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A Survey of Power Consumption Minimization in WSN Using Feedback Control Strategies

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Abstract— *Wireless Sensor Network (WSN) represents a key network in the present and future Internet of Things (IoT) technology. WSN has an uncountable number of applications and is commonly used to aggregate information and control the physical environment remotely through small embedded devices known as wireless sensor nodes. Power consumption is one of the main challenges in WSN due to the limitation of power resources. Consequently, several techniques have been followed to optimize power consumption. The feedback control system is one of the routes that has been utilized to minimize power consumption in WSN using the mathematical model of power and rate control in WSN. In this paper, a concise review of various types of control systems that are deployed for power saving in WSN will be discussed. The comparison between the applied control strategies is the key finding.*

Index Terms— *WSNs, power Consumption, feedback control, rate control, adaptive control.*

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have been utilized largely in numerous applications, and one of them will be the foremost significant columns in the Internet of Things (IoT) technology. The WSNs consist of a huge number of sensor nodes that are conveyed over one region to perform nearby computations based on data gathered from the surroundings. Because the nodes' sources of energy are restricted that communicate wirelessly; the Energy consumption of data transmission gathering needs designate protected at the last level. Hence, one of the most important aspects of network architecture in WSN is energy efficiency. In other words, the sensor node has to be able to control and adjust its transmission rate and power source. [1].

WSNs have a fixed amount of energy to provide to the system. The key source of energy loss in WSN is idle mode consumption. Retransmission of packets is another source of energy loss in WSN. Agriculture, health care, home management, and medical applications are all available with WSN [1]. A sensor node, cluster head, and base station are the three components of a WSN shown in *Fig. 1*. The processing of WSNs is the data is sent from the sensor node to the head of the cluster node, which then sends it to the BS for more transmission.

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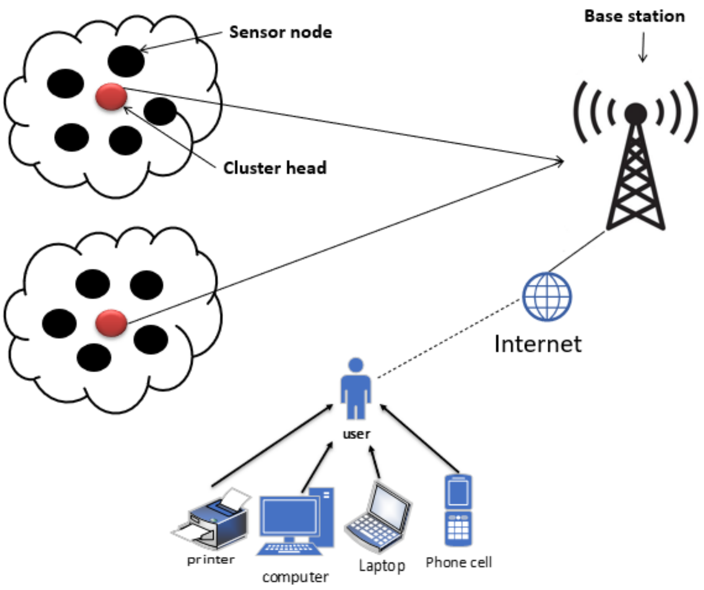

FIG. 1. WIRELESS SENSOR NETWORK.

A sensor node is a node capable of performing some processing collecting information wirelessly and communicating with another node in the network. A cluster head is normally elected by a distributed algorithm; a cluster head acts as an interface between sensor nodes and the base station, which represents a transceiver station for communication.

The WSN should have a long enough lifetime to satisfy the application's needs; In many circumstances, for several months or even years, a lifetime may be necessary [2]. It can be used for a variety of tasks, including target tracking, environmental monitoring, health monitoring hostile environment, control of a system, urban. and exploration [3]. The applications can be classified into other options. Smart cities, wearables, car and building automation, and smart infrastructures can show in *Fig. 2*. Smart cities for example smart lighting, smart parking, noise and pollution monitoring, traffic management. Wearables such as wristwatches, wristbands, glasses, shoes, and even a regular jacket, which are intelligent sensor nodes that can now be found in products. Car and building automation are intelligent machines with the Internet service. Finally, smart infrastructures include military, environmental monitoring and industry [4].

