http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

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

Information Technology Journal 12 (14): 2762-2767, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.2762.2767

A Study of Cluster-tree WSN Based on F and LMAC Protocol

Wang Jian and Wen Han-yun
College of Computer Science, Yangtze University, Jingzhou, Hubei, 434000, China

Abstract: The cluster-tree wireless sensor network has been widely used in monitoring and controlling fields. On the base of this network, this paper has proposed a new hybrid network protocol F&LMAC. It adopts the clustering algorithm which uses the optimized LMAC protocol within the clusters and the FDMA protocol between clusters. Data transmission is realized by a combination of proactive and reactive routine. This design has been tested in the reservoir dynamic monitoring system in the permanent well. The test results show that it has low energy consumption, short time delay and great extendibility.

Key words: Cluster-tree, F and LMAC, Reservoir dynamic monitoring system, WSN

INTRODUCTION

Wireless sensor network has been widely used in monitoring and controlling systems. Along with its development, the design for network topology also grows rapidly. The cluster-tree wireless sensor network, which is notable for its practicability, good extendibility and low energy consumption, has been increasingly used in different fields. On analyzing the cluster-tree topology commonly-used in wireless sensor network, we proposed a hybrid network protocol F&LMAC, aiming at low power-consumption and low time-delay. This plan has been applied in the reservoir dynamic monitoring system in the permanent well.

CLUSTER-TREE WIRELESS SENSOR NETWORK AND LMAC PROTOCOL

The cluster-tree wireless sensor network offers a convenient way to reduce the energy consumption and to expand the size of network. As is shown in Fig. 1, the cluster-tree wireless sensor network is composed of layers of clusters which resemble the shape of a tree. The sensor nodes and the cluster heads constitute the first layer and all the first-level cluster heads make up the second layer and so on until SINK, the top layer. The data are transmitted from the sensor nodes to the first-level cluster heads, which forward the data to the second-level cluster heads and so on until they reach SINK.

The cluster-tree topology is favorable for network deployment. We can use the existing terminal nodes as cluster heads and then all the sensor nodes within a geographical region make up a cluster. This structure facilitates data fusion and fault judgment. As the sensor nodes communicate with their cluster heads in a jump, their energy consumption for unnecessary transmission is decreased greatly. Another advantage of this topology is the good extendibility, which favors the application of wireless sensor network (Chen *et al*., 2010).

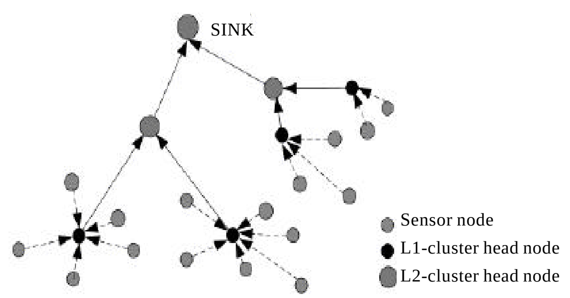

Fig. 1: Topology architecture of cluster-tree wireless sensor network

LMAC protocol is a channel access protocol based on distributed TDMA. LMAC divides the data transmission time of a channel into different time slots, which make up a fixed-length frame structure. A time slot consists of a control time segment and a data time segment. As each node is assigned a time slot, it waits for its own time slot to transmit data packets. In the control time segment, the node first broadcasts the message head, which elaborates the destination and the message length, after that data would be transmitted at once. The nodes monitoring the message head will power off their wireless devices if they are not the receiver of the message. Therefore, LMAC doesn't require time synchronization (Anastasi *et al*., 2009).

Compared with other MAC protocol, the LMAC needn't send an ACK to the transmitter after receiving a message. It schedules a frame structure within a cluster in

Coresponding Author: Wen Han-yun, College of Computer Science, Yangtze University, Jingzhou, 434000, Hubei , China

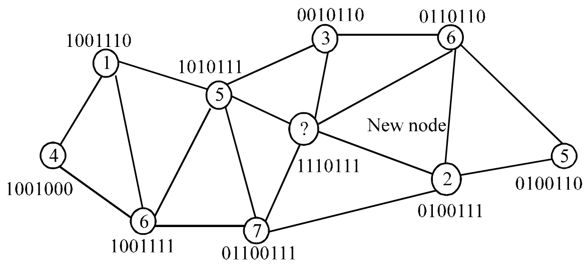

Fig. 2: Time slots scheduling for LMAC nodes

a way which a node dynamically chooses an unshared time slot within a two-jump range. The control segment contains groups of digits describing the time slot occupation information. The new access node will monitor the frame structure first and scans the digits information to calculate the spare slots. Then it would occupy the nearest one and mark it "occupied" and monitor the digits at the corresponding time slot in the next frame (Zheng *et al*., 2012). Fig. 2 shows the time slots scheduling for LMAC nodes.

