Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: https://www.science-gate.com/IJAAS.html

EduForestAPI: An application programming interface (API) framework to support biota research in Malaysia

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ARTICLE INFO

Article history:
Received 2 February 2026
Received in revised form
9 August 2026
Accepted 25 October 2026

Keywords:
Forest data
Forest IoT
Bioacoustics
Data sharing
Application programming interface

ABSTRACT

Rainforest conditions affect not only the country in which a rainforest is located but also the entire planet, depending on its size. This is due to the important role rainforests play in absorbing carbon, producing oxygen, and regulating the global climate. Malaysia, as one of the countries with some of the largest and oldest rainforests in the world, has a significant capacity and responsibility to protect its rainforests and biodiversity. Local technology-driven Internet of Things (IoT) infrastructure has been established to support this role. However, such efforts should not be limited to the national level, as ideas for improving existing practices may also come from external or international parties. This is only possible when seamless data sharing is available. One suitable approach is the use of a controlled Application Programming Interface (API) to regulate the publication and subscription of rainforest data. Through this approach, both data sharing and security can be monitored and controlled. Consequently, third-party organizations can conduct data analytics, and their findings can be used to support the conservation of Malaysian rainforests. Rainforests in other countries or regions with similar characteristics may also benefit from the proposed solution. Finally, this novel forest-driven API framework could help balance the progress of Industrial Revolution 5.0 (IR 5.0) with the protection of the natural environment.

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1. Introduction

Data sharing for the purpose of common benefits is a part of today's Industrial Revolution 5.0 (IR 5.0), where human-computer interaction becomes the driver of various systems integration. Multiple parties that analyze the data may produce different insights and values, which are beneficial for the well-being of humans and other living creatures. Such an objective is devised in a set of sustainable development goals (SDGs) established by the globally recognized United Nations (UN). Logically, most collaborative data analytics revolve around the welfare of human beings; for example, business, finance, and health (Bakare et al., 2024; Dave et al., 2025). However, the higher purpose involves not just humans, but also biota since the Earth's ecosystem is affected by them. The harmony between humans and nature is imperative for all developmental progress in IR 5.0. As such, the SDGs cover nature-related goals as well, i.e., Goal 6 that mentions clean water, Goal 7 that targets sustainable energy, Goal 11 that aims for sustainable cities and communities, Goal 12 that talks about responsible consumption and production, Goal 13 that specifies climate action, Goal 14 that focuses on life below water, and Goal 15 that takes care of life on land.

Despite the explicitly mentioned importance of biota (Goal 14 and 15), the efforts to drive data-driven conservation efforts are still scarce (Romani et al., 2023). In most cases, conservation data resides in silo where only a group of researchers/scientists in the same center would have access to the data. This practice is commonly done to protect data privacy. This machine learning-driven data analytics method managed to achieve high recognition

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accuracy of up to 90%. Similar conservation research on gorillas in Congo has also been accomplished (Brust et al., 2017). Neither work provided a platform for collaborative data sharing, therefore making it inaccessible for potential new researchers who may come up with better detection algorithms to improve the results.

Another biota that was monitored is bats. This study was done in Portugal (Lang et al., 2024). Instead of camera traps, this work utilized acoustic sensors to detect bats' movements and conclude whether a farm had been plagued by pests. It took advantage of the natural behavior of bats that have the tendency to swarm a location that is infested by pests. Likewise, as with the earlier-mentioned gorilla conservation attempts, this research also did not share its data. The flights of birds were also analyzed by deploying similar bioacoustics sensors to sense and conserve thousands of bird species in Kenya (Raval et al., 2024). A classifier algorithm based on a Convolutional Neural Network (CNN) was implemented and achieved above 95% accuracy. However, the resulting database of discovered birds was not shared in their paper. A shared database would have encouraged other biologists to join in the conservation efforts. A different approach was made by digesting camera traps' images instead of analyzing bioacoustics sensors' data to classify peccaries in the Amazon forest using machine learning algorithms (Zurita et al., 2023). The classification was limited to only two (2) species of peccary, and the framework managed to accurately categorize the peccaries, except when there was an overlap of multiple peccaries in an image. As with previously mentioned works, they also did not share the outcome database nor the trained model. And the restricted ability of the model to only recognize two species may hinder the wider purpose of future case studies.

Monitoring of biota is not restricted to land animals, as some researchers have shown. Underwater acoustic sensors were deployed to detect the population of marine biota (Wilby et al., 2016). This infers the robustness of bioacoustics even for underwater ecosystem. Similar to the previously discussed sensor-driven research, the collected dataset has not been shared, hence prohibiting collaboration and external perspectives. Besides acoustic sounds, chemical and other physical parameters have also been measured underwater to gauge the water quality level, which could then be used to monitor and predict the biota's varieties (Wang et al., 2022). Such a granular approach involves diverse elements, i.e., oxygen, nitrogen, and phosphorus, along with common hydrological variables. Likewise, in most biota research, the resulting dataset from this work is also not publicly available – making crucial third-party engagement unfeasible. In this case, data sharing would be even more critical since water quality effectively affects not only biota, but also human beings. However, confidentiality could be preferred due to the government's national data policy.

