New Polling Scheme based on Busy/Idle Queues Mechanism

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Abstract

Polling control system is widely used in production and life including time-sharing computer systems, industrial control, communications, and computer networks. The article proposes a new polling control system based on Busy/Idle queues, which sorts normal polling queues into Busy Queues (BQ) and Idle Queues (IQ) according to if there are customers in the queue. Then, BQ is served by a Gated access policy and IQ keeps a sleeping state until it is woken up by arriving customers. Moreover, parallel scheduling is used to save switch-over time. We build a system model using the embedded Markov chain, probability mother function, the throughput, cycle time, mean queue length and mean waiting time of significant system characteristics. Theoretical calculated values are approximately equal to the simulated values, indicating that the new system is correct and achieves a better performance than the traditional polling scheme.

Keywords: polling system; parallel scheduling; busy/idle queues; Gated service

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1. Introduction

As a kind of reservation-based scheduling control model, polling control system has wide applications including computer communication network, traffic control, and industrial control. Polling systems can be used to provide delay guarantees for time-sensitive services [1-3]. More recently, many polling system model researches and analyses have been triggered toward the development of new application fields and discover that polling control systems are significant in modeling various applications [4-7].

The polling control systems generally have three main considerations: the order in which queues are served, the service regulation, and the order customers of a given queue are served. The critical performance characteristics used in polling system analysis are throughput, mean queue length, mean waiting time and mean cycle time. Analysis and research become more difficult as the model becomes more complex [8-10]. Most researches can obtain the results of the mean cycle time, throughput and mean queue length. The exact analysis of mean waiting time is usually too difficult to get any results.

A polling control system consists of N queues and a single server. The process of polling system includes: arrival of information packets in each queue, conversion process between queues, and service process of information packets. A normal polling system cannot distinguish queues with customers from ones without customers in which the IQs result in the waste of service resources [11-12]. It will be more efficient to poll only BQs [13]. This paper proposes a new polling model to sort normal polling queues into BQs and IQs according to if there are customers in a queue. Then, BQs are served by a Gated access policy and IQs keep a sleeping state until it is woken up by arriving customers. Moreover, a parallel scheduling is used to save switch-over time. Once this model is set up, we analyze performance characteristics of throughput, cycle time, mean queue length, and mean waiting time. Simulation results show that the new system meets actual needs well and has better efficiency.

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2. Wireless Sensor Networks

As a new technology for obtaining information, wireless sensor networks (WSN) have become a hot technology in network research. WSN provides a new and effective way to study the physical world by interacting with the real-time parameters of the surrounding environment and the ability to analyze and fuse the measured data. In particular, with the continuous development of sensor technology, wireless communication networks, computer processing systems, signal processing and data analysis, and ultra-large-scale integrated circuits in today's science and technology fields, the development of wireless sensors has become more and more popular. The huge application value and greater and wider application prospects have attracted great attention from various fields and research institutions at home and abroad, and have made more and more research results. In more in-depth research and more extensive application of people, wireless sensor networks will be deeply involved in all areas of human life, and will have a profound impact on human production, life, and development.

Wireless sensor networks mainly include sink nodes, administration nodes and sensor nodes. Figure 1 shows the architecture of a wireless sensor network. As shown, after each node is randomly distributed in the area to be monitored and self-organized to form the network, the sensor node monitors the surrounding target objects and periodically monitors the collected data via other sensor nodes according to a specific routing protocol jump to send. The data collected from monitoring may reach the management node through the effective processing of multiple nodes during the transmission to the convergence node. The user collects, analyzes, and makes decisions on the data monitored by each sensor node by means of the management node so that the sensor network can be effectively configured and managed.

![Figure 1. Wireless sensor network architecture](image)

2.1. MAC Frame Structure

Wireless sensor network MAC layer frame contains: MAC Header, Sequence Number, Addressing Fields, MAC Footer and Frame Control. The structure of the MAC frame control domain is shown in Figure 2.

![Figure 2. MAC frame control](image)

According to the principle of this paper, based on the characteristics of the original frame to redesign the frame control domain format in wireless sensor network system, four bits of the seven reserved bits are set as the B/I address field to the busy and idle state, as shown in Figure 3.

