QUALITY OF SERVICE OPTIMIZATION OF WIRELESS SENSOR NETWORKS USING A MULTI-OBJECTIVE IMMUNE CO-EVOLUTIONARY ALGORITHM

Xing-Jia Lu, Zhi-Rong Chen
School of Sciences, Ningbo University of Technology, Ningbo 315016, China

Lin Guo, Yong-Sheng Ding
School of Traffic and Transportation , Ningbo University of Technology, Ningbo 315016, China
College of Information Sciences and Technology, Donghua University, Shanghai 201620, China

Keywords: Wireless sensor networks, Quality of service, Multi-objective immune co-evolutionary algorithm.

Abstract: Quality of Service(QoS) is the the performance level of a service offered by the wireless sensor networks (WSNs) to user, which is an important topic of WSNs. The goal of QoS is to achieve a more deterministic network behavior. QoS of WSNs is an extension of the multi-objective optimization problem, which is modelled as a optimal model with constraint of network connection. The QoS must satisfy the multi-objectives such as energy consumption, bandwidth, delay jitter, packer loss rate. In order to search the optimal solution of the QoS of WSNs, we propose a multi-objective immune co-evolutionary algorithm (MOICEA) for QoS of WSNs. The MOICEA is inspired from the biological mechanisms of immune systems including clonal proliferation, hypermutation, co-evolution, immune elimination, and memory mechanism. The affinity between antibody and antigen is used to measure the optimal set of QoS, and the affinity between antibodies and antibodies is used to evaluate the diversity of population and to instruct the population evolution process. In order to examine the effectiveness of the MOICEA, we compare its performance with that of genetic algorithm (GA) in terms of four objectives while maintaining network connectivity. The experiment results show that the MOICEA could obtain promising performance in efficiently searching optimal solution by comparing with other approaches

1 INTRODUCTION

Wireless sensor networks (WSNs) have recently attracted much research due to their ability of collecting data from the environment and reporting them back to a sink. Although they were originally driven by military applications (I. F. Akyildiz and Melodia, 2005), WSNs are being applied in many different civilian applications, such as habitat monitoring, earthquake observationc (I. F. Akyildiz and Vuran, 2009), vehicle tracking system, and healthcare applications (I. F.Akyildiz and Wang, 2005). WSNs are composed of a number of small, autonomous, and energy limited sensor nodes(P. Baronti, 2007) (Yang and Cao, 2008)(Y. P. Aneja, 2010). Due to the limitation of battery size and weight, and recharging sensor's battery is not easy, many strategies have been proposed to reduce the energy consumption to prolong the lifetime as long as possible(Chou, 2010)(Y. B. Trkoullari, 2010)(J. Bahi and Mostefaoui, 2008). Energy saving techniques can generally be classified into two categories: Sensor schedule and adjusting sensing ranges(Marta and Cardei, 2009).

Much research has been carried out on the energy-awareness of WSNs, especially from the perspective of energy-efficient routing whose focus is to find the most energy-efficient route given the current energy status of each node in the networks with one objective being prolonging the network's lifetime(R.Rajagopalan and Varshney, 2009)(W. Xue, 2010). The study purpose of energy-efficient route is to minimize the global power consumption of WSNs while keeping its connectivity constraint. In this paper, the Quality of Service problem is modelled by the optimization constraint problem, which have been intensively researched by graph theory or set theory, such as dominating set and connected dominating set. The dominating set must satisfy the multi-objectives such as energy consumption, delay jitter, loss packet rate, and traffic flow. It is also termed as the better

Lu X., Chen Z., Guo L. and Ding Y..
QUALITY OF SERVICE OPTIMIZATION OF WIRELESS SENSOR NETWORKS USING A MULTI-OBJECTIVE IMMUNE CO-EVOLUTIONARY ALGORITHM.
DOI: 10.5220/0003510601600164
In *Proceedings of the 13th International Conference on Enterprise Information Systems* (ICEIS-2011), pages 160-164
ISBN: 978-989-8425-56-0