The wireless sensor network is less expensive than devices that require a wired connection since it does not require the construction of cable or cabling channels. Sensor network management platform, for example, offers an affordable approach to managing hardware, software, and cyber threats in wireless sensor networks while also providing near real-time visibility of network status via monitor station applications [5].

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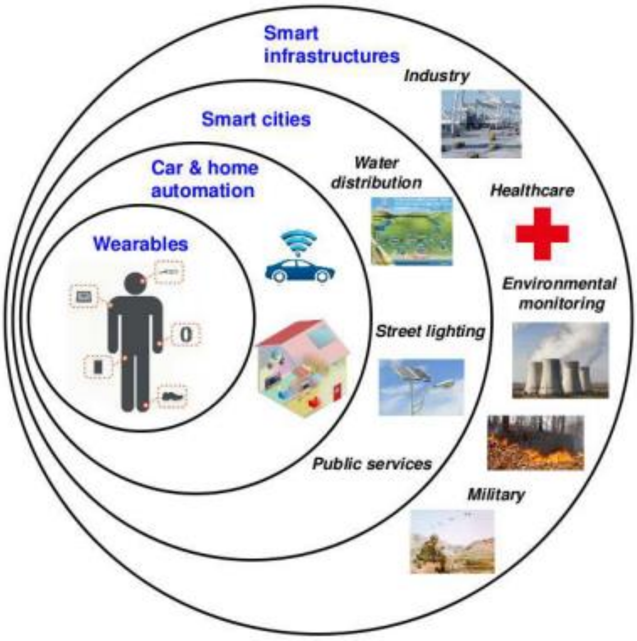

FIG. 2. WSN APPLICATIONS [4].

The objective of this paper is to provide an overview of modern control methods of joint and rate in WSNs. The first section begins with a general overview of WSN. Section 2, summarizes a review of the challenges of WSN with the techniques of minimizing the power. Section 3 describes a mathematical model that has been used to minimize power consumption. Different control methods are reviewed in section 4. Finally, in section 5 the conclusion of the paper is presented.

II. THE CHALLENGES OF POWER IN WSN

A sensor node's energy consumption may come from either "useful" or "wasteful" sources. Transmission and receipt of data, query requirements are processed, and inquiries and data are forwarded to surrounding nodes. can all result in useful energy consumption. One or more of the following facts could contribute to wasteful energy consumption. Firstly, idle listening (fail Network), that is, (listening to an idle channel to receive possible traffic). Secondly the Collision (When a node receives several packets at the same time, they are referred to as collided packets). Collision-causing packets must be rejected, and these packets must be retransmitted., resulting in increased energy consumption. Thirdly the overhearing (when a node receives packets intended for other nodes). Finally, the absence of the control- pact (to make a data transmission, a minimum amount of control packets should be employed.) [6].

WSNs suffer a number of common obstacles, including limited energy sources, computing speed, memory, and communication capacity, all of which cause sensor network performance to deteriorate and network lifetime to decrease. Creating distinct algorithms for various purposes is a difficult endeavor [7]. With a proper data compression technique, the problem of limited storage of a sensor node can be improved, resulting in a reduction in transmitted data size and, as a result, a reduction in power consumption per node. A smart routing algorithm also ensures that data is transferred efficiently between sensor nodes [8].

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Eenergy consumption is the main issue in WSNs that several researchers have studied and employed different approaches to tackle this problem. The authors in [9] suggested a clustering technique that uses the Minimum Spanning Tree (MST) to detect the shortest path in wireless sensor networks. The author in [10] applied the concept of intelligence in energy saving which is the capacity to perform reflection and conceptualization to gather data, make choices, and execute actions. In [11], the authors employed the duty cycle and data-driven methods, the networking subsystems are the center of the duty cycle. that is the radio transceiver is put into sleep mode when the communication is not needed, where, the data-driven technique can be used to improve energy efficiency. The authors [12] provide a stochastic analysis of the energy consumption in a random network environment with noisy measurements in WSNs.