Here we can see 7 nodes numbered and circled from 1 to 7, which also refer to the slots number for each node during a frame cycle. Near the nodes we can see bit sequences showing whether a slot is occupied. Here "0" represents a spare slot. When a node is allowed access to the net, it monitors the control time segments first to get the digits information of its neighbor nodes. After calculation, only the fourth digit is "0", so the new node chooses this slot as its control segment. When the new node's time slot comes, the digit information would be changed into "1", which means occupied.

A COMBINATION OF CLUSTER-TREE NETWORK AND HYBRID LMAC

The weaknesses of LMAC protocol lie in two aspects. One is that the new nodes must monitor all the control segments in a frame structure. Another is the deficiency in expanding the network. As the duration of a slot is related to the size of network, when the net expands, the length of frame also extends, which results in an increase of time delay for data passing.

Therefore, we proposed a combination of cluster-tree topology with LMAC protocol. We can use FDMA to divide the network into clusters, each cluster communicating on different frequencies. By reducing LMAC sub-network, the extendibility of LMAC is improved. And by optimizing time slot distribution mechanism, we designed a mixed, low energy-consumption LMAC protocol-F and LMAC. Every cluster in F and LMAC contains a node head, a redundant head for components fail and burst data traffic and some sensor nodes.

Basic Process of F&LMAC:The basic process of protocol is as follows:

- SINK starts, scans the channel periodically and gets ready to receive requests from cluster heads
- The sensor node starts and scans the channel. It examines the surrounding cluster heads and chooses a head of the best communication quality. The node joins that cluster and is assigned a node number by the cluster head
- The sensor node enters a suspended state to gather data periodically, waiting for its time slot. When the slot comes, it first broadcasts the message head, which describes the message receiver's ID and the message length and then transmits fixed-length data packets to the cluster head during its control time slot. The nodes that are not the receiver will shut down their wireless devices
- The cluster head fuses the data gathered by the nodes and asks SINK for a channel and then transmits the data to SINK

LMAC within a cluster doesn't require clock synchronization, so the key is allocation of time slot. As the new access nodes must monitor all control slots including the unused ones, this protocol would only sample the control segment of unused slots in order to reduce the energy consumption. When it detects message sent from the unoccupied time slot, this slot would be marked "occupied" and monitored in the corresponding slot in the next frame (Lee *et al*., 2009).

Frequency division mechanism between clusters: The second-level clusters are composed of the first-level cluster heads. The transmission approach is the same as in the first-level except that when the first-level heads transmit data to the second-level, they should change their communication channels. For example, if first-level cluster 1 uses CH1, first-level cluster 2 uses CH2, their second-level cluster head uses CH3, then the first-level clusters should use CH3 when they communicate with the second-level cluster heads.

SINK cycles through all the channels of different clusters. Suppose there are m first-level cluster heads for m channels respectively. SINK switches these m channels in a time period of Tr (Tr<<T, where T represents the value of time slot for a node). When there is a need for data passing, the first-level cluster head will send a data transmission request to SINK in a time cycle of Tr. When

SINK switches to the same channel as that for the cluster head and receives the request, it will immediately stop switching and return an acknowledgement to the head. Then data transmission begins. After transmission, SINK starts the cycle over again. In this way all the scattered clusters get access to SINK and thereby form a unified network(Liao *et al*., 2011).

A dynamic routing based on cluster-division: The cluster-tree wireless network routing protocol is a hybrid F&LMAC protocol composed of proactive and reactive routing. All the nodes within the cluster maintain the routing messages periodically to guarantee a respond time. As to the inter-cluster communication, when a node needs to send data packets but doesn't know the routing, it will send a routing request to the cluster head. The cluster heads maintain the neighbor cluster table periodically so as to reduce the responding time for communication between the clusters.

The cluster topology receives and processes topology notices to get information concerning a cluster head and its members within the scope of certain jumps. The cluster topology of the overall network is included in two tables: neighbor cluster table and cluster topology table. The cluster topology messages are stored in the cluster topology table.

Neighbor cluster table: The cluster head maintains the neighbor cluster table and records their information including the address of neighbor cluster heads, the gateway address between the clusters and the number of jump from current node to the neighbor head (Urie and Chugg, 2010).

