QoS Performance Analysis for Slotted CSMA/CA in IEEE802.15.4

Yong Lan
School of Information Engineering, Chang'an University, Xi'an, China
Email: address:blue_ly2002@163.com

Bo Zhang
Information Center of Land and Resources Bureau, Xi'an, China
Email: address:zhangbonpu@hotmail.com

Zhicheng Chen
School of Computer Science, Beijing University of Posts and Telecommunications, Beijing, China
Email: address:czc0910@163.com

***Abstract*—Aiming at researching the QoS performance of slotted CSMA/CA mechanism in beacon-enabled IEEE802.15.4, this paper analyzes the effect relationship between QoS and superframe parameters through analytic mathematical model and simulation method. Firstly, the nodes' sleeping time of WSNs is deduced from duty cycle mathematical formulation. Therefore, the energy consumption directly related to sleeping time can be evaluated. In order to analyze and evaluate the effect relationship between QoS and superframe parameters more accurate and more comprehensively, all kinds of simulation instances with different superframe parameters, including different duty cycles as well as same duty cycle but with different values of Beacon Order (BO) and SuperFrame Order (SO) are simulated. The results show that the mathematical model analysis of QoS performance is consistent with the simulation. The studies also provide a reference to further research of adaptive transmission mechanism in beacon-enabled IEEE802.15.4.**

***Index Terms*—QoS Performance; IEEE802.15.4; Beacon-Enabled; Slotted CSMA/CA; Duty Cycle;**

I. Introduction

The IEEE 802.15.4 [1] is an important protocol of wireless personal area network (WPAN). It is widely used as a communication standard for Wireless Sensor Networks (WSNs) because of its low data rate, low power consumption and low cost. In order to achieve a better transmission performance, the Media Access Control (MAC) protocol of IEEE 802.15.4 provides two optional mechanisms which are beacon enabled mode and non beacon mode. On the other hand, the CSMA/CA is a well-kown MAC protocol for wireless network as well as for IEEE802.15.4. Slotted CSMA/CA is just the mechanism that the transmission progress control is based on both CSMA/CA and beacon schemes [2]. Hence, the QoS performance of slotted CSMA/CA is different from other CSMA/CA (e.g. DCF in IEEE 802.11). Because Slotted CSMA/CA is particularly suitable for transmitting discrete or non-cyclical traffic source [3, 4] in WSNs, it is necessary to analyze the QoS performance of slotted CSMA/CA for a better WSNs application and further researches on adaptive superframe parameters mechanism in IEEE 802.15.4.

As we all know, the QoS performance of WSNs is affected by many factors such as the topology, network scale, network load, type of traffic source and so on. In slotted CSMA/CA of IEEE802.15.4, the QoS performance is further affected by the superframe parameters. In recently years, there have been some studies [5-13] about the QoS performance analysis of beacon enabled IEEE802.15.4 and slotted CSMA/CA. Ref. [6] analyzed QoS performance of slotted CSMA/CA by analytic model, but the conclusions are not applicable for unacknowledged frames transmission. The study of [7] has evaluated the performance metrics but only dealt with some specific value of duty cycle.

There are two main ways of analyzing and evaluating the performance of WSNs. One is research by analytic model and the other is simulation investigation. For example, Ref. [8-9] used Markov chain to model the IEEE 802.15.4 protocol and analyzed the performance. Ref. [10-11] researched and evaluated the performance of the IEEE 802.15.4 protocol based on simulations. Analytic method, such as Markov chain model used in [8-9], can exactly describe the detailed behavior of the protocol. However, since analytic mathematical model of this method is always based on some assumed conditions, the practicality and universality of the conclusion is limited. By contrast, the study method of simulation are very close to the real application scenarios. In our research work, we firstly adopt analytic mathematical model based on the duty cycle formula to analyze the impact of superframe parameters (i.e. BeaconOrder and SuperFrameOrder) on the QoS performance of slotted CSMA/CA, and then we use simulation method to research the performance metrics of slotted CSMA/CA in IEEE 802.15.4; Especially, by using these two methods,

doi:10.4304/jnw.9.7.1764-1769

our research focuses not only on the performance metrics but also on the comprehensiveness of effect relationship between QoS performance and duty cycle.