The authors in [13] used nature-inspired algorithms for the limited lifetime of sensors in WSNs. This method can maintain the optimal coverage of the network by using two algorithms of optimization one of them is Improved Genetic Algorithm and Binary Ant Colony Algorithm (IGABACA) anther is Lion Optimization (LO) then compared between them. The comparison shows that the Lion Optimization (LO) is better and faster than the IGABACA. The author in [14] presents the classical and modern protocols to solve the lifetime of WSNs. They classified this protocol by depending on the structure of the network, how data is passed around, whether the location information is used or not, and whether or not several paths or Quality of Service (QoS) are maintained.

In addition, the authors in [15] present the Fuzzy logic (FL) that can be used to select the most appropriate and efficient cluster head to achieve a long-life span based on clustering algorithms discussion in two cases. First, CHEF, in this case, can choose the CH is based on two factors the proximity distance and energy output. Secondary, F-MCHEL, utilize to elected using fuzzy criteria based on energy and distance proximity F-MCHEL is a step forward from CHEF. It increases the network's stability. In [16] the authors presented different cases of Energy Efficient Routing (EER) depending on the applications of them are classified in data relaying protocols, data-centric protocols, location-based or geographical protocols, hierarchical or clustering-based protocols, heterogeneous protocols, mobility-based protocols. All of these protocols are focused on energy-efficiency in WSN. Finally, the authors in [17] presented a power-saving protocol along with topologies of energy consumption for WSN. The power-saving protocols try to save energy by laying the node's radio transceiver to sleep mode. Information on the list of the nodes' neighbors is required in this technique.

III. MATHEMATICAL MODEL OF POWER AND RATE CONTROL IN WSN

The techniques that have been used commonly to minimize the power in WSNs as shown below:

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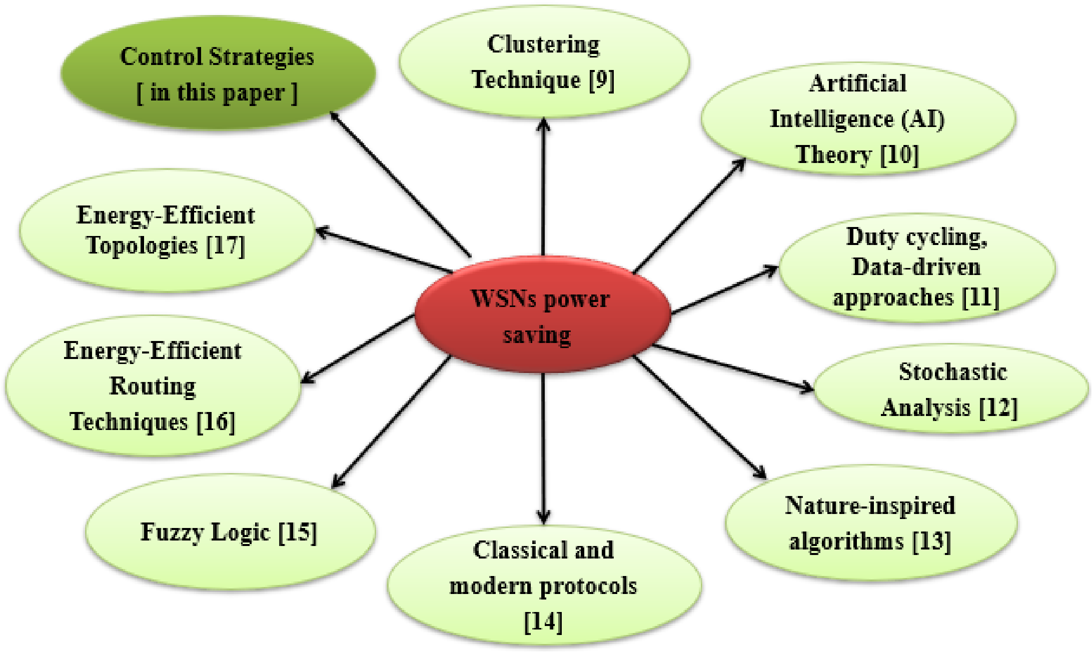

FIG. 3. WSNS POWER MINIMIZATION TECHNIQUES.

