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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (23): 7809-7814, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.7809.7814

Study of Time-sync for WirelessHART Networks

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Abstract: WirelessHART is becoming widely used industrial communication standard due to its features such as low cost, low power consumption and strong interoperability. As a research hotspot, time-sync is one of key technologies for WirelessHART networks. Firstly this study summarizes the existing time-sync methods. Secondly, by means of building slot timing model, this study focuses on time slot setting up, active time-sync and passive time-sync processes for WirelessHART network time-sync. The calculation method of time cycle for keep-alive data packets used for keeping time-sync is proposed. The keep-alive data packet cycle of 30 sec is proved reasonable in WirelessHART standard. Finally, test platform is set up using the self-development WirelessHART communication module WH-M and the time-sync mechanism of WirelessHART network is realized. The time-sync error of testing data is small enough to meet the time demand of TDMA in industrial communication fully.

Key words: WirelessHART, network, time-sync, TDMA, active time-sync, passive time-sync

WIRELESSHART NETWORK OVERVIEW

With the development of microelectronics and wireless sensor networks, wireless for process industry becomes possible. In September 2007, WirelessHART standard was published and speeded up the progress of industrial wireless networks (Zhao *et al*., 2010). WirelessHART communication standard is designed for process control field in special and the typical application is shown as Fig. 1. WirelessHART is the extension of HART fieldbus in wireless field, adopting TDMA (Time Division Multiple Access) mechanism and IEEE STD 802.15.4-2006 specification in physical layer (IEC 62591, 2010). WirelessHART networks divide time into periodic superframe. In further, the superframe is divided into a number of time slots. Network nodes communicate with others in the time slots. The time-sync for the network is a premise of secure, reliable and conflict-free communication.

TDMA IN WIRELESSHART NETWORK

WirelessHART networks adopt TDMA mechanism dividing time into superframes and superframes are divided into time slots (Xu and Cheng, 2002), as shown in Fig. 2.

In WirelessHART networks, the length of a time slot is 10 ms which is fixed. In a superframe, a number of time slots are allocated to nodes in WirelessHART networks for sending packets to or receiving from other nodes. In order to make sure TDMA to work normally, every node in the network has a precise clock and slot timer. In WirelessHART networks, APs (Access Point) are chosen as primary time source nodes. Others synchronize their clock with AP or source nodes assigned by network manager and as a result the uniform network clock is formed.

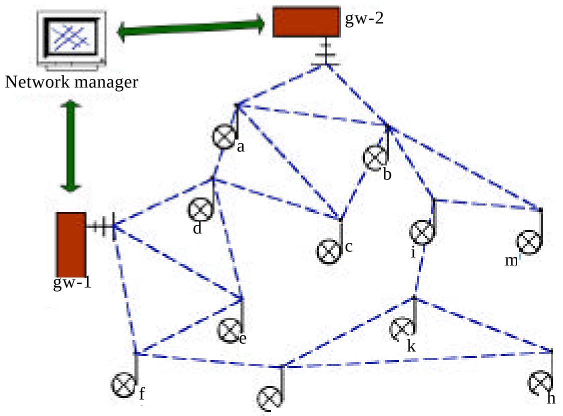

Fig. 1: WirelessHART mesh structure

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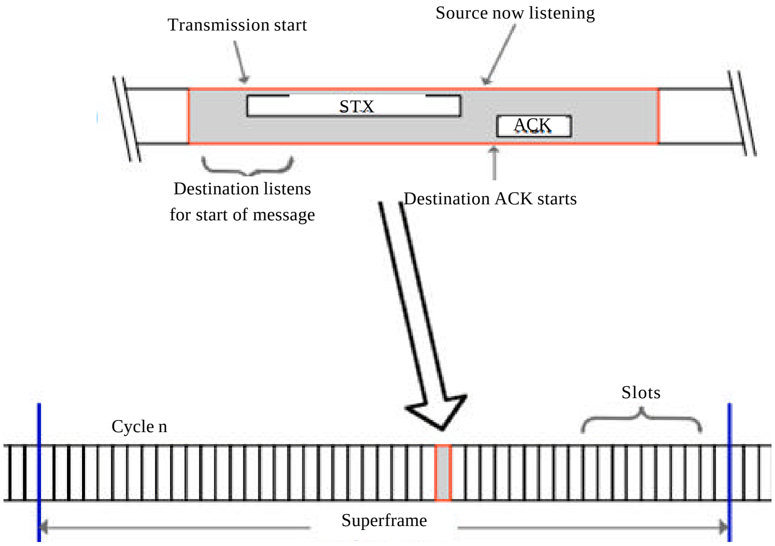


