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Research Article

Improving Efficiency and Reliability in The Seismic Monitoring Systems Based on The Internet of Things by Applying Redundancy in Sensors and Controllers

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Abstract

Earthquakes are usually associated with damage. Therefore, any action to predict it is necessary. In data monitoring systems, real-time and accuracy of data play a key role. In this article, a monitoring system based on the Internet of Things was proposed for the messaging of seismic data. In the first solution, the lightweight protocol Message Queuing Telemetry Transfer (MQTT) was chosen for messaging. In the second solution, redundancy was applied in the sensor layer using the gray wolf algorithm, and in the third solution ،redundancy was applied in the controller layer. The simulation results showed that the redundancy in the sensor and controller layer saved energy consumption by more than thirty percent. Also, the average end-to-end delay was significantly reduced in the second and third solutions. Finally ،in the first solution, the rate of successful package delivery for different number of packages was a constant value of 78.98%. But by applying redundancy in the sensor and controller, the package delivery rate increased to over 92%, which can be the result of increasing the number of sensors and controllers and their proper placement.

Keywords: Seismic, Internet of Things, Energy Consumption, Packet Delivery Rate, Bit Error.

Highlights

- Improving the efficiency of the seismic monitoring system by applying the redundancy of the sensors of the sensors layer based on the Internet of Things.
- Applying redundancy in the controller layer of the seismography system based on the Internet of Things.
- Improving fault tolerance in the communication layer of the Internet of Things by modifying the information transmission mechanisms from the controller to the infrastructure layer.

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1. Introduction

Earthquake refers to a series of tremors and seismic vibrations that are caused by the sudden release of a large amount of energy in the Earth's lithosphere. The main cause of earthquakes is the activity of tectonic plates [1]. As a result, earthquake prediction as one of the most complex and expensive natural disasters has become a challenging and vital task for humanity. Effective earthquake forecasting has the potential to significantly reduce earthquake damage. On the other hand, unlike weather forecasts or even tsunami warnings for distant earthquakes, there is not enough time for the seismologist to review the seismic data and adjust, correct and send the warning message [2].

So far, various approaches have been used to predict and announce earthquake warnings, approaches such as wireless data transfer, simplified measuring methods, acoustic emission, MEMs-based approach, Using Tilt and Displacement Sensors, and Internet of Things-based approach [3].

One of these approaches, which is expanding rapidly, is based on the Internet of Things. This technology brings new technology such as natural disaster monitoring [4]. On the other hand, the performance of the earthquake early warning system is often related to the density of its stations. In seismology, due to the high density of the seismic network and the complexity of data processing, the development of a high-performance real-time earthquake early warning system still faces a great challenge [5].

In recent years, the seismological community has focused on the study of low-cost devices to build denser seismic monitoring networks to implement earthquake early warning services. Dense seismic networks provide faster response times and higher accuracy in earthquake detection and location [6].

Therefore, in this article, a monitoring system based on the Internet of Things is proposed, relying on the density and redundancy of messaging devices. For messaging, Message Queuing Telemetry Transport (MQTT) lightweight protocol is used according to different environmental conditions. To increase the accuracy, speed, reliability and efficiency of the messaging system in the proposed three-layer model, we will have redundancy in both the sensor layer and the controller layer of the proposed model based on the Internet of Things.

2. Innovation and contributions

In this article, a three-layer architecture for a seismic monitoring system is presented.

Among the innovations of this paper, the following can be stated:

- Use of MQTT protocol for seismic monitoring network
- Providing a three-layer architecture for seismic data monitoring system based on the Internet of Things
- Using redundancy in the sensor and controller layers of the proposed architecture for the seismic network using heuristic algorithms

3. Materials and Methods

MATLAB software environment has been used to simulate the proposed design. The simulation has been done on nodes with the number of 80 to 160 nodes in a range of 3000 meters. It is assumed that 100 to 1000 event (earthquake) detection operations will occur in 50 rounds. The simulation was implemented on a system with an Intel Core i5 processor and 4 GB and on the Windows 10 operating system. The case simulation parameters are stated in Table 1. Of course, in the simulation modeling, a limiting assumption regarding the nodes, topology and architecture of the sensor network nodes is not included. This issue exists in different values of the simulation parameters such as the number of nodes, their distance, the energy of the sensor nodes, and the simulation can also be performed with different values, so that for environments with dimensions on the scale and range of 3000 meters tested, these parameters produce similar results have produced.