However, certain cases may require data to be shared in a limited manner to enable collaboration and provide different insights from different angles. Such controlled data access can be done using a software-based method called an Application Programming Interface (API), where a publish-and-subscribe model is applied to provide authentication and authorization on the shared data. An example in the area of agriculture was done by building a set of APIs that regulated the sharing and access of agricultural data among authorized agencies in Brazil that analyzed the data and delivered the conclusions for the benefit of local farmers (Romani et al., 2023). Another country that followed suit to share pre-processed biological data is Greece who ingested satellite-given images and pre-processed them so that they could be further distributed and analyzed as data cube via an API (Fotakidis et al., 2024). This polished dataset may be utilized to improve other data-driven biodiversity conservation efforts, where the existing dataset missed several regions due to missing data (Marín et al., 2021). Such practice of complementing each other's research is the main driver of collaborative data analytics via API. The previously mentioned work in Greece was inspired by shared data cubes from earlier related work in Brazil (Ferreira et al., 2020), and it was also an improvement on a similar satellite-driven image data analysis in Italy (Parisi et al., 2023), whereby it did not proceed to share their pre-processed data through an API. This shows that collaborative data sharing may go as far as intercontinental orchestration provided that the API is publicly accessible. Also, it could lay a foundation for more sophisticated future work. Such an open model of Earth-related data sharing provided by API technology complies with the principles of fairness, where all responsible parties could get access to environmental data concerning life on Earth (Sudmanns et al., 2023). Bespoke analytics may be done sequentially according to the scope – be it location-wise, biota-wise, and the purpose of every authorized party. Eventually, the result of each specialized analytics may be re-shared also via the same API technology.

This paper focuses on developing the API for rainforest data sharing to be further used for analytics. Per current literature, an API set for such a case has not been devised. The significance of rainforest data-driven orchestration has been previously published (Nurika et al., 2025); hence, this article extends it.

2. Methodology

This section presents the proposed API design that would allow the sharing of rainforest-generated data for collaborative research purposes.

The API infrastructure would use a Pub/Sub (Publish/Subscribe) model, which mirrors the standard request and response API messages. Each pair would serve different purposes as presented in Table 1. This whole package of API would be named

EduForest. For the record, the domain part is pseudo and/or has not necessarily been registered. Detailed API endpoint specifications, including the HTTP methods, URLs, and complete sample request–response structures, are provided in Supplementary Material.

Table 1: EduForest proposed API requests and responses

No.	Purpose/resource	HTTP method	Endpoint
1	List sensors	GET	/royalbelum/sensors
2	Retrieve a specific sensor	GET	/royalbelum/sensors/{sensorID}
3	List incidents	GET	/royalbelum/incidents
4	Retrieve a specific incident	GET	/royalbelum/incidents/{incidentID}
5	List incidents by WWF branch (tenant)	GET	/royalbelum/incidents/{tenant}
6	List incidents by species	GET	/royalbelum/incidents/{species}

The orchestration of request and response API messages (Pub/Sub model) in Table 1 would be managed by an API manager, which bridges between the publishers (sensors) and subscribers (data warehouse, analytics platforms, and whatnot). Each message published by the sensors would be categorized into topics.

And every subscriber would subscribe to one or more topics in order to get the data. Such a model is visualized in Fig. 1.