In fact, several mathematical models have been used for WSNs to minimize power consumption. For instance, one of them is called the dual power assignment problem. In this model, only two transmission power levels are utilized, when the node is provided a high (low) power level, it is referred to it as a high (low) power node $\boldsymbol{\rho_h}$ ($\boldsymbol{\rho_I}$). The reader refers to [18] for more details:

$$\epsilon_h = \{e\,(u,v) |\, \rho_h \geq d(u,v) > \rho_I\} \; and \; \epsilon_I = \{e\,(u,v)| \leq d(u,v) > \rho_I\} \qquad (1)$$

where, $\boldsymbol{\epsilon_h}$: the higher energy, $\boldsymbol{e}$: the energy between the node $\boldsymbol{u}$ and $\boldsymbol{v}$ node, $\boldsymbol{d}$: the distance between these two nodes, $\boldsymbol{\epsilon_I}$**:** lower energy.

Edges with high and low power assets, respectively. two fault-tolerance models are given below:

- Bi-connectivity dual power assignment model: remove any node from a biconnected graph without causing it to be disconnected.
- Dual power assignment model for k-edge connectivity: a k-edge indicates that information is one in which removing any k-edges does not result in it becoming disconnected.

In the former model above, based on the fault-tolerant it minimizes overall power consumption in WSN, as a result of reducing the number of the high (low) pomades.

Another model is used with QoS routing as multi-constrained optimal path (MCOP) problem, that the WSNs have N randomly of nodes in a WSN, each node has the sensing range that allows it to observe events or objects, as well as a communication range that allows it to interact with other nodes. An NP-complete problem is the MCOP. Consider the network graph $D = (X, F)$, where X represents the nodes and F represents the edges. For $N = 1,2,$ ancap each link in D has a cost parameter $\mathrm{C}(X, F)$ and an N additive QoS parameter $W_N(X, F)$ The challenge with N restrictions is to find a path P from the source to the sink that [19]:

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$$W_N(P) = \sum(X,F)\ D_P = W_N(X,F) \leq C(X,F)\ For\ \ N = 1,2,\ \ \ldots N \tag{2}$$

The minimized of all possible paths that fulfill is $C(X,F)$. This model reduces the power based on the Packet Reception Ratio (PRR) is obtain the reliability of links for QoS provisioning.

In this paper, consider this model as three requirements must be the management between them, first one is the consumed power, the second data rates, finally is the level of congestion, by minimizing the consumed power and enhance the transmitted data rate simultaneously with the level of congestion. That occurred by maintaining the minimum between the actual and desired Signal-to- Interference-plus-Noise-Ratio (SINR) and also in the network ensure a low likelihood of packet loss [1,20-22].

When the sensor node must reliably deliver the given data rates, a particular level of (SINR) or, equivalently, a certain level of transmission control is required. As a result, without proper management of the data rate and control, energy consumption performance may suffer, particularly when desired rates change within the organization. Several power control strategies based on various types of objective measures have been presented.

We find the desired SIR by using the fact by the equation below:

$$\bar{Y}_h(k+1) = [1 - \mu\, C(k)\,]\, \bar{Y}_h(k) + \mu' d_{ar}(k) \tag{3}$$

Where $\mu' = 20\mu \,/ \log_2 10$ and $\bar{Y}_h(k) = 10 \log Y_h(k)$ the objective is to set up the power control so that the actual SINR values contest the desired ones. The strategy for reaching this objective is based on wireless communications system power control ideas.

The objective is to build the power control system so that the SIR level tends to the SIR levels that are desired. This design issue should be addressed by defining a robust quadratic control issue. We can find the system model in the state-space model by the following:

$$\left.\begin{aligned} X_d(k+1) &= Ax_d + B\mu_d(k) + w_d \\ y_d &= Cx_d \end{aligned}\right\} \tag{4}$$

where,

$$\boldsymbol{A} = \begin{bmatrix} \mathbf{1}-\boldsymbol{\alpha} & \boldsymbol{\alpha} \\ \mathbf{0} & \mathbf{1}-\boldsymbol{\mu}\, \boldsymbol{c}(\boldsymbol{k}) \end{bmatrix}, \boldsymbol{B} = \begin{bmatrix} \boldsymbol{S_p} \\ \boldsymbol{S_f} \end{bmatrix}, \boldsymbol{C} = \begin{bmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{bmatrix}, \boldsymbol{w_d} = \begin{bmatrix} \boldsymbol{n}(\boldsymbol{k}) \\ \boldsymbol{\mu}'\boldsymbol{d}(\boldsymbol{k}) \end{bmatrix} \tag{5}$$

This model enables saving the power of WSN based on rate control via using the control systems strategies because we will used a controller for my work. With this concept, different control mechanisms have been created and implemented. The following sections will provide a quick overview of all forms of applied controllers.