Quality of Service problem by Reddy(Reddy, 2006) and Cardei (Y. Yang and Cardei, 2010), and has been proved to be a NP complete problem. In order to search the optimal solution of the Quality of Service problem, we propose a multi-objective immune co-evolutionary algorithm (MOICEA) for Quality of Service optimization of the WSNs. In the MOICEA, the immune operators, which includes Antibody initialization, Clonal selection, Clonal proliferation, Hypermutation, Immune selection, Recruitment, Immune update and Termination criterion(R. L. King, 2001). Antibody initizlization process generate the initial solution of feasible set of population, Clonal selection is used to select the parent's population by roulette method, Clonal proliferation is used to generate a new population with offsprings. Hypermutation is used to diversity the search process. Immune selection is considered as the domain knowledge of Quality of Service and to eliminate the inferior ones to keep the stable population. Immune update is used to store the feasible solutions and update the population. Termination criterion is used to judge whether meet the exit condition. In MOICEA, The affinity between antibody and antigen is used to measure the objective of quality of networks, and the affinity between antibodies and antibodies is used to evaluate the diversity of population and to instruct the population evolution process. The MOICEA employs an improvement procedure to further minimize the overall energy consumption, bandwidth allocation, and delay jitter of the network as much as possible. The main contributions of this study lie in the follows: Firstly, the energy consumption, bandwidth, and delay jitter are regarded as the objective functions of the WSNs, and the solution of the connection set would be meet with the constraint of sensor node's battery capacity and network connectivity. Secondly, an encoding method of Quality of Service and route information for each node into an antibody is proposed. Thirdly, the MOICEA is proposed for solving optimal solution of Quality of Service in WSNs, and demonstrated its out-performance over the existing heuristic solutions. The rest of the paper is organized as follows. Section 2 briefly describes the related work in Quality of Service for the WSNs. The proposed MOICEA for Quality of Service in the WSNs is presented in Section 3. Simulation results of performance comparison between the MOICEA, Genetic Algorithm (GA) in terms of four objectives while maintaining network connectivity are provided in Section 4. Finally, Section 5 presents the conclusion of the whole paper.

2 RELATED WORKS

The general Quality of Service of WSNs is introduced and pointed out by Reddy, Quality of Service is a measure of the WSNs of the sensing function and is subject to a wide range of interpretations due to a large variety of sensors and applications. The goal is to have each location in the physical space of interest within the sensing range of at least one sensor. A survey on Quality of Service in WSNs presented by Reddy, and the Quality of Service can be classified in the following(S. Chen, 1999):

Quality of Service is the performance level of a service offered by the network to the user. The goal of Quality of Service provision ing is to achieve a more deterministic network behavior, so that information carried by the network can be better delivered and network resources can be better utilized. A network or a service provider can offer different kinds of services to the users. Here, a service can be characterized by a set of measurable prespecified service requirements such as minimum bandwidth, maximum delay, maximum delay variance (jitter), and maximum packet loss rate. After accepting a service request from the user, the network has to ensure that service requirements of the user,As flow are met, as per the agreement, throughout the duration of the flow (a packet stream from the source to the destination). In other words, the network has to provide a set of service guarantees while transporting a flow. After receiving a service request from the user, the first task is to find a suitable loop-free path from the source to the destination that will have the necessary resources available to meet the Quality of Service requirements of the desired service. This process is known as Quality of Service routing. After finding a suitable path, a resource reservation protocol is employed to reserve necessary resources along that path. Quality of Service guarantees can be provided only with appropriate resource reservation techniques.

3 MULTI-OBJECTIVE IMMUNE CO-EVOLUTIONARY ALGORITHM FOR QUALITY OF SERVICE

3.1 Network Assumptions

We consider the WSNs investigated here have the following features: The sensor nodes are located in a two-dimensional space, and the location of each sensor node can be obtained after the deployment. The location information is used for calculating the distance between two sensor nodes. The sensor uses the omnidirectional antenna, which means that a sensor radiates and receives equally in all directions. If a sensor transmits with a power level: $p_t = \zeta \times d^a$, then any sensor within the distance d and the power threshold ζ can receive the signal. The path loss exponent a is between 2 and 4. Suppose there are two nodes n_i and n_j , then the distance between the two nodes can be calculated by using the Euclidean distance formula $\| x_i - x_j \|$, where and is the location vector of node x_i and x_j, respectively. The power threshold ζ is considered as a constant and can be ignored since the receivers in the network have the same power threshold. The MOICEA uses transmission power in energy calculation without considering the transmission time. Sensor nodes can operate in different initial power levels, with a lower and an upper bound. This consequently leads to asymmetric wireless links and a directed graph. The asymmetry of the communication links combined with a request for a different initial power level makes the problem more complex and renders the topology control problem more challenging.