Fig. 2: TDMA mechanism

TRADITIONAL TIME-SYNC METHODS

At present, widely used time-sync methods are mainly GPS (Global Positioning System) and NTP (Network Time Protocol). GPS synchronization precision is high, but its shortcomings are high power consumption and cost. In a terrible environment, synchronization precision is affected. NTP time-sync is accuracy and needs large amount of calculation, so the computing cost can't be ignored. In wireless network application, to realize large scale deployment, sensor nodes are often small in size and low cost. Therefore, power consumption is strict. Further, the nodes are deployed in a hostile environment, so the above two methods for time-sync in wireless sensor networks is unsuitable.

On the international conference HotNets-I in August 2002, Elson and Romer presented and described the time-sync research topic for the first time and caused wide attention. Universities and research institutes have carried out research on the subject in succession. Sorts of time-sync methods were put forward and they could be divided into three classes in general (Kang *et al*., 2005): Based on receiver-receiver method, based on pair-wise method and based on sender-receiver time-sync method. Based on receiver-receiver method has typical synchronization algorithms such as RBS (Elson *et al*., 2002) (Reference broadcast Synchronization). The representative algorithms for pair-wise method are TPSN (Ganeriwal *et al*., 2003) (Timing-Sync Protocol for Sensor Networks), LTS (Lightweight Tree-based Synchronization). DMTS (Ping, 2003) (Delay Measurement Time Synchronization), FTSP (Flooding Time Synchronization) time-sync algorithms belong to the class of sender-receiver method.

TIME-SYNC METHOD OF WIRELESSHART

In WirelessHART network, time-sync technology is not only the base of node location, data fusion, synchronization measurement and other application, but it is also the guarantee of network normal operation for communication (Ferrigno *et al*., 2011) and (Tian and Yang, 2011). WirelessHART time-sync method adopts the combination of pair-wise and sender-receiver methods. Using the model of data sending or receiving ideal time point in time slots, WirelessHART time-sync can be set up. By transmitting normal data packets in the network, the time of every node in the network realizes to be synchronized. Thus extra synchronization data packets are avoided, so network load has decreased, at the same time, getting a high accuracy for time-sync among different network nodes.

Time slot setting up: WirelessHART network slot model (Hart Field, 2008) is shown as Fig. 3, the length of time slot is 10 ms. For the data sending, the current time slot must be data sending slot of the sender node, if CCA (Clear Channel Assessment) mode is enabled, the sender waits for TsCCAOffset from the beginning of the slot, then carries out CCA detection. If the channel is busy, the sender gives up the data sending. If the channel is free, the sender switches to data sending mode in the period of

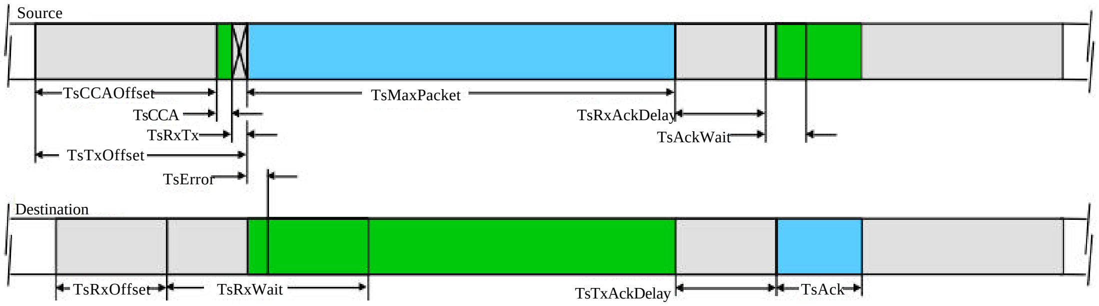


Fig. 3: WirelessHART time slot model

TsRxTX. At the time point of TsTxOffset, the sender node sends out the data. After the sending process completes, the sender waits for TsRxAckDelay and then switches to data receiving mode for ACK from the receiver. If the ACK is received correctly in TsAckWait period, the whole process of communication is regarded successful, otherwise the communication fails.

