

# The Earthquake Network project: a platform for earthquake early warning, rapid impact assessment and search and rescue

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## 2 ABSTRACT

3 Earthquake Network is a citizen science research project implementing an earthquake early  
4 warning system based on smartphone crowdsourcing. People join the project by installing a  
5 smartphone application and they receive real time alerts when earthquakes are detected by the  
6 smartphone network. Started at the end of 2012, the project has involved more than 5.5 million  
7 people and the application currently has around 500'000 active users. This makes Earthquake  
8 Network one of the largest citizen science project and an earthquake early warning system  
9 operational at the global scale. This paper aims at describing the main features of the project,  
10 of the smartphone application and of the data which are made available when an earthquake is  
11 detected in real time or reported by the application users.

12 **Keywords:** smartphone network, crowdsourcing, citizen science, real time alerts, statistics

## 1 INTRODUCTION

13 Earthquake Early Warning (EEW) systems are timidly becoming operational in some areas of some seismic  
14 countries (Cremen and Galasso, 2020). Despite EEW technology is mature, liability issues about who  
15 send the alerts and who is responsible for false/missed detections limit the pace at which EEW are made  
16 available to the general public. Additional, the high implementation and operation costs are an obstacle for  
17 the diffusion of EEW systems in underdeveloped and developing countries.

18 In parallel to EEW systems run by government agencies at the national level, the last decade has witnessed  
19 the development of “unofficial” platforms providing fast earthquake alerts at the global level. This was  
20 possible thanks to smartphone technology and to the crowdsourcing model, with people making their  
21 smartphone available in order to receive a useful service in return. Well known examples are the LastQuake  
22 project (Bossu et al., 2018) by the European-Mediterranean Seismological Centre and the MyShake project  
23 (Kong et al., 2016) by the UC Berkeley Seismological Laboratory. For LastQuake, a smartphone application  
24 (app hereafter) is used to monitor people activity soon after an earthquake. If many people from the same  
25 area open the app at the same time, it is likely that an earthquake has just occurred and an alert is sent. For  
26 MyShake, a smartphone app is used to continuously monitor the smartphone accelerometer in order to  
27 measure earthquakes and possibly send alerts.

28 This paper is about the Earthquake Network project (Finazzi, 2016) that, despite it has been on the scene  
29 long before LastQuake and MyShake, it has only recently gain the attention of the seismological community.  
30 As the other two projects, Earthquake Network has its own smartphone app which is used for earthquake  
31 detection. In its functioning, the Earthquake Network app is similar to the MyShake app, with the exception  
32 that it does not try to make any seismological analysis of the data recorded by the accelerometer and early  
33 warnings are issued when many smartphones from the same area detect accelerations above a threshold.

34 Earthquake Network, however, is more than just EEW and this paper comprehensively describes for the  
35 first time all the features of the Earthquake Network platform and of the Earthquake Network app.

## 2 HISTORY OF THE PROJECT

36 The Earthquake Network app was first published on the Android Market (now known as Google Play) on  
37 20 December 2012. At that time, the app was only available in Italian and it was designed to work with  
38 Android version 2.3.3. With an average of 50 installs per day, it took the network around 5 months to reach  
39 the critical mass for detection. The first detection took place in Italy on 8 May 2013 at 00:52:33 UTC.  
40 According to the EMSC catalog (ID 315886), a M3.6 earthquake occurred at 00:52:17 UTC with a depth  
41 of 8 km. The earthquake was detected by 4 smartphones located at 23 km from the epicentre and an alert  
42 was immediately sent to people with the app installed. This was the evidence that smartphones can actually  
43 detect earthquakes and this is when the Earthquake Network project officially started.

44 Since then, more than 5.5 million participants took part to the project, a number higher than the 5.2  
45 million participants of the famous SETI@home project (Anderson et al., 2002) searching for signs of  
46 extraterrestrial intelligence since 1999.