II. BEACON-ENABED IEEE802.15.4 AND SUPERFRAME STRCTURE

The MAC protocol of IEEE 802.15.4 supports two transports mechanism, which are Non beacon-enabled mode and beacon-enabled mode. In the beacon enabled mode, all communication behavior in the network is constrained by superframe structure, which should be synchronized by the periodically generated beacon frames from the coordinator, and each device's communication process is limited in the slot time allocated. According to IEEE802.15.4 MAC, the superframe structure is described as Fig. 1.

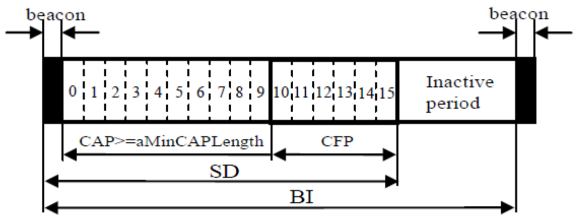

Figure 1. The IEEE 802.15.4 superframe structure

In Fig. 1, BI is beacon interval, including active period and inactive period. In the inactive period, devices are in sleeping mode and the WSNs' energy consumption is low. Other QoS performance such as end-to-end delay is also impacted by the length of the inactive period. The active period, corresponding to the Superframe Duration (SD), is divided into 16 equal time slots, during which data transmission is allowed. Each active period can be further divided into a Contention Access Period (CAP) and an optional Contention Free Period (CFP). If the communication process has no CFP, CAP is equal to SD. This situation is the pure Slotted CSMA/CA communication process. Hence, we can research the performance metrics of Slotted CSMA/CA by using the superframe structure with no CFP.

In slotted CSMA-CA mechanism, each device' communication process is controlled not only by the CSMA/CA protocol but also by the superframe structure. Regarding how the parameters of CSMA/CA(such as the Backoff Exponent, the Contention Window and the Number of Backoffs) can impact the performance has a lots of mature research results, so we will not repeat it. Instead, our research work focuses on the effect relationship between QoS performance and superframe parameters.

The BI and SD can further be defined by BeaconOrder (*BO*) and SuperFrameOrder (*SO*) individually as follow:

$$
\begin{aligned}
& BI = \text{aBaseSuperframDuration} \times 2^{BO} \\
& \text{SD} = \text{aBaseSuperframDuration} \times 2^{SO} \\
& (0 \le SO \le BO \le 14)
\end{aligned}
\tag{1}
$$

Furthermore, the Duty Cycle (DC) of beacon-enabled IEEE802.15.4 is defined as:

$$
\begin{aligned}
& DC = SD / BI \\
& = \text{aBaseSuperframDuration} \times 2^{SO} / \\
& \quad \text{aBaseSuperframDuration} \times 2^{BO} \\
& = 2^{SO\text{-}BO}
\end{aligned}
\tag{2}
$$

where, DC is only related with *BO* and *SO*. For example, (*BO*-*SO*=2) is equivalent to (Duty Cycle = 25%). Therefore, analyzing the relationship between duty cycle and QoS performance is equivalent to analyzing the relationship between the values of *BO* (*SO*) and QoS performance. Obviously, the larger the (*BO*-*SO*), the smaller the Duty Cycle, and vice versa.

III. QOS PERFORMANCE ANALYSIS BASED ON DUTY CYCLE FORMULAR

The QoS performance of slotted CSMA/CA in IEEE802.15.4 is markedly affected by superframe parameters, especially by the value of duty cycle, beacon order and superframe order [12]. Ref. [13] proposed a model of service curve and used network calculus method to analyze the relationship between the delay and the duty cycle for GTS mechanism. Ref. [9] Proposed a discrete Markov chain model to evaluate the performance of slotted CSMA/CA. In our work, we firstly deduce the sensor nodes' sleeping time according to analytic mathematical formula of duty cycle, and further analyze the QoS performance based on the amount of sleeping time.

