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DETERMINATION OF QoS METRICS IN SENSOR NODES WITH BUFFER AND SINGLE MULTIMEDIA CLASSES

In this paper, we proposed QoS metrics determining queue/buffering management of single multimedia traffic class in the system with two servers. Given three QoS models illustrate clear picture of how system specification should be chosen in order to decrease data loss. Based on the proposed model we can handle arrival packet in the buffer in order to reduce packet loss. It is the main benefit of the proposed model. According to probability of blocking in buffer and average waiting time in the system we can determine buffer size. Undesirable situation of system – blocking state also can be reduced by determining buffer size, arrival and service intensities.

Key words: *Wireless sensor networks, QoS, buffer, queuing theory, multimedia data.*

Introduction

Development of Micro-Electro-Mechanical System (MEMS) opened a number of new application area of wireless sensor networks (WSNs). WSNs are combination of tiny, energy limited sensor nodes that are scattered throughout the observation areas and wirelessly connected [1]. These sensor nodes include sensor boards and are strewn across the unattended area in order to sense environmental phenomenon and get observed data. Tiny and low-cost sensor nodes can be placed densely throughout an experimental area for gathering and delivering information to other nodes. Dense deployment of sensor node helps to increase high connectivity between nodes. Furthermore, sensor nodes plays role of router to deliver data as well as environmental monitoring. It sends gathered data to the sink through mediate nodes and receives the packet coming from the neighbor nodes.

Up to date there isn’t available any unique standard for sensor nodes in terms of utilization, connection and etc. However, there are different standards for WSNs developed by different vendors, such as WirelessHART, ISA100, IEEE 1451, ZigBee/802.15.4. WSNs have many application areas such as indoor/outdoor fire fighting, country border control, temperature and humidity control and etc.

Sensor nodes are assembled of off the shelf devices and have limited and low processing capacity, storage and power supply. Because of these constraints sensor nodes should be effectively assembled so that to keep sensor network life as much as possible and therefore minimize energy consumption.

Since the sensor nodes are deployed in remote, unattended areas that are not easy to reach, their batteries are irreplaceable. In this context power supply becomes main challenge in sensor node and network implantation. To reduce energy consumption, most of the node’s components, mainly the radio and CPU, go to turn off mode. A battery-depleted or failed nodes change network topology and directly or indirectly shorten the life of the sensor networks [2].

As a main problem, energy consumption should be taken into account in network and sensor design, network management and etc. A key factor in network design is implementation new algorithms for delivering data and protocols that effectively consume energy in order to maximize a network life and to use strained resources efficiently.

Packet size is one of the main challenges in conventional WSNs because of resource constraints. In traditional sensor networks packets consist of text-based data.

However, in multimedia WSN packets might include pictures, sound and video files as well as video streaming. Size of multimedia packet is significantly bigger than text-based data, where it uses more energy to transfer data through the sensor networks. Therefore, multimedia WSNs need other standards different from conventional sensor networks. In multimedia WSNs energy consumption still remains one of the main challenges. As we expand hardware specifications, more energy will be consumed for computation. One of the ways to prolong the life of nodes is to add additional power supply such as a solar cell. However, it will increase the cost of the sensor nodes and therefore will squeeze the application areas [3]. Furthermore, there also should be trade-off between resource utilization and arrival packet size. Since size of multimedia data is comparatively big to be served by sensor node, selection of relevant hardware devices plays essential role in sensor node design. So that, if computational speed of the sensor devise is low then there will become long queue for arrival multimedia packets in the buffer. The loss of some video and voice packets might not seriously affect overall data in destination, so that remaining packet can convey the necessary message to the listener. In the case of loss of image packet, it is difficult to recollect whole frame in order to get original picture back.

In this paper we proposed QoS model based on Queueing Theory in order to control blocking of arrival packets and waiting time in the system were analyzed. These measurements give us clear understanding on what service rate should be servers own in order to decrease packet loss and to minimize waiting time in the system.

System Overview

A. Multimedia WSNs

In addition to traditional WSN, multimedia WSNs includes low-cost video cameras or sound recorders. Once a sensor senses observed phenomenon or intruders, video cameras or sound recorders are activated [4]. Modern sensor nodes can analyze data and deliver relevant part of them; where in turn perform less processing computation. Main energy-deplete parts of sensor networks are transmission and receiving data, in other words is radio part [5].

