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Priority-based transmission rate control with a fuzzy logical controller in wireless multimedia sensor networks

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ABSTRACT

Wireless multimedia sensor networks (WMSNs) are usually troubled by network congestion due to large packet transmission amounts, and such congestion will not only lose data packets but also lead to too much energy consumption. Therefore, in order to enhance the transmission performance of WMSNs and reduce the delay time, it is necessary to adjust the transmission rate and control network congestion. WMSNs use different kinds of sensor nodes to collect different kinds of data. In multimedia applications, it is necessary to provide a reliable and fair protocol so as to meet the requirements of quality of service (QoS) of different formats of data. In past research, for WMSNs, priority-based rate control (PBRC) algorithms and exponential weight (EW) algorithms were used to control congestion through the adjusting of the transmission rate among different data formats. However, the weight parameter of the EW algorithm is fixed; when the change in data transmission amount is large, the difference between input transmission rate and estimated output transmission rate for the sink node will be large. In this paper, we have proposed an algorithm where a fuzzy logical controller (FLC) is used to estimate the output transmission rate of the sink node. The FLC is associated with the EW algorithm for selecting the appropriate weight parameter, and then, on the basis of the priority of each child node, an appropriate transmission rate is assigned. Simulation results show that the performance of our proposed algorithm has a better transmission rate as compared to that of PBRC, and hence, the transmission delay and loss probability are reduced; in addition, our proposed algorithm can control effectively the different transmission data types in order to achieve the QoS requirement of the system.

1. Introduction

A wireless sensor network (WSN) [1] is a node set formed by one or several sink nodes and a large amount of sensor nodes, and they are deployed in wireless sensor areas. A wireless sensor network has a real-time device for the integration of information sensing, calculation and wireless communication. There is mutual propagation of data from a neighboring node to the base station (BS). A wireless multimedia sensor network (WMSN) [2] is an extensional application based on wireless sensor networks, and the sensor can, on the basis of different needs, be equipped with a necessary multimedia module, for example a mini-microphone or camera. Therefore, WMSNs have the capability of transmitting multimedia data, for example, still pictures, streamed video and monitoring data. WMSNs have resource limitations such as those of energy, memory, bandwidth buffer area size and data processing capability; however, since multimedia data transmission needs the capability of a high transmission rate and the processing of a large amount of data, the high data transmission rate of WMSNs usually leads to congestion, which in turn reduces the quality of service (QoS) of multimedia applications.

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WMSNs use packets to carry important information and transmit it in a hop-by-hop manner. The transmission priorities of heterogeneous WMSNs are all different, and the priority types can be divided into real-time transmission and non-real-time transmission. Real-time transmission has an immediate time limitation, for example, a tolerance to packet delay, bandwidth jitter and packet loss. In the real-time transmission type, the priority is highest, and there is no need to consider the control of the transmission rate; however, the non-real-time transmission type uses an active queue management algorithm [3] to distribute the transmission rate. In network data transmission, general study on QoS includes packet loss probability, delay and packet throughput, and it is usually hoped that the warranty on packet loss probability and delay can be reduced [4].

QoS, in network transmission, provides a stable and predictable data transmission service to satisfy the requirements of network users. The data flow on the Internet, like e-commerce, multimedia data transmission and large file download, etc., usually needs an impulse of a large data transmission amount, which in turn causes congestion [5], and the Internet efficiency is then affected accordingly; however, increase of the bandwidth cannot solve the insufficient network resource issue. The Internet Engineering Task Force (IETF) proposed a service differentiation [6,7] model to ensure the QoS of end-to-end transmission.

In the literature [8], this was proposed with a fuzzy logical controller (FLC) to achieve rate management and energy control for code division multiple access (CDMA) systems. A FLC is used to achieve self-adapted rate adjustment and power control on the transmission rate, and two input values of the signal-to-interference ratio and error to error variation are used to adjust the power control and transmission rate control. References [9,10] propose the use of FLC power control to select the appropriate channel from non-linear time variation characteristics. Reference [11] associated a fuzzy neural network method to be applied in the linear system; then through neural network training, self-adapted control can be achieved.

In a WMSN, it was proposed to use a model based on transmission priority [12] to reduce the network transmission congestion problem. As regards the transmission rate, an exponential weight (EW) algorithm was used for adjusting and control. In the EW algorithm, the weight parameter was fixed; when there is large variation of the transmission data, the difference between the input transmission rate and estimated transmission rate for the sink node will be large, and the network resource distribution will not be even; hence, the transmission delay and loss probability for a WMSN is increased.

In this paper, we have proposed an algorithm using a FLC in controlling the transmission rate for the sink node, and this is to avoid resource waste due to too much adjustment of the transmission rate; however, if the transmission rate is too small, it could lead to too much transmission delay. In our algorithm, we have selected the transmission rate error and error change as two input variables of the FLC; through the FLC, the weight parameter of the EW algorithm is adjusted so as to achieve transmission rate optimization at the sink node, and then through the rate management unit, the transmission rates at the sink node and other child nodes are adjusted; meanwhile, on the basis of the geographical location priority of each node and all the transmission data priorities within the nodes, an appropriate transmission rate is distributed to all the nodes.

The architecture of organization of this paper is the following: Section 2 will be an investigation of related research regarding WMSNs in transmission congestion control, Section 3 will propose the research algorithm for the improvement of the transmission amount, Section 4 will give the results of the simulation experiment, and Section 5 is the conclusion of this paper.

