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An Effective Polling MAC Scheme for Wireless Sensor Networks

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Abstract: Wireless Sensor Network (WSN) is an effective information acquiring and processing technology. To increase the life of WSN, each sensor node has to transmit the queuing data efficiently and conserve its energy, how to share the query of transmission for the collected information of sensor nodes becomes a new problem. Based on polling scheme with the unique characteristics of contention-free of access, this study presents an efficient polling MAC scheme with M-gated service for WSN. By the embedded Markov chain theory and the probability generation function method, we give closed form expressions for obtaining the Mean Queue Length (MQL) and the Mean Cycle Period (MCP) characteristics of the sensor nodes and the analytical results are verified through extensive computer simulations. The performance results reveal that the proposed scheme can be enrolled in design of MAC protocols to improve the efficiency of data transmission and reduce unnecessary energy consumption for sensor nodes.

Key words: WSN, polling scheme, M-gated service, mean queue length

INTRODUCTION

Wireless Sensor Network (WSN) is an emerging technology; its potential applications span a wide spectrum from military to industry, from commercial to environmental monitoring, from medical to target tracking systems. In fact, a wide range of real time applications, e.g., surveillance, habitat monitoring, or target tracking systems, are likely to be delay-sensitive, each sensor node has to transmit the query data efficiently and conserve its energy (Lu *et al*., 2004). So, WSN is expected to support real-time services with guaranteed Quality of Service (QoS) for diverse traffic types (video, voice and data) and research on WSN relates to many techniques, MAC layer protocol which is crucial for the design of the whole network, is one of them. The MAC protocol in WSN must achieve two goals. The first is the creation of the network infrastructure; the second is to fairly and efficiently share communication resources between sensor nodes (Clemente *et al*., 2012). In the past few years, various MAC protocols with different objectives were proposed for WSN, they are generally classified as three types (Raissouni *et al*., 2013). The first type is the protocol based on contention of access, such as Sensor MAC (S-MAC), Timeout MAC (T-MAC), Sift, Mediation Device (MD) *et al*. The second type is the protocol based on contention-free of access, such as Distributed Energy-Aware Node Activation (DEANA), Traffic Adaptive Medium Access (TRAMA), Time Reservation Using Adaptive Control for Energy Efficiency (TRACE), Variable TDMA (V-TDMA) *et al*. The third type is the hybrid protocol based on contention and contention-free of access, such as ultra-low power MAC, Self-organizing Medium Access Control for Sensor network/Eavesdrop and Register (SMACS/EAR), Channel Adaptive energy Management (CAME), Cluster Management and Power Efficient (CUMPE) *et al*. However, several kinds of present MAC protocols for WSN can hardly meet the demands of supporting real-time services (Wang and Zhong, 2012). Therefore, how to efficiently utilize the limited amount of energy and transmit the collected query information packets has been the primary concern in designing MAC protocols for WSN (Lin *et al*., 2009).

In recent years, polling schemes have been successfully enrolled in design of MAC protocols for Broadband Wireless Access (BWA) areas (Sikdar, 2007; Zhao *et al*., 2010; Li *et al*., 2006; Perahia, 2008; Liu *et al*., 2011a, 2011b). According to the feature of dynamic architecture of WSN, polling strategy with the unique characteristics of contention-free of access can be good approaches to tackle this kind of problem of end-to-end latency (Zhao *et al*., 2010; Li *et al*., 2006), but research work for this area is still not well investigated. Having these in mind, we propose an effective polling MAC scheme with m-gated service and Fig. 1 illustrates the function of the polling scheme.

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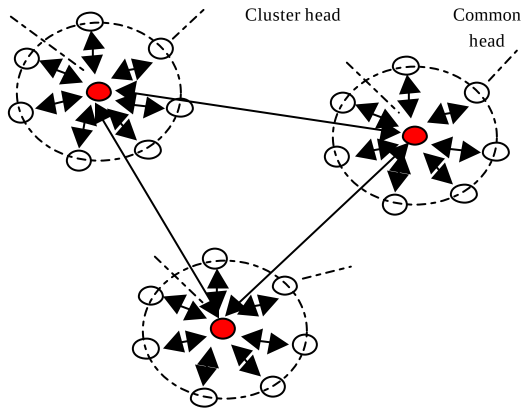