Resource limitation and power supply create main barrier to sensor nodes sensor nodes to work with traffic classes-video, voice, picture and stream data effectively. State-of-the-art, small sized and low-cost Complimentary Metal Oxide Semiconductor (CMOS) cameras give more opportunity to handle multimedia data in WSNs. However, file (packet) size taken by these cameras is still big to transfer and requires high bandwidth. Routing protocols, encoding/decoding mechanism, path selection and etc modeled for conventional WSNs, where they were considered only small sized packets, won't work effectively in multimedia WSNs. Furthermore, probability of packet loss in multimedia data is higher than the conventional one, because of packet size [6, 7]. Therefore, minimization of probability of arrival packet is the main factor in multimedia WSNs. From technical point of view, data loss happens in queue/buffer management system at the MAC layer [8]. In this paper we analyzed queue mechanism in the processing unit where the buffer is placed in order to increase Quality of Services.

B. Protocol Stack and Queuing Management

Protocol stack used in WSNs are given in Fig. 1. It consists of the application layer, transport layer, network layer, data link layer, physical layer. Application software are programmed and launched at the Application layer.

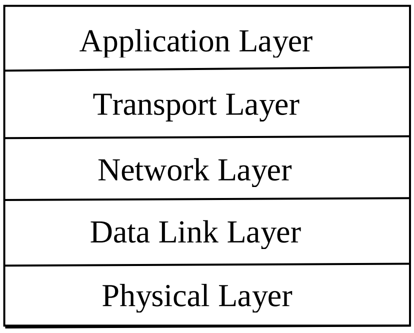

Fig. 1. The sensor network protocol stack

These application software carry application-specific characteristics, namely they are designed exactly only for one application purpose. The entire data gathered at the application layer are decomposed into segment at the transport layer. Furthermore this layer controls data flow from the application layer to lower layers and controls number of segment of whole data and re-combination of arriving packets. The network layer carries out routing the data supplied by the transport layer. Since the environment is noisy and sensor nodes can be mobile, the MAC protocol should be power aware and minimize collision with neighbors' broadcast. Creating frames, packet modulation, transmission and receiving techniques are take place in the physical layer addresses [9, 10].

C. Queueing in the MAC Layer

As in other packet circuits buffering is required to diminish the loss of the arrival datagrams when arrival rate is bigger than service rate. Queued datagrams are chosen on the bases of scheduling discipline [11]. The queueing and buffer management techniques are required to manage with the datagrams delivering from the physical layer to the upper layer. Selection of one datagram among the queued datagrams might be done on a simply basis, such as First Come First Serve (FCFS). There are many scheduling discipline in queueing and buffer managements systems. The important issue in queueing management is to provide the best QoS metrics. The less the loss of arrival packet, the bigger the QoS guarantees.

Proposed framework

In the proposed model queue/buffering management mechanism were analyzed. In the model two types of QoS metrics were proposed: probability of blocking and waiting time in service of arrival packets. We are interested in minimization of probability of data loss, which in turn will decrease number of retransmission. In this model, we studied system in two parts, where each part was given as a server (see Fig. 2). First server covers the physical layer and the data link layer. But second server consists of aggregation of reaming layers – the network layer, the transport layer and the application layer. In order to prevent data loss we put buffer with size R before the first server with service intensity μ_1 in order to move arrival packets in it when the server is busy. Second server with service intensity μ_2 receives packets coming from the first server.

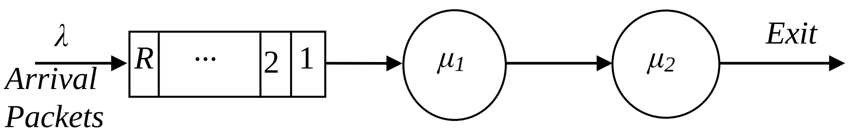

Fig.2. Structure of Queuing Process

A state diagram for the given model is illustrated in Fig. 3. When packet arrives to the server 1, they go the buffer if the server is busy, other vise they are being transferred to the server 2. However if the server 2 is busy, where it cannot accept packets coming from the server 1, system goes to the *block state.* In this state served packets in the server 1 wait until the server 2 is idle. Moreover, arrival packets in the server 1 wait in queue. If buffer size reaches to R, then arrival packet will be dropped.