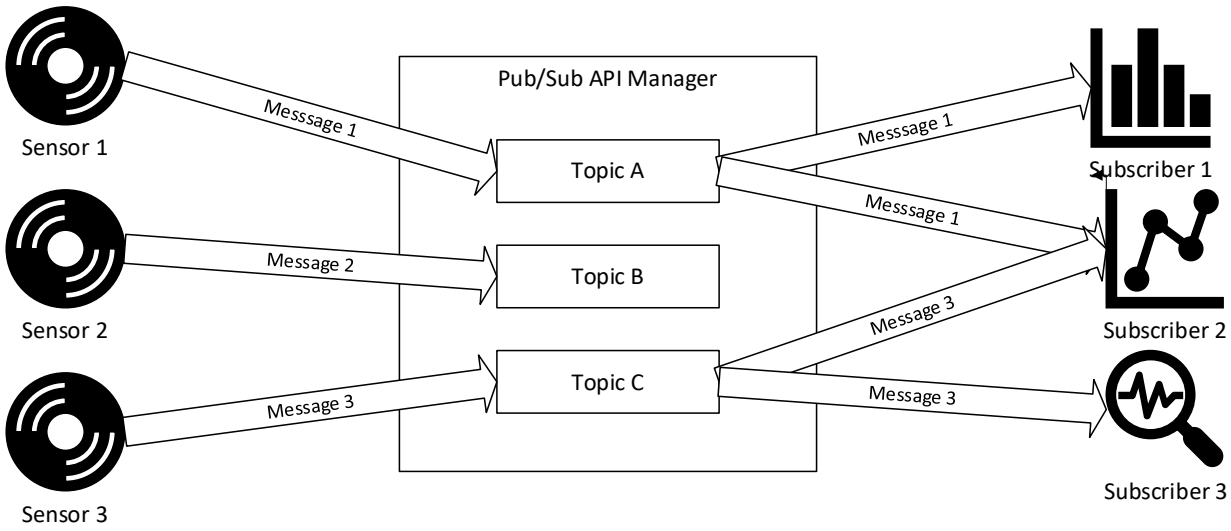


Fig. 1: Pub/sub model for EduForest API

Fig. 1 presents the modular API management and distribution, which simplifies collaborative data sharing. The categorization of sensor data may assist subscribers in their data pre-processing stage, where data is already pre-selected by the API manager. This may also significantly reduce the required computation load on the subscribers' side. Normally, the data pre-processing stage is the most time-consuming stage in data analytics, however, this proposed infrastructure may lift such a burden off the subscribers. The subscription model allows for both free and paid subscriptions. However, due to this paper's focus on collaboration, API commercialization is not discussed in detail.

EduForest API management requires registration in order to secure and monitor the usage of APIs. Every subscriber must be registered first before subscribing to the API topic/s. Afterwards, they may send requests to the subscribed topics accordingly to get data. This data can then be used and/or analyzed to generate meaningful insights, for example, the paths of tigers and elephants, the path of poachers, the required number of rangers to be deployed to patrol the forest, the most frequent biosynthesis process in the forest, etc. Data-driven international efforts can also be executed accordingly, such as providing emergency assistance across the border by a neighbouring country. Possible forms of it could be deployment of water-carrier airplanes/drones towards a burning forest, delivery of army/robots support to fend off aggressive poachers, or transport of medics to treat injured animals. They could also further represent the insights in an application or dashboard with appropriate visuals. Such a platform may accelerate the execution of necessary actions that may protect and preserve nature.

3. Prototype functional testing

The functions of the prototypes of the previously designed APIs have been developed and tested with successful results according to the following secure specifications:

- Encrypted HTTP traffic using Transport Layer Security (TLS) that would encipher data inside the API requests and responses.
- Excluding sensitive data from the URLs, such as credentials (username/password), API key, and API token.
- Implementing API request validation to prevent brute force attacks.

- Limiting the allowed HTTP methods to prevent loss of data, i.e., the DELETE method is prohibited.

The workability proofs of every set of API are summarized in Table 2 that were generated by browser's requests. The complete screenshots of the six prototype testing outcomes are provided in Supplementary Material. The previously listed outcomes infer that all the API sets are functioning and fit for purpose and deployment.

4. Prototype performance testing

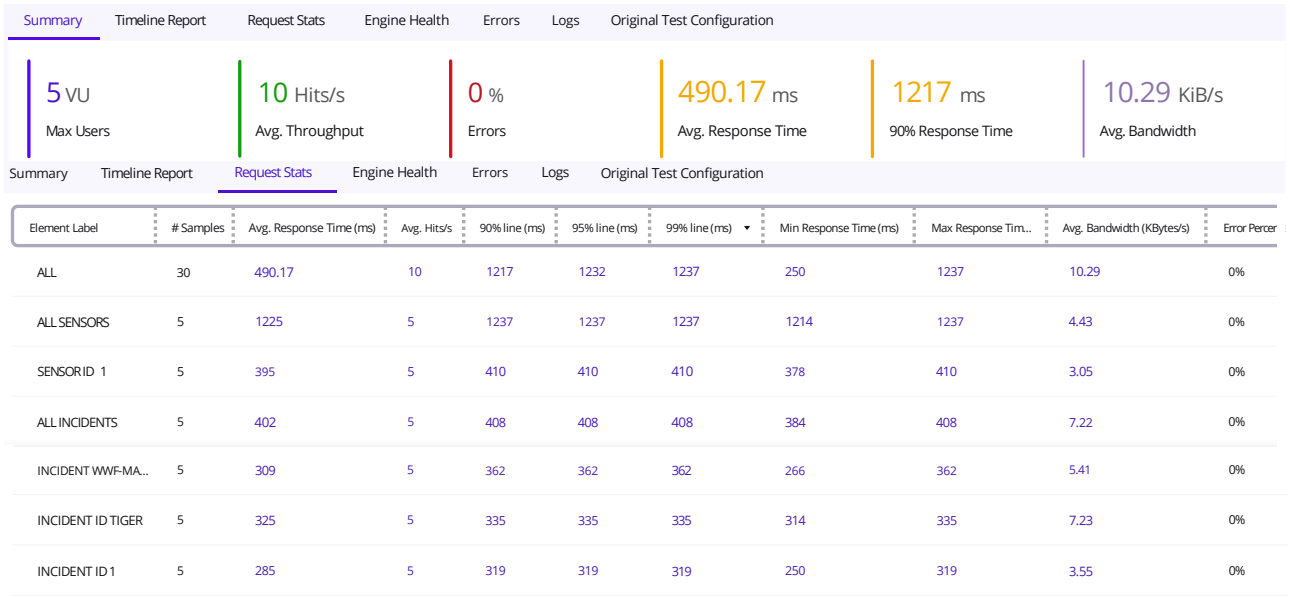
Besides functional testing, the APIs have also gone through performance tests to verify their load threshold in serving requests. All the performance tests were conducted using BlazeMeter software. There were five test scenarios that were configured with different settings, i.e., number of users, number of iterations, durations, and ramp-up times. The result summary for every scenario and their corresponding timeline of response times are presented in the next sub-sections.