![Figure 3. Improved MAC frame control](image)
1) State=0, indicating that the state of the node is 0, which means the node is in the idle queue.
2) State=1, indicating that the state of the node is 1, which means the node is in the busy queue.
3) Flag=0, the identifier of the node's requirement is 0, which means the node has no service requirement.
4) Flag=1, the identifier of the node's requirement is 1, which means the node has service requirement.

2.2. Polling Table Setup and Maintenance

Wireless sensor networks often convert self-organizing network to a separate fixed cluster in a clustered manner. At the same time, data is transmitted in the cluster by cluster heads polling each member node. This article proposes a query control method that distinguishes busy and idle state, and the node to be polled is recorded by establishing a polling table at the cluster head node. When the cluster head node performs a query, only busy nodes with service requirements are served. That is, query service is used for busy nodes. For idle nodes that do not have service requirements, they use piggybacking to query. In this way, sensor nodes in the idle loop can enter a low-power state when they are not queried, thus achieving energy saving.

The head node of cluster sends communication address, and polling control system table is set up through the feedback of each member node to note nodes to poll. The polling control system table mirrors the correspondence between polling node's query sequence number and the real node address. In a wireless network sensor network, when a node is detached from the cluster, it means that the battery is exhausted. Delete the node from the polling table, assign its sequence number to the following nodes, and add the following sequence of nodes in order. The polling control system table has the function of recording the dynamic changes of the nodes in the cluster and the service conditions of the nodes. Distinguishing between the busy and idle state of the nodes to realize the differentiation of whether or not there is a network service requirement maximizes energy saving. Therefore, increase the busy/idle identification column in the polling table. The polling table is shown in Table 1.

<table>
<thead>
<tr>
<th>Query sequence number</th>
<th>Node address</th>
<th>Busy/idle state identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0X0002</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0X0005</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0X0007</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0X0012</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0X0010</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0X0003</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0X0016</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0X0014</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0X0018</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0X0015</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0X0020</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>0X0013</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0X0006</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>0X0009</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0X0017</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>0X0004</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>0X0008</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>0X0011</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>0X0021</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1 is a polling control system table of cluster head used in the wireless sensor network. Use 1, 2, 3, … to indicate the node query order. When the number of nodes \( N \) is 19 and \( N \) takes other values, its polling table is similar to Table 1. It can be seen that its query sequence number is not the same as the real node’s address sequence. The cluster head queries each node in turn according to the query sequence. Nodes with the address “0X0019” is not in the table and may leave, run out of battery or be in hibernation. The relationship between the busy/idle state identifier value and the node query serial numbers are also dynamically changing. When a node’s business requirements change, its own identity state changes.
3. Model Description

As it shown in Figure 4, the busy/idle queues distinguished polling system consists $N$ queues $Q_1, Q_2, \ldots, Q_N$ and a server. $N$ queues are divided into two subsystems: a busy customer system (busy ring), in which there are customers to wait for being served, and an idle customer system (idle ring), in which there are no customer in each queue. The server only polls and serves the busy queues. Meanwhile, once one queue of the idle ring needs customers to arrive, which will be moved to the busy ring and queried in sequence. When the busy queues are queried, the server serves the customers in the queues according to the rule of Gated service, only are those customers proceeded which arrived before the polling time. Other customers are still waiting in line for the next polling. Furthermore, a parallel mechanism was carried out to save the overhead time. When the server serves BQs, it simultaneously listens for the next busy queue.

![Query the busy queue](image1)
![Query the idle queue](image2)
![Figure 4. Busy ring/idle ring-distinguished polling system model](image3)

### 3.1. System Work Conditions

The system work conditions are as follows:

1) In the arrival process, type $j (j = 1, 2, \ldots, N)$ customers arriving in $Q_j$ obey Poisson arrival process with probability distribution. Its probability mother function in queue $j$ is $A_j(z_j)$ and variance is $\sigma^2_{A_j} = \lambda_j^2(1) + \lambda_j^2 - \lambda_j^2$ and the arrival rate of $\lambda_j = A_j'(1)$.

2) When serving customers stored in queue $j (j = 1, 2, \ldots, N)$. Customer service time on each queue is independent. Their probability mother function is $B_j(z_j)$, the mean value $\beta_j = B_j'(1)$, with the variance of $\sigma^2_{B_j} = B_j'(1) + \beta_j - \beta_j^2$.