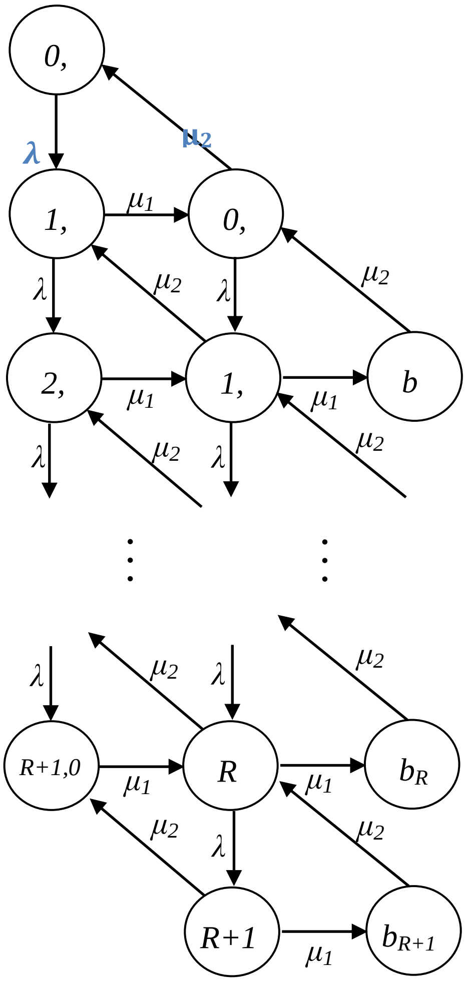

Fig.3. State diagram of data flow datagram with buffer

State probabilities for given state diagram are given in the form *balance equation* as below:

$$\pi(0,0)\,\lambda=\pi(0,1)\,\mu_2 \quad (1)$$

$$\pi(i,0)(\lambda+\mu_1)=\pi(i\text{-}1,0)\,\lambda + \pi(i,1)\,\mu_2,\; i=\overline{1,R} \quad (2)$$

$$\pi(R+1,0)\,\mu_1=\pi(R,0)\,\lambda + \pi(R+1,1)\,\mu_2 \quad (3)$$

$$\pi(0,1)(\lambda+\mu_2)=\pi(1,0)\,\mu_1 + \pi(b_1)\,\mu_2 \quad (4)$$

$$\pi(i,1)(\lambda+\mu_1+\mu_2)=\pi(i+1,0)\,\mu_1 + \pi(b_{i+1})\,\mu_2 + \pi(i\text{-}1,1)\lambda, i=\overline{1,R} \quad (5)$$

$$\pi(b_i)\,\mu_2 = \pi(i,1)\,\mu_i,\; i=\overline{1,R+1} \quad (6)$$

$$\pi(R+1,1)(\mu_1+\mu_2)=\pi(R,1)\,\lambda \quad (7)$$

Here (1), (3), (4) and (7) are the equations for *boundary states.*

Normalizing condition for the given model is:

$$\sum_{i=0}^{R+1}\pi(i,0)+\sum_{i=0}^{R+1}\pi(i,1)+\sum_{i=1}^{R+1}\pi(b_i)=1 \quad (8)$$

In the given state diagram it is too complicated to figure out a price formula for each π state probabilities. Since number of variables and equations are the same $3R$+5, we used matrix calculation in MATLAB 10.0 version to calculate values of each state probabilities π.

