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Research Article

A Real-Time and Low Power Working Method for Mobile WSN

Xiaotong Du, Wei Zhang, and Dong Li

School of Control Science and Engineering, Shandong University, Jinan 250061, China

Correspondence should be addressed to Xiaotong Du; lwjdms@sdu.edu.cn

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In many mobile wireless sensor network (WSN) applications, the low power problem is often ignored to maintain the real-time property of monitoring nodes. To solve the long-time working problems of mobile nodes and the whole WSN network, this paper provides a new working method. First, the real-time and consumption features are compared between the Random Mechanism (RM) and Time-Division Mechanism (TDM) through experiments. Secondly, a mobile Time-Division Mechanism based on subnet node ID is designed to reduce the power consumption on the premise of real-time requirements effectively. At the same time, relevant experimental results demonstrate that time synchronization mechanism cannot improve the real-time performance effectively.

1. Introduction

Wireless sensor network (WSN) is widely used in many areas such as military, civilian use, and medical biology, because it has the key features of self-organizing capability, low power, and easy maintenance [1]. The demand for network mode, power consumption, and maintenance is often different in applications such as food safety tracking system, transportation and monitoring of hazardous goods, and firearms management in the bank remittance process [2]. First, the wireless nodes need to shift between different networks, and they must upload the status of the monitoring objects at the given time, or they must emit the alarm signal, which means that the whole network must have real-time function. Secondly, as the nodes are only used for active labels or simple information collection, they communicate little with the network manager (coordinator) after being woken up from the dormancy. At last, the realization of safety monitor function depends on the coordination of multiple WSNs. Although many existing studies explored the real-time and energy consumption problems of wireless sensor network [3–6], few studies have ever considered the problem with mobile nodes in multiple WSNs.

Therefore, not only the real-time and power consumption in the subnetwork of WSN but also the influence of whole network coordination should be considered.

In this kind of WSN real-time applications, there exist conflict packages which have great influence on the real time and power consumption, because the time of different nodes in the WSN is not synchronized [7]. Provided that the time is synchronized among all the network nodes, it can satisfy the real-time acquirement through allocating different slot time and using certain dispatch algorithms [8–10].

In order to assure a proper synchronization, many protocols have been proposed in the last few years. However, the time synchronization methods at present are still the commonly used DMTS [11–13], RBS [14, 15], and TPSN [16, 17]. DMTS (delay measurement time synchronization) adjusts the receiver's time by estimating the network delay reasonably with the sender's time stamp, which means that the coordinator needs to send at least one time synchronization package to the monitoring nodes before the nodes upload the status of the monitoring objects. However, this method does not estimate and compensate the clock skew [18], so the precision is very low. Besides, in the practical application, more than three packages are needed to complete the time synchronization as the number of the wireless nodes grows. RBS needs the receiving nodes to adjust the time difference by exchanging the receiving time sent by the sender with each other. As the nodes need to exchange the time with each other, the mutual time and power consumption will increase significantly, especially when the number of nodes increases. TPSN provides an algorithm to adjust the time difference between the sender and receiver. As the wireless nodes increase, it will cost more power consumption and time latency.

Consequently, due to the influence of transmission distance and crystal oscillator craftwork, the abovementioned time synchronization methods cannot solve the synchronization problem efficiently and even reduce the real-time performance of the whole network.

In this paper, we first use contrastive experiments to demonstrate that the Time-Division Mechanism can improve the real-time feature and reduce the power consumption dramatically in a subnetwork of WSN. On this foundation, a new real-time and low power working method for mobile WSN is proposed. It is demonstrated that the proposed method can effectively satisfy the requirements of real-time and low power consumption.

The remainder of this paper is organized as follows. The experiments of RM and TDM used for the WSN subnetwork are set up and analyzed in Section 2. Section 3 presents the contrastive experiments to analyze the influence of time synchronization in TDM. Section 4 designs a new working method for the whole mobile WSN considering the optimism of real time and power consumption. Some concluding remarks are provided in Section 5.