4. Results and Discussion

4.1. Network energy consumption

To check the status of the proposed system, simulation was done up to 50 rounds and the performance of the design in different solutions was compared, respectively, the first solution without redundancy, the second solution with redundancy in the sensor, and the third solution with redundancy in the sensor and controller. The simulation results showed that the energy consumption of the nodes, for different iterations, in the second and third solutions is generally lower than the basic solution. Therefore, it is possible to increase the lifetime of the network by applying redundancy in the first and second layers.

Next, the energy consumption in the proposed solutions was evaluated by changing the number of sent packets and we observed the effect of the change in the number of packets and the resulting traffic. The simulation showed that the energy consumption in the second and third solutions, despite the increase in the number of sensor and controller objects, has a significant decrease compared to the first solution for different packages, so that this decrease is more significant with the increase in the number of packages. Also, the third solution consumes less energy than the second solution. Therefore, it can be said that redundancy has reduced the energy consumption in messaging.

4.2. Bit error rate

By applying intelligent redundancy in sensors and controllers, fault tolerance increases in the seismic event monitoring network. Because this work will cover the network in different places. The data in the extension nodes is received and the correct data is sent, to better cover the environment and less data, it will have an error due to not sending correctly. Bit error rate is used to measure this index. The lower the bit error rate, the higher the error tolerance in the network. The simulation showed that in triple solutions, with the increase in the number of different sent packets, the performance of the solutions will be different.

4.3. propagation Delay

The end-to-end delay defines the average time used by the sensor node to monitor an event, deliver the packet from the source node to subsequent nodes, and finally deliver to the master station. Investigations have shown that for 50 rounds in low repetitions, the

end-to-end delay is not significantly different in all three methods; so until the 30th iteration, the values of the solutions are similar, but gradually with the increase of the iterations, this value decreases significantly in the second and third solutions, which have an excess, compared to the first method, so that this reduction is evident in the 50th iteration. Is. The reason can be that as the number of nodes increases, the probability of error-free nodes increases and the messaging error decreases.
We performed the same evaluation to record the end-to-end delay, during the simulation run, with different number of packets sent in the network. The obtained results showed that the propagation delay in data transmission in the second and third solutions with different packages is better than the basic method without redundancy.

4.4. packet delivery rate

One of the standard parameters in the efficiency and quality of the service is the successful delivery rate depending on the destination, which is the percentage of the number of successfully delivered packages to the total number of packages sent. The results showed that the packet delivery rate in the second and third solutions is better than the first solution. This issue is expected due to the redundancy in sensors and controllers and the increase of healthy nodes in the messaging network topology. An important point here is that in this simulation, the package delivery rate for the first solution is 79.98% for packages with different numbers of one hundred, two hundred, three hundred to one thousand packages. That is, the change in the number of packages does not change the packet delivery rate in the first solution.

5. Conclusion

To validate the results obtained from the simulation observations, we applied the analysis of variance test on it. The results of the test are summarized in Table 8 for α equal to 0.05. The test for six parameters of total energy consumption, energy consumption with different numbers of packets, bit error rate, propagation delay, propagation delay with different numbers of packets and packet delivery rate has been done and the final value of Fisher F test statistic has been obtained. The assumptions of the test are also given in equation 1.

$$\begin{cases} H_0 : \overline{X_{mqqt}} = \overline{X_{mqtt\_sensor\_redundant}} = \overline{X_{mqtt\_sensor\_controller\_redundant}} \\ H_1 : \overline{X_{mqqt}} \neq \overline{X_{mqtt\_sensor\_redundant}} \neq \overline{X_{mqtt\_sensor\_controller\_redundant}} \end{cases} \quad (1)$$