IV. RECENTLY APPLIED CONTROL METHODS

Recently, several research studies are deployed and used the controllers to solve the problem of power compression. A set of research considers has explored the joint model broadly using different controllers. It has been noticed that the WSN can be treated as a control system. Accordingly, energy consumption can be formulated as control design problem. Since then, many research studies have been conducted in this field for the purpose of saving energy in WSN.

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A. ADAPTIVE FAULUT-TOLERANT

This controller combines the functions of a feedforward controller and a robust feedback controller. For WSNs the authors in [23] present the evaluating transmitter failures in wireless communication networks, a variable uncertainty, and bounded peripheral disturbances that require adaptive fault-tolerant power and rate control. To compensate for the network's fault effect, The online estimation of potential faults automatically modifies the adaptive fault-tolerant controller variable. The authors in [24] with transmutation present faults in the adaptive fault-tolerant controller parameters are automatically adjusted based on the online prediction of future faults to compensate for the fault impact on the network by the fault-tolerant H_ power and rate controller via dynamic output feedback. The authors in [25] presented adaptive power and rate control based on a new model of uncertain wireless communication networks with nonlinear channel fading and time-varying delay, its analysis using Lyapunov - Krasovskii functional and linear matrix inequality for uncertain wireless communication networks with nonlinear channel fading and time-varying delay. In [26] the authors used versatile fault-tolerant control and rate control for remote communication systems with transmitter issues, this controller is based on LMI approach.

B. ROBUST CONTROL

The main flaw in present control techniques is that they can't explicitly account for plant model uncertainty in the control system formulation, this robust control is considered by many researchers. The authors in [27] presented A robust H_∞ power and rate control is intended for unpredictable wireless networks with time-varying state and input delays. The power and rate controller uses a control technique with LMI and is based on a new system model. In addition, the authors in [28] with time-varying delay the power and rate control are used them H_∞ control method is used to create a delay-dependent robust power and rate control algorithm. While the authors in [29] present a power constraint method based on Model Predictive Control (MPC), and the state feedback control law of this system is obtained to solve the problem by optimization which is derivative by using LMI for the unknown with time-varying delays and input constraints. For uncertain wireless networks with time-varying and input delays, the authors in [30] designed power and rate control strategy in WSNs based on H_∞ control approach with LMI. The authors in [31] have used WSN with nonlinear channel fading and the model was designed. the analysis of stability and performance of the power and rate control method are achieved by the Lyapunov approach.

C. SLIDING MODE CONTROLLER

The authors in [1] presented the Unity Sliding Mode Control (USMC) with an optimal Linear Quadratic Regulator (LQR) controller to solve the energy consumption in WSNs. The controller can drive the sliding mode to reach the defined sliding surface and ensure the closed-loop system's stability by establishing a sufficient condition for the existence of stable sliding surfaces through linear matrix inequality. While the author in [32] proposed the LMI approach was utilized to derive the requisite control law, an appropriate Lyapunov function was created to establish the sliding surface's quadratically stability in the discrete sliding mode control in WSN based on IoT.

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D. OPTIMAL CONTROLLERS FOR THIS MODEL

There are multiple time delays in power and rate control for wireless communication networks with external disturbance the authors presented in [33]. A compensation algorithm for multiple time delays based on the mathematical state-space model developed for wireless communication networks with state delay and input delay is investigated and can be applied to our model based on the mathematical state-space model developed for wireless communication networks with state delay and input delay. The optimal tracking method and control rule can be achieved by solving the matrix Riccati algebraic equation. Other authors in [34] presented the new power and rate control system for wireless communication networks based on QoS priority, allowing QoS to be guaranteed It is planned to construct a dual closed-loop power and rate controller. The transmission rate is regulated by the outer loop, and the target transmission rate is calculated based on the priority of QoS, the target signal-to-inference ratio (thus the optimum target signal-to-inference ratio can be determined relatively).