As we mentioned above, two kinds of QoS metrics were proposed in the paper: probability of blocking (*PB*) and average waiting time in the system (W_s). Furthermore, in the proposed model probability of blocking is available in two sections –in the buffer and in the *blocking state.* Based on the probability of blocking in the *blocking state* (PB_2), hardware specification of the second server can be determined so that it would serves packet coming from the first server without delay. Average waiting time in the system (W_s) gives us opportunity to analyze video streaming in the system. Packet delay for the video streaming should be less in comparison with picture and video file in the multimedia WSNs. As a consequence of all the above the following approximate formula for calculation of QoS metrics can be suggested.

$$PB_1 = \pi(R+1,0) + \pi(R+1,1) + \pi(b_{R+1}) \quad (9)$$

$$PB_2=\sum_{i=1}^{R+1}\pi(b_i) \quad (10)$$

$$W_s = L_q + \mu_1^{-1} + \mu_2^{-1} \quad (11)$$

where $L_q = \sum_{i=1}^{R} \pi(i+1,0) + \pi(i+1,1) + \pi(b_{i+1})$, PB_1- Probability of Blocking in the buffer; PB_2-Probability of Blocking in *blocking state*; W_s – Average waiting time in the system.

Based on the exact formulas of state probabilities, we did numerical analyses as below.

Numerical Results

Given QoS metrics – probability of blocking in the buffer (PB_1); probability of blocking in *blocking state* (PB_2) and average waiting time in the system (W_s) were analyzed depending on buffer size (R) and packet arrival rate (λ). For simplicity we didn't distinguish the traffics classes (video, sound, picture and video streaming), namely they were studied as a single class. Considering the fact that size of all traffics is quite big, that makes it difficult to transfer them via the sensor nodes. In Fig. 4–9 are given results of probability of blocking in buffer (PB_1) and in the *blocking state* (PB_2) and average waiting time in the system (W_s) versus buffer size (R) and packet arrival rate (λ), respectively. As main characteristics of the QoS metrics, the probability of blocking of arrival packet should be minimized. Probability of blocking is buffer (PB_1) negatively related with buffer size R (see Fig. 4). As given in Fig. 4 PB_1 gets its lowest values when $\mu_1 < \mu_2$ (μ_1=50, μ_2=70). It implies that packets delivering from the first server will be served faster in the second server. The same behavior can be seen in the probability of blocking in the *blocking state* (PB_2) which is undesirable situation (see Fig. 5). Main factor affecting PB_2 is ratio between μ_1 and μ_2. In order to analyze this effect we took fixed value of μ_1 and increased value of μ_2 with large interval as shown in Table 1. From Table 1 it is clear that the bigger ratio of μ_2/μ_1, the smaller PB_2.

Table 1

Depending of PB_2 on μ_2, R=70, λ=100, μ_1=70

N	PB_2	μ_2
1	0.981	1
2	0.788	10
3	0.142	100
4	0.047	200
5	0.009	500
6	0.0023	1000
7	0.0006	2000
8	0.0001	5000
9	0.00002	10000

The worst case for PB_1 and PB_2 is when $\mu_1 > \mu_2$. Figs. 4–5 show that probability of blocking is higher at μ_1=70, μ_2=60. It implies that the second server cannot serve the entire packet coming from the first server because of smaller service rate, where it leads to increase in packet loss in buffer, and in longevity of the *blocking state*. Moreover, the case of $\mu_1 = \mu_2$ probability of data loss and blocking is less than when $\mu_1 > \mu_2$ (see Figs. 4–5).

High values of average waiting time in the system (W_s) is not good options for video streaming as well as other types of multimedia traffics. Because of duration in which packets waiting in queue for long period of time reserve channel, probability of new arrival packets increases. As given in Fig. 6, average waiting time in the system (W_s) becomes optimal when $\mu_1 < \mu_2$ and $\mu_1 = \mu_2$, where μ_1=50, μ_2=70 and μ_1=70, μ_2=70, respectively. Like PB_1 and PB_2, W_s gets it high values when $\mu_1 > \mu_2$ (μ_1=70, μ_2=60).