Cluster topology table: Cluster topology table is set up and maintained by the head of each cluster. The nodes communicate by sending cluster topologies. The inter-cluster gateway nodes record the information about all heads in the network and their member nodes. The information includes the target head address, the next head address in a jump, the number of jump from current head to the target head, the gateway node address in a jump and the address table of cluster members.

Process implementation is realized by setting up and maintaining the routing table to get the information about the target node. The routing table mainly includes: target and target head address, the address and head address within next jump, the number of jumps and the significant interval for a jump. The way that a cluster head establishes and maintains an in-cluster routing table resembles the proactive routing protocol (Tharini *et al*., 2009). Figure 3 is a flowchart of electing a cluster head. The setup and maintenance of inter-cluster routing table

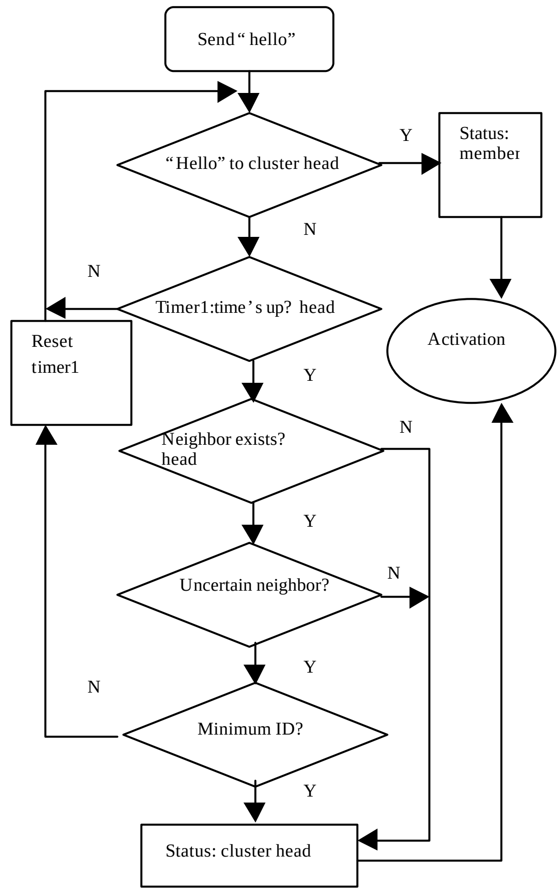

Fig. 3: Process of electing cluster head

is the key to reducing time delay for inter-cluster data passing. To improve the quality of data forwarding, every cluster head can use a redundant node to ensure two transmission routes. If one of the target head failed, the data can be transmitted by the redundant head.

EXPERIMENTAL NETWORK TESTING

Design of reservoir dynamic monitoring system based on Cluster-tree WSN: We have applied the above theories to a reservoir dynamic monitoring system. We used a cluster-tree Zigbee network based on F and LMAC to perform an uninterrupted real-time measurement of multi-core parameters in multi-regions. The test results can be shared by GPRS and INTERNET. Figure 4 shows the reservoir dynamic monitoring system using F&LMAC protocol with GPRS and ZigBee. The numerous ZigBee nodes distributed in the permanent well carried sensors measuring temperature, pressure, flow and etc. These nodes, together with gateway nodes, constitute the real-time quality monitoring network.

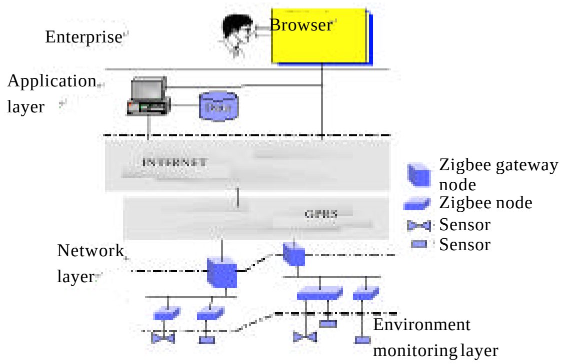

Fig. 4: reservoir dynamic monitoring system

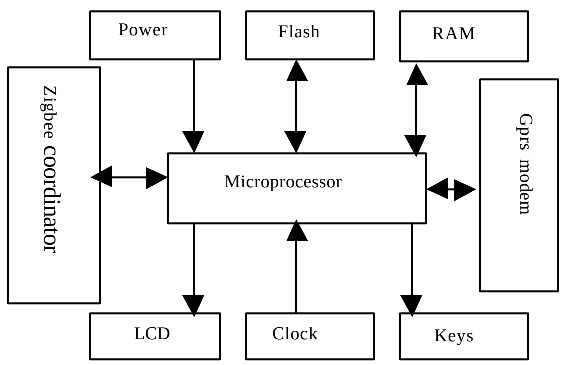

Fig. 5: The gateway node structure

As the gateway nodes should work in the permanent well, the volume of the entire system should be as small as possible so as to be installed easily and have no major impacts on the measuring environment. It is also capable of exchanging information with the monitoring center by GPRS and constituting the wireless monitoring system by ZigBee module. Figure 5 shows the structure of a gateway node.