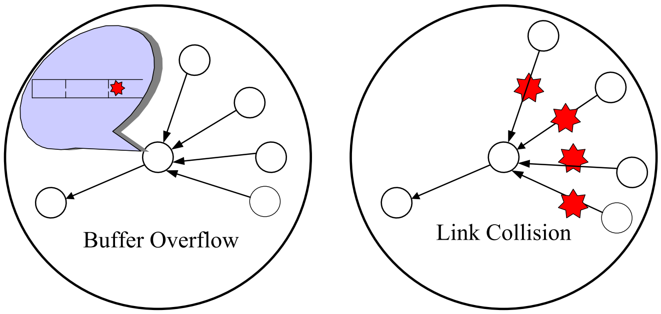
2. Related work

In this section, the effect of transmission congestion on network resources and QoS will be introduced. The traditional transmission control protocol (TCP) is widely used in today's computer networks, and TCP uses packet confirmation to provide reliable transmission; furthermore, we also investigate the congestion control architecture in order to achieve the QoS requirement of WMSNs in different formats of data.

For data transmission in WSNs, the coordination of a network transmission model layer should be done. Different layers have different control issues. In data transmission, a media access control layer (MAC) uses request to send (RTS), clear to send (CTS) and acknowledgement (ACK) mechanisms to provide transmission for the sensor node of each activity. In WMSNs, the MAC layer is used to collect the transmitted information and to measure the queuing delay and transmission delay, then using the above two measured times, the transmission rate is calculated [13].

In WSNs, the transmission rate congestion control is an important issue in much research. The occurrence of congestion will lead to massive packet loss, and the re-transmission of lost packets not only will lead to the occurrence of congestion again, but also will lead to the waste of network resources and will reduce the reliability of data detection and collection. Fig. 1 shows that there are two types of congestion [14]: node-level congestion and link-level congestion. The first type is node-level congestion; in each sensor node, when the packet arrival at the node is larger than the buffer size, it will lead to buffer overflow and increasing packet loss when the node is in the data transmission process. The second type is link-level congestion, which occurs in wireless transmission and occurs when the nodes are in the same utilization channel, for example, carrier sense multiple access with collision detection (CSMA/CD). Such a situation occurs when multiple active nodes perform access on the same channel and collision is then the result [15]; when the occurrence of collision is detected, the node in collision will have to send out a congestion signal to the entire network, and at this moment, all the nodes in the network have to stop transmission and enter a waiting state to wait for the next chance.

Generally, there are two general approaches for controlling congestions, namely, network resource management and traffic control [14]. The first type is network resource management; when there is traffic congestion in the network,



(a) Node-level congestion. (b) Link-level congestion.

Fig. 1. Congestion in a wireless sensor network.

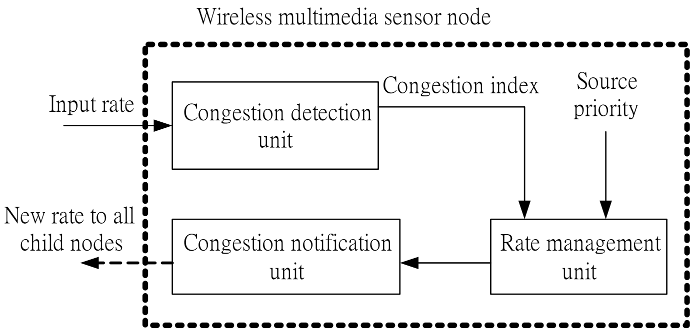


Fig. 2. Structure of a congestion unit.

through the enhancement of network resources, the congestion is reduced. For example, through the increase of bandwidth, congestion is slowed down. When this method is used, accurate adjustment of network resources is necessary to avoid resource overloading. The second type is transmission control, and traffic control is used to adjust the source node or medium node of congestion so as to save network resources and to enhance the resource effectiveness. Most of the current congestion control protocols are of this type. There are two ways to control traffic: end-to-end and hop-by-hop. The end-to-end method can be used to adjust the rate of each source node accurately, but the drawback is that the response is slow and the round-trip time (RTT) of the packet needs to be considered. As compared to the end-to-end method, the hop-by-hop method has a faster response time for congestion control; meanwhile, since that method is mainly used under MAC layer communication protocol, the adjustment of the packet forwarding rate of the intermediate node is then more difficult.

Yaghmaee and Adjeroh [12]proposed a congestion control unit within sensor nodes, and Fig. 2 shows that the congestion control unit in the sensor node is formed of three components, namely, a congestion detection unit (CDU), a congestion notification unit (CNU) and a transmission rate management unit (RMU). CDU measures the input rate for determining the congestion; then CNU will use the intensity of congestion to notify the transmission child node, and then RMU will be used for transmission rate adjustment. The congestion control component will, at each time interval, calculate the transmission rate of the parent node and the transmission rate of the child node, and then each sensor node will detect the occurrence of congestion and adjust the transmission rate.

3. A FLC with exponential weight in a priority-based rate control algorithm

In this section, the research algorithm proposed for the improvement of the transmission performance will be introduced; then FLC will be associated with an exponential weight (EW) algorithm to control the optimal transmission rate of the sink node, and then the transmission rate of the sink node will follow the priority of the priority-based rate control (PBRC) algorithm [12] to achieve a transmission rate distribution on all the child nodes so as to enhance the transmission performance and to reduce the transmission delay time and loss probability.