Fig. 1: Polling MAC scheme with M-gated service for WSN

Considering the distinct feature of the proposed scheme, the big challenge for analysis of the system is to set up the specific mathematics model and give a closed form of expression for obtaining the key system parameters. On the basis of research in polling multiple-access system (Zhao *et al.*, 2010; Raissouni *et al.*, 2013; Liu *et al.*, 2011a, 2011b), we study the performance of our proposed scheme using the mathematics model based on embedded Markov chain theory and the probability generation function method and derive the closed form of expression for the key system parameters, such as the Mean Queue Length (MQL) and the Mean Cycle Period (MCP). Finally, we verify the performance of proposed system through computer simulated experiments and results show that the polling MAC scheme can be adopted as a good method to solve the transmission problems of the nodes for WSN.

SYSTEM MODEL DESCRIPTION

Definitions of system variables: According to the controlling mechanism of M-gated service, we give the following assumption for N nodes in a WSN:

- During the continuous time period, the arrivals of the message packets waiting for transmission follow an independent distribution with generation function $A_i(z)$, mean value $\lambda_i = A'_i(1)$ and variance $\sigma^2_\lambda = A''_i(1)+\lambda_i-\lambda_i^2$ for the station
- The timing variables for each node to transmit message packets are independent of each other in the probability distribution which has a generation function $B_i(z)$, mean value $\beta_i = B'_i(1)$, variance $\sigma^2_\beta = B_i''(1)+\beta_i-\beta_i^2$
- The variable walking time between common head and cluster head are independent of each other in the probability distribution which has a generation function R(z), mean value $\gamma = R'(1)$ and variance $\sigma^2_\gamma = R''(1)+\gamma-\gamma^2$
- Each node has enough storage so that no message packets are lost under the First Come and First Service (FCFS) rule and the system work in the condition of continuous time state while $\bar{\theta}$ denotes the mean cycle time

System generation function: Considering the polling mechanism with the m-gated service, we use embedded Markov chain theory (Sikdar, 2007; Zhao *et al.*, 2010; Li *et al.*, 2006) to characterize this model and the generation function of the node i+1 for the probability distribution is:

$$G_{(i+1)1}(z_1,z_2,\cdots,z_N) = \lim_{n\to\infty} E\left[\prod_{j=1}^{N} z_j^{\xi_j(n+1)}\right] = R_i\left(\prod_{j=1}^{N}\lambda_j(1-z_j)\right) G_{im}\left(z_1,z_2,\ldots,z_{i-1},B_i\left(\prod_{j=1}^{N}\lambda_j(1-z_j)\right),z_{i+1},\ldots,z_N\right) \quad i = 1, 2,\ldots, N \tag{1}$$

$$G_{i2}(z_1,z_2,\cdots,z_N) = G_{i1}\left(z_1,z_2,\ldots,z_{i-1},B_i\left(\prod_{j=1}^{N}\lambda_j(1-z_j)\right),z_{i+1},\ldots,z_N\right) \quad i = 1, 2,\ldots, N \tag{2}$$

ANALYSIS OF SYSTEM PARAMETERS

Mean queue length: Let the average number of message packets at node j at t_n be defined as $g_{ix}(j)$, then:

$$g_{ix}(j) = \lim_{z_1,z_2,\cdots,z_N\to 1} \frac{\partial G_{(i+1)x}(z_1,z_2\cdots,z_N)}{\partial z_j} \quad i = 1, 2,\ldots, N \tag{3}$$

With the help of our works (Zhao *et al.*, 2010; Liu *et al.*, 2011a, 2011b), we have obtained Eq. 4 (the MQL of 3-gated service), Eq. 5 (the MQL of 5-gated service) and Eq. 6 (the MCP of m-gated polling system) through the similar method:

$$g_{i3}(i) = \frac{N\gamma\lambda(1-\rho)\rho^2}{(1-\rho^3)(1-N\rho)} \quad i = 1, 2,\ldots, N \tag{4}$$

$$g_{i5}(i) = \frac{N\gamma\lambda(1-\rho)\rho^4}{(1-\rho^5)(1-N\rho)} \quad i = 1, 2,\ldots, N \tag{5}$$

Mean cycle period:

$$\bar{\theta}_i = \frac{N\gamma}{1-N\rho} \tag{6}$$

THEORETICAL AND SIMULATED RESULTS

On the condition of symmetric polling system and data transmission with no errors, we assume that a WSN has the data rate of 250 kbps, message packet length of 50 bit, walking and polling times of 10 m sec and time slots of 10 m sec, the arrival process of message packets conforms Poisson distribution and the serving time and walking time both are general constant distribution. According to the derived equations, the theoretical mean queue length of message packets has been calculated for every node and computer simulations according to the following flow chart are used to obtain the comparison results on the condition of the same values. The theoretical and simulated results for the system are shown in Fig. 2-5.