The ZigBee module and master controller module communicate by serial interruption communication. When the ZigBee module receives the data collected by the ZigBee nodes, it would trigger the main controller module by interruption to receive the data and store them and it would also trigger the GPRS to transmit the data. Serial interruption communication is also applied between the master controller module and GPRS module. When the master controller module is given the query task from the monitoring center, it would trigger the ZigBee module through interruption to inquire about the related nodes information. So when no interruption is triggered, the whole system is in power-down mode, which greatly reduces energy consumption and extends the service life of the system.

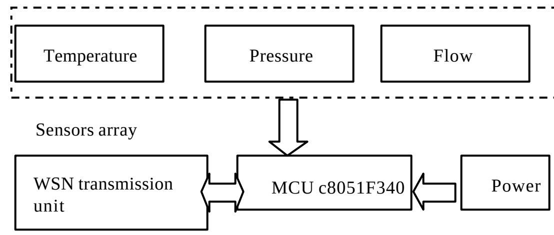

Fig. 6: A terminal node structure

In order to meet the requirements of reliability and data-processing ability for the gateway node, the main controller of gateway node uses the ARM S3C2410, which is the microcontroller for the 16/32 bits ARM9TDMI-STM CPU manufactured by NXP. It also has a 16 bits on-chip static RAM and can be connected with different external equipments. Two low-power modes are available for S3C2410. In the power-down mode, the current consumption is only 30 μA.

Wireless Communication Module. Given the costs and convenience in using it, we use CC2430 by Chipcon as the ZigBee wireless communication module. It is a 2.4 GHz RF chip which meets the IEEE 802.15.4 protocol and is made of 0.18 μm CMOS. With the minimal external components, it has a stable performance, small volume and low power consumption. The protocol stack of CC2430 is Z-Stack. Its current loss is 27mA in working and in the receiving and transmitting mode the loss is less than 27 and 25 mA, respectively.

GPRS Module. GPRS module is responsible for the transmission of data from gateway nodes to the monitor center. It uses TC35 wireless modem based on SIEMENS TC35 and can work in the network of 900 MHz and 1800 MHz. It provides a standard AT command and a RS-232 interface to connect with the external application system.

The terminal node uses C8051F340 high-speed microcontroller as processor core as shown in Fig. 6. It is an integrated single chip microcontroller including a USB function controller, 8 flexible endpoint canals, an integrated transceiver, a 1K FIFO RAM, a 10-bit 200-ksps single-ended/differential ADC unit with analog multiplex. We use numbers of C8051F340 I/O ports to gather signals from sensor arrays. These signals include temperature, pressure, flow and so on. Serial 1 is connected with XL02-232AP1 the wireless data transmission chip to realize a transparent transmission between different devices. The sensor nodes are battery-powered, so the chief concern is energy consumption in the design. When the sensor node is not collecting the data, it enters a sleep mode, the power consumption being only 0.19 mA.