E. PID CONTROLLER

The author in [35] has presented the power management of WSN with PID controller because it only considers the available energy in the supercapacitor used as the storage device, the PID controller is simple and practical. It keeps the supercapacitor in equilibrium by adjusting the wake-up period. Another author in [36] used the PID controller to solve the issue of network congestion in WSN routing nodes produced by a huge number of transmissions of data. To begin, PID control theory was used to manage the queues of sensor nodes in WSN. Then, using neurons' self-organizing and self-learning abilities, online weight adjustment was achieved for the proportion, integral, and differential parameters of the PID controller. Finally, the Neural PID (NPID) algorithm of initial proportion value is applied to the standard particle swarm optimization algorithm. The authors in [37] have presented a new congestion control mechanism for WSNs. Fuzzy and PID control is collective with cuckoo search with control in this system are used. The PID controller is used to calculate the real-time packet loss rate to control the node's instantaneous queue length. Mold and control are used to modify PID parameters to improve self-adaptive optimization ability and the corresponding mold and rules are provided.

V. DISCUSSION

In this paper, we examined several key research papers on the recently applied control strategies for WSN. The control approaches that have been created so far to produce systems with stable SINR, were summarized in Table I.

TABLE I. PRESENTS A COMPARISON OF THE APPLIED CONTROL METHODS FOR POWER MINIMIZATION IN WSN THAT HAVE BEEN REVIEWED.

	Controller Type	Specifications	Advantages	Limitations
1	**Adaptive Fault-Tolerant**	It has gotten a lot of attention in recent decades as one of the most common system design strategies for controlling component failures, which keeps the system safe while	To compensate for the network repercussions of faults, the variables are automatically updated	It is demonstrated that the resulting adaptive closed-loop system is uniformly bounded using the Lyapunov approach.

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		achieving appropriate results whether the components are healthy or malfunctioning.	using online estimation of potential faults.	
2	**Robust Control**	A feed-forward controller is paired with a powerful feedback controller.	Improve the performance of the power and rate in WSNs	It can produce asymptotic output only when the system is subject to parametric uncertainty. Usually, more modifications are necessary.
4	**Sliding mode controller**	coupled with one of the two control strategies listed below: pole placement or basic optimal control (as LQR).)	When compared to traditional approaches, monitoring performance is improved.	1-No precise assessment of uncertainty is provided 2- The inevitable chattering effect may have an impact on the performance of the regulated system.
5	**PID Controller**	Is the traditional control method converting all types of active waiting line system methods into the controller	It's employed in energy harvesting wireless nodes to reduce power management.	PID control has a fundamental fault in that it is a feedback control method with constant parameters and no direct knowledge of the process, and as a result, it does not provide the best control.

VI. CONCLUSIONS

The power consumption aspect is one of key challenges in WSNs. This is due to fact that this network normally deployed in a sever environment. The most pressing concerns to address are how to reduce node energy consumption so that network lifetimes can be extended to realistic durations in the face of uncertainties and external disruptions. The goal is to reduce power consumption while maintaining required data speeds in WSNs. The trade-off between the power consumption, transmission rate, and network congestion, can be relatively managed to improve energy efficiency in WSN. In this paper, a brief overview of various types of the applied control systems in WSN for power savings has been discussed. The major findings are the comparisons of the various control mechanisms that have been utilized during the last two decades. The feedback control system is one of the routes that has been exploited to minimize power consumption in WSN using the mathematical model of power and rate control in WSN.

NOMENCLATURES

$C(k)$	Measurement of congestion in the network
d(k)	External disturbance
$d_{ar}(k)$	Controls the value of rate increase for each iteration
$\bar{Y}_h(k)$	Actual SINR for node i
$n(k)$	Zero-mean disturbance of variance ${\partial_n}^2$
$S_p S_f$	1

GREEK SYMBOLS

μ	Positive step-size
${\sigma_\propto}^2$	White Gaussian noise power.
$\propto$	zero-mean Gaussian random variable

ABBREVITIONS

WSNs	The Wireless Sensor Networks
BS	Base Station

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SINR	Signal-to- Interference-plus-Noise-Ratio
IGABACA	Improved Genetic Algorithm and Binary Ant Colony Algorithm
EER	Energy-Efficient Routing
QoS	or quality of service
MPC	model predictive control

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