By the superframe structure in Fig. 1, for each beacon interval (BI), the inactive period is the node sleeping time (ST), and ST can be calculated as follows:

$$
\begin{aligned}
& \text{ST=BI-SD} \\
& \text{=BI-BI} \times \text{DC} \\
& \text{=BI-BI} \times 2^{\text{SO-BO}} \\
& = \text{aBaseSuperframDuration} \times 2^{\text{BO}} \times \left(1 - \frac{1}{2^{\text{BO-SO}}}\right)
\end{aligned}
\tag{3}
$$

It is known from (2) that (*BO*-*SO*) is equivalent to duty cycle. So (3) shows that the amount of node sleeping time is affected by two factors, one is the value of *BO*, and the other is the duty cycle. Furthermore, for the whole period of WSNs' life, the longer the sleeping time of each beacon interval, the longer the total sleeping time of whole WSNs life.

On the other hand, the amount of sleeping time of sensor node is directly related to the energy consumption of WSNs. Therefore, we can further analyze the QoS performance based on the amount of sleeping time, which is described as follows:

(1) If the value of *BO* is fixed, the larger the value of (*BO*-*SO*), the longer the sensor nodes' sleeping time. Therefore, as the Duty Cycle decreases (i.e. *BO*-*SO* increases), the energy consumption reduces, the end-to-end delay increases and the network output decreases.

(2) If the duty cycle (i.e. *BO*-*SO*) is fixed, the larger the value of *BO*, the longer the sensor nodes' sleeping time. Hence, as *BO* increases, the energy consumption reduces, the end-to-end delay increases and the network output decreases.

TABLE I. PARAMETERS OF TYPICAL TRAFFIC SOURCE

Traffic Source	MSDU Interarrival Time (s)	MSDU Size (bits)	Start Time (s)	Stop Time (s)
ACK	Poission (1.0)	Poission (100)	0.0	Infinity
UnACK	Uiform (0.5,1.5)	Poission (50)	0.0	Infinity

(3) If the value of *BO* is fixed, as the (*BO-SO*) increases from 0 to 14, the changing of the sleeping time gets smaller and smaller. So the energy consumption is affected more significantly by small duty cycle than by large one.

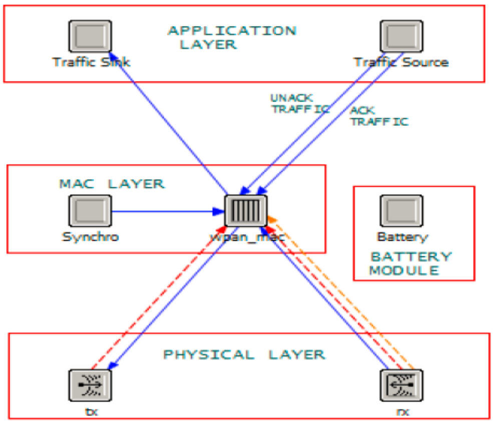

Figure 2. The simulation model of Slotted CSMA/CA based on OPNET modeler

IV. Analysis of QoS Performance by Simulation Method

Ref. [10-11] analyzes and evaluates the performance of beacon enabled IEEE802.15.4 by simulation method. Ref. [10] further analyzes how QoS performance can be affected by duty cycle in Slotted CSMA/CA, which concerned with delay, energy consumption, throughput etc., but the relationship revealed is relatively vague. In order to reveal the relationship more accurately and comprehensively, we further use simulation method to research the performance metrics of slotted CSMA/CA in IEEE 802.15.4. The simulation model is built by modifying the model of wpan_ieee802_15_4_v2_1 [14] based on OPNET modular. It is shown in Fig. 2 and described as follow:

In 10m×10m area of simulation Scenario, 1 PAN Coordinator and a number of End Devices are random deployed to compose a star-topology network.