3.1. A traffic class model

Fig. 3 shows the definition of the experimental model, symbol and algorithm for our proposed and simulated WMSN environmental hypothesis. There are ten nodes, one sink node and the BS; among the ten nodes, we have defined four different types of data amount and priority class, which are the rapid traffic of real-time (RT) transmission type, and three

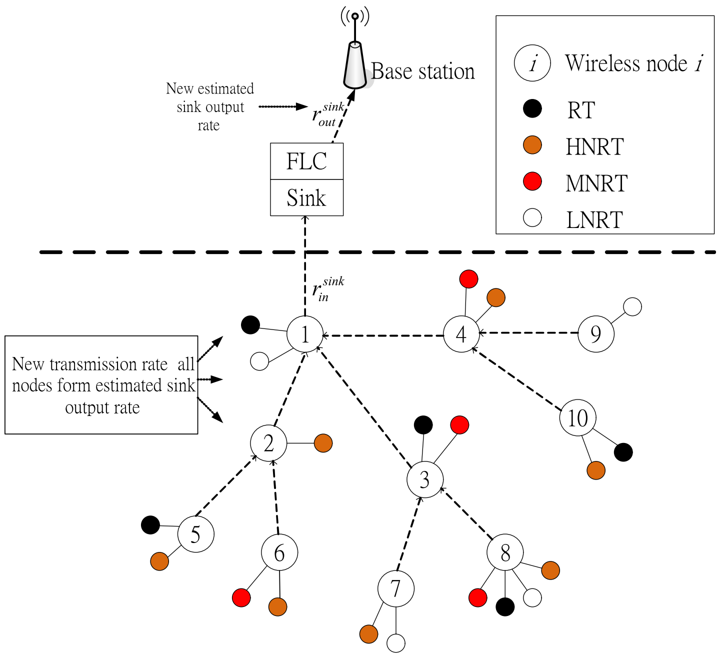


Fig. 3. A traffic class model for WMSNs.

types of non-real-time transmission type, namely, high-priority non-real-time (HNRT), medium-priority non-real-time (MNRT) and low-priority non-real-time (LNRT). Moreover, the transmission rate of the node is adjusted according to the priority of the data type and the geographical location of the node, and $r_{\text{in}}^{\text{sink}}$ is the sum of input transmission rates for all the child nodes for transmitting data to the sink node. In Fig. 3, our proposed algorithm has used the FLC to follow $r_{\text{in}}^{\text{sink}}$ to estimate the output transmission rate $r_{\text{out}}^{\text{sink}}$ of the sink node where $r_{\text{out}}^{\text{sink}}$ is the transmission rate for the sink node to transmit data to the BS.

3.2. Service differentiation

In WMSNs, transmission service differentiation is supported. The transmission type of the data is defined first; then the priority class of the data is followed for the transmission so that the network resource can be effectively distributed, and then optimal performance can be provided based on a different type of flow rate. RT is the real-time traffic class; hence, it has the highest class of transmission rate and the lowest transmission delay, and HNRT, MNRT and LNRT are non-real-time transmissions, and based on the high, medium or low class, the service class of the transmission rate and transmission delay is provided. In this paper, four transmission types as mentioned above are followed to give the highest transmission rate for achieving maximal throughput, T, and minimal delay, D, and the definition and limitations are as follows:

$$\begin{aligned} &T_{\text{RT}} \geq T_{\text{HNRT}} \geq T_{\text{MNRT}} \geq T_{\text{LNRT}} \\ &D_{\text{LNRT}} \leq D_{\text{MNRT}} \leq D_{\text{HNRT}} \leq D_{\text{RT}} \end{aligned} \tag{1}$$

where in T_x is the transmission rate of the x data type, and D_x is the allowable delay time when the x data type is transmitting data. The sensing node transmits a queuing model, which is as shown in Fig. 4. For each traffic class, it will be given with a respective traffic queue; hence, when a data packet enters a transmission traffic classifier, the data type will be classified to enter the respective queue that it belongs to, then there will be a traffic priority weight allocated, and then a transmission traffic scheduler will be entered for data transmission.

3.3. Exponential weight of the priority-based rate control

In [12], it was mentioned that one could use an EW algorithm to be associated with the PBRC algorithm for transmission rate adjustment and that the algorithm is defined as having exponential weight of priority-based rate control (EWPBRC). Moreover, a weight parameter is used to adjust the transmission rate of the sink node; then the traffic class and geographical location priority are based on distributing to all the child nodes, and finally, network transmission and topological transmission rate equilibrium are achieved to reach the objective of congestion control.

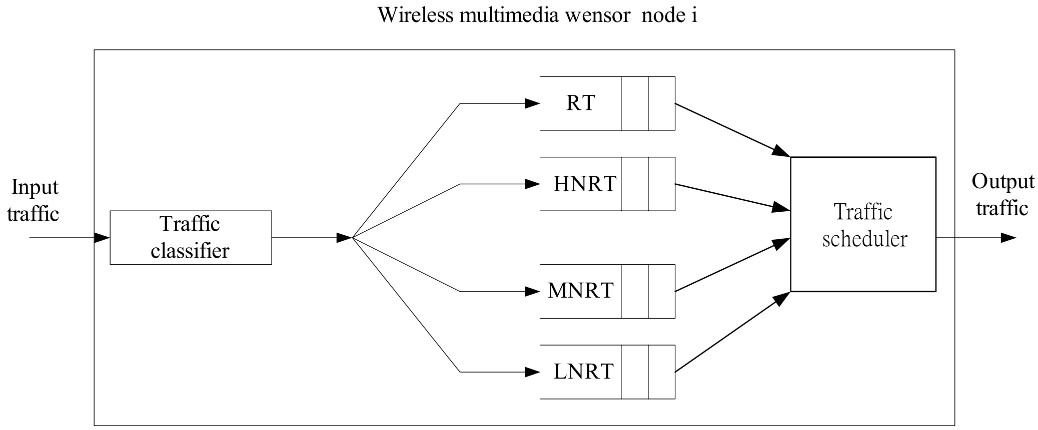


Fig. 4. Queuing model of each sensor node.