4.1. Test scenario 1

Test specifications: 5 users, 1 iteration, 0 ramp-up minutes. Ten hits per second of average throughput were successfully handled with non-linear response times as shown by the following Figs. 2 and 3.

Table 2: Prototype outcomes of EduForest API requests and responses

No.	API operation tested	Evidence to report	Outcome
1	List sensors	Successful response; sensor list returned	Successful
2	Retrieve a specific sensor	Successful response; requested sensor returned	Successful
3	List incidents	Successful response; incident list returned	Successful
4	Retrieve a specific incident	Successful response; requested incident returned	Successful
5	List incidents by tenant	Successful response; tenant-filtered incidents returned	Successful
6	List incidents by species	Successful response; species-filtered incidents returned	Successful



Element Label	# Samples	Avg. Response Time (ms)	Avg. Hits/s	90% line (ms)	95% line (ms)	99% line (ms)	Min Response Time (ms)	Max Response Tim...	Avg. Bandwidth (KBytes/s)	Error Percer
ALL	30	490.17	10	1217	1232	1237	250	1237	10.29	0%
ALL SENSORS	5	1225	5	1237	1237	1237	1214	1237	4.43	0%
SENSOR ID 1	5	395	5	410	410	410	378	410	3.05	0%
ALL INCIDENTS	5	402	5	408	408	408	384	408	7.22	0%
INCIDENT WWF-MA...	5	309	5	362	362	362	266	362	5.41	0%
INCIDENT ID TIGER	5	325	5	335	335	335	314	335	7.23	0%
INCIDENT ID 1	5	285	5	319	319	319	250	319	3.55	0%