47 Table 1 shows the distribution by country of the 3130 alerts issued as of 26 May 2020. Note that the  
48 first and last alert dates are quite heterogeneous among countries. This is due, on the one hand, on the  
49 local seismicity varying with time, and on the other, on the app being installed by the population at  
50 different stages of the project life. Usually, people install the app after a strong earthquake hits their  
51 area, and the network of smartphones grows up to the point it is able to detect aftershocks and future  
52 earthquakes. Similarly, people may loose interest in the project and uninstall the app in periods of “seismic  
53 calm”, actually jeopardising future detections in the area. For instance, Nepal had enough users to detect 6  
54 earthquakes in real time in 2015 but it currently only has 150 users with the app installed and new detections  
55 are unlikely. The same problem affected Japan and Taiwan for which the two detections are related to  
56 aftershocks after large earthquakes. Mainly because the app is not translated into the local languages,  
57 however, the smartphone network did not last long.

## 3 SMARTPHONE APP

58 The Earthquake Network app is both the instrument to detect an earthquake and to receive the early warning.  
59 When the smartphone is charging and unused, the app starts monitoring the accelerometer for detecting  
60 vibrations possibly due to an earthquake. If something is detected, a signal is sent to a server that collects  
61 signals from all the smartphones. Thanks to a statistical algorithm, the server decides in real time if an  
62 earthquake is occurring. If this is the case, an alert is sent to the smartphone users around the epicentre,  
63 which may be received before the user experience the shaking.

64 Earthquake Network, therefore, provides an early warning service to users which are keen to make their  
65 smartphones available for detection when the smartphone is not used. On the other hand, the impact of the

Country	Alerts	First alert	Last alert	Participants
Chile	952	08 Jan 2014	25 May 2020	801k
Mexico	770	21 May 2014	24 May 2020	2200k
Puerto Rico	728	13 Aug 2014	22 May 2020	181k
Peru	186	03 Jun 2014	26 May 2020	437k
Ecuador	147	14 Aug 2014	16 May 2020	567k
U.S.	109	17 Mar 2014	10 May 2020	272k
Venezuela	55	23 Nov 2015	11 Mar 2020	40k
Italy	46	08 May 2013	11 May 2020	487k
Albania	33	22 Sep 2019	31 Jan 2020	20k
Croatia	20	22 Mar 2020	23 Apr 2020	12k
El Salvador	16	11 Apr 2017	09 Feb 2020	18k
Colombia	10	14 Oct 2015	31 Dec 2019	135k
Argentina	10	13 Nov 2015	07 Apr 2020	74k
Costa Rica	8	07 Aug 2014	17 Apr 2019	16k
Nicaragua	7	11 Apr 2014	24 Mar 2019	33k
Guatemala	6	22 Jun 2018	19 Apr 2020	30k
Nepal	6	12 May 2015	22 Jul 2015	27k
Indonesia	6	22 Aug 2018	15 Nov 2019	20k
North Macedonia	5	14 Sep 2016	13 Jul 2017	5k
Panama	5	14 Mar 2019	13 Mar 2020	20k
Dominican Rep.	3	03 Jun 2018	12 Nov 2018	30k
Taiwan	1	07 Aug 2019	07 Aug 2019	5k
Japan	1	04 May 2014	04 May 2014	7k

**Table 1.** Geographical and temporal distribution of the 3130 alerts sent by the Earthquake Network platform since 2013. The participants column gives the total number of participants (in thousands) by country since the start of the Earthquake Network project.

app on the user daily experience with her/his smartphone is practically zero, nor the app has any impact on battery consumption unless the user interacts with the app.

Figure 1 shows the warning message appearing on the smartphone when the alert is received. If the lead time is greater than zero, a count down and a simulation of the expected location of the P-phase front are displayed.