At the receiver side, the current time slot must be data receiving slot of the receiver node. From the time point of TsRxOffset the receiver switches to receiving mode. If no data comes in the period of TsRxWait, then there is no data to be received in this time slot. If data is received correctly, the receiver waits from the end of the receiving process for TsTxAckDelay and prepares ACK data packet. At the deline of TsTxAckDelay, the ACK data packet is transmitted to the sender (Hart Field, 2008). WirelessHART standard has strict rules for data sending and receiving sequences. Only in the condition of internal time slices of time slot aligned strictly, the information can be send or receive correctly.

Suppose a network N is a normally operating WirelessHART network, node A is one of existing nodes in the network, node B is a new node to join the network. In order to network's extension, node A sends advertisement packets periodically. When node B begins to join, its receiver is open and B is on active searching state, listening to all the packets from the network. If the first packet received is not advertisement packet, node B will record its local time RxLocal at the moment of receiving that packet and B switches its state to packet received. According to the ideal sending and receiving data model and some calculation, B can get that RxLocal-TsTxOffset-TsError is the network N's current time slot beginning, so the end of the time slot is RxLocal-TsTxOffset-TsError+10ms. From the moment of receiving advertisement packet node B abstracts the ASN (Absolute Slot Number) of N, changes its local ASN, set up its own time slot. As a result, node B is synchronized with the network N and changes its state to synchronized state.

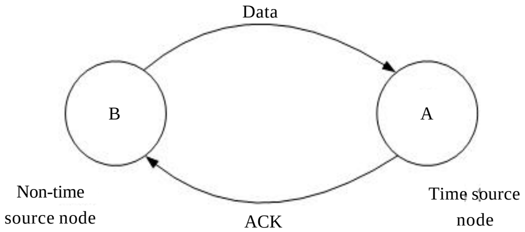


Fig. 4: Active time-sync process

Active time-sync: The local clock of wireless nodes is driven by crystal oscillators (Wu *et al*., 2011). Because of the difference and clock drifting among crystal oscillators, the time error among nodes always exists (Rhee *et al*., 2009). For the sake of keeping the time error in an enough small range, time-sync is necessary. In a WirelessHART network, the network manager assigns some nodes to be time source nodes and others need to be synchronized with time source nodes.

As is described above and shown in Fig. 4, in the WirelessHART network N, if node A is the time source for node B, node B needs to synchronize with node A. When node B takes means of active time-sync method, node B sends data packets to node A at the offset time point of TxTsOffest from the time slot beginning. Node A records its local time RxLocal_A at the arrival of the data packet from B. After data received successfully, node A sends ACK to B. The ACK's payload is the time difference between time source node A and node B which is T_Adj = TsTxOffset+TsError-RxLocal_A. When B receives the ACK, reads the information and adjusts its local time T_B = T_B-T_Adj, realizing the synchronization between node B and node A.

Passive time-sync: As is shown in Fig. 5, when passive time-sync is adopted, time source node A send data packet to B at the time point of TsTxOffset. B records its local time at the arrival of the packet, then calculates its time error with time source A T_Adj = TsTxOffset+TsError-RxLocal_B. According to T_Adj, node B adjusts its local time T_B = T_B+T_Adj, realizing the synchronization between node B and node A.

Synchronization cycle: From the time-sync mechanism above described, if there is no communication between two nodes in a period of time, they can't synchronize with each other. To keep local time is the same as network time, a node must send keep-alive data packets to its time source node if they have no communication with each other for a long time. If the cycle of keep-alive packets is P, the upper bound of time error among network nodes is delt_T, the drifting error of crystal oscillator is delt ppm, then $2\times delt\times P\leq delt\_T$ is get, that is $P\leq delt\_T/(2\times delt)$. In further, if there are n hops in time-sync tree, keep-alive packet cycle is $P\leq delt\_T/(2\times delt)(n+1))$. From the communication in a time slot above mentioned, if network nodes send and receive successfully, then the following inequalities need to be satisfied:

