Research Journal of Applied Sciences, Engineering and Technology 11(4): 396-399, 2015
DOI: 10.19026/rjaset.11.1793
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: April 9, 2015 Accepted: April 22, 2015 Published: October 05, 2015

Research Article

A Novel Energy Efficient Algorithm for Wireless Hart Applications

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Abstract: Over the past few years, Wireless HART (WHART) is a fast growing wireless sensor network protocol. In this study, we propose a novel Power predicting, Association and Transmission (PpAT) algorithm for improving the overall power consumption in wireless sensor network. This objective is achieved by means of maintaining, equilibrium among the overall throughput required by the system and the power consumed for receiving and transmitting the information. Here, the power required for transmission is selected by the novel algorithm without the influence of repeated power level measurement in the received signal. This power management is designed in three levels, (i) Cluster Scanning, (ii) Sub-node Association and (iii) Beacon Transmission. Cluster scanning is the process of discovering a new neighborhood cluster for the association of nodes and data transfer. During the association process for achieving robustness, a sub node is associated with the head node. PpAT algorithm gives an opportunity to transmit beacon signals at two different power levels (0 and -20 dBm), so that when both the signals are received successfully a node estimates that it is nearest region of the head node and selects low transmission power. In the other case conventional techniques choose the high transmission power. But, PpAT selects high transmission power only if no near head node is visited by the sub node. Beacon transmission is done based on time-stamp synchronization between master and slave nodes. Simulation results show that the proposed algorithm extends the network lifetime. With these proposals there is scope for increasing their autonomy in wireless sensor networks.

Keywords: Beacon, cluster scanning, lifetime, power, wireless HART

INTRODUCTION

For the purpose of advanced industrial automation, Wireless HART (WHART) has been recognized as the first international protocol for wireless communication since 2007. Since the evolution of Wireless HART, it has gathered attention from industries like oil refineries, mining industries and other industries where control and process automation are the major roles of operation. As the sensor nodes operate on batteries for rapid and scalable deployment, they energy utilization of nodes are limited (Kunzel *et al*., 2013; Muller *et al*., 2011; Yun *et al*., 2010; Muller *et al*., 2012). According to the standardization Wireless HART is designed as a mesh network and is capable of operating by IEEE 802.15.4 standard. For energy efficient operation TDMA is employed as the MAC protocol in the data link layer (Dust Networks, 2007). Though TDMA is a traditional method, it is proven that TDMA based MAC protocols is a good choice for energy efficient operation of sensor nodes (Dust Networks, 2007; El-Hoiydi *et al*., 2003). Under practical scenario due to the factors like draining power and time-delay WHART face major challenges. When considering the draining power, when battery power hits zero, the sensor node will detach from the network, leading to a network paralysis. On the other hand, time-delay should be avoided to have a proper data transmission in the correct timing link. This will in turn help in saving draining power and also screens the redundant data exchange. With all these factors as constraints, algorithms with low complexity and less power consuming algorithms were proposed Elson *et al*. (2002), Wang *et al*. (2012), Maróti *et al*. (2004), Ganeriwal *et al*. (2003) and Samanta *et al*. (2010) for Wireless Sensor Networks (WSNs). These proposals are promising for WSN, not for Wireless HART network. This is due to the standard advancement in terms of reliability and time delay improvement in Wireless HART than the WSNs. Though ERBS, proposed in Wang *et al*. (2012) is designed for large scale networks to reduce energy consumption, it failed consider lesser transmission power for Wireless HART. In Maróti *et al*. (2004), an efficient Flooding Time Synchronization in wireless sensor networks (FTSP) has been proposed for WSN.

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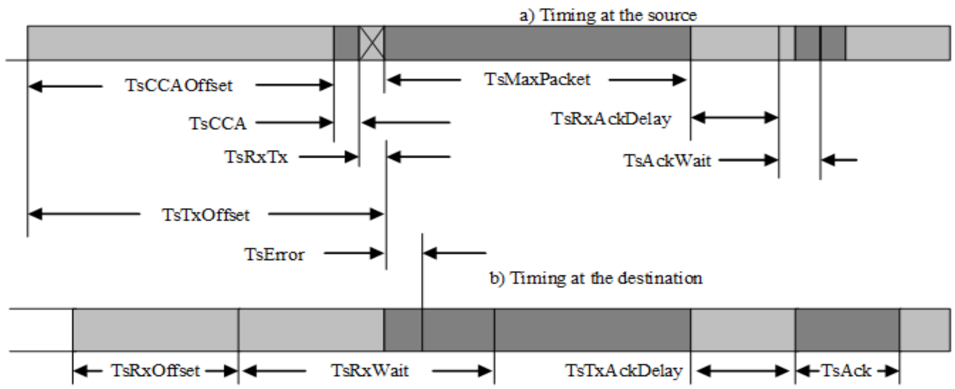

Fig. 1: Time slot allocation at source and destination nodes

This study presents a proven optimized energy efficient algorithm of Wireless HART networks. The core operation of this algorithm is when the gate broadcasts messages; timestamp based on WHART protocol is used by the sub nodes to exchange messages. At the same time for achieving optimum time offset, maximum-a-posteriori estimation is carried out for the time offset.