The Physical Layer consists of a wireless radio transmitter and a receiver compliant to the IEEE 802.15.4 specification, operating at 2.4 GHz frequency band and a data rate equal to 250 kbps. The transmission power is set to 1 mW and the modulation technique is Quadrature Phase Shift Keying (QPSK).

The MAC Layer implements the slotted CSMA/CA mechanism. The maximum backoff number and minimum backoff is set to 4 and 3 respectively.

The Application Layer generates Traffic Source of unacknowledged (UnAck) and acknowledged (ACK) data frames transmitted as a MAC Service Data Unit (MSDU) during the CAP.

The Battery Module computes the consumed and the remaining energy levels. The Traffic Sink Module computes the end-to-end delay in real time and network output load is computed by the wpan_mac Module.

A. Relationship between QoS and Duty Cycle

Compared with [6], our research is concerned not only with acknowledged data frames but also with unacknowledged ones. Hines, the research result would be more comprehensive and objective. The traffic source of each node is designed as in Table 1.

Based on the model designed above, the instances of the same value 14 of *BO* but different *SO*, which corresponds to the changing of duty cycle from 0 to 14, was simulated to analyze the comprehensive relationship between QoS and duty cycle. Furthermore, in order to reveal the relationship more accurately and comprehensively, the instance of 10-nodes was simulated as well as the other ones of 30-nodes and 50-nodes. The simulation time of each instance is 600s and the results are shown in Fig. 3 to Fig. 5.

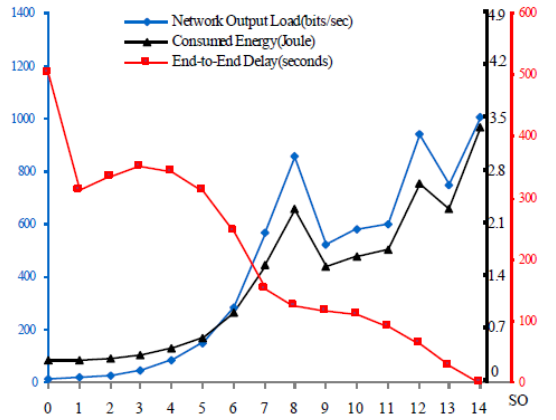

Figure 3. Relationship between QoS and different duty cycle (BO=14,10 Nodes)

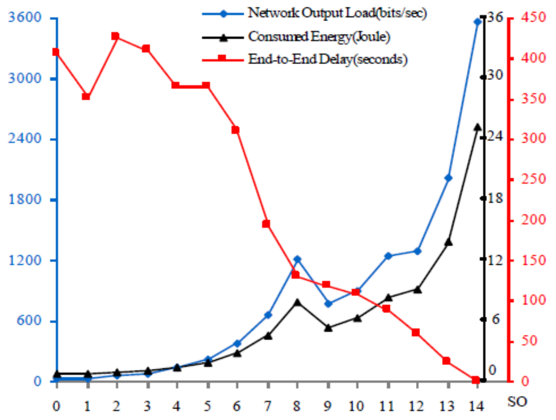

Figure 4. Relationship between QoS and different duty cycle (BO=14,30 Nodes)

TABLE II. PARAMETERS OF VARIABLE TRAFFIC SOURCE

Traffic Source		MSDU Interarrival Time(s)	MSDU Size (bits)	Star Time(s)	Stop Time(s)
Node1,2	ACK	exponential(2)	poisson(100)	0.0	infinity
	UnACK	poisson (0.2)	constant(200)	0.0	infinity
Node3,4,5,6	ACK	none	none	infinity	infinity
	UnACK	poisson (1)	constant(200)	0.0	nfinity
Node7,8	ACK	exponential(2)	poisson(100)	3.0	9.0
	UnACK	none	none	infinity	infinity
Node9,10	ACK	constant(3)	poisson (50)	0.0	infinity
	UnACK	poisson(0.2)	uniform(50,200)	0.0	infinity
Node11,12,13,14	ACK	none	none	infinity	infinity
	UnACK	exponential(0.5)	constant (160)	0.0	infinity