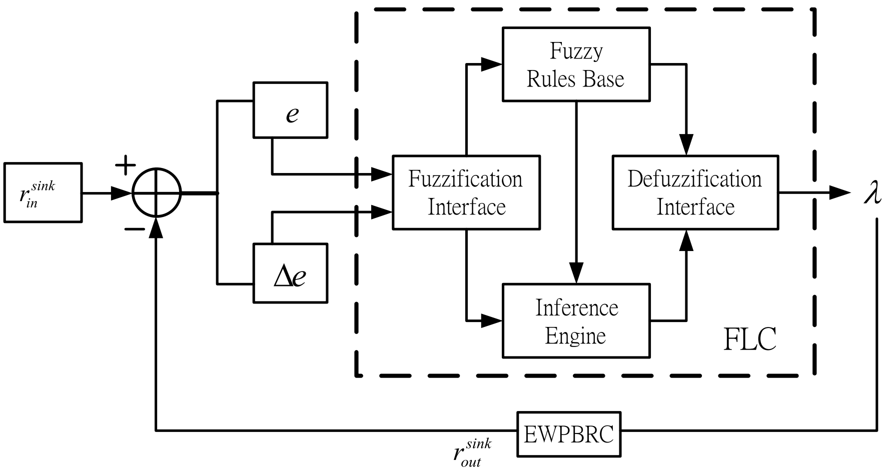


Fig. 5. Block diagram of the FEWPBRC rate control.

3.4. Our proposed FLC model

Fig. 5 shows the block diagram of our proposed algorithm which combines the FLC with the exponential weight of priority-based rate control (FEWPBRC) algorithm. In our proposed FLC model, there are two input values and one output value; that is, the error (e), which is the difference between the input transmission rate $r_{\text{in}}^{\text{sink}}$ and the output transmission rate $r_{\text{out}}^{\text{sink}}$, and the variation of e, that is, the error change (Δe), are used as two input variables. The weight parameter is used as the output variable. The FLC is formed from four components: the fuzzification interface, interface engine, fuzzy rule base and defuzzification interface.

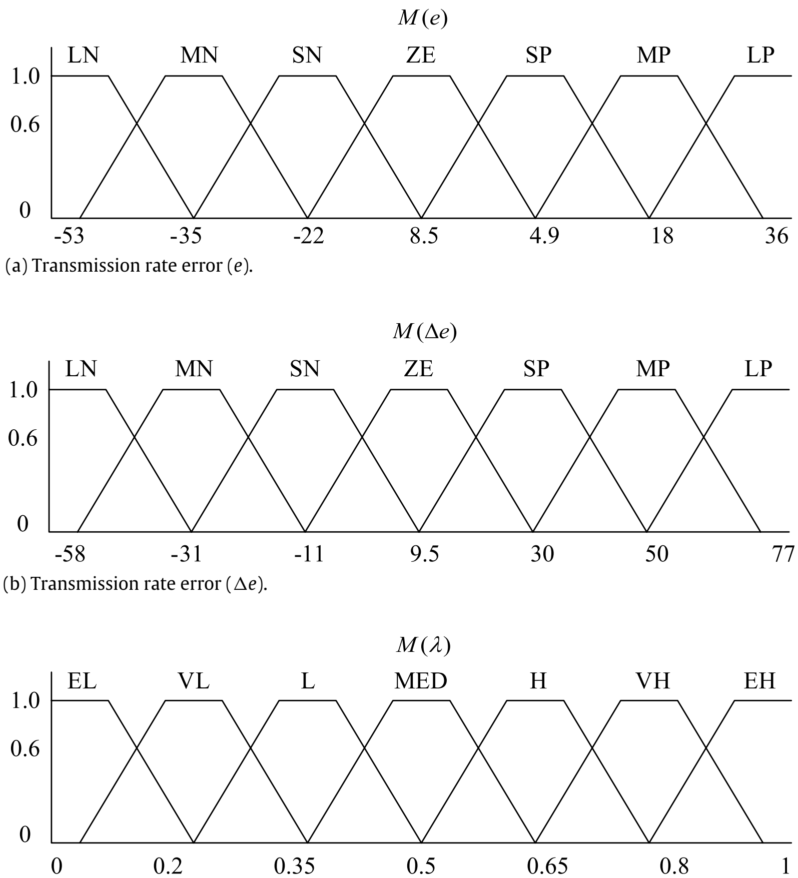
In our proposed FLC, input variable values contain seven membership functions, namely, large positive (LP), medium positive (MP), small positive (SP), zero (ZE), small negative (SN), medium negative (MN) and large negative (LN) ones. Output values contain seven membership functions, namely, extremely low (EL), very low (VL), low (L), medium (MED), high (H), very high (VH) and extremely high (EH) ones. The input and output value membership functions are as shown in Fig. 6.

The fuzzy rule base consists of the knowledge of the application domain and the attendant control goal, and fuzzy data are used as the basic rule base to control the system. The control rule is the if–then sentence [16], and in this paper, the FLC contains a total of 7×7 fuzzy rules as in Table 1.

The interface engine is used as the control mechanism for the FLC, and it handles fuzzy variables and infers fuzzy rules. The defuzzification interface, through fuzzy control, can transform the fuzzy controlled signal into a definite value, and the defuzzification output is calculated using the center of area defuzzifier [17,18].

$$\lambda = \frac{\sum_{i=1}^{n} u_i U_i}{\sum_{i=1}^{n} u_i} \tag{2}$$

where n is the number of fuzzy output sets, U_i is the output value of i, and u_i is the membership value of U_i.



(a) Transmission rate error (e).

(b) Transmission rate error (Δe).

(c) Output parameter (λ).

Fig. 6. Membership functions for the fuzzy set values.