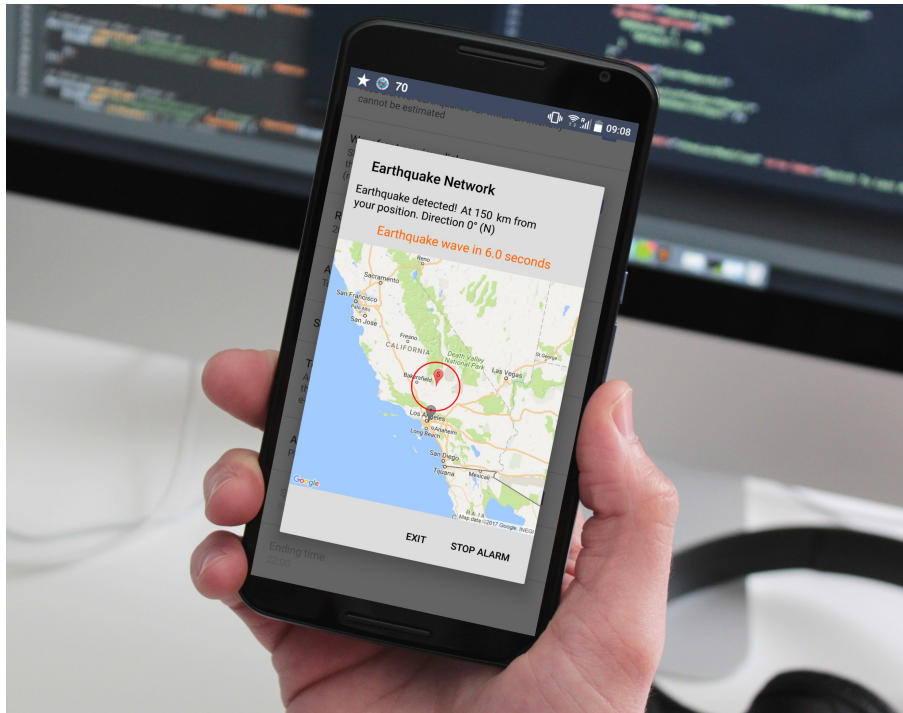
## 4 WARNING SYSTEM

The smartphone network sends signals to a server located in Europe for real time detection of earthquakes. The infrastructure is actually based on a total of 9 servers which cope with the large number of signals coming from the network and the large number of users opening the app when an earthquake strikes.

Any new signal received by the server infrastructure triggers a statistical algorithm that decides if an earthquake is happening. The analysis is thus in real time and at the global scale. This implies that multiple earthquakes occurring at different places of the world can all be detected at the same time and separate warnings are issued.

### 4.1 Statistical algorithm

On average, only one trigger out of a million is due to an earthquake and adopting a statistical algorithm is the only way to reduce and control the probability of false alarm. Although the algorithm is detailed in Finazzi and Fassò (2017), it is worth describing here the general idea behind its functioning.



**Figure 1.** Early warning message as received on smartphones with the Earthquake Network app installed.

82 The algorithm is based on statistical hypothesis testing which is a statistical inference method for choosing  
 83 between two hypothesis, one called null hypothesis and the other called alternative hypothesis. The null  
 84 hypothesis usually describes a favourable condition and, as long as it is true, no action is required. The  
 85 null hypothesis is thus supposed to be true unless there is enough evidence to reject it in favour of the  
 86 alternative hypothesis, and evidence is brought by the data.

87 In this context, the null hypothesis is that no earthquakes are undergoing while the alternative hypothesis  
 88 is that an earthquake is currently happening and an alert must be sent. Data used for accepting or rejecting  
 89 the null hypothesis are the triggers send by the smartphones and the number of active smartphones in a  
 90 given area.