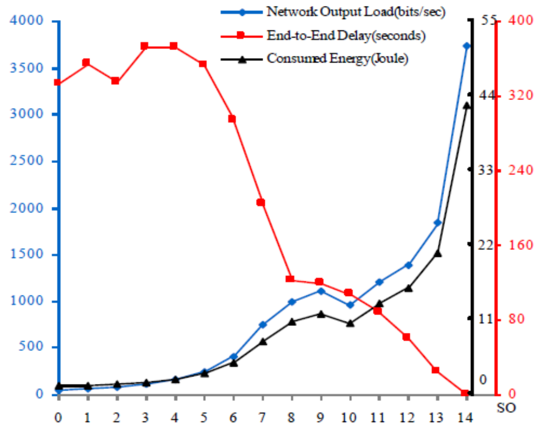

Figure 5. Relationship between QoS and different duty cycle (BO=14,50 Nodes)

In Fig. 3 to Fig. 5, the abscissa represents *SO*. Because of the same value 14 of *BO*, the *(BO-SO)* changes as SO changes. Therefore these figures show the QoS performance metrics impacted by different duty cycle.

As the results shown above, the smaller the value *SO* (which means smaller the duty cycle), the lower the energy consumption and the network output load; the smaller the value *SO*, the larger the end-to-end delay. This result is consistent with the conclusion of analytic method in section 3. Moreover, because multiple QoS performance such as energy consumption, the network output load and the end-to-end delay are synchronously impacted by the same duty cycle, the trade-off should be considered for duty-cycle setting when a WSNs application instance is designed.

Fig. 3 to Fig. 5 also tell us: if *SO* =1 (i.e., the Duty Cycle is roughly equivalent to 0.012%)in Fig. 3 and in Fig. 4, or if *SO*=2(i.e., the Duty Cycle is roughly equivalent to 0.024%)in Fig. 5, there is a minimum of end-to-end delay within the local changing range of duty cycle closed to 0. This can be explained as: a very small duty cycle can increase channel contention and then the backoff number will be increased [11], and delay will rise correspondingly. As duty cycle increasing properly, channel contention is reduced and delay lower too. Because it is not the major effect factor compared with the duty cycle, the delay is back in high values fast by the next value of *SO*. However, when *SO* is larger than 3, 2, 5, which is in Fig. 3, Fig. 4 and Fig. 5 respectively, the end-to-end delay reduces fast as *SO* increasing. On the other hand, the energy consumption and network output load also go into reverse at the point of *SO*=8(in Fig. 3 and Fig. 4)and *SO*=10(in Fig. 5). But because of the major effect factor of duty cycle, it turns rises by the following *SO*.

The Fig. 5 of [10] shows that the energy consumption decreases linearly as the duty cycle decreases. However, our simulation results in Fig. 3 to Fig. 5 shows the energy consumption impacted by duty cycle non-linearly. Because the QoS performance is impacted by many complex factors, we believe that our conclusions are more objective.

Furthermore, the relationship between QoS performance and different number of nodes is also shown in Fig. 3 to Fig. 5, which is: with the same duty cycle (i.e. the same *SO*), the end-to-end delay decreases and network output load increases as the number of nodes increases. However the energy consumption is relatively low in the situation of 30 nodes. This performance metrics is also due to the channel competition caused by the nodes in slotted CSMA/CA.

B. Relationship between QoS and Different Value of BO

For the same duty cycle, there are several optional (*BO*, *SO*) couple in slotted CSMA/CA. For example, when (*BO-SO*) is 4 (i.e., the Duty Cycle is 6.25%), the corresponding (*BO*, *SO*) couple would be (14, 10), (13, 9),…, and (4, 0). Hence, the QoS performance is affected not only by duty cycle but also by different (*BO*, *SO*) couple [15-16] in beacon-enabled IEEE802.15.4. In our studies, each same duty cycle but with different value of *BO*, which are 120 kinds of value, was further set to simulate and analyze the QoS perfomance. The number of end devices is 14, and considering the complexity and variety of the real environment information which WSNs works in, we designed variety of traffic source in the simulation model, which is shown as Table 2.

