Quality of Service Management of Wireless Sensor Networks Based on Geotechnical Environmental Safety

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Abstract. In order to meet the requirements of data transmission reliability, a geotechnical environment security monitoring system based on wireless sensor network is proposed. The optimization control strategy uses the deadline miss rate as the QoS performance evaluation index. For the data transmission between the sensor node and the coordinator node, the PID controller is used to calculate the network bandwidth requirement of all sensor nodes, and then the system optimal problem is solved to realize the dynamic. The transmission period of the sensor node is adjusted to maintain the deadline miss rate at a normal set level, thereby improving the QoS of the network. Experiments show that the optimized control strategy improves the performance of the system and has good practicability in geotechnical environmental safety monitoring.

1. Introduction

With the continuous development of electronic technology, information technology and communication technology, wireless sensor network technology is widely used in social life and social production, and it is one of the hot research technologies currently in the research [1-3]. While the traditional wireless sensor network is convenient to construct the geotechnical safety monitoring system, it is still difficult to completely avoid channel congestion, time-varying transmission delay, and data packet loss during transmission [4]. These phenomena will seriously affect the performance of the geotechnical safety monitoring system, and even cause the system to not work properly. Therefore, the traditional wireless sensor network is difficult to meet the requirements of data transmission reliability in geotechnical environment monitoring.

Based on the above analysis, this paper proposes a PID based feedback control strategy from the perspective of improving the QoS of wireless sensor networks [5]. The strategy uses the deadline miss rate as the evaluation index [6-7], and the aggregation node calculates the deadline miss rate based on the number of network deadline miss events. The PID controller calculates the bandwidth requirement of the sensor node in the next calling period according to the measurement error of the deadline miss rate, thereby adjusting the DPSP value of the sensor node to maintain the QoS level, and the entire wireless sensor network system cycles to maintain the system. In a good running state.
2. Design of QoS Management Optimization Control Algorithm

Based on the previous research, the relationship between the acquisition period (SP) and the packet transmission period (DPSP) of the sensor node data is studied. In order to reduce network congestion and improve network QoS and performance, an application is based on Real-time optimization control algorithm for QoS state management.

The periodic data transmission of the sensor node is triggered by its own periodic sampling. Once the sampling is completed, the node automatically enters the data packet transmission state. There is a certain linear relationship between SP and DPSP, as described in formula (1):

$$h_i(k) = \frac{b}{a} s_i(k)$$  \hspace{1cm} (1)

Above parameters, i is the sensor node number, hi(k) is the transmission period of node i, si(k) is the sampling period of node i, k is the sampling order, k=0, 1..., a is the sampling data length in the data packet , b is the effective data length in the packet.

It can be derived from (1). When a and b are constants, the relationship will be linear:

$$h_i(k) \pm \Delta h_i(k) = \frac{b}{a} [s_i(k) + \Delta s_i(k)] \implies \Delta h_i(k) = \frac{b}{a} \Delta s_i(k)$$  \hspace{1cm} (2)

It can be seen from the above relationship that the purpose of the adaptive sampling method can be achieved by transforming the adaptive change $s_i(k)$ into the adaptive $h_i(k)$ . In order to improve network QoS, it is necessary to reduce the data transmission request of a single node per unit time, which can be realized by increasing $\Delta h_i(k)$. However, as $h_i(k)$ increases, more and more data packets will accumulate at the sensor nodes, and the data storage space of the nodes is very limited. The large amount of data accumulation can easily lead to data overflow and waste of bandwidth. Therefore, a mechanism for self-determination of wireless sensor network congestion is designed, and a self-adjusting method is used to solve the problem.

The optimization control method is based on the automatic control theory. The principle is to add an additional closed-loop feedback control to the original system to adjust the real-time state of the network. This closed-loop feedback is saved as a function running on the aggregation node. The universal deadline miss rate of this method is used as an evaluation index of network real-time QoS. The aggregation node calculates the deadline miss rate based on the number of missed events in the network deadline. The PID controller calculates the bandwidth requirement of the sensor node in the next calling period according to the measurement error of the deadline miss rate, thereby adjusting the value of the DPSP of the sensor node to achieve a high level of QoS. The entire wireless sensor network system circulates to maintain the system in a good operating state.

In a controller call period T(k), the number of deadline miss events corresponding to the sensor node i and the sink node is $n_i(k)$, the transmission period $h_i(k)$ of the sensor node i in T(k), and Satisfy $h_i(x) \leq T(k), \ x = 0,1,..., \left\lceil \frac{T(k)}{h_i(k)} \right\rceil; \ i=1,2,...,n$. The formula for calculating the miss rate of the sensor node i during the kth call cycle of the controller is as follows:

$$d_i(k) = \frac{n_i(k)}{\left\lceil \frac{T(k)}{h_i(k)} \right\rceil}$$  \hspace{1cm} (3)

The error formula for the miss rate is as follows:

$$e_i(k) = D_p - d_i(k)$$  \hspace{1cm} (4)

$D_p$ is the set value of the deadline miss rate.
The PID control formula for the sensor node's bandwidth requirements and the deadline miss rate error is as follows:

\[
    u(k) = k_p[e(k) + \frac{T}{T_1}\sum_{j=0}^{k} e(j) + \frac{T_0}{T}[e(k) - e(k-1)]]
\]