Table 1
Fuzzy rules.

		e						
		LN	MN	SN	ZE	SP	MP	LP
	LN	EL	EL	VL	L	L	MED	MED
	MN	EL	VL	L	L	MED	MED	H
	SN	VL	L	L	MED	MED	H	VH
Δe	ZE	L	L	MED	MED	H	VH	VH
	SP	L	MED	MED	H	VH	VH	EH
	MP	MED	MED	H	VH	VH	EH	EH
	LP	MED	H	VH	VH	EH	EH	EH

3.5. The FLC with exponential weight of priority-based rate control

We have proposed a block diagram for the FEWPBRC algorithm in Fig. 5, and the FLC is associated with the EWPBRC algorithm [12] in order to adjust the output transmission rate of the sink node. In the EW algorithm, the weight parameter is fixed; when the variation of transmission data is too much, the error between $r_{\text{in}}^{\text{sink}}$ and $r_{\text{out}}^{\text{sink}}$ will be very large, and hence, the entire network performance cannot be optimized. First, in the FEWPBRC algorithm, on the basis of throughput variation, the FLC is used to adjust the weight parameter λ in the EPBRC algorithm to obtain the optimal $r_{\text{out}}^{\text{sink}}$ for the sink node. Furthermore, we use the priority of each child node to adjust the transmission rate.

Fig. 7 is the congestion control unit of our proposed FEWPBRC algorithm, when input rate $r_{\text{in}}^{\text{sink}}$ passes through the CDU unit, we calculate e and Δe, and then after the adjustment of the output transmission rate by the FEWPBRC controller and RMU unit, a new rate is generated to adjust the rate for transmitting from the sink node to the BS and the transmission rate for transmitting from all the child nodes to the sink node.

In the simulation model, each node i is divided into priorities of two different classes, namely, the traffic class priority (P_{TRC}^{i}) and the geographical location priority (P_{GEO}^{i}). SP_j^i denotes the traffic source priority j in sensor node i; the priority order

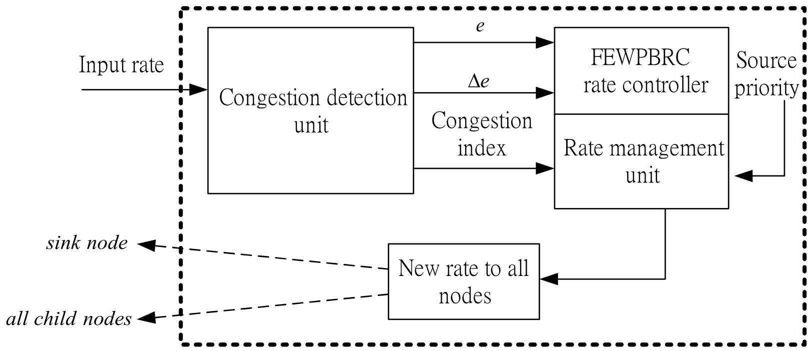


Fig. 7. Structure of the FEWPBRC congestion control unit.

SP_j^i of the source priority can be manually set up with service differentiation, and the higher the SP_j^i value, the higher the traffic class. P_{TRC}^i is the sum SP_j^i of traffic classes of source data of node *i* itself. It is represented as follows:

$$P_{TRC}^i = \sum_j SP_j^i \tag{3}$$

where *j* is the traffic class; *j* belongs to {RT, HNRT, MNRT, LNRT}.

The following is the transmission rate calculation algorithm, which can be divided into three steps: the FLC for the sink output transmission rate step, the new output transmission for the child node step and the new output transmission rate for each parent node step.

Step 1: *The FLC for the sink output transmission rate adjustment phase*

As shown in Fig. 5, we have used the FLC to adjust parameter λ of the EW algorithm, and the error *e* and error change Δ*e* are used as input variables.

$e(n)$ is the error between $r_{in}^{sink}(n)$ and $r_{out}^{sink}(n)$ at the time instant *n*, which is represented by

$$e(n) = r_{in}^{sink}(n) - r_{out}^{sink}(n). \tag{4}$$

$\Delta e(n)$ is the error change of two continuous times of *e* at time instant *n*, which is represented as follows:

$$\Delta e(n) = e(n) - e(n-1). \tag{5}$$

From Eq. (2), we can obtain the defuzzification output value, which is the weight value λ of the EW. From the transmission rates of $r_{in}^{sink}(n)$ and $r_{out}^{sink}(n)$ at time instant *n*, we can obtain the $r_{out}^{sink}(n+1)$ output transmission rate at time instant $n+1$:

$$r_{out}^{sink}(n+1) = r_{in}^{sink}(n) \cdot (1-\lambda) + \lambda \cdot r_{out}^{sink}(n) \tag{6}$$

where λ is constant, $0 \leq \lambda \leq 1$.

Finally, the mean square error (MSE) is calculated as the accuracy index reference:

$$\mathrm{MSE} = \frac{1}{N}\sum_{n=1}^{N}(r_{out}^{sink}(n) - r_{in}^{sink}(n))^2. \tag{7}$$

Step 2: *The new output transmission rate for the child node phase*

In WMSNs, based on the functionality, different types of sensor node will be equipped, and a node will be deployed at a related geographical location according to the different levels of importance. In data transmission, on the basis of the geographical location, an appropriate priority and transmission rate will be given. P_{GEO}^i is the geographical location priority of node *i*. The total priorities P^i of node *i* are the traffic class priority P_{TRC}^i and geographical location priority P_{GEO}^i, defined as follows:

$$P^i = P_{TRC}^i \cdot P_{GEO}^i. \tag{8}$$

$C(i)$ is the set of child nodes of node *i*; the global priority GP^i of each node *i* is calculated as follows: in the simulation, if there are no other child nodes in node *i*, its global priority will be equal to its total P^i value:

$$GP^i = \sum_{k\in C(i)} GP^k + P^i. \tag{9}$$

Table 2
The state of traffic classes in each sensor node.