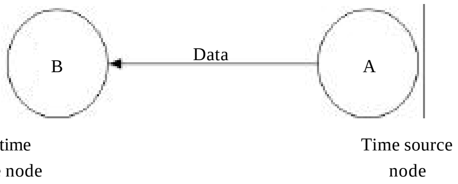


Fig. 5: Passive time-sync process

$$delt\_T+TsRxOffest\leq TsTxOffset \quad (1)$$

$$delt\_T+TsTxOffset+TsError\leq TsTxOffset+TsRxWait \quad (2)$$

In the WirelessHART the following are satisfied:

$$2020\ \mu s\leq TsTxOffset\leq 2220\ \mu sec \quad (3)$$

$$1020\ \mu s\leq TsTxOffset\leq 1220\ \mu sec \quad (4)$$

$$2100\ \mu s\leq TsTxOffset\leq 2300\ \mu sec \quad (5)$$

$$TsError = 192\ \mu sec \quad (6)$$

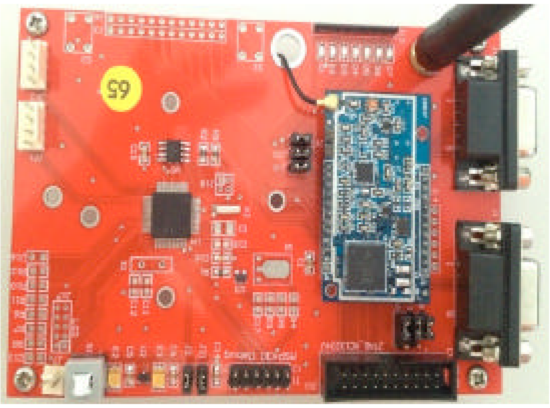
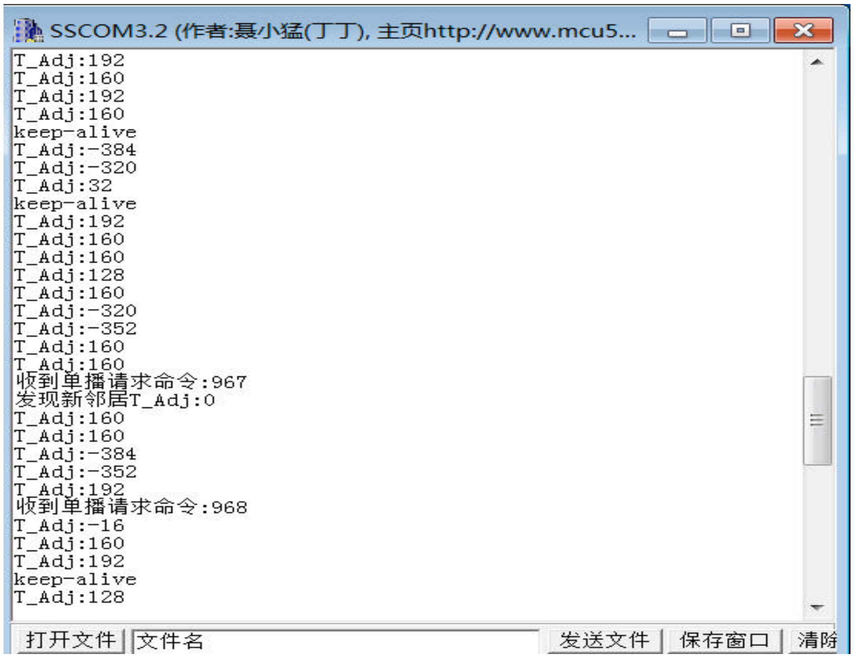