The null hypothesis states that the average value of the results of the investigated parameters for three solutions without redundancy, redundancy in sensors and redundancy in controllers are equal. Assumption one also states that the average value for one of the solutions (solution without redundancy) is different from the other two solutions. As observations include three categories of data, and three solutions, so the degree of freedom is equal to 2. Also, for total energy consumption and propagation delay, the results include three groups of 50 observations, so the degree of freedom of the denominator is 147, and for the other four parameters, the results include three groups of 10 data, and therefore, the degree of freedom of the denominator is 27.
According to Table 8, the F value calculated for the total energy consumption is equal to 4.016487 and is more than the standard value of 3.05 in the Fisher table, and therefore the hypothesis H_1 is established, which means that the average value for the total energy consumption in the non-redundancy solution is different from the two The solution has redundancy. In other words, as the simulation observations also showed, it can be concluded that with an accuracy of over 95% (this accuracy is maintained for other tested parameters) in the solution without redundancy, more energy is consumed on average than the two solutions with redundancy. And the modifications made improve the performance of the system in terms of energy consumption. In the energy consumption test, for packages with different numbers of packages, the F value calculated for the total energy consumption is equal to 5.787592 and more than the standard value of 3.35 in the Fisher table. This also means that it can be inferred that the energy consumption for different number of packages will be more than the other two solutions in the non-redundancy mode. Calculations on the bit error rate show that the value of F with the size of 6.943163 was higher than the value of Fisher's table and it can be concluded that the bit error rate in two solutions with redundancy has a significant improvement compared to the solution without redundancy. Similarly, by calculating the value of 3.987118 larger than Fisher's standard value for the propagation delay, we conclude that the improvement and application of redundancy in the system results in the reduction of the propagation delay time. But the F obtained with the size of 1.178727 for the propagation delay test for packets with different numbers is less than Fisher's standard value, which means that despite the reduction of propagation delay in the simulation results through the test, in general, it cannot be argued that redundancy leads to reduce propagation delay. Finally, with a high value of 14.9431 for the successful rate of packet delivery, it can be concluded that the redundancy applied in the system leads to an increase in the rate of packet delivery.

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Appendix

Table 1. Simulation parameters

Parameter	Value
Dimensions of the environment	3000 meters
Number of nodes	80-160 nodes
Number of sent packages	100-1000 packets
Nodes signal transmission board	200 meters
Distribution of nodes in the environment	Random
Primary energy	0.01 kilo joule
Primary population in gray wolf algorithm	50
number of rounds in the gray wolf method	50
Filter size	100

Table 2. Comparison of square root of average energy consumption in three solutions

Proposed solution	RMSD amount of energy consumption in different iterations
$MQTT_1$	0.702304001
$MQTT_2$	0.558049572
$MQTT_3$	0.542788824

Table 3. Comparison of square root of average energy consumption for different number of packages in three solutions

Proposed solution	RMSD amount of energy consumption in triple solutions
$MQTT_1$	6.977473128
$MQTT_2$	5.803213695
$MQTT_3$	5.366242187

Table 4. Comparison of root mean square bit error rate for three solutions

Proposed solution	Bit Error Rate RMSD
$MQTT_1$	0.042059006
$MQTT_2$	0.051907591
$MQTT_3$	0.051570253

Table 5. Average end-to-end delay in three solutions

Proposed solution	RMSD of propagation delay in triple solutions
$MQTT_1$	188.447583
$MQTT_2$	1736.552018
$MQTT_3$	1770.932605

Table 6. Comparison of end-to-end root mean square delay for different number of packets in triple solutions

Proposed solution	RMSD of propagation delay
$MQTT_1$	2.11792839
$MQTT_2$	1.881600128
$MQTT_3$	1.862586003

Table 7. Comparison of RMSD of packet delivery rate in three solutions

Proposed solution	RMSD amount of packet delivery rate in triple protocols
$MQTT_1$	0.799806
$MQTT_2$	0.947431348
$MQTT_3$	0.958444278

Table 8. Variance analysis test on simulation data for α=0.05

Test parameter	Degree of deduction freedom	degree of denominator freedom	MS_b	MS_w	Calculated F	Fisher table value
Total energy consumption	2	147	0.366423	0.09123	4.016487	3.05
Energy consumption for different packet number	2	27	37.05299	6.402143	5.787592	3.35
Bit error rate	2	27	0.002374	0.000342	6.943163	3.35
Propagation delay	2	147	3230553	810247.7	3.987118	3.05
Propagation delay for different packet number	2	27	0.0766351	0.650152	1.178727	3.35
Package delivery rate	2	27	0.818644	0.05478	14.9431	3.35

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