The symbols represent the simulation results for different arrival rate of message packets with 5, 10 and 20 nodes. The three figures show that the MQL has close relation to the number of nodes, arrival rate of packets and the control value of m-gated service on the condition of keeping service time and walking time in specific values:

- With increasing of the number of nodes, for a specific arrival rate of packets, the MQL increases
- With increasing of the arrival rate of packets, for a specific number of nodes, the MQL increases
- When $N\rho$ amounts to 0.95, the MQL will increase dramatically
- The value m of m-gated service system is greater than 3, the trend of the mean queue length has become very small

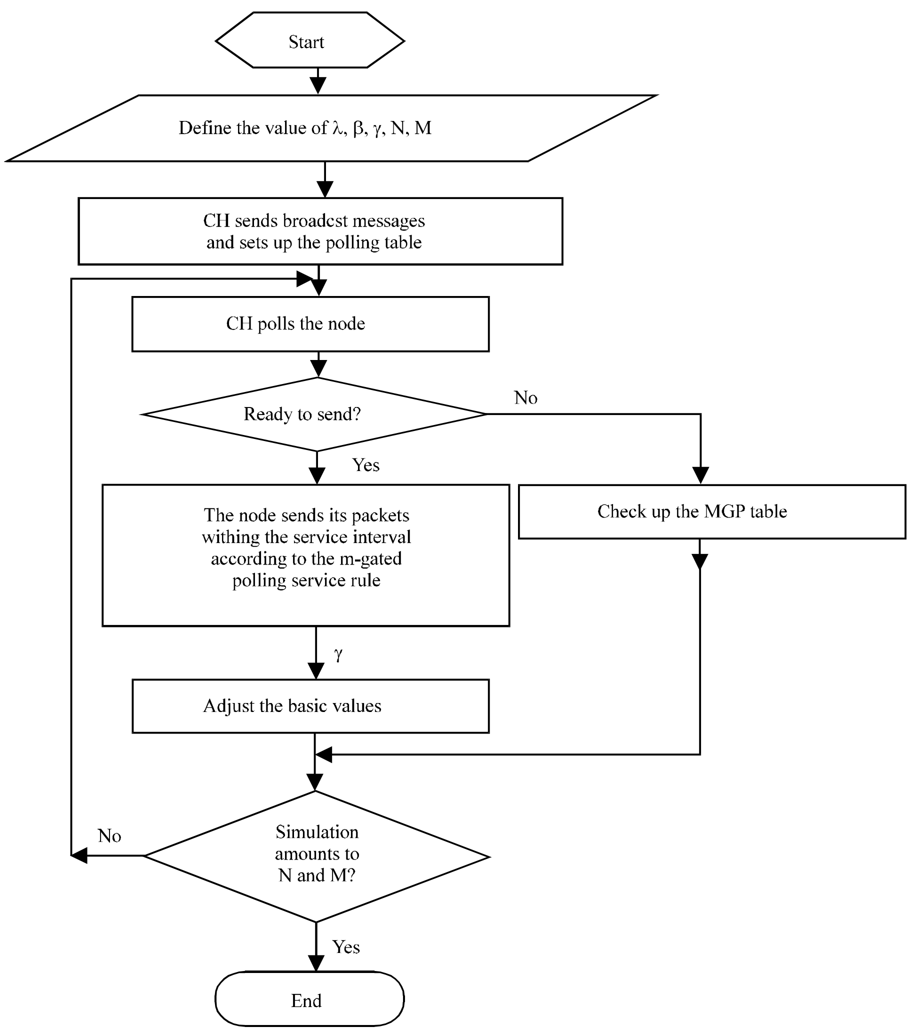

Fig. 2: Flow chart of computer simulations for m-gated polling system

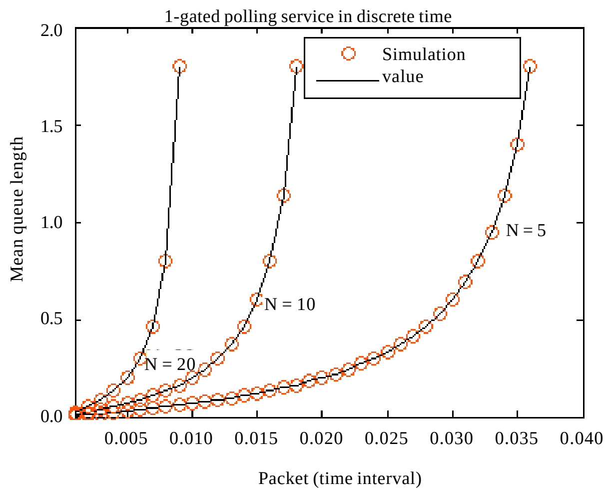

Fig. 3: Mean queue length with m = 1, β = 5, γ = 1

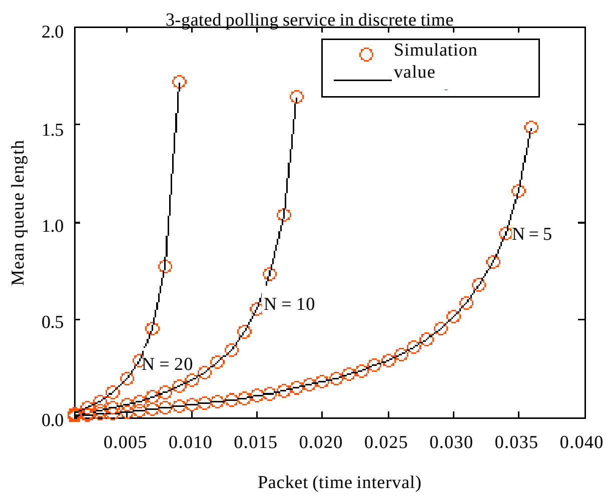

Fig. 4: Mean queue length with m = 3, β = 5, γ = 1

- Simulation results have been verified to agree well with the theoretical results