3.2 Quality of Service

The Quality of Service problem is the optimization problem of finding a optimal route in a given graph. In this paper, we describe the Quality of Service optimization as follows: Let's denote V as the set of wireless sensor nodes, denote C as route nodes set, and denote $G(V,E)$ as the hypergraph on V that contains all possible edges if each node transmits signal. The edge set E of G is constructed in such a manner that there is a directed edge from u to v if and only if u can reach v. In Quality of Service problem, Graph G is an instance, and the smallest number k such that is a nodes set C for G of size k. The optimal Quality of Service can be formulated as the following, Assume that every vertex has an associated cost of $c(v)$,

$$\begin{aligned} & min \sum_{v \in V} c(v) x_v \\ \text{s.t.} \quad & x_u + x_v \geq 1 \quad \text{for all} \quad \{u,v\} \in E \\ & x_v \in \{0,1\} \quad \text{for all} \quad v \in E \end{aligned} \tag{1}$$

Constraint condition 1 denotes covering every edge of the graph, and Constraint condition 2 denotes every sensor is either in the route set or not. Graph G sets a lower bound on the connectivity that a wireless network can have. The algorithm returns a topology graph T constructed from G , i.e., T is a hypergraph of T on V . WSNs should fulfill the following connectivity requirement: For any pair of nodes u and v, if there is a path from u to v in G then there is also a path from u to v in T.

Since our study is the extension of the Quality of Service, the route set must satisfy the multi-objective such as energy consumption, delay jitter, loss packet rate, and traffic flow, and additional constraint condition should include network connectivity. The formal definition of the problem is given as follows: Given a set of wireless nodes s, a set of route nodes t, the sensing ranges r, and corresponding energy consumption e, the route nodes set is to determine the power assignment of the nodes such that: (1) The induced directed graph T is strongly connected. (2) The total energy consumption, bandwidth, and time delay of the network $\sum_{i=1}^{n} E_{pi}$ is minimized, where p_i denotes the power assigned to node s_i. The optimal multi-objective as follow:

$$min: \quad E_{min}(c_1 + ...c_k) \tag{2}$$

$$min: \quad Delay jitter_{min}(c_1 + ...c_k) \tag{3}$$

$$min: \quad Losspacketsrate_{min}(c_1 + ...c_k) \tag{4}$$

$$min: \quad Traffic flow_{min}(c_1 + ...c_k) \tag{5}$$

3.3 Multi-objective Immune Co-evolutionary Algorithm for Quality of Service

This section starts with a presentation as to how the Quality of Service optimization is represented by MOICEA. Then it gives a detailed presentation as to how each step is designed and implemented for the Quality of Service following the MOICEA flow in Fig. 1.

Multi-objective immune co-evolutionary algorithm designed for optimal route selection incorporates the main immune strategies as follows: (1) clonal proliferation, (2) hypermutation, (3) affinity measures, (4) co-evolution, and (5) immune memory mechanism. These strategies are implemented as operators, procedures or memory mechanism on the antibody vector structure to generate new antibodies with diversity and evolve the superiors for optimization. An overview framework of the algorithm is shown in Algorithm 1. The detailed concepts and procedures are studied in the following sub sections.

4 SIMULATION RESULTS

In order to examine the effectiveness of the MOICEA, we compare its performance with that of GA in terms of total four objectives while maintaining network

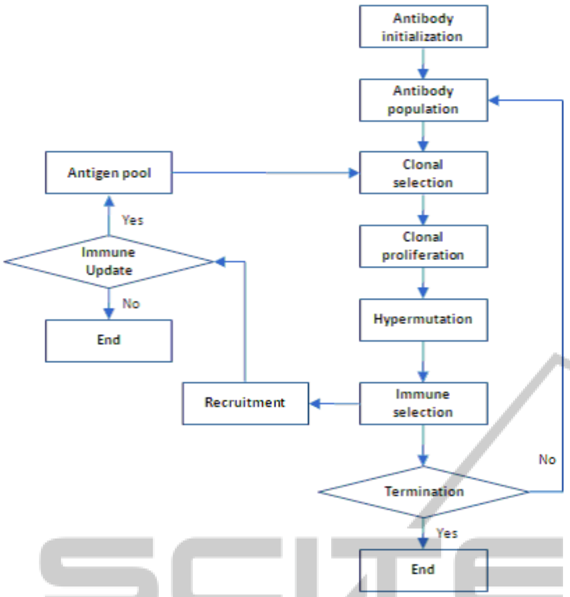

Figure 1: The diagram of the multi-objective immune co-evolutionary algorithm.