Sensor node No.	EF ($W = 4$)	HNRT ($W = 3$)	MNRT ($W = 2$)	LNRT ($W = 1$)	P^i_{TRC}
Node 1	ON	OFF	OFF	ON	5
Node 2	OFF	ON	OFF	OFF	3
Node 3	ON	OFF	ON	OFF	6
Node 4	OFF	ON	ON	OFF	5
Node 5	ON	ON	OFF	OFF	7
Node 6	OFF	ON	ON	OFF	5
Node 7	OFF	ON	OFF	ON	4
Node 8	ON	ON	ON	ON	10
Node 9	OFF	OFF	OFF	ON	1
Node 10	ON	ON	OFF	OFF	7

GP^{sink} is the sum of global priorities of the sink node, $C(\text{Sink})$ is the set of all the child nodes with the sink as their parent, and GP^{sink} is the sum of the priorities of all the nodes, and is represented as follows:

$$\text{GP}^{\text{sink}} = \sum_{k \in C(\text{Sink})} \text{GP}^k. \tag{10}$$

To calculate the optimal output transmission rate r^i_{out} of node i, r^i_{out} is calculated on the basis of the distribution of the output transmission rate $r^{\text{sink}}_{\text{out}}$ from the sink node to node i according to the proportion between the global priority of child node GP^i and the global priority of the sink node GP^{sink}:

$$r^i_{\text{out}} = r^{\text{sink}}_{\text{out}} \cdot \frac{\text{GP}^i}{\text{GP}^{\text{sink}}}. \tag{11}$$

Step 3: *Computing a new output transmission rate for each parent node phase*

We define that r^i_{in} is the input transmission rate of node i, which is obtained through the summation of the r^k_{out} of the connected child nodes, and r^i_{in} is calculated as follows:

$$r^i_{\text{in}} = \sum_{k \in C(i)} r^k_{\text{out}} \tag{12}$$

where $C(i)$ is the set of node i, and r^k_{out} represents the output rate of the kth child of parent node i.

Δr^i is the transmission rate difference of node i and is as follows:

$$\Delta r^i = \mu \cdot r^i_{\text{out}} - r^i_{\text{in}} \tag{13}$$

where μ is a constant close to 1.

Node i generates a new transmission rate to be distributed to all the child node k output transmission rates; this is calculated as follows:

$$r^k_{\text{out}} = r^k_{\text{out}} + \Delta r^i \cdot \frac{\text{GP}^k}{\text{GP}^i}. \tag{14}$$

4. Simulation results

We have used NS2 to simulate the performance assessment of network transmission. In Fig. 3, the simulation model has ten sensor nodes, one sink node and the BS, and the transmission route of that model is a single-path transmission; the transmission data collected by sensor nodes are generated randomly, and there are four types of traffic class, namely RT, HNRT, MNRT and LNRT. Each packet size is 500 bytes, the buffer size of each child node is set up as 50 packets, and the buffer size of the sink node is 100 packets; the implementation time of each round is 100 s.

Table 2 represents an experiment, and it is assumed that all the sensor nodes will collect the data of four different traffic classes, RT, HNRT, MNRT and LNRT, and the weight values are respectively 4, 3, 2 and 1. Each node will be distributed with a transmission rate according to the priority weight of the data transmission rate class. The transmission rate of each child node for getting distributed from the sink node will be distributed according to the weight of the data amount. From Fig. 3, we have calculated P^1_{TRC} for Node 1, which contains the EF and LNRT traffic classes and is equal to $4 + 1 = 5$, which is represented as in Table 2.

Fig. 8 shows that $r^{\text{sink}}_{\text{in}}$ is the total input transmission rate for all the child nodes for transmitting data to the sink node in each round. As shown in Fig. 9, we have compared the output transmission rates $r^{\text{sink}}_{\text{out}}$ of three algorithms, namely the fixed-rate PBRC algorithm, the EWPBRC algorithm with $\lambda = 0.5$ and the FEWPBRC algorithm. In Fig. 8 and in the first round, $r^{\text{sink}}_{\text{in}}$ is 295.88 MB; from the simulation results of Fig. 9, it can be seen that the output transmission rates $r^{\text{sink}}_{\text{out}}$ of the fixed-rate PBRC

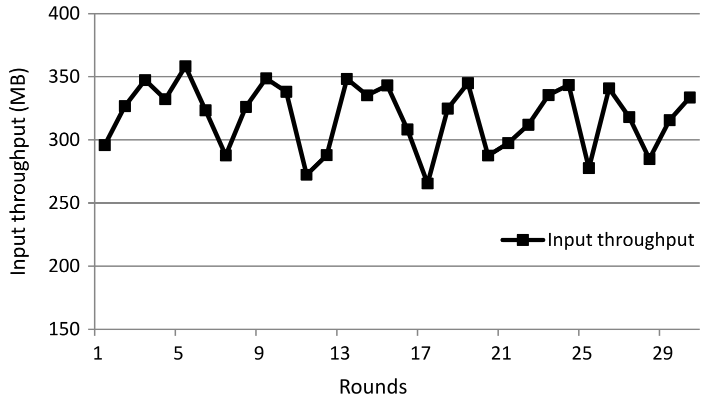


Fig. 8. r_{in}^{sink} total transmission rate for all the child nodes over rounds.