(5)

\[
    \Delta u(k) = k_p[e(k) - e(k-1)] + k_fe(k) + k_d[e(k) - 2e(k-1) - e(k-2)]
\]

(6)

The bandwidth requirement of the sensor node in the T(k+1) call cycle of the coordinator is \( u(k+1) \),

\[
    u(k+1) = u(k) + \Delta u(k)
\]

(7)

The relationship between the bandwidth requirement \( u(k+1) \) of the sensor node \( i \) at T(k+1) call cycles and its transmission period \( h_i(k+1) \) is as follows:

\[
    h_i(k+1) = \frac{c_i}{u_i(k+1)} = \frac{(b+L)\nu}{u_i(k+1)}
\]

(8)

The \( c_i \) represents the single packet transmission time of sensor node \( i \), \( L \) represents the communication overhead outside the valid data domain in the data packet, and \( \nu \) represents the network data transmission rate.

The transmission period \( h_i(k+1) \) of the sensor node \( i \) in the T(k+1) calling cycle of the coordinator needs to satisfy the following conditions:

\[
    h_i(k+1) = \begin{cases} 
        h_{imin} & h_i(k+1) \leq h_{imin} \\
        h_i(k+1) & h_{imin} < h_i(k+1) < h_{imax} \\
        h_{imax} & h_i(k+1) \geq h_{imax}
    \end{cases}
\]

(9)

The \( h_{imin} \) indicates the minimum value of the packet transmission period allowed by the sensor node \( i \), and the \( h_{imax} \) side indicates the maximum value of the packet transmission period allowed by the sensor node \( i \).

3. Design of QoS Management Optimization Control Algorithm

In order to verify the effectiveness of the proposed QoS based optimization control strategy, this paper compares the Zigbee protocol stack method with the Zigbee protocol stack method, and compares the threshold miss rate of node D3. The various parameters are set as follows:

- The initial value of the transmission period is set to 20ms, the minimum transmission period \( h_{imin} \) is 20ms, the maximum transmission period \( h_{imax} \) is 80ms, \( a \) is equal to \( b \), the controller call period \( T(k) \) is 1s, and the deadline miss rate \( D_p \) is 10%.
- The value of \( b+L \) is 80 bytes, the network data transmission rate \( \nu \) is 250 kbps, the single packet transmission time of sensor node \( i \) is \( c_i \) is 2.56 ms, the initial value of bandwidth requirement is 0.128, \( k_p \) is 0.021, \( k_f \) is 0.012, \( k_d \) is 0.003.
- The total duration of each set of experiments was 360s. Open nodes D1, D2, and D3, run for 120s, then open nodes D4, D5, and D6, run for 120s, then open nodes D7, D8, and D9 for 120s.
The results of the experiment are shown below:

**Figure 1.** Experimental node distribution map.

In the range of 0~120s, there is no increase in interference. The value of the deadline and the miss rate of the Zigbee protocol stack method are about the same. Because of the small network load, whether
QoS management has little effect on the deadline miss rate. When 120s~240s, the interference of nodes is increased, and the value of the deadline of the protocol stack method increases significantly. The method increases briefly and then decreases to the vicinity of the given value. The short increase is due to the system needing a certain adjustment time. When 240s~360s, the system increases the interference, and the value of the deadline of the protocol stack method rises again, even close to 100%. The method in this paper only increases briefly and then falls to the vicinity of the given value. In the case of QoS management, the transmission period is dynamically adjusted as the deadline miss rate is changed. During the entire experimental process, the value of the deadline miss rate is maintained at 8% and has a high QoS.

4. Conclusion
In the case of QoS management, the system can dynamically adjust the transmission period according to its own deadline miss rate, thereby ensuring that the network is in a higher QoS, reducing channel congestion, time-varying transmission delay, and data packet loss. Improve the reliability of network data transmission.

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References
[1] H.B.Li. Research on Fault Tolerance Mechanism and Algorithm of Wireless Sensor Networks [D]. ChongQing University, 2014.
[2] S.T.Yuan. Research and implementation of wireless sensor network based on security policy [D]. Shenyang Normal University.
[3] H.Yan, Z.H.Wang, X.H.Li. Wireless Sensor Network Technology and Its Application in Xinjiang Agriculture[J]. Journal of Xinjiang Normal University(Natural Science Edition), 2009,28(3):102-104.
[4] C.Y. Lee, H.I. Cho, G.U. Hwang, et al. Performance modeling and analysis of IEEE 802.15.4 slotted CSMA/CA protocol with ACK mode[J]. AEU-International Journal of Electronics and Communications, 2011, 65(2):123-131.
[5] K. Zhao. Remote Control System and Quality of Service (QoS) Based on MESH Wireless Network [D]. Beijing Jiaotong University, 2017.
[6] H.Chen. Dynamic Assignment Strategy of RealTime Task Priorities [J]. Small Computer Systems, 2010, 31(7): 1385-1388.
[7] Y.D.Sun, C.F.Xing, L.Xu. Real Time Deadline Allocation in Distributed Weapon Target Allocation. Journal of Beijing University of Aeronautics and Astronautics, 2012, 38(12): 1661-1665.