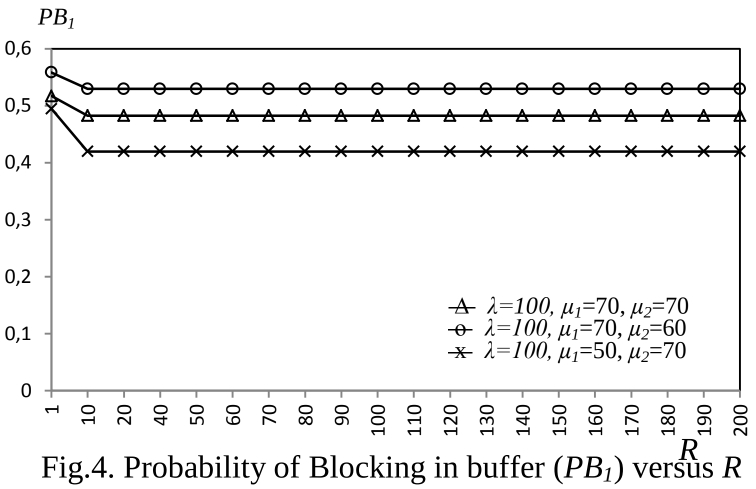

Fig.4. Probability of Blocking in buffer (PB_1) versus R

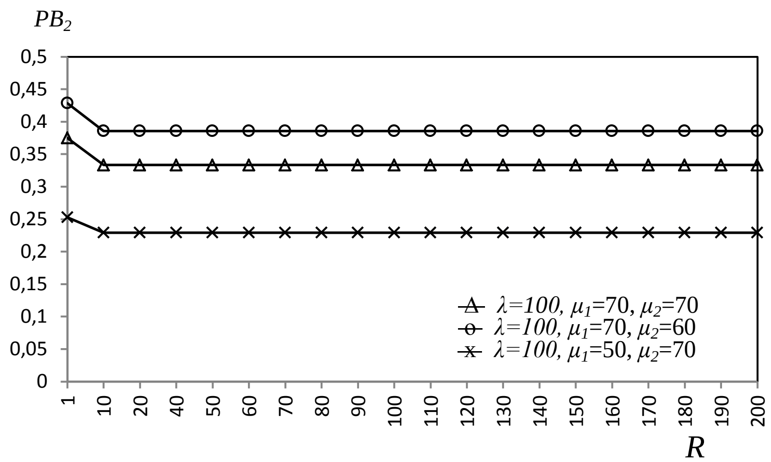

Fig.5. Probability of Blocking in the *blocking state* (PB_2) versus R

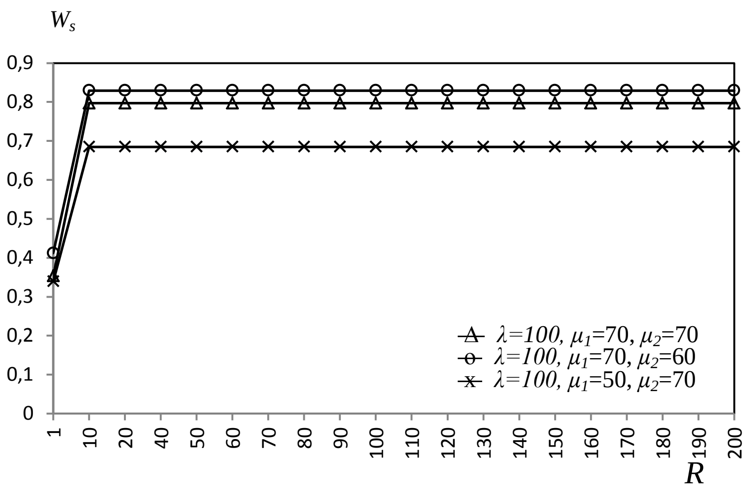

Fig.6. Average waiting time in the system (W_s) versus R

Increase in buffer size R is favorable for PB_1, because new arrival packet can wait in queue if system is busy which in turn result in decrease in packet loss. However, it is not good choose for Ws, because to make video streaming wait in the queue for a long period of time is not desirable situation. In this context, in order to find optimal value of R we can propose the following optimization problem for the given model:

Find the maximum R subject to $PB_1 \le \varepsilon$ and $W_s \le \delta$, where ε and δ are fixed and given in advance, i.e.

$$R \to \max, \tag{12}$$

$$\text{s.t. } PB_1(\mathrm{R}) \le \varepsilon \tag{13}$$

$$W_s(\mathrm{R}) \le \delta \tag{14}$$

By using monotone increasing property of function PB_1 and monotone decreasing property of W_s, we can increase the values of R step by step till (13) and (14) are satisfied. The results of a solution of the optimization problems (12)-(14) are given in tables 2. A symbol Ø given in the table means that there isn't any solution for the given problem.