The simulation time is 400s and the results of the QoS performance are shown as follow:

1) Relationship between Energy Consumption and BO

In Fig. 6, when duty cycle is fixed, as the value of *BO* changes in the local range which closed to value of 0, the energy consumption lower fast as *BO* increasing. This is due to that too much beacon frames generated by too small value of *BO* can intensify the channel contention and the collision. The intensive channel contention results in significant carrier-sensing overhead for devices, and thus increases energy consumption. However, if *BO* increasing properly, the increased active period will properly reduce the collision, so the energy consumption decreases correspondingly. But as *BO* further increases, the active period and inactive period increase simultaneously. So Fig. 6 also shows the variation of energy consumption is less affected by relatively large *BO*, which is about 6-13.

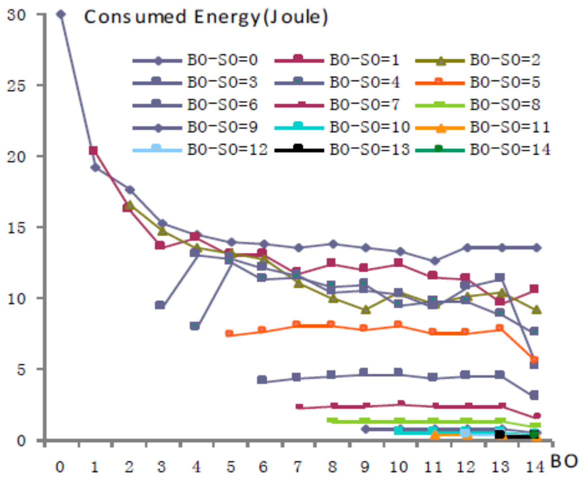

Figure 6. Relationship between energy consumption and BO

2) Relationship between Network output Load and BO

The relationship between network output load and Duty cycle which is shown in Fig. 7 is very similar to Fig. 6, and further shows the variation trend of network output load is consistent with energy consumption affected by duty cycle.

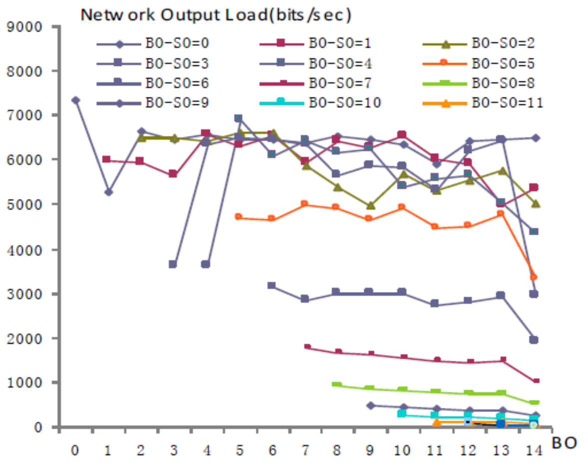

Figure 7. Relationship between network output load and BO

3) Relationship between End-to-End Delay and BO

Fig. 8 shows: with the same duty cycle, the larger *BO* and *SO*, the larger the end-to-end delay. The more close the value 14 of *BO*, the more obvious the variation. When Duty Cycle is same, for a relatively large *BO*, inactive periods will be markedly extended. Hence, the data packets will contend the channel intensively at the start of the next active period. Therefore, the end-to-end delay increases obviously.

The results of Fig. 6 to Fig. 8 further show:

As *SO*=0 (and *BO*=14), the energy consumption and the network output load will be close to minimum, the end-to-end delay is close to maximum.

As *SO*=0 (and *BO*=0), the energy consumption and the network output load will be close to maximum, the end-to end delay will be close to minimum.