Fig. 2: Result summary for Scenario 1

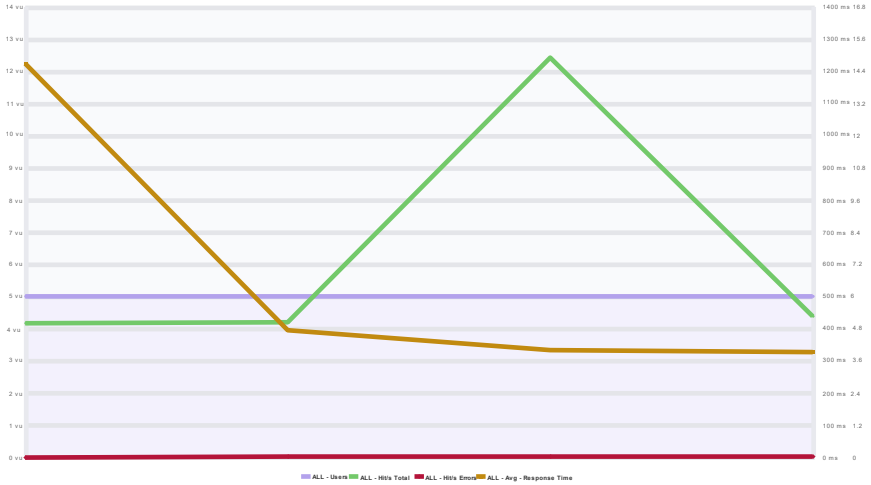


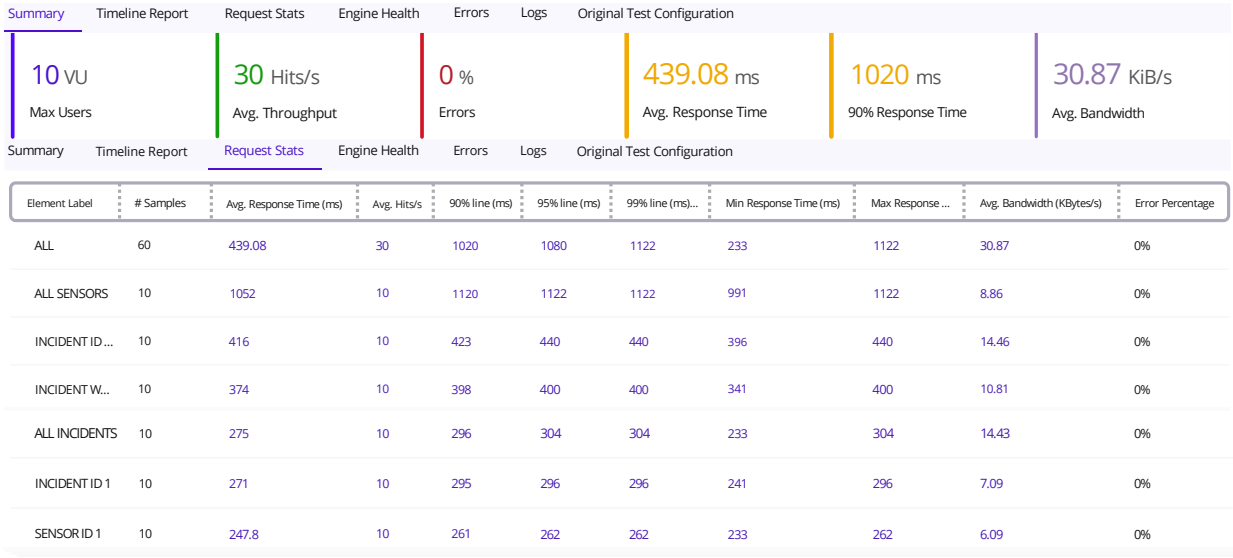
Fig. 3: Timeline of response times for all requests in Scenario 1

4.2. Test scenario 2

Test specifications: 10 users, 1 iteration, 0 ramp-up minutes. Thirty hits per second of average throughput were successfully handled with non-linear response times as shown by Figs. 4 and 5.

4.3. Test scenario 3

Test specifications: 10 users, 5 iterations, 0 ramp-up minutes. Thirty-three hits per second of average throughput were successfully handled with non-linear response times as shown in Figs. 6 and 7.



Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

10 VU	30 Hits/s	0 %	439.08 ms	1020 ms	30.87 KiB/s
Max Users	Avg. Throughput	Errors	Avg. Response Time	90% Response Time	Avg. Bandwidth

Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

Element Label	# Samples	Avg. Response Time (ms)	Avg. Hits/s	90% line (ms)	95% line (ms)	99% line (ms)...	Min Response Time (ms)	Max Response ...	Avg. Bandwidth (KBytes/s)	Error Percentage
ALL	60	439.08	30	1020	1080	1122	233	1122	30.87	0%
ALL SENSORS	10	1052	10	1120	1122	1122	991	1122	8.86	0%
INCIDENT ID ...	10	416	10	423	440	440	396	440	14.46	0%
INCIDENT W...	10	374	10	398	400	400	341	400	10.81	0%
ALL INCIDENTS	10	275	10	296	304	304	233	304	14.43	0%
INCIDENT ID 1	10	271	10	295	296	296	241	296	7.09	0%
SENSOR ID 1	10	247.8	10	261	262	262	233	262	6.09	0%