2. Experiment Setup and Analysis for Subnetwork

The management and monitor application differs in the areas of the food safety tracking system, transportation and monitoring of hazardous goods, and management and monitoring of firearms used in the bank remittance process. However, they can all be seen as the process of nodes coming in and out of the different WSNs with strict given time, as shown in Figure 1.

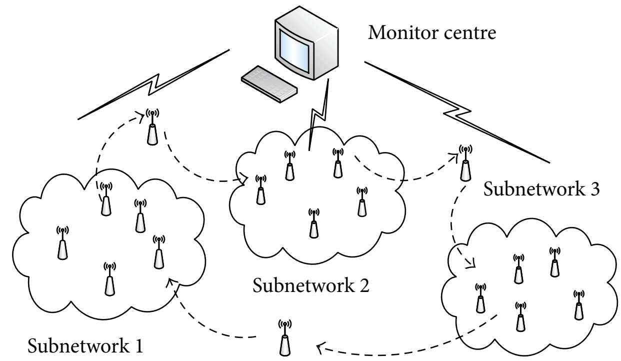

Figure 1: Schematic description of multiple mobile WSNs.

Although these applications need to consider the coordination of multiple WSNs when satisfying the specific requirements of real time and low power consumption, the key factor is still the realization of these requirements in subnetworks. Therefore, the working mechanism in a subnetwork should be investigated first.

To study the time and power consumption features in the subnetworks, we design the Random Mechanism (RM) and Time-Division Mechanism (TDM) to compare the time and power consumption in the monitoring networks. The two mechanisms will be introduced in the following section.

2.1. Random Mechanism. When all the generic nodes are powered, they all stay in the sleep state first and wait for the coordinator node to wake them up. All the generic nodes will apply to join the network immediately after waking up. In this mechanism, the application time of all the generic nodes is almost the same. Assuming that the time for all the nodes to join the network is T, we can express the best time $T_{\min}$ as follows:

$$T_{\min} = nt_0, \tag{1}$$

where n represents the nodes number and t_0 is the ideal joining time that one node just needs to apply once. However, the worst time $T_{\max}$ is variable. It can equal tens of and even hundreds of $T_{\min}$ at the worst condition.

2.2. Time-Division Mechanism. The initial join time is divided artificially and we assume that the time interval is t. As we do not know how many nodes remained without joining the network, we cannot allocate the slot time again. Thus, these remaining nodes will join the network with the RM. We can get the join time in this mechanism as follows:

$$T = nt + jt_0, \tag{2}$$

where j represents the remaining nodes number and satisfies $j \in [0, n]$.

It is known that the work process of monitor nodes mainly has three statuses, which are sleep, idle, and working. Thus, we can describe the system consumption as follows:

$$P_0 = P_s + P_i + P_w, \tag{3}$$

where P_s, P_i, and P_w represent the sleep, idle, and work consumption, respectively.

The idle status is an alerted status between the sleep and working with short time and little power consumption, which can be ignored. Therefore, (3) can be simplified into

$$P_0 = P_s + P_w. \tag{4}$$

Because the sleep status has a very low consumption, the power consumption mainly depends on the work status. When generic nodes are woken up, they stay in the reception status most of the time and the only difference in power consumption depends on the transmission times. Assuming that the system consumption is P, we can get

$$P = CP_w, \tag{5}$$

where C represents the transmission times of all nodes. Considering the fact that P_w is almost the same for every node, we can measure the consumption with the transmission times C. If the node number is n, C can be expressed as follows:

$$C = \sum_{i=1}^{n} C_i, \tag{6}$$

where C_i represents the transmission times of node i.

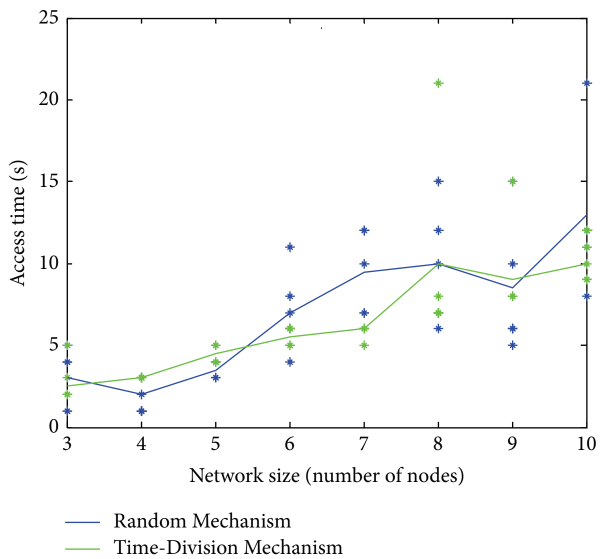

Figure 2: Access time comparison over network density.