3) In the rest of this article, we studied the distribution of queue length during polling of $Q_j$. Let $\xi_j(n)$ indicate number customers stored in $Q_j$ at $t_n$ when server of this article starts to visit. The probability distribution of $\xi_j(n+1)$ expressed by the probability mother function $G_{i,n}(z_1, \ldots, z_N)$.

4) It is impossible for customers to get lost.

5) Each queue proceeds according to first in-first out (FCFS).

### 3.2. Variable Definition

In order to establish the model the following variables are defined:

$v_i(n)$: The serving time for busy queue $i$.

$\eta_j(n)$: Indicates number customers arriving at busy queue $j$ during time of $v_i(n)$.
3.3. Probability Generating Function

Suppose the server starts to service \( Q \) at time of \( t_n \), define a variable of \( \xi_j(n) \) as the number of type \( j \) \((j=1,2,\ldots,N)\) customers at time \( t_n \). Then, the status of whole polling system at time \( t_n \) could be indicated as \([\xi_1(n),\xi_2(n),\ldots,\xi_N(n)]\). The probability distribution of system state variables at this time is \( P[\xi_1(n)=x_1; j=1,2,\ldots,N] \), and the probability distribution function describing \( N \) system state variables in the model are \( \pi_i(x_1,x_2,\ldots,x_j,\ldots,x_N) \). Define \( \xi_j(n+1) \) as the quantity of type \( j \) \((j=1,2,\ldots,N)\) customers at \( t_{n+1} \); the status of whole polling system at time \( t_{n+1} \) can be represented as \([\xi_1(n+1),\xi_2(n+1),\ldots,\xi_N(n+1)]\). The probability distribution of system state variables at this time is \( P[\xi_1(n)\ldots j; j=1,2,\ldots,N] \), and the probability distribution function describing \( N \) system state variables in the system is \( \pi_i(y_1,y_2,\ldots,y_j,\ldots,y_N) \). Under the condition \( \sum_{i=1}^N\lambda_i=\lambda \rho \leq 1 \) and \( \rho=\lambda \beta \). The probability distribution is defined as Equation (1):

\[
\lim_{n\to\infty} p_i[\xi_j(n)=x_j;i=1,2,3,\ldots,\infty]=\pi_i(x_1,x_2,\ldots,x_j,\ldots,x_N)
\]

The probability generating function of \( \pi_i(x_1,x_2,\ldots,x_j,\ldots,x_N) \) at time \( t_n \) is defined as Equation (2):

\[
G_i(z_1,z_2,\ldots,z_i,\ldots,z_N)=\sum_{y_1=0}^\infty\sum_{y_2=0}^\infty\ldots\sum_{y_i=0}^\infty\sum_{y_N=0}^\infty \pi_i(x_1,x_2,\ldots,x_j,\ldots,x_N)\cdot z_1^{y_1}\cdot z_2^{y_2}\ldots z_i^{y_i}\ldots z_N^{y_N}, \quad i=1,2,\ldots,N
\]

There is a relation when the server starts serving site \( i+1 \) at time \( t_{n+1} \) as Equation (3):

\[
\begin{cases}
\xi_j(n+1) = \xi_j(n) + \eta_j(u_j) \\
\xi_i(n+1) = \eta_i(u_i)
\end{cases}
\]

The probability distribution function of the system state at this time \( t_{n+1} \) is Equation (4):

\[
G_{i+1}(z_1,z_2,\ldots,z_N)=\lim_{N\to\infty} E[G_i(z_1,z_2,\ldots,z_N)]
= G_i(z_1,z_2,\ldots,B_j(\prod_{j=1}^N A_j(z_j)),z_{i+1},\ldots,z_N) - G_i(0,0,\ldots,0) + \prod_{j=1}^N A_j(z_j)G_i(0,0,\ldots,0)
\]

4. Mathematical Analysis

4.1. Analysis Mean Queue Length

The system mean queue length is noted as the average of the customers in the queue. Let the mean number of customers in queue \( j \) at \( t_n \) be defined as \( g_j(j) \) when queue \( i \) is polled, as Equation (5):

\[
g_j(j) = \lim_{n\to\infty} E[G_j(z_1,z_2,\ldots,z_N)]
= \frac{\partial G_j(z_1,z_2,\ldots,z_N)}{\partial z_j}
\]

Derivative of Equation (1-5). We can acquire mean queue length, as shown in Equation (6):

\[
g_j(i) = \frac{N\lambda C}{1-N\rho}
\]