connectivity. The GA is selected because it is an evolutionary algorithm to the Quality of Service and also popularly selected as a benchmark in Quality of Service. To evaluate the performance of the MOICEA, we design a corresponding simulation scenario upon the Linux platform. The simulation experiment is constructed on Red Hat 9.0 operating system with Intel Pentium 4 processor (2.4 GHz) and 512 MB RAM. The simulator is NS2-allonine-2.29, and scripting language is TCL. The Awk and GNU Plot are used to present the simulation results. Before conducting simulation experiments, we need to configure the simulation environment of NS2: 10 to 40 sensor nodes are randomly deployed on a two-dimensional plane ($1000 \times 1000m^2$). We assume the sensors are homogeneous and have the same energy (1200mAh), whose sensing radius are 300 meters and communication radius are 600 meters. The sensor nodes are deployed randomly and the largest bandwidth of the WSNs is 2Mb/s. The nodes of WSNs are located at coordinates (1000, 1000), which receives the data of source node. The size of WSNs is the same for different algorithms and the affinity functions (four objectives) are then measured. Fig. 2 presents the final result of the MOICEA how to find the optimal route set and build the route to the sink after 300 runs. It depicts the route building information with N = 7 and R = 200m. When the source nodes set out data packets during the first run, the pheromone has accumulated on any nodes. On the route set building, In Fig.2. The attributes of each link are shown in a tuple ⟨Bandwidth, Delay⟩, Where Bandwidth repre-

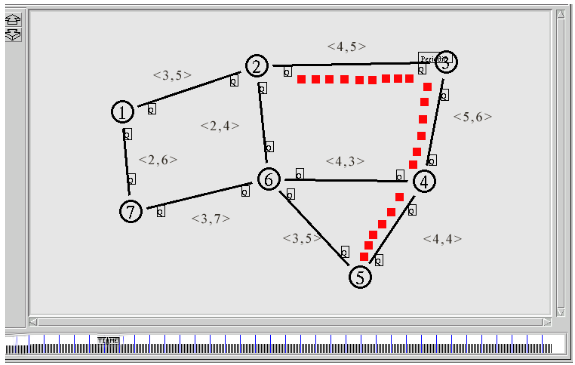

Figure 2: Seven nodes WSNs.

Table 1: Available paths from node 2 to node 5.

No	Path	Hop	Mbps	Delay(ms)
1	2–6–5	2	2	9
2	2–6–4–5	3	2	11
3	2–3–4–5	3	4	15
4	2–3–4–6–5	4	3	19
5	2–1–7–6–5	4	2	23
6	2–1–7–6–4–5	5	2	25

sent available bandwidth in Mbps and Delay represent transmission delay,propagation delay and queuing delay. Suppose a packet-flow from node 2 to node 5 requires a bandwidth guarantee of 4Mbps. Quality of Service routing searches for a path that has sufficient bandwidth to meet the bandwidth requirement of the flow.Here 6 paths are available between nodes 2 to 5 are shown in Table 1,Quality of Service routing selects path 3 (2–3–4–5).

in Fig.3.It depicts the route building information with N = 200 and R = 200m.The MOICEA can find suitable paths In table 2, as a summery, the WSNs on the four main objectives are statistically studied

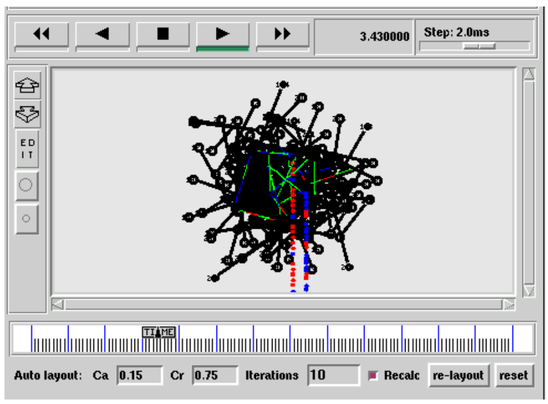

Figure 3: 200 nodes WSNs.