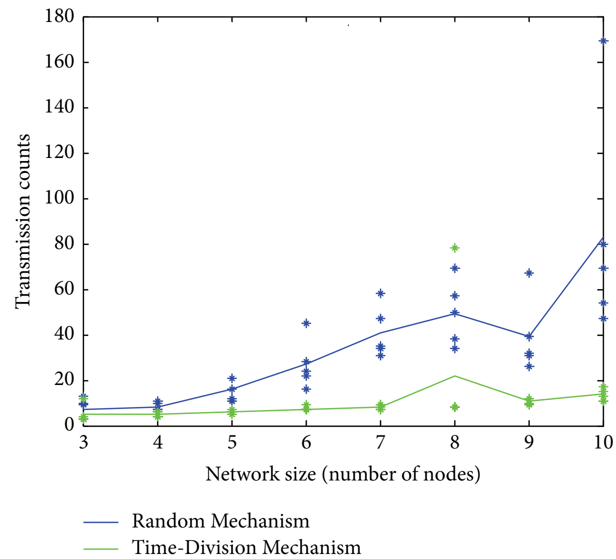

Figure 3: Transmission counts comparison over network density.

For RM, C_i is uncertain because of the uncertain conflicts. However, for TDM, $C_i \in [1, 3]$ and the transmission times are less than three times of the node number.

The experiment setup consists of ten generic nodes and one coordinator node. There are few conflicting packets when there are fewer than two generic nodes in a wireless network. Therefore, we take eight small networks of varying size from 3 to 10 nodes. According to every network, five experiments are run. The joining time and transmission times with varying node densities are recorded. At last, we average the test values for different node densities and plot Figures 2 and 3.

Figure 2 gives the access time sequences X_t and Y_t in the two modes, which can be seen as follows:

$$X_t = \{3, 2, 3.5, 7, 9.5, 10, 8.5, 13\},$$
$$Y_t = \{2.5, 3, 4.5, 5.5, 6, 10, 9, 10\}. \quad (7)$$

For RM, when the node number is less than five, the access time satisfies the minimum time given by (1). However, as the number grows, the access time gets more uncertainties and increases significantly. For example, the access time is two times longer in RM than that in TDM when the node number is seven.

For TDM, the access time almost satisfies the minimum time given by (1) and is linear with the number of the nodes. However, when there are 8 nodes in the network, the access time reaches 22 seconds, which is caused by the conflicts of clock skew. Fortunately, TDM has a low probability of conflicts.

In Figure 3, we can get the power consumption sequences X_n and Y_n as follows:

$$X_n = \{7, 8, 16, 27, 41, 49, 39, 83\},$$
$$Y_n = \{5, 5, 6, 8, 8, 22, 11, 14\}. \quad (8)$$

For RM, the transmission times are three times more than the node number when the node number is less than five. However, as the node number grows, the transmission times grow rapidly. The transmission times are ten times more when the node number is ten. It demonstrates that the conflict grows rapidly as the node number grows.

For TDM, the transmission times are almost equal to the node number. The power consumption is much lower in TDM than that in RM, even when there are conflicts in the TDM occasionally. For example, when there are 8 nodes in the WSNs, the average transmission times are significantly less in TDM than those in RM.