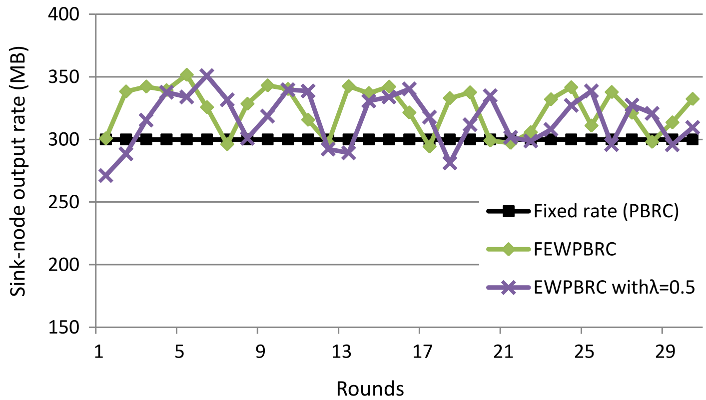


Fig. 9. Compared different algorithms for transmission rate r_{out}^{sink}.

Table 3
Values of MSE.

MSE	Throughput
FEWPBRC	0.016709
EWPBRC with $\lambda = 0.1$	0.103825
EWPBRC with $\lambda = 0.2$	0.097001
EWPBRC with $\lambda = 0.3$	0.097844
EWPBRC with $\lambda = 0.4$	0.109632
EWPBRC with $\lambda = 0.5$	0.114329
EWPBRC with $\lambda = 0.6$	0.119031
EWPBRC with $\lambda = 0.7$	0.114329
EWPBRC with $\lambda = 0.8$	0.119031
EWPBRC with $\lambda = 0.9$	0.12372
EWPBRC with $\lambda = 1$	0.128478

algorithm, EWPBRC algorithm with $\lambda = 0.5$ and FEWPBRC algorithm are respectively 300 MB, 271.23 MB and 300.75 MB. In the second round of Fig. 8, r_{in}^{sink} is 326.82 MB; Fig. 9 shows that the output transmission rates r_{out}^{sink} of the fixed-rate PBRC algorithm, EWPBRC algorithm with $\lambda = 0.5$ and FEWPBRC algorithm are respectively 300 MB, 288.49 MB and 338.28 MB, and obviously, our proposed FEWPBRC algorithm has r_{out}^{sink} superior to that of the EWPBRC algorithm, that is, our algorithm can obtain the optimal r_{out}^{sink}.

Furthermore, we have compared the FEWPBRC algorithm and EWPBRC algorithm with $\lambda = 0.5$; from Eq. (7), we have calculated the MSE values to be respectively 0.016709 and 0.114329. And we found that our proposed algorithm has minimal MSE, in Table 3.

In Fig. 10, we have compared the delay time of the three algorithms: the fixed-rate PBRC algorithm, EWPBRC algorithm with $\lambda = 0.5$ and FEWPBRC algorithm, and the average delays are respectively 0.002125 s, 0.002057 s and 0.001996 s. The average delay is the time for the sink node to transmit data to the BS. We can obviously see that for dynamically adjusted transmission rates, the EWPBRC algorithm with $\lambda = 0.5$ and the FEWPBRC algorithm, the delay time is smaller than that of the fixed-rate PBRC algorithm. The FEWPBRC algorithm has the shortest transmission delay time; in our proposed algorithm,

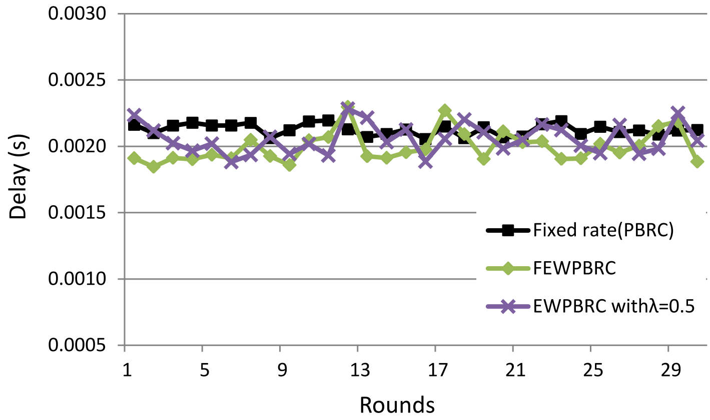


Fig. 10. Delay of the sink node over rounds for different algorithms.

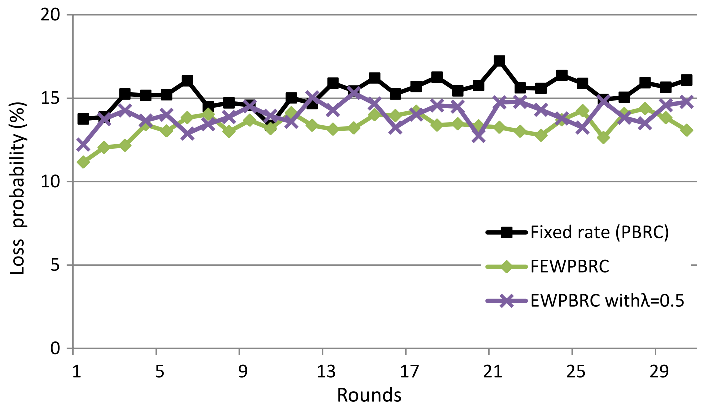


Fig. 11. Loss probability over rounds for different algorithms.