Table 2

Result of optimization problem of (12)–(14)

λ	20	20	20	20	30	30	30	30	30	30	30	30	30	30
μ_1	50	50	50	50	50	50	50	50	70	70	70	70	70	70
μ_2	100	100	100	100	100	100	100	100	110	110	110	120	130	140
ε	10^{-1}	10^{-2}	10^{-3}	10^{-2}	10^{-1}	10^{-2}	10^{-3}	10^{-3}	10^{-1}	10^{-2}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
δ	2	2	2	3	2	2	2	5	2	2	2	2	2	2
R^*	16	96	Ø	96	18	96	118	118	17	91	128	117	117	113

It is evident from table 2 that R decreases as ε increases, where it was also expected in advance. Furthermore, as given in Table 2, if to analyze R^* in fixed values of μ_1 and λ, say λ=20, μ_1=50, we can see huge jump in values of $\varepsilon=10^{-1}$ and $\varepsilon=10^{-2}$. It is important to note that reasonable selection of relevant and sufficient values of arrival and service intensities affects the cost of the microprocessor and transceivers. Moreover, as a main factor of QoS in WSNs – longevity of the network should also be calculated based on the selected devices. It could be done by comparing the power supply of battery and required computational energy based on the selected device parameters.

Intensity of arrival packet λ also affects the probability of blocking in buffer (PB_1). If the buffer is full, new arrival packet will be dropped. Therefore, the bigger the arrival intensity, the bigger the probability of blocking. As shown in the Fig. 7 PB_1 increases at increasing rate till it reach μ_1, and then it increases at decreasing rate. Unlike PB_1, PB_2 and W_s is negatively related to arrival intensity λ (see Fig. 8-9). One reason for that case might be that at high rate of arrival intensity a buffer becomes always full and PB_1 gets bigger and bigger, and therefore packet forwarding from the first server to the second server get reduced, which in turn decreases probability of blocking in *the blocking state.* Simultaneously, because of less number of packets in the system, as λ get increased, average waiting time in the system W_s get reduced.