Fig. 4: Result summary for Scenario 2

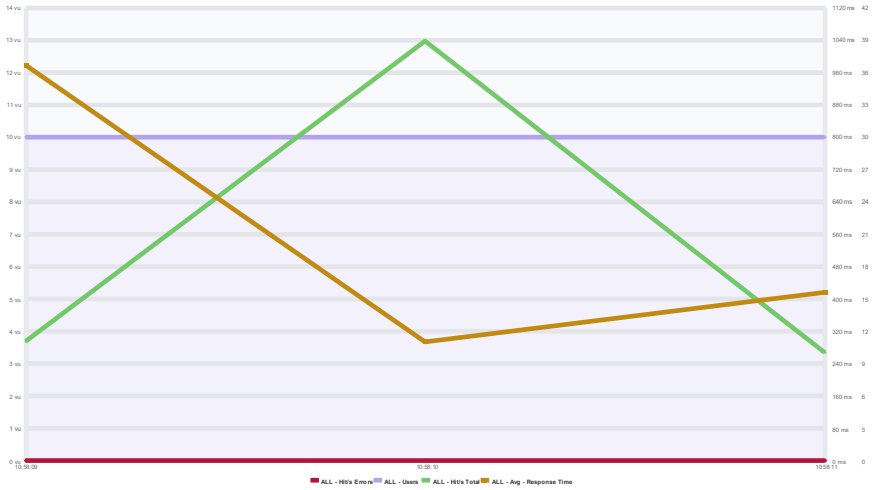
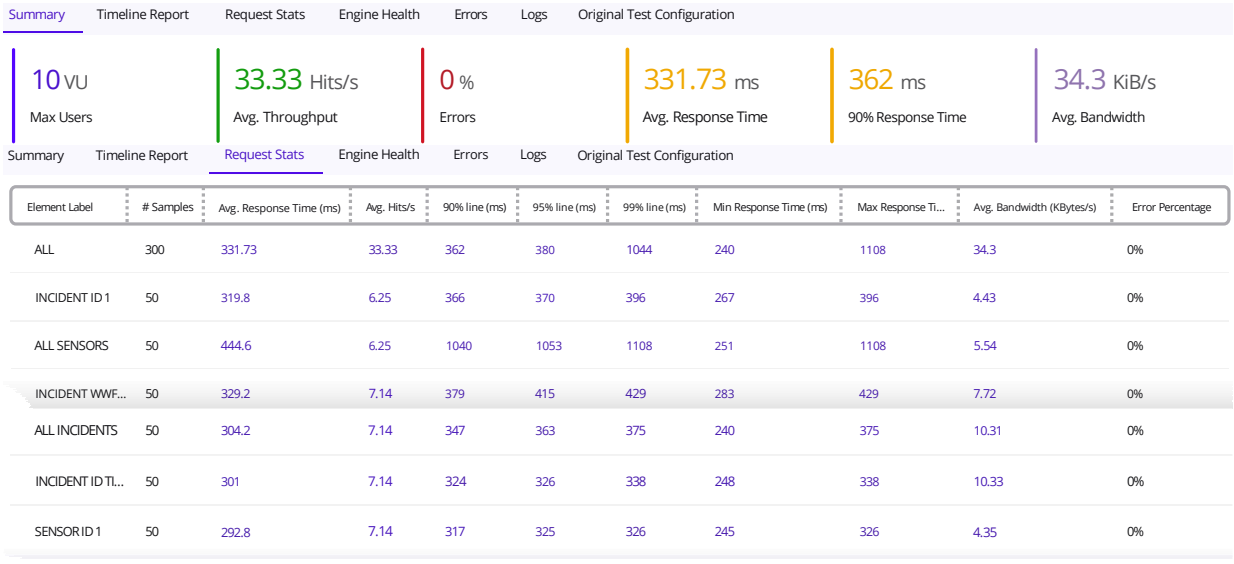


Fig. 5: Timeline of response times for all requests in Scenario 2



Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

10 VU	33.33 Hits/s	0 %	331.73 ms	362 ms	34.3 KiB/s
Max Users	Avg. Throughput	Errors	Avg. Response Time	90% Response Time	Avg. Bandwidth

Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

Element Label	# Samples	Avg. Response Time (ms)	Avg. Hits/s	90% line (ms)	95% line (ms)	99% line (ms)	Min Response Time (ms)	Max Response Ti...	Avg. Bandwidth (KBytes/s)	Error Percentage
ALL	300	331.73	33.33	362	380	1044	240	1108	34.3	0%
INCIDENT ID 1	50	319.8	6.25	366	370	396	267	396	4.43	0%
ALL SENSORS	50	444.6	6.25	1040	1053	1108	251	1108	5.54	0%
INCIDENT WWF...	50	329.2	7.14	379	415	429	283	429	7.72	0%
ALL INCIDENTS	50	304.2	7.14	347	363	375	240	375	10.31	0%
INCIDENT ID TI...	50	301	7.14	324	326	338	248	338	10.33	0%
SENSOR ID 1	50	292.8	7.14	317	325	326	245	326	4.35	0%

Fig. 6: Result summary for Scenario 3

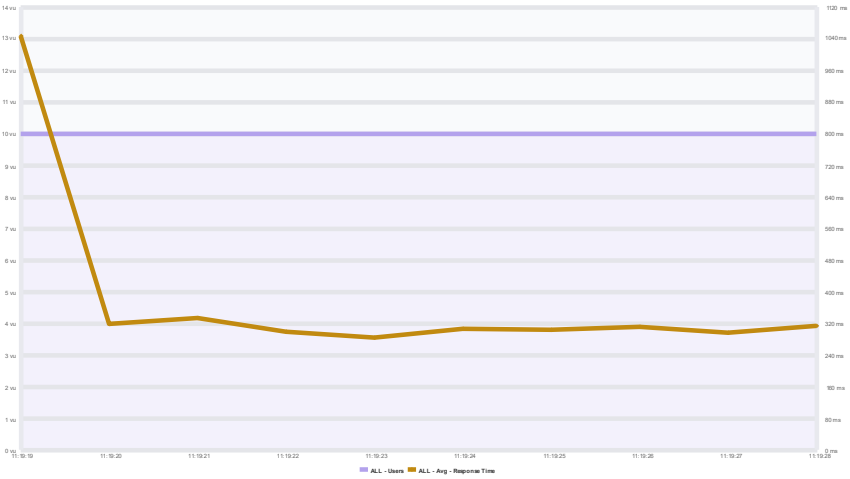


Fig. 7: Timeline of response times for all requests in Scenario 3

4.4. Test scenario 4

Test specifications: 10 users, 10 iterations, 0 ramp-up minutes. Twenty-eight hits per second of average throughput were successfully handled with non-linear response times as visualized by the ensuing Figs. 8 and 9.