METHODOLOGY

Wireless hart system model: Though the WHART has been finalized on 2007, it was approved as an IEC standard only in 2010. According to the standardization Wireless HART is designed as a mesh network and is capable of operating by IEEE 802.15.4 standard. In the physical layer, Wireless HART uses TDMA based MAC protocol and the hopping pattern is estimated from a pseudo-random sequence. The major component of the Network is the Network Manager (NM), which controls the TDMA slot allocation and those slots are allocated at network configuration time. To add more reliability, the NM can dynamically re-schedule the network based on the updates from the live nodes for every 11.5 min. This re-scheduling happens only at critical situations. In Elson *et al*. (2002), the Reference Broadcast Synchronization (RBS) algorithm is based on receiver-receiver model, where sensor nodes broadcasts reference beacon signals to their neighbors. In RBS, the reference beacon does not have timestamp, but for time synchronization the time of reception is used for comparing the clocks. We consider a (n, m) network model, where n is the number of receiving nodes and m is the number of reference packets transmitted by the transmitter. With these parameters, the arrival time of reference packet is evaluated based on the Eq. (1):

$$\forall i \in n, j \in n: \text{offset} = \frac{1}{m}\sum_{k=1}^{m} \left(T_{j,k} - T_{i,k}\right) \quad (1)$$

The major components in developing an energy efficient synchronization algorithm are timeslot and time synchronization. As explained in Industrial communication networks (Wireless communication network and communication profiles-Wireless HART IEC 62591) the transmission time slot for WHART protocol is shown in Fig. 1. It shows the time slot at the source and destination nodes. One timeslot is allocated to complete full data and the fixed length of timeslot is limited to 10ms, which is the minimum time unit in the network. In the physical layer, the data packet is split as Preamble (4 byte), SFD (1 byte) and PHR (1 byte). At the end of PHR (sender), the receiver node places itself in the window to receive the acknowledgement under the following conditions. The max Δt in the network is limited to 200 μsec:

$$\Delta t + \text{TsRxOffset} \leq \text{TsTxOffset} \quad (2)$$

$$\Delta t + \text{TsRxOffset} + \text{TsRxWait} \geq \text{TsTxOffset} \quad (3)$$

$$\Delta t + \text{TsTxAckDelay} \leq \text{Ts RxAckDelay} + \text{TsAckWait} \quad (4)$$

$$\Delta t + \text{TsTxAckDelay} \geq \text{Ts RxAckDelay} \quad (5)$$

For a sensor node to join in the network, clock cycle and phase synchronization are needed in Wireless HART. The process of time synchronization is to trace the time of reception of SFD and sets the global clock register. Remaining energy level available in each sensor node is gathered by the NM to allocate the reference clock value to the neighboring nodes in the networks. The native clocking time of node_i is mentioned in Eq. (6):

$$C_i(t) = \int_{t_0}^{t} f_i(t)\,dt + C_i(t_0) \quad (6)$$

Here, frequency of node i at time t is given as $f_i(t)$; initial start-up time of the node i is t_o. As the variation in frequency in considerably very low, the integral part in Eq. (6) can be rewritten as:

$$C_i(t) = f_i(t - t_0) + C_i(t_0) \quad (7)$$

There is a certain deviation between the crystal oscillator frequency and the nominal value of node. Within the time T, the time deviation of node j is:

Table 1: Pseudocode for proposed study

initialize data_Size to 0	% associating sub-nodes with	for t = 1: N
(zero)	the head node	time_S_A = Stack_S_i (S_A)
N = size (nodes)	initialize associating	lastSync (t).time
% Cluster Scanning	if (beacon received) then	time_S_B = Stack_ S_i(S_B)
initialize scan	end scan	lastSync (t).time
if (beacon received)	if (#_beacons received == 2)	target_S_A = Stack_S_i(S_A)
if (t_{elp}<t_{bec-p} &&	then	lastSync (t).target
!timed$_{out}$)	select low power mode	target_S_B = Stack_S_i (S_B)
goto step A	else	lastSync (t).target
else	select high power mode	if (time_S_A>time_S_B) ||
end scan	end if	(time_S_A == time_S_B &&
end if	else if (timed$_{out}$ || high power mode)	target_S_A>target_S_B)
else if (!timed$_{out}$)	initialize New Cluster Scan	transfer beacons between S_A and S_B
goto step A	else	data_size = sum (size of beacons transferred)
else	repeat New beacon	calc time used as a frac of data_size and
end scan	search	bandwidth
end if	end if	end if
% end-of cluster scanning	get status of Headnode and	end for
	begin association Tx	
	if (ACK received	
	node associated)	
	else	