Table 2: Four main component comparision with GA, MOICEA methods.

Network Size (50)	GA	MOICEA
Energy of consumption (mAh)	1.8	1.8
delay jitter(s)	2.7	2.6
Loss packages	18	13
Traffic flow (Kb/s)	14.1	13.9

in 200 nodes. We develop the energy consumption model to compute the battery consumption in an hour, each node has one Alkaline Battery with 1200(mAh) capacity.The experiment present results in energy consumption, delay jitter, Loss packages, and traffic flow in the two methods.

5 CONCLUSIONS

In this paper, we propose the MOICEA for the Quality of Service of WSNs. The MOICEA is studied with the immune operators of clonal proliferation, hypermutation, co-evolution, immune elimination, and affinity measure. Based on real scenario, the experiment presents the promising ability of the MOICEA. Simulation results have shown that better solutions can be obtained by the MOICEA than GA. The MOICEA also demonstrates its strength in generating initial route information, fault tolerance, and robustness. As for future suggestion, the following directions are under the way: Firstly, the experiment's scale needs to be enriched. The current scale is difficult to study adequate size of affections. Secondly, a guided mutation based on the feature of the optimal objectives is to be investigated, and how to reduce the computational complexity is also the next-step when accommodating the above future research plans. Thirdly, it is valuable to incorporate the MOICEA into the Zigbee protocol and 802.15.4 protocol, so that the optimal multi-objective can be tried virtually.

ACKNOWLEDGEMENTS

This paper was sponsored by the NingBo University of Technology, 2009 research project "Wireless Sensor Networks on NingBo harbor emergency management"; National Natural Science Foundation of China (Funding No.40901241); Natural Science Foundation of Zhejiang Provincial(Funding No.Y5090377)

REFERENCES

Chou, C. C. (2010). An efficient algorithm for relay placement in a ring sensor networks. Expert Systems with Applications.

Akyildiz, I. F. and Melodia, T. (2005). Underwater acoustic sensor networks: research challenges. Ad Hoc Networks.

Akyildiz, I. F. and Vuran, M. C. (2009). Signal propagation techniques for wireless underground communication networks. Physical Communication.

Akyildiz, I. F. and Wang, W. (2005). Wireless mesh networks: a survey, computer networks. Computer Networks.

Bahi, A. M. and Mostefaoui, A. (2008). Hilbert mobile beacon for localisation and coverage in sensor networks. International Journal of Systems Science.

Marta, M. and Cardei, M. (2009). Improved sensor network lifetime with multiple mobile sinks. Pervasive and Mobile Computing.

Baronti, P. and Pillai, P. and et al (2007). Wireless sensor networks: A survey on the state of the art and the 802.15.4 and zigbee standards. Computer Communications.

King, R. L. and Russ, S. H. and A. B. L. e. a. (2001). An artificial immune system model for intelligent agents. Future Generation Computer Systems.

Reddy, T. B. (2006). Quality of service provisioning in ad hoc wireless networks: a survey of issues and solutions. Ad Hoc Networks.

Rajagopalan, R. and Varshney, P. (2009). Connectivity analysis of wireless sensor networks with regular topologies in the presence of channel fading. Wireless Communications, IEEE Transactions on.

Chen, S. K. N. (1999). Distributed quality-of-service routing in ad hoc networks. IEEE Journal on Selected Areas in Communications.

Xue, W. and Junjie, M. and W. S. e. a. (2010). Distributed energy optimization for target tracking in wireless sensor networks. Mobile Computing, IEEE TransactiXueons on.

Trkoullari, Y. B. and Aras, N. and I. K. A. e. a. (2010). An efficient heuristic for placement, scheduling and routing in wireless sensor networks. Ad Hoc Networks.

Aneja, Y. P. and Chandrasekaran, R. and X. L. e. a. (2010). A branch-and-cut algorithm for the strong minimum energy topology in wireless sensor networks. European Journal of Operational Research.

Yang, Y. and Cardei, M. (2010). Improving network lifetime with mobile wireless sensor networks. Computer Communications.

Yang, S. and Cao, Y. (2008). Networked control systems and wireless sensor networks: theories and applications. International Journal of Systems Science.