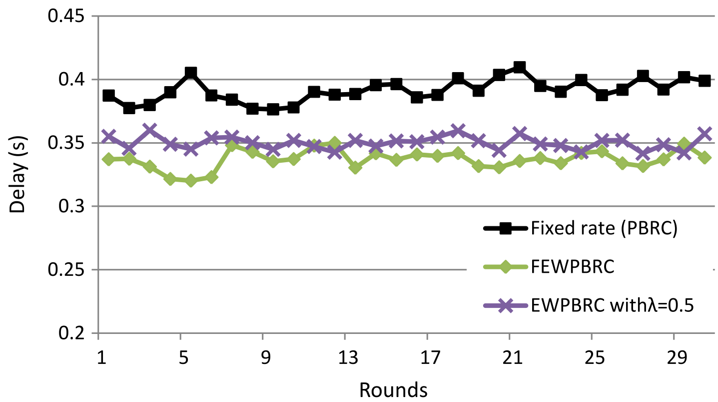


Fig. 12. Delay of all nodes over rounds for different algorithms.

the optimal output transmission rate can be given according to different data transmission amounts, and the delay time can then be reduced.

In the transmission process, the transmission rate of each node is adjusted; then Eq. (11) is based on distributing the new output transmission rate r^i_{out} to all the child nodes to improve the packet loss probability. From Fig. 11, it can be seen that the average packet loss probabilities of the fixed-rate PBRC algorithm, EWPBRC algorithm and FEWPBRC algorithm are respectively 15.34%, 14.28% and 13.35%; our proposed FEWPBRC algorithm has the lowest packet loss probability.

In Fig. 12, we have compared the transmission delays of the fixed-rate PBRC algorithm, EWPBRC algorithm and FEWPBRC algorithm, and the average delays are respectively 0.3913 s, 0.35 s and 0.3369 s. The average delay is the average time for all the child nodes to transmit data to the sink node in each round. Our proposed FEWPBRC algorithm has the lowest delay.

5. Conclusions

In this paper, we have proposed the FEWPBRC algorithm for adjusting the node transmission rate in WMSNs; in our algorithm, in order to select the appropriate parameter λ in the EW algorithm for estimating the transmission rate, in the transmission period, the FLC can select the appropriate parameter λ so as to change the output transmission rate of sink node r_{out}^{sink}, and the sink node can decide on the appropriate packet transmission rate. In the simulation, we have used MSE as the reference index, and the MSE values of the FEWPBRC algorithm and EWPBRC algorithm with $\lambda = 0.5$ are respectively 0.016709 and 0.114329. Our proposed FEWPBRC can effectively reduce congestion so as to improve packet loss and transmission delay, and it meets the QoS requirement of network transmission.

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References

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey, Computer Networks 38 (4) (2002) 393–422.
[2] I.F. Akyildiz, T. Melodia, T.R. Chowdhury, A survey on wireless multimedia sensor networks, Computer Networks 51 (2007) 921–960.
[3] S. Floyd, V. Jacobson, Random early detection gateways for congestion avoidance, IEEE/ACM Transactions on Networking 1 (4) (1993) 397–413.
[4] C.T. Ee, R. Bajcsy, Congestion control and fairness for many-to-one routing in sensor networks, in: Proc. of ACM SenSys, Baltimore, MD, 2004.
[5] C. Wang, Member, K. Sohraby, M. Daneshmand, Y. Hu, Upstream congestion control in wireless sensor networks through cross-layer optimization, IEEE Journal on Selected Areas in Communications 25 (4) (2007) 786–795.
[6] K. Nichols, V. Jacobson, L. Zhang, A two-bit differentiated services architecture for the internet, IETF RFC 2638, 1999.
[7] T. Li, Y. Rekhter, A provider architecture for differentiated services and traffic engineering (PASTE), IETF RFC 2430, 1998.
[8] Y.L. Chen, Y.S. Lin, J.W. Wang, J.H. Wen, Adaptive fuzzy rate management and power control for in multimedia CDMA cellular systems, Computer Communications 31 (2008) 1901–1910.
[9] P.R. Chang, B.C. Wang, Adaptive fuzzy power control for CDMA mobile radio system, IEEE Transactions on Vehicular Technology 45 (2) (1996) 225–236.
[10] P.R. Chang, B.C. Wang, Adaptive fuzzy proportional integral power control for a cellular CDMA system with time delay, IEEE Journal on Selected Areas in Communications 14 (9) (1996) 1818–1829.
[11] X. Wu, L. Ge, G. Liang, Adaptive power control on the reverse link for CDMA cellular system, in: Proc. of IEEE 5th APCC/OECC 99, Beijing, China, 1999, pp. 608–611.
[12] M.H. Yaghmaee, D.A. Adjeroh, Priority-based rate control for service differentiation and congestion control in wireless multimedia sensor networks, Computer Networks 53 (2009) 1798–1811.
[13] N.C. Wang, Y.F. Huang, W.L. Liu, An improved transport protocol for mobile ad hoc networks with fuzzy logic control, Journal of Internet Technology 10 (3) (2009) 229–236.
[14] B. Hull, K. Jamieson, H. Balakrishnan, Mitigating congestion in wireless sensor networks, in: Proc. of ACM SenSys, Baltimore, MD, 2004, pp. 3–5.
[15] C.Y. Wan, et al. Siphon: overload traffic management using multi-radio virtual sinks in sensor networks, in: Proc. of ACM SenSys, San Diego, CA, 2005, pp. 2–4.
[16] H.X. Li, H.B. Gatland, A new methodology for designing a fuzzy logic controller, IEEE Transactions on Systems, Man, and Cybernetics 25 (1995) 505–512.
[17] P.R. Chang, B.C. Wang, Adaptive fuzzy proportional integral power control for a cellular CDMA system with time delay, IEEE Journal of Selected Areas in Communications 14 (1996) 1818–1829.
[18] H.X. Li, E.S. Lee, Interpolation representations of fuzzy logic systems, Computers and Mathematics with Applications 45 (2003) 1683–1693.