Fig. 6: WH-M WirelessHART module



```
T_Adj:192
T_Adj:160
T_Adj:192
T_Adj:160
keep-alive
T_Adj:-384
T_Adj:-320
T_Adj:32
keep-alive
T_Adj:192
T_Adj:160
T_Adj:160
T_Adj:128
T_Adj:160
T_Adj:-320
T_Adj:-352
T_Adj:160
T_Adj:160
收到单播请求命令:967
发现新邻居T_Adj:0
T_Adj:160
T_Adj:160
T_Adj:-384
T_Adj:-352
T_Adj:192
收到单播请求命令:968
T_Adj:-16
T_Adj:160
T_Adj:192
keep-alive
T_Adj:128
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Fig. 7: Window of T_Adj value

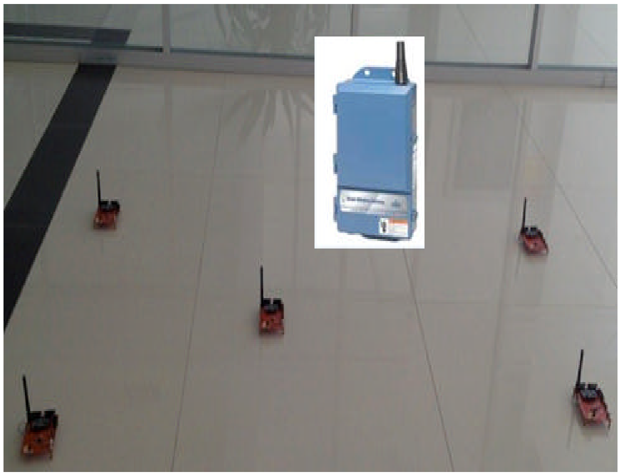

Fig. 8: WirelessHART test network

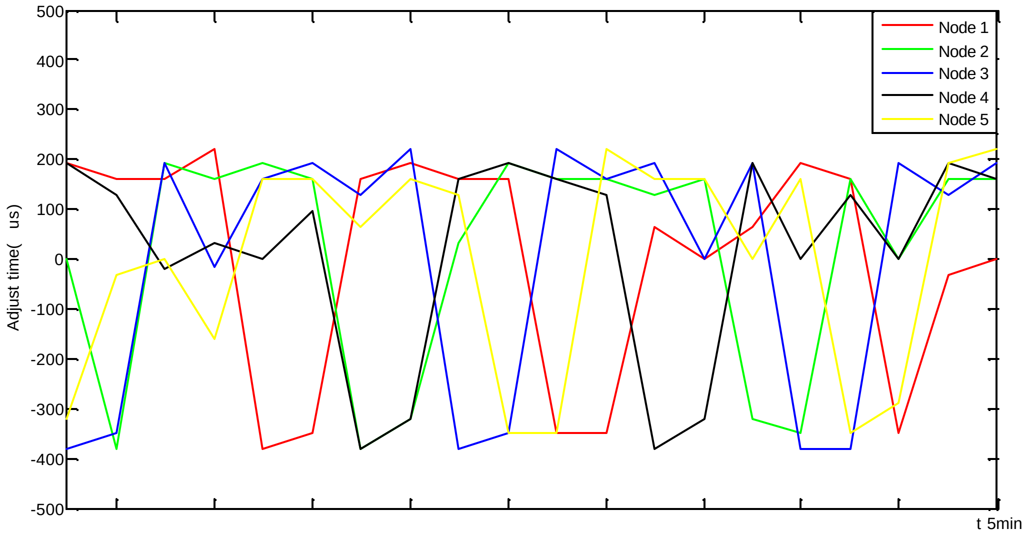

Fig. 9: Curves of T_delt value in the test experiment

Given crystal oscillator error is delt ppm, the hop n = 1, on the simultaneous inequalities Eq. 1-6, getting the results delt_T≤800 µsec, P = 40 sec. Obviously, the keep-alive cycle 30 sec recommended in WirelessHART standard is enough.

TIME-SYNC EFFECT TEST

Time-sync effect test runs on WirelessHART module WH-M developed independently, shown as Fig. 6. WH-M adopts Freescale MC13224 single chip solution with radio frequency. The system clock is 24M, drifting error is 10 ppm. The test platform also includes WirelessHART Gateway, a PC and serial port tool SSCOM32.exe. A network including 5 nodes is set up, shown as Fig. 8. When the network is operational, each node prints its adjust time value through the serial port, shown as Fig. 7.

The T_Adj value of the window is the adjust time in a time-sync process and the unit is microsecond. After the network setting up, the cycle of keep-alive packets is set to 30 sec. The view window is chosen randomly for 5 min long, recording the adjust time T_delt of all 5 nodes for each time-sync and then the curves in Fig. 9 are drew. In the graph, each value of T_delt is between -400 to 500 µsec, satisfying the demand of time error range +800 µsec fully in WirelessHART standard.

CONCLUSION

This study has summarized the existing time-sync methods. On this base, WirelessHART network time-sync mechanism is researched deeply and intensively. The calculation method of keep-alive packet cycle is put forward which is closely related to time-sync effect. Lastly, on the experiment platform, time-sync mechanism of WirelessHART is realized. According to the test data of WirelessHART network, the good effect of time-sync is confirmed.

ACKNOWLEDGMENTS

This study is supported by the Project of High-end Foreign Experts of State Administration of Foreign Experts Affairs, the People's Republic of China (GX20110491004) and the Program of Chinese Academy of Sciences Visiting Professorship for Senior International Scientists.

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