Where \( C = G_j(0,0,\ldots,0) \).
4.2. Analysis Mean Cycle Time

Mean cycle time is noted as the interval between serving the same queue twice. Set the cycle of the site as \( \theta \). It can be given as Equation (7):

\[
N \times E(\theta) = \sum_{i=1}^{N} g_i(i)\beta 
\]

Calculation of Equation (6) and Equation (7) gives mean cycle time as Equation (8):

\[
E(\theta) = \frac{N \rho C}{1 - N \rho}
\]

4.3. Analysis Mean Waiting Time

The quantity of customers stored in queue \( j \) and \( k \) at \( t_n \) be defined as \( g_i(j, k) \) when queue \( i \) is polled as Equation (9):

\[
g_i(j, k) = \lim_{t_1, t_2, \ldots, t_{i-1}, t_{i-1} \to \infty} \frac{\partial^2 G_i(z_1, z_2, \ldots, z_j, \ldots, z_k, \ldots, z_N)}{\partial z_j \partial z_k}, \quad i = 1, 2, \ldots, N; \quad j = 1, 2, \ldots, N; \quad K = 1, 2, \ldots, N
\]

Substituting the second derivative of Equation (4) and Equation (9) gives, acquire Equation (10-13):

\[
g_{i,i}(j, k) = C_1 \lambda^2 + [\lambda^2 B(1) + \lambda \rho] g_i(i) + N \rho^2 g_i(i), i \neq j \neq k
\]

\[
g_{i,i}(j, i) = C_1 \lambda^2 + [\lambda^2 B(1) + \lambda \rho] g_i(i) + N \rho^2 g_i(i), i \neq j
\]

\[
g_{i,i}(j, j) = CA_1(1) + [B(1) \lambda^2 + A_1(1) \beta] g_i(i) + N \rho^2 g_i(i) + \rho g_i(i, j) + g_i(j, i), i \neq j
\]

\[
g_{i,i}(i, i) = CA_1(1) + [B(1) \lambda^2 + A_1(1) \beta] g_i(i) + g_i(i, i)
\]

Use Equation (10) and Equation (11) to calculate \( \sum_{j=1}^{N} g_{i,i}(j, k) \), as shown in Equation (14):

\[
2g_i(j, k) = NC \lambda^2 + N[\lambda^2 B(1) + \lambda \rho] g_i(i) + N \rho^2 g_i(i, i) + 2 \rho \sum_{i=1}^{N} g_i(i, k)
\]

Use Equation (12) and Equation (13) to calculate \( \sum_{j=1}^{N} g_{i,i}(j, j) \) gives, as shown in Equation (15):

\[
g_i(j, j) = NCA_1(1) + N[\lambda^2 B(1) + \beta A(1)] g_i(j) + N \rho^2 g_i(j, j) + 2 \rho \sum_{i=1}^{N} g_i(i, k)
\]

Summing Equation (14) over \( j = 1, N \) and over \( k = 1, N \) \( (k \neq j) \) and Equation (15) over \( i = 1, N \) and simplifying gives the following expression, Equation (16):

\[
g_i(i, i) = \frac{N^2 \lambda C}{(1 + \rho)(1 - N \rho)} \left\{ (1 - \frac{1}{N}) \lambda \rho + \frac{1}{N} \rho + \frac{1}{(N - 1) \lambda A(1) + \beta A(1)} \right\}
\]
The customer waiting time $W_c$ is the time that a customer arrives queue $i$ ($i = 1, 2, \ldots, N$) when is sent. According to the principle of the system, the mean waiting time can be calculated as Equation (17):

$$E(W_c) = \frac{(1 + \rho)g(i,i)}{2\lambda g(i)}$$

Substituting Equation (6) and Equation (16) into Equation (17) gives the expression for the mean waiting time, Equation (18):

$$E(W_c) = \frac{1}{2} \left[ (N-1) \rho + \frac{1 - (N-1) \rho}{\lambda^2} \right] + \frac{1}{1 - N \rho} \left[ N(N-1) \rho^2 + \lambda B^*(1) \right] + \frac{1}{1 - N \lambda \beta} \left[ 1 - (N-1) \rho \beta A^*(1) \right]$$

4.4. Throughput

System throughput refers to the number of information packets that the system can transmit in a unit of time, as shown in Equation (19):

$$T = N \lambda \beta$$

5. Theoretical Calculation and Simulation

According to the new model established above, numerical calculations and simulation experiments are performed under stable conditions of the system, and the theoretical values of the new model are calculated by Equations (6), (8), (18) and (19). Experimental simulation is completed in the Matlab2014a platform.