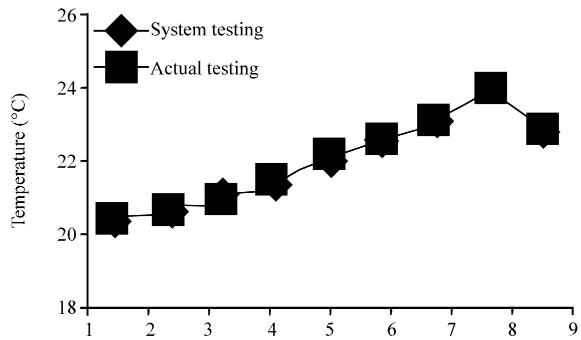

Fig. 7: Changes of measuring parameters in a time period

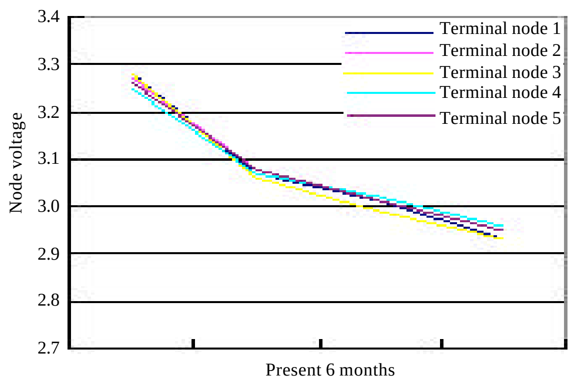

Fig. 8: Power supply for nodes in 6 months

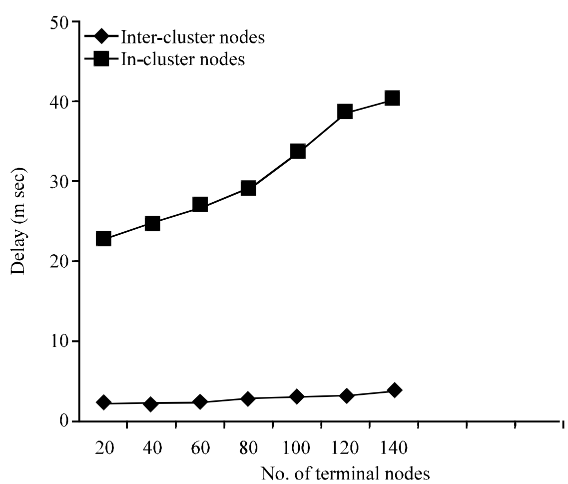

Fig. 9: Time delay between nodes

Experiment tests: We chose parameters temperature as our research model. 182 terminal nodes were distributed in the reservoir dynamic monitoring system in the permanent well. Figure 7 shows a change of parameters measured by a node in 8 h. After a comparison with the data from field sampling model, the measurement error of the parameters met the due requirement. Meanwhile, all the distributed nodes got access to the network successfully. It was measured that the actual network management expense, which refers to the ratio of routing and administrating data to total data, was less than 3.5%

Figure 8 reveals a change of power supply for the terminal nodes in the tested network in 6 months. As we can see, the value decreased only 0.35V in 6 months, which meant low power consumption. The in-cluster and inter-cluster time delay between terminal nodes is also measured. The time delay between nodes within a cluster is less than 4 ms, as shown in Fig. 9.

CONCLUSION

The cluster-tree network is a commonly-used topology in wireless sensor network. This paper, based on a study of LMAC protocol, has proposed a combination of LMAC and cluster-tree topology to design the wireless sensor network. The system is featured by low energy consumption and low time delay. LMAC protocol is used within the clusters; FDMA is applied between the clusters. Frequency division approach solves the problems of time delay and low extendibility characteristic of LMAC protocol. The experimental results of the monitoring system in the reservoir dynamic monitoring system of permanent well proved it effective in solving the mentioned problems. Next we will further optimize the inter-cluster routing protocol to make it less affected by the number of nodes. And simulation for other indexes concerning the routing protocol will also be conducted comprehensively and completely.

ACKNOWLEDGMENT

This work was supported by Natural Science Foundation (41372155), Program of Hubei Education Department (B20121203) and Key Program of Hubei Education Department (D20111306).

REFERENCES

Anastasi, G., M. Conti, M. di Francesco and A. Passarella, 2009. Energy conservation in wireless sensor networks: A survey. Ad Hoc Networks, 7: 537-568.

Chen, H., Q. Shi, R. Tan, H.V. Poor and K. Sezaki, 2010. Mobile element assisted cooperative localization for wireless sensor networks with obstacles. IEEE Trans. Wireless Commun., 9: 956-963.

Lee, S., E. Kim, C. Kim and K. Kim, 2009. Localization with a mobile beacon based on geometric constraints in wireless sensor networks. IEEE Trans. Wireless Commun., 8: 5801-5805.

Liao, W.H., Y.C. Lee and S.P. Kedia, 2011. Mobile anchor positioning for wireless sensor networks. IET Commun., 5: 914-921.

Tharini, C. and P.V. Ranjan, 2009. Design of modified adaptive huffman data compression algorithm for wireless sensor network. J. Comput. Sci., 5: 466-470.

Urie, M.T. and K.M. Chugg, 2010. Designing beacon mobility to improve target localization from range measurements. Proceedings of the Military Communications Conference, October 31-November 3, 2010, San Jose, CA, pp: 1281-1285.

Zheng, H., S. Xiao, X. Wang and X. Tian, 2012. Energy and latency analysis for in-network computation with compressive sensing in wireless sensor networks. Proceedings 0f the INFOCOM, March 25-30, 2012, Orlando, FL., pp: 2811-2815.