4.5. Test scenario 5

Test specifications: 10 users, 10 minutes, 1 ramp-up minute. Thirty-three hits per second of average throughput were successfully handled with non-linear response times as presented by the succeeding Figs. 10 and 11.

Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

10 VU	28.57 Hits/s	0 %	334.86 ms	484 ms	29.4 KiB/s
Max Users	Avg. Throughput	Errors	Avg. Response Time	90% Response Time	Avg. Bandwidth

Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

Element Label ...	# Samples	Avg. Response Time (ms)	Avg. Hits/s	90% line (ms)	95% line (ms)	99% line (ms)	Min Response Time (ms)	Max Response Time...	Avg. Bandwidth (KBytes/s)	Error Percen...
ALL	600	334.86	28.57	484	511	1142	235	1147	29.4	0%
ALL INCIDENTS	100	319.23	5.56	480	494	595	236	602	8.02	0%
ALL SENSORS	100	407.59	5	604	1142	1144	235	1147	4.43	0%
INCIDENT ID 1	100	309.92	5.56	444	479	482	239	483	3.94	0%
INCIDENT ID T...	100	323.15	5.56	491	506	524	238	524	8.04	0%
INCIDENT WW...	100	317.7	5.26	465	480	505	241	511	5.69	0%
SENSOR ID 1	100	332.24	5.26	504	512	591	238	603	3.21	0%

Fig. 8: Result summary for Scenario 4

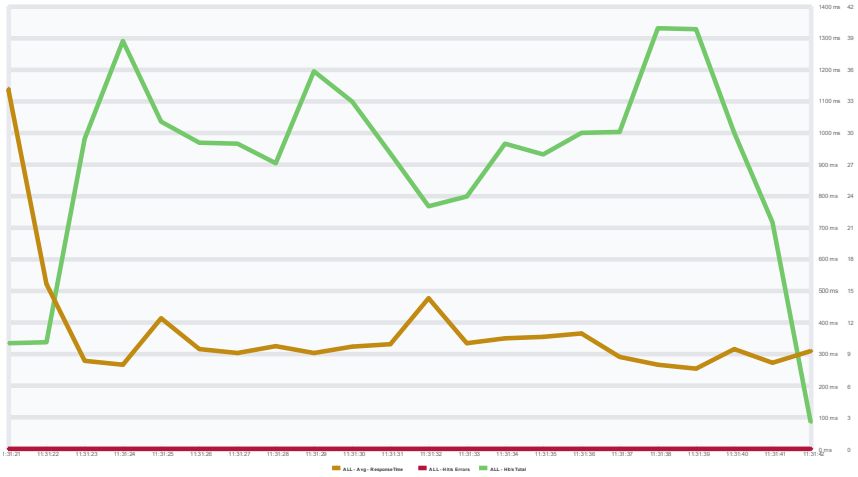


Fig. 9: Timeline of response times for all requests in Scenario 4

Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

10 VU	33.47 Hits/s	0 %	285.34 ms	358 ms	34.44 KiB/s
Max Users	Avg. Throughput	Errors	Avg. Response Time	90% Response Time	Avg. Bandwidth

Summary | Timeline Report | Request Stats | Engine Health | Errors | Logs | Original Test Configuration

Element Label	# Samples	Avg. Response Time (ms)	Avg. Hits/s	90% line (ms)	95% line (ms)	99% line (ms)	Min Response Time(ms)	Max Response Ti...	Avg. Bandwidth (KBytes/s)	Error Percentage
ALL	19980	285.34	33.47	358	451	604	223	1230	34.44	0%
ALL SENSORS	3334	285.56	5.58	357	452	606	223	1230	4.95	0%
INCIDENT ID TIGER	3326	285.91	5.59	360	458	611	223	1228	8.09	0%
SENSOR ID 1	3332	284.82	5.59	357	440	613	223	760	3.41	0%
ALL INCIDENTS	3331	286.02	5.59	360	450	592	223	1228	8.07	0%
INCIDENT WWF -...	3327	285.33	5.59	356	456	598	223	1226	6.05	0%
INCIDENT ID 1	3330	284.48	5.6	353	440	581	224	1226	3.97	0%