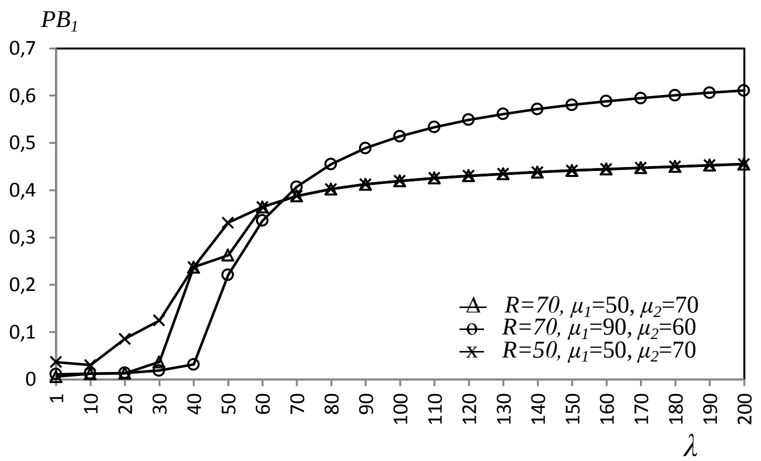

Fig.7. Probability of Blocking in buffer (PB_1) versus λ

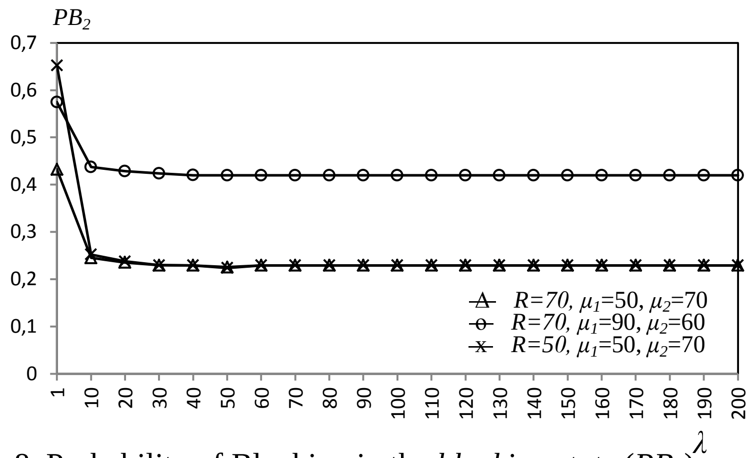

Fig.8. Probability of Blocking in the *blocking state* (PB_2) versus λ

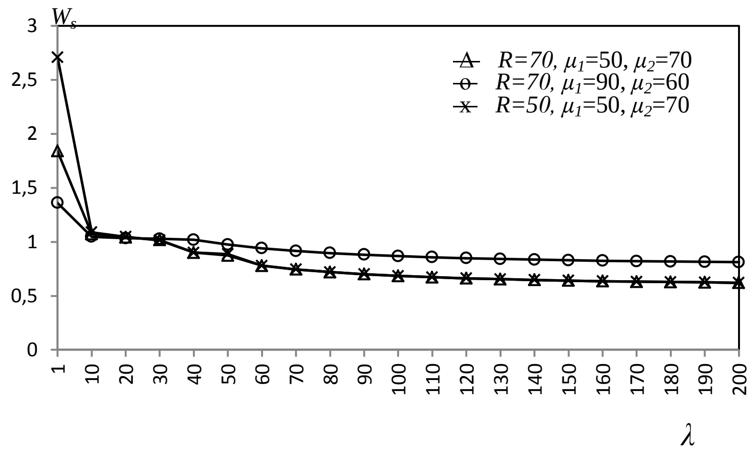

Fig.9. Average wainting time in the system (W_s) versus λ

Conclusion

In this paper, queue/buffering management based QoS metrics were proposed. Because of resource constrains and limited power supply, these QoS metrics should be designed so that network life would be prolong as long as possible. Proposed QoS metrics – probability of blocking in buffer (PB_1) and in *the blocking state* (PB_2), and average waiting time in the system (W_s) give us a big picture of how sensor devices should be chosen in order to get desirable arrival intensity and service intensity in each server. Different side of the proposed model from other methods is that within the proposed model we can handle arrival packet in the buffer in order to reduce packet loss. Unlike wired and other wireless networks, proposed QoS metrics can be widely used in sensor networks. It is the main benefit of the proposed model. Based on PB_1 and W_s we can determine buffer size. Undesirable situation of system – *blocking state* PB_2 also can be reduced by determining buffer size, arrival and service intensities.

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Buferli simsiz sensor şəbəkələrdə keyfiyyət göstəricilərinin təyin edilməsi

Məqalədə sensor şəbəkə qovşağında tək sinif trafik üçün xidmətin keyfiyyət göstəricilərinin müəyyən edilməsinin model və üsulları təklif edilmişdir. Model birinci serverin girişində buferi olan iki ardıcıl serverli kütləvi xidmət sistemindən ibarətdir. Təklif edilmiş modellər əsasında daxil olan paketlərin itməsi ehtimalını azaltmaq mümkündür. Paketlərin itməsi ehtimalına və buferdə gözləmə müddətinə qoyulan məhdudiyyətləri nəzərə almaqla buferin minimal həcmini müəyyən etmək olar. Buferin zəruri həcmini, daxil olan paketlərin intensivliyini və onların emalı intensivliyini təyin etməklə sistemin blok vəziyyətlərinin ehtimallarını minimallaşdırmaq mümkündür.

Açar sözlər: *simsiz sensor şəbəkələri, keyfiyyət göstəriciləri, bufer, kütləvi xidmət nəzəriyyəsi, multimedia verilənləri.*

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Определение показателей качества обслуживания в сенсорных узлах с буфером

В статье предложены модели и методы определения показателей качества обслуживания (QoS) одного класса трафика в сенсорных узлах с двумя последовательными серверами и очередями перед первым сервером. На основе предложенных моделей удается уменьшить вероятность потери пакетов. По заданным ограничениям вероятности блокировки в буфере и среднего времени ожидания в системе можно определить минимальный размер буфера. Нежелательные ситуации блокировки системы также могут быть уменьшены путем определения необходимого размера буфера, интенсивности поступления и обслуживания.

Ключевые слова: *беспроводные сенсорные сети, QoS, буфер, теория массового обслуживания, мультимедийные данные.*