3. Analysis of Time Synchronization

The above experiments do not consider the time synchronization. Nevertheless, the real-time property and power consumption may not change better with it. The access time will not improve effectively with the strict time synchronization for the Random Mechanism, because it may bring more conflict packages. For the Time-Division Mechanism, there will be no conflict theoretically if we synchronize the initial time of application and allocate different time slots. We first analyze the performance of common time synchronization algorithms, including RBS, TPSN, and DMTS. RBS and TPSN methods need the nodes to interact with each other. Although they can provide higher precision, the synchronization time may be nearly the same as the access time considering the actual situations in the practical applications. Therefore, these two methods can be hardly used in the real-time applications. DMTS may need less time to finish the synchronization, but it has specific limits. First, it has low precision and cannot improve the clock precision effectively. Secondly, it cannot be guaranteed that the broadcast synchronized packages are received by all the receiving nodes every time in actual situations, so about one to three broadcast synchronized packages may be needed to complete the time synchronization. At last, if the coordinator node does not wake up all the sleeping generic nodes in the first waking

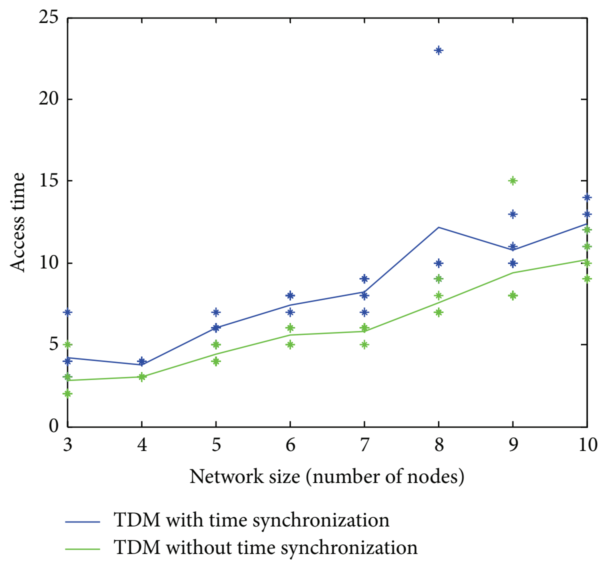

Figure 4: Access time comparison with or without time synchronization.

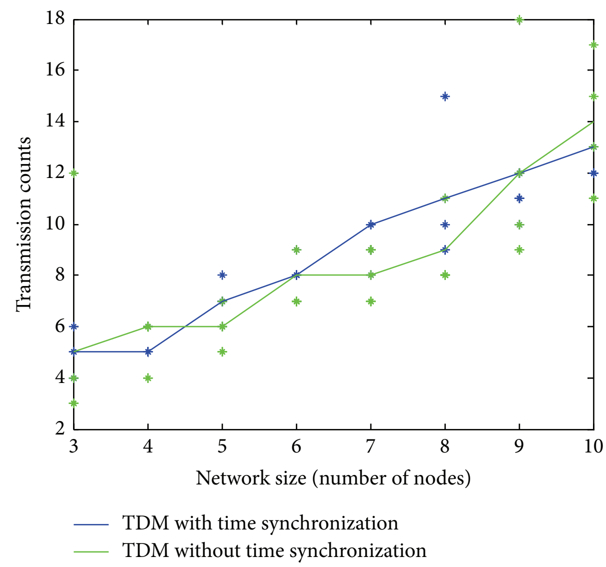

Figure 5: Transmission counts with or without time synchronization.

period, the sleeping nodes will stay in the sleeping state until the next waking period, which may reduce the real-time performance. However, if we use the potential conflict packages, the sleeping nodes can be woken up ahead of time. Figures 4 and 5 show the comparative experiments with and without time synchronization.

As is shown in Figure 4, when time synchronization is adopted, we must leave enough time for the time synchronization, and the time for joining the network will be longer. In this situation, if some generic nodes are not woken up in the first waking period, they are waiting until the next waking period, which will result in poor performance. For example, when the network size is 8, it takes as long as 24 seconds for the TDM with time synchronization to finish the ad hoc network, just because some sleeping nodes are not woken up until the next waking period. Comparatively, when there are 9 nodes in the network, the access time is only 15 seconds for the TDM without time synchronization, because the conflict packages wake up the sleeping nodes ahead.