From the above conclusions, we can see that our model is well distinguished in the current scheme with the little mean queue length and performs better performance than the traditional gated polling mechanism for the same number of nodes. Thus, this model can efficiently guarantee the QoS of the WSN system. Therefore, this polling mechanism can efficiently differentiate services to guarantee better QoS and system stability in WSN MAC protocol.

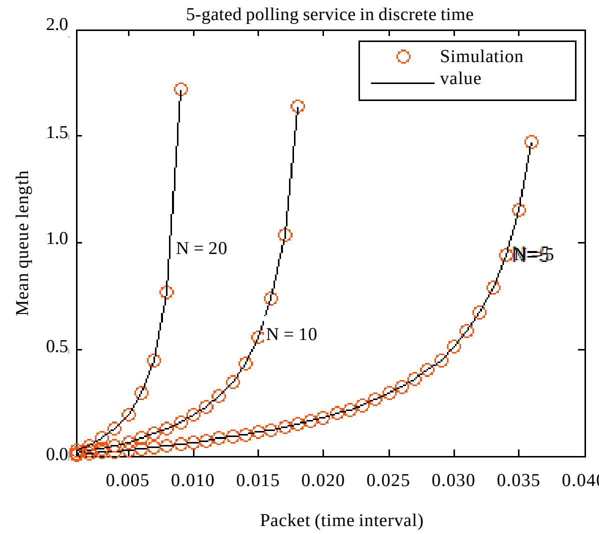

Fig. 5: Mean queue length with m = 5, β = 5, γ = 1

CONCLUSION

In this study, we propose an efficient system model for polling mechanism to serve the real-time traffic with the QoS classes differentiated by m-gated access policies, the MQL has been obtained by using the mathematics model based on embedded Markov chain theory and the generation function method and simulations with the help of Matlab have been verified to agree well with the theoretical results. According to the analysis of the model, we draw conclusion that the proposed model can efficiently differentiate services to guarantee better QoS and system stability in WSN and it has better efficiency than that under the polling system with gated service.

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