Fig. 10: Result summary for Scenario 5

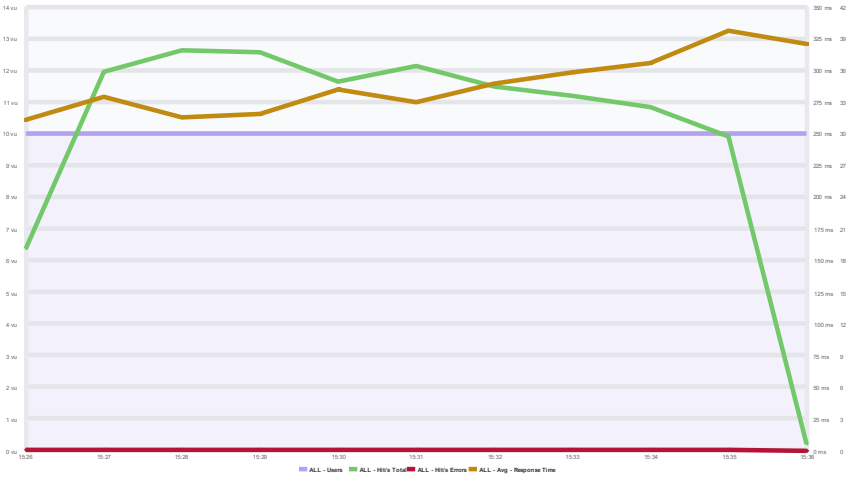


Fig. 11: Timeline of response times for all requests in Scenario 5

All the above completed performance test scenarios deliver a 0% error rate with less than 1000 ms (1 second) of average response time, and only require average bandwidth below 40 KiloBytes/s. Thus, it is concluded that the proposed API server infrastructure could handle the estimated request load.

5. Discussion and conclusion

The proposed collaborative data analytics may inspire countries to deploy similar Internet of Things (IOT) based infrastructure and APIs to monitor and manage their forests and biota. In such a case, external collaborators/subscribers will be able to help them with the necessary strategies.

APIs are driven by textual data, which is simple to ingest by different varieties of machines and applications. This would make cross-platform integration seamless and quick. For example, the sensor data published from the forest can be consumed by a web application that displays the data in a neat visualization, or it can also be digested and analyzed by a data analytics tool. Moreover, it may also trigger an actuator to execute a mitigative activity, such as sounding the alarm, activating a water sprinkler, alerting the authorities, deploying drones, capturing images/motions, etc.

Despite the benefits of EduForest APIs, concerns are present that may disrupt their operations. For instance, abuse of API requests in case subscribers go rogue due to malfunction or a man-in-the-middle attack. This incident may cause the API manager to crash and stop working. A preventive security measure could be installed, e.g., rate limiting (the number of allowed requests per second), load balancing, or quantum computing to rapidly detect anomalous requests. Essentially, encryption will be applied to ensure data confidentiality even after the data is stolen or intercepted. Confidentiality is put in high regard since compromised forest data may provide apprehension about the whereabouts of high-value animals, e.g., a tiger, which may help guide poachers/hackers to abduct it.

Performance-wise, the load tests statistics have shown that the API server is able to cater massive load including brute force attack since it managed to avoid high CPU and high memory utilizations in every test scenario. Extra anticipation may also be deployed by upgrading the server's CPU and memory capacities. The physical security aspect is also considered, which covers the secure placement of

sensors at discrete locations where they are not easily seen (undisclosed information). In addition, the sensors' materials are ensured to be robust to be able to withstand external forces e.g. shock, water, and fire intrusions. The locations of sensors would be monitored as well to detect theft attempts.

In the future, more forest parameters can be identified and extracted; for example, the detailed health of biota and the balance rate of the biota ecosystem. This information can provide knowledge about which biota is in excess or scarcity, including smaller-sized biota. Eventually, the orchestrated API-based international collaboration would help patch and adjust the balance of forest ecosystems through exchange of resources.

The above-mentioned utopian future is forecasted to be enabled by advancements in hardware technology, computation techniques (quantum computing), high-speed cellular networks, and multi-tenancy distribution among bordering nations.

List of abbreviations

API	Application programming interface
CNN	Convolutional neural network
CPU	Central processing unit
IoT	Internet of things
IR 5.0	Industrial Revolution 5.0
Pub/Sub	Publish/subscribe
SDG	Sustainable development goals
TLS	Transport layer security
vu	Virtual users
WWF	World Wide Fund for Nature

Acknowledgment

We sincerely thank P&G and World Wide Fund for Nature (WWF) Malaysia for funding this project titled 'Design Specification of IoT Requirements Including Infrastructure, Challenges, and Potential - Integrated Bioacoustics for Forest Conservation' via External International Industrial Grant, Research Code: 2025-0248-104-11. This research is also an initiative of the Centre of Embedded Education Green Technology of Universiti Pendidikan Sultan Idris (EduGreen@UPSI).

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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