Furthermore, as the value of *(BO-SO)* changes from about 4 to about 8, the QoS performance is affected very markedly by the value of duty cycle. This is due to the active and inactive behavior of devices is affected more significantly by the changing of Duty Cycle within this rang.

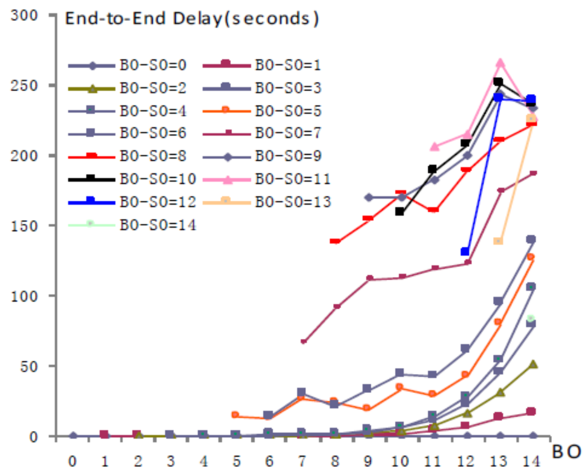

Figure 8. Relationship between end-to-end delay and BO

V. Conclusions

By using analytic formula based on the duty cycle and model simulation method, we analyzed and evaluated the QoS performance of slotted CSMA/CA which impacted by different Duty Cycle and different value of (*BO*, *SO*) Couple in IEEEE802.15.4. The results of our studies show that: the QoS performance of slotted CSMA/CA in beacon-enabled IEEE is markedly affected by duty cycle and *BO* and *SO*, and the performance metrics is usually non-linear. Although it is non-linear, the overall trend can be described as: with duty cycle decrease, the energy consumption and the network output load lower, and the end-to-end delay increase, and vice versa. On the other hand, if duty cycle is fixed, as *BO* increases, the energy consumption and the network output load lower, and the end-to-end delay increases. However, since many potential factors impact on the QoS performance synchronously, for some particular value of (*BO*, *SO*) couple, such as too small or too large value, the QoS performance always deviates the overall trend. Therefore, a trade-off should be considered among multiple QoS indexes for parameters setting in designing the application of WSNs.

Furthermore, based on our conclusions in the paper, our future research work will focus on the QoS-constrained adaptive Duty Cycle mechanism in IEEE802.15.4.

ACKNOWLEDGMENTS

The authors thank the editors and the anonymous reviewers for their valuable comments that helped to improve the paper. This Project is supported by the Special Fund for Basic Scientific Research of Central Colleges, Chang'an University (CHD2010JC079) and (CHD2010JC045) , by the Special Fund for Basic Research Program of Chang'an University, by the open Fund for Shaanxi Road Traffic Detection and Equipment Engineering Research Center and by the Key Technologies R&D Programme of Shaanxi Province (2011K06-21).

REFERENCE

[1] IEEE 802.15.4 Standard-2003, "Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer(PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)", *IEEE-SA Standards Board,* 2003

[2] Lee, Junhee, Jeong, Wun-Cheol, Performance analysis of IEEE 802.15.4e DSME MAC protocol under WLAN interference, *International Conference on ICT Convergence (ICTC),* pp. 741-746, 2012

[3] Kumar, Vinay, Tiwari, S., Performance of routing protocols for beacon-enabled IEEE 802.15.4 WSNs with different duty cycle, *Proceedings: International Conference on Devices and Communications (ICDeCom),* 2011

[4] Li Xiaoyun, Bleakley, Chris J., Bober, Wojciech, Enhanced Beacon-Enabled Mode for improved IEEE 802.15.4 low data rate performance, *Wireless Networks,* 18(1), pp. 59-74, 2012

[5] Fan Shurui, Li Jingbo, Sun Hexu, Wang Rui, Throughput analysis of GTS allocation in beacon enabled IEEE 802.15.4, *Proceedings: the 3rd IEEE International Conference on Computer Science and Information Technology (ICCSIT),* v4, pp. 561-565, 2010