For the transmission counts, there is no obvious difference with or without time synchronization. Although there may be some conflict packages without time synchronization, the TDM with time synchronization also needs to send some synchronized packages. As is shown in Figure 5, the power consumption is nearly the same for both of the two mechanisms.

From the analysis above, it can be concluded that time synchronization cannot improve the real-time and consumption performance effectively. Besides, when the nodes need to move between different networks, the different networks need time synchronization every time the moving nodes enter the networks, which can reduce the real-time performance dramatically. Therefore, TDM without time synchronization is a better working mechanism in the subnetworks.

4. An Optimized Working Mechanism for Multiple WSNs

From the above experimental analysis, it is proven that the TDM without time synchronization mechanism is a better working method and the time slot is based on the node ID. Thus, when the nodes move from one network to another, there may be nodes with the same ID, which will cause conflict packages. A solution is allocating different node IDs for the nodes in all the networks. However, when there are too many nodes in the networks, the solution will increase the network latency and the real-time performance cannot be guaranteed. Therefore, an optimized working mechanism for multiple WSNs is designed.

Assuming that the node number, node ID, joining and leaving network time, and power consumption are certain in a subnetwork, we will analyze the working mechanism based on two networks. At the initial time, the IDs of the two different networks are X_i and X_j, which can be expressed as

$$X_i = X_j = i \quad \{i = 1, 2, \dots, n\}. \tag{9}$$

When there are m nodes that will leave subnetwork 1, the node IDs will subtract 1 until they become zero. We can get the expression as follows:

$$X_k = X_{i-k}, \tag{10}$$

where $k \in \{1, 2, \dots, m\}$, $i \in \{1, 2, \dots, n\}$. X_0 will leave the subnetwork first. Thus, the m node IDs that will leave subnetwork 1 can be given by

$$Y_i = i \quad \{i = 1, 2, \dots, m\}. \tag{11}$$

At this time, the remaining node IDs of subnetwork 1 will be updated as follows:

$$X_i' = i \quad \{i = 1, 2, \dots, n-m\}. \tag{12}$$

When the m nodes leave subnetwork 1, they should first update their IDs to Y_i, as their IDs have already become zero. Besides, the coordinator of subnetwork 1 will notify the monitor centre that the m nodes will leave subnetwork 1 and join subnetwork 2. Then, the monitor centre will require subnetwork 2 to change generic node IDs to avoid confliction. The node IDs in subnetwork 2 will add m. Thus, the IDs in subnetwork 2 will be updated as follows:

$$X'_j = j \quad \{j = m+1, m+2, \ldots, m+n\}. \tag{13}$$

In this condition, there will be m reserved ID space in subnetwork 2 for the m moving nodes from subnetwork 1. When the m moving nodes join subnetwork 2, network 2 will become a network that contains k nodes, where $k = m + n$. The node IDs will be modified as

$$X''_j = j \quad \{j = 1, 2, \ldots, m, m+1, m+2, \ldots, m+n\}. \tag{14}$$

As is shown in (14), there is no conflict node ID in subnetwork 2, so it can use the TDM to complete the ad hoc network and satisfy the real-time and low power consumption requirement.

When the m nodes need to leave subnetwork 2 and return to subnetwork 1, they will use the same mechanism as before. The m nodes with IDs becoming zero will leave subnetwork 2. Considering that the remaining nodes IDs have become X'_j in subnetwork 1, the m nodes IDs will add $n-m$ to avoid conflict. Thus, the m nodes IDs will be updated as follows:

$$Y'_i = i \quad \{i = n-m+1, n-m+2, \ldots, n\}. \tag{15}$$

It can be seen that there is no conflict node ID from (12) and (15). The nodes can access subnetwork 1 at the optimized mechanism. At the same time, if nodes leave subnetwork 1 next time, the remaining nodes will leave first, because they own small IDs, as is shown in (12).

5. Conclusions

Aiming at solving the real-time and power consumption problems in the mobile WSNs applications, a new working mechanism is addressed in this paper. First, it is proven that Time-Division Mechanism (TDM) works better than the Random Mechanism (RM) in a subnetwork through comparative experiments. Besides, the experimental results demonstrate that time synchronization cannot improve the network performance effectively. On the contrary, the conflict packages under the TDM without time synchronization can improve the real-time performance. Finally, the mobile TDM based on node ID for the multiple WSN applications is designed.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," *IEEE Communications Magazine*, vol. 40, no. 8, pp. 102–114, 2002.

