly improved control compared to single-hop, and is also superior to ZigBee or WiredHART.

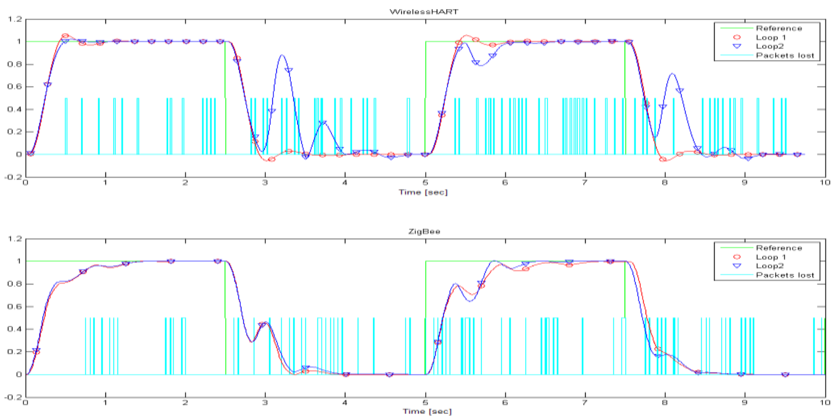

Fig 4- Simulation results of WirelessHART (Top) and Zigbee/WiredHART (Bottom)

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5. Conclusion & Future Prospects

As we summarize our results in the previous section we observe that there is a vital and bright indication for the implementation of technology laid out in the manuscript. Wireless Control to a complete extent for the overall plant operation is definitely possible including closed loop systems also in accordance with the proof that we have defined in the previous sections.

The technology can be strengthened further on with possibility of carrying out modification in the HART protocol and communication protocol. The communication system is soon to adapt the 5th Generation(5G) with the research already going on in South Korea. This will lead to less time lags, more security and continuous operation at a rapid rate. The function can be made more application oriented in order to cater compatibility issues arising with several manufacturers. The security measures will also get advanced in the upcoming future moving beyond the 128AES. The research is on and will continue with bright prospects of glory.

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