[6] Chan Yong Lee, Hong I Cho, Gang Uk Hwang, Yoonmee Doh, Noseong Park, Performance modeling and analysis of IEEE 802.15.4 slotted CSMA/CA protocol with ACK mode AEU - *International Journal of Electronics and Communications,* 65(2), pp. 123-131, 2011

[7] Anis KOUBAA, Mário ALVES, Eduardo TOVAR, A Comprehensive Simulation Study of Slotted CSMA/CA for IEEE 802.15.4 Wireless Sensor Networks, *Proceedings: IEEE International Workshop on Factory Communication Systems,* pp. 183-192, 2006

[8] He J, Tang Z, Chen H, Wang S, An accurate Markov model for slotted CSMA/CA algorithm in IEEE 802.15.4 networks, *IEEE Commun Lett,* 12(6):420–2. 2008

[9] Wen Hao, Lin Chuang, Chen ZhiJia, Yin Hao, He Tao, Dutkiewicz, Eryk, An improved markov model for IEEE 802.15.4 slotted CSMA/CA mechanism, *Journal of Computer Science and Technology,* 24(3), pp.495-504, 2009

[10] Lu G, Krishnamachari B, Raghavendra CS, Performance evaluation of the IEEE 802.15.4 MAC for low rate low power wireless networks, *Proceedings: 23rd IEEE International Performance, Computing, and Communications Conference,* v23, pp. 701-706, 2004

[11] Yonghong Ma, Ning Wei, Minhua Lv, Performance analysis of wireless network based on IEEE 802.15.4 in Smart Home environment, *Proceedings: 4th International Conference on Multimedia and Security,* pp. 208-211, 2012

[12] Alvi, A.N., Naqvi, S.S., Bouk, S.H., Javaid, N., Qasim, U., Khan, Z.A., Evaluation of slotted CSMA/CA of IEEE 802.15.4, *Proc of the7th International Conference on Broadband, Wireless Computing, Communication and Applications(BWCCA),* pp. 391-396, 2012

[13] KOUBAA A, Alves M., Tovar E, i-GAME: An implicit GTS allocation mechanism in IEEE 802.15.4 for time-sensitive wireless sensor networks // *Proc of the 18th Euromicro Conference on Real-time Systems, New York: IEEE ECRTS,* pp. 356-361, 2006

[14] IEEE 802.15.4 OPNET simulation model [EB/OL], [2009-03-31], http://www.ope n-zb.net/.

[15] Wang Feng, Li Dou, Zhao Yuping, On Analysis of the Contention Access Period of IEEE 802.15.4 MAC and Its Improvement, *Wireless Personal Communications,* 65(4), p955-975, 2012

[16] Kumar, Vinay, Raghuvansi, A.S., Tiwari, S., Performance study of beacon-enabled IEEE 802.15.4 standard in WSNs with clustering, *International Conference on Power, Control and Embedded Systems(ICPCES),* 2010

Yong Lan was awarded a PhD of Computer Science & technology in 2003 from Northwestern polytechnical University of China. He further spent two years as a postdoc research at Tsinghua University from 2004 to 2006. Now he works as an academic in the College of Information Engineering of Chang'an University and his current research interests are in the area of wireless sensor networks (WSNs), Internet of things, etc.

Bo Zhang was awarded a PhD of Computer Science & technology in 2005 from Northwestern polytechnical University of China. He further spent two years as a postdoc research at NWPU of China. Now he works as a researcher in the Information Center of Land and Resources Bureau of Xi'an city. His current research is interesting in the area of wireless sensor networks used in intelligent traffic system (ITS).

Zhicheng Chen was awarded a PhD of Computer Science & technology in 2003 from Northwestern polytechnical University of China. He further spent two years as a postdoc research at Tsinghua University from 2004 to 2006. He is a professor in the School of Computer Science at Beijing University of Posts and Telecommunications. Now he is interesting in the research of cloud computing, Internet of things, etc.