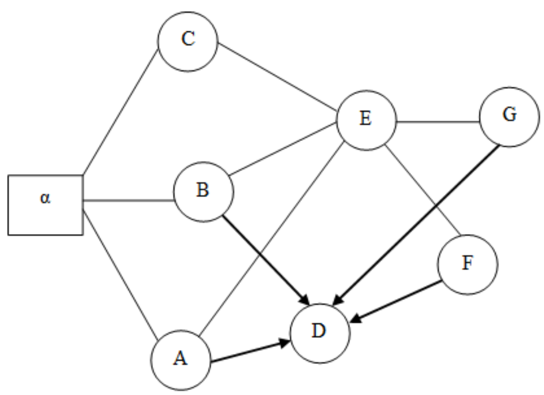

Fig. 2: Simulation setup of graph topology

$$\Delta t = f_0 \Delta f_i T \quad (8)$$

The proposed algorithm is divided into two sections. In the initial phase broadcast the aggregated data among the neighbors and in the later stage apply maximum a posteriori estimation to estimate the time offset on each sensor node. The conventional algorithms estimates the average time offset by considering the all the sensor nodes non-adjacent to the network manager. But in real time applications time offset between sensor nodes is directly proportional to distance between them. This will result in draining the available energy in the sensor nodes. To reduce the computation complexity and to improve the reliability, time offset calculation is done only for the neighbor nodes.

The graph topology of the simulation setup is shown in Fig. 2. The neighbor nodes of ‘D’ are ‘A’, ‘B’, ‘F’ and ‘G’. And also ‘D’ and ‘E’ are sibling nodes with no connections between them. During the initialization *A*, *B*, *F&G* transmits the arrival time of data packets to *D*. With these arrival times ‘D’ estimates median time offset and uses maximum a posteriori estimation for the approximation. For *x* number of neighboring nodes, the complexity of the proposed will be *x*n*m*. Accordingly, when a node (*I*) receives reference packets (m) from it’s any one of the neighbor node (*J*), then the computation complexity will be derived as in Eq. (9):

$$\theta = \frac{1}{m}\sum_{k=1}^{m}\left(T_{p,k} - T_{q,k}\right) \quad (9)$$

To add further, for the estimation of time offset by maximum a posteriori, in Elson *et al*. (2002), it is proven that time offset between the nodes at the receiving end follow Gaussian Distribution. If time offset follows zero-mean GD, then the conditional probability density of time offset at θ is given by Eq. (10) (Fig. 2):

$$p\,(x|\theta) = \left(\frac{1}{\sqrt{2\pi}\delta_n}\right)^N \exp\left(-\sum_{i=1}^{N}\frac{(x_i-\theta)^2}{2\delta_n^2}\right) \quad (10)$$

The probability density of the time offset with $\mu = 0.054$ and $\delta = 11.357$ (Table 1):

$$p\,(\theta) = \frac{1}{\sqrt{2\pi}\delta}\exp\left(-\frac{(\theta-\mu)^2}{2\delta^2}\right) \quad (11)$$

CONCLUSION

In this study, the Energy-efficient Local Optimization Time Synchronization algorithm (ELOTS) is proposed on the basis of analyzing the traditional RBS algorithm and its improved version ERBS algorithm. Firstly, the mean time offset is obtained for neighboring receiving nodes (parent node and child node) with multiple reference broadcast messages and reduces the computational complexity of the synchronizing process. Since the time offset of receiving nodes follows the Gaussian distribution, the maximum a posteriori estimation is conducted for time offset. Each receiving node adjusts its node time according to the estimated value of time offset and thus correcting the time offset. The results of theoretical analysis and simulation prove that, the ELOTS algorithm has better synchronization precision and much less energy consumption than the RBS and ERBS algorithms. In future work, the ELOTS algorithm will be combined with the FTSP algorithm for achieving the cross-layer time synchronization for Wireless HART network and further improving the time synchronization precision and expanding the scope of applications for the time synchronization scheme.

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