5.1. Result Analysis

First, we can see from Figure 5-11 that the theoretical analysis method can describe the model system more reasonably, and the theoretical calculation value and the computer experimental value are similar to each other.

![Figure 5. Throughput and arrival rate relationship](image1)

![Figure 6. Mean waiting time and arrival rate relationship](image2)

Next, Figure 6 describes the relation between the arrival rate and the mean waiting time of queue information packets. As shown in the figure, the mean waiting time increases linearly with the increase in arrival rate. This is because the arrival of information packets increases with the arrival rate and the mean waiting time of the whole system is increased.

Figure 5 describes the relation between the arrival rate and the throughput of queue information packets. The system throughput increases linearly with the increase of the arrival rate of the queue information packet. On the other hand, the increase in the arrival rate, as shown in Figure 6, simultaneously causes an increase in the mean waiting time. Therefore, when considering how to increase the system throughput, the system mean waiting time should also be used as a constraint.
The core of the control of the new model is to distinguish the busy and idle state of the queue to improve the polling work efficiency. Compared with the ordinary query polling (OQP) model, we come to the following conclusions:

As seen from Figure 7-9, the new model compares OQP. The mean circle time of system, mean waiting time of system and mean queue length of system have been greatly improved. As the system arrival rate increases, the mean waiting time of OQP, mean queue length of OQP and mean circle time of OQP increases sharply. On the other hand, the mean waiting time of new system, mean queue length of new system and mean circle time of new system tends to be stable. This is because the system no longer queries the idle queue so that the busy queue can obtain higher frequency access with a smaller cycle time; thus, system service efficiency can be improved.

From Figure 10-11, it can be seen that the mean waiting time of the OQP and the mean queue length of the OQP system increase rapidly when the throughput increases. Under the same conditions, the mean waiting time of the new system and the mean queue length of the new system increase slowly. Under the same mean waiting time of system or mean queue length conditions, the new system has greater throughput and thus improves system efficiency and resource utilization.
5.2. New Model Energy Saving Analysis

In a wireless sensor network, the node connected to the node of cluster head is working. The more nodes connected to the cluster head, the more nodes that are in working condition, and the higher the system energy cost. In the dense node WSN, the nodes will be in the long-term wake-up work state at the same time. Considering two aspects of node redundancy and data collision rate will inevitably cause a lot of extra energy loss. So, this paper uses the system to automatically distinguish the busy/idle state method to design the node scheduling algorithm to achieve effective switching of the sleep and wake-up state of the node. The cluster head node association diagrams before and after the improvement are shown in Figure 12 and Figure 13 below. The sensor node connected to the solid line CH of the cluster head in Figure 13 represents a busy node that is in a wake-up state. An idle node connected to the dotted line CH of the cluster head indicates that the it is in the dormant state. From Figure 13, it can be seen that the improved sensor network can maximize the sleep state of the node without affecting the network performance. Each sensor node automatically switches the busy/idle state according to the transmission of its own data, thereby reducing energy consumption and extending the network lifetime.

![Figure 12. Cluster head associated nodes](image1)

![Figure 13. Improved cluster head associated nodes](image2)

6. Conclusion

This paper presents a new polling scheme based on busy/idle queues mechanism after distinguishing busy queues from idle queues according to if there are customers in a queue. Only BQs can be polled and served. IQs keep a sleeping state to save resources until a customer has arrived. We build a mathematical model using the embedded Markov chain and probability mother function, and analysis important performance parameters of the model. The theoretical and simulations values have a small error, which is approximately equal. The theoretical values and simulated values indicate that the new polling system works more efficiently compared with ordinary polling system.

The polling method can provide conflict-free information access and provide delay guarantee for delay-sensitive services. It has always been an important scheduling control method for the MAC layer of wireless sensor networks. The traditional ultra-dense wireless sensor network is recommended as a supplement to cellular networks. A 5G ultra-high density cellular network was proposed based on MIMO communication technology. It is believed that the model of the experience polling control system proposed in this paper will certainly play an outstanding role in the optimization and improvement of 5G [14].

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Reference

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