[2] M. M. Aung and Y. S. Chang, "Temperature management for the quality assurance of a perishable food for supply chain," *Food Control*, vol. 40, pp. 198–207, 2014.

[3] Z. Hanzálek and P. Jurčík, "Energy efficient scheduling for cluster-tree wireless sensor networks with time-bounded data flows: Application to IEEE 802.15.4/ZigBee," *IEEE Transactions on Industrial Informatics*, vol. 6, no. 3, pp. 438–450, 2010.

[4] G. Anastasi, M. Conti, and M. Di Francesco, "Extending the lifetime of wireless sensor networks through adaptive sleep," *IEEE Transactions on Industrial Informatics*, vol. 5, no. 3, pp. 351–365, 2009.

[5] S. Yoo, P. K. Chong, D. Kim et al., "Guaranteeing real-time services for industrial wireless sensor networks with IEEE 802.15.4," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 11, pp. 3868–3876, 2010.

[6] H. Aydin, R. Melhem, D. Mossé, and P. Mejia-Alvarez, "Power-aware scheduling for periodic real-time tasks," *IEEE Transactions on Computers*, vol. 53, no. 5, pp. 584–600, 2004.

[7] B. Sundararaman, U. Buy, and A. D. Kshemkalyani, "Clock synchronization for wireless sensor networks: a survey," *Ad Hoc Networks*, vol. 3, no. 3, pp. 281–323, 2005.

[8] F. Sivrikaya and B. Yener, "Time synchronization in sensor networks: a survey," *IEEE Network*, vol. 18, no. 4, pp. 45–50, 2004.

[9] L. He and G. Kuo, "A novel time synchronization scheme in wireless sensor networks," in *Proceedings of the IEEE 63rd Vehicular Technology Conference (VTC '06)*, vol. 2, pp. 568–572, Melbourne, Australia, July 2006.

[10] C. N. Xu, L. Zhao, Y. J. Xu, and X. W. Li, "Time synchronization improvement strategy for wireless sensor networks," *Chinese Journal of Computers*, vol. 30, no. 4, pp. 514–523, 2007.

[11] W. R. Shi, Y. Zhang, and P. C. Deng, "The research of local time synchronization protocol of sensor network," in *Proceedings of the 26th Chinese Control Conference*, Hunan, China, July 2007.

[12] J. R. Xie, Y. M. Hu, C. X. Liu, and L. Liu, "Fundamental technique for wireless sensor networks Time synchronization," *Computer Engineering and Design*, vol. 28, no. 1, pp. 76–86, 2007.

[13] P. Su, "Delay measurement time synchronization for wireless sensor networks," Tech. Rep., 2003.

[14] F. Wang and J. Liu, "RBS: a reliable broadcast service for large-scale low duty-cycled wireless sensor networks," in *Proceedings of the IEEE International Conference on Communications (ICC '08)*, pp. 2416–2420, Beijing, China, May 2008.

[15] J. Elson, L. Girod, and D. Estrin, "Fine-grained network time synchronization using reference broadcasts," in *Proceedings of the 5th Symposium on Operating Systems Design and Implementation (OSDI '02)*, 2002.

[16] S. Ganeriwal, R. Kumar, and M. B. Srivastava, “Timing-sync protocol for sensor networks,” in *Proceedings of the First International Conference on Embedded Networked Sensor Systems (SenSys ’03)*, pp. 138–149, November 2003.

[17] X. Zhou, W. Wei, and B. Qin, “Research on time synchronization in wireless sensor network,” *Chinese Journal of Sensors and Actuators*, vol. 19, no. 1, pp. 20–29, 2006.

[18] S. M. Zhou, J. Y. Zhou, S. B. Pan, and Y. M. Sun, “The research of time synchronization in WSN,” *Application of Electronic Technique*, vol. 32, no. 9, pp. 24–26, 2006.