91 The rule for rejecting the null hypothesis is defined by studying the statistical distribution of the smartph-  
 92 one triggers when no earthquakes are happening. Due to human interaction, smartphones send triggers  
 93 also when the ground is not actually shaking and the statistical distribution of the number of triggers has a  
 94 natural variability that mainly depends on the number of active smartphones. Defining the rejecting rule  
 95 essentially means to set a threshold on the number of triggers, above which an earthquake is claimed.  
 96 Currently, the minimum value for the threshold is 5, meaning that at least 6 smartphones must be active in  
 97 the area affected by the shaking and that all of them must send a trigger at around the same time. Below this  
 98 value, the smartphone network is not reliable. Also note that having 6 active smartphones does not imply  
 99 that, in case of an earthquake, 6 triggers will be received by the server. Smartphones are not seismometers  
 100 and, for a large number of reasons, they may not send the trigger even if affected by the shaking. This  
 101 implies that 6 is a critical mass for detection but also that it is not guaranteed that the detection will occur.

## 102 4.2 False alarms and missed detections

103 When the statistical algorithm is running, two kinds of errors can be made. An earthquake is detected but  
104 nothing is happening (false alarm) or the earthquake is happening but the null hypothesis is not rejected  
105 (missed detection). There is a trade-off between the probability of false alarm and the probability of missing  
106 a detection. Decreasing the former implies to increase the latter and vice-versa.

107 The choice made by Earthquake Network is to control the probability of false alarm and to fix it at the  
108 desired value. Currently, the algorithm is designed to have a nominal false alarm rate of one false alarm per  
109 year per country. In practice, this probability is often exceeded due to events which, for the smartphone  
110 network, are indistinguishable from an earthquake. These event include explosions, strong thunders, sonic  
111 boom and, more rarely, soccer fans celebrating a goal <sup>1</sup>.

112 The probability of missing an earthquake, instead, cannot be easily controlled. While the probability  
113 of false alarm is controlled by studying the behaviour of the network when no earthquakes are occurring  
114 (namely most of the time), the probability of missing an earthquake can only be studied by simulating  
115 the response of the smartphone network during that particular earthquake. The response of the network  
116 is affected by the spatial distribution of the shaking level, the number of active smartphones, the spatial  
117 distribution of the smartphones, the smartphone sensor sensitivity and many other factors which are specific  
118 to a given earthquake at a given time.

119 What is observed is that, when the earthquake epicentre is close to a town with enough smartphones with  
120 the app installed, the network is able to detect earthquakes down to magnitude 2. On the other hand, strong  
121 earthquakes with epicentre far from any town may not be detected, despite they are mildly felt in different  
122 towns. This behaviour of the network is currently under investigation.

123 Additionally, the probability of missing an earthquake is affected by the number of active smartphones at  
124 the time of the event. This probability reaches its minimum at around 3 AM when many smartphones are  
125 charging while it is maximum at around 2 PM. Nonetheless, this probability tends to zero when the number  
126 of active smartphones increases. When the minimum number of active smartphones, within a town and  
127 during the day, is above 500, the time of day does not matter anymore.

## 128 4.3 Alert distribution

129 When an earthquake is detected, the server infrastructure sends the alert to smartphones located in the  
130 expected affected area. This is done using the Firebase Cloud Messaging (FCM) messaging platform which  
131 allows to send notifications to a large number of smartphones in near real time. The current alert strategy of  
132 Earthquake Network is based on the distance between the preliminary epicentre and the smartphones, where  
133 the preliminary epicentre is simply the centre of gravity of the locations of smartphones that contributed to  
134 detect the earthquake.

135 Smartphones close to the epicentre are thus alerted first. This strategy is not necessarily optimal since  
136 smartphones very close to the epicentre cannot be alerted before the shaking and priority should go on  
137 smartphones with a lead time greater than zero. Nonetheless, the actual epicentre may be far from the  
138 preliminary estimate and the distance-based criterion is the “safest” option under this uncertainty condition.

139 By default, smartphones receive the alert if located within 300 km from the epicentre but users can  
140 change this setting at any time from the app configuration page.

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<sup>1</sup> <https://www.foxnews.com/tech/soccer-fans-in-peru-celebrate-crucial-goal-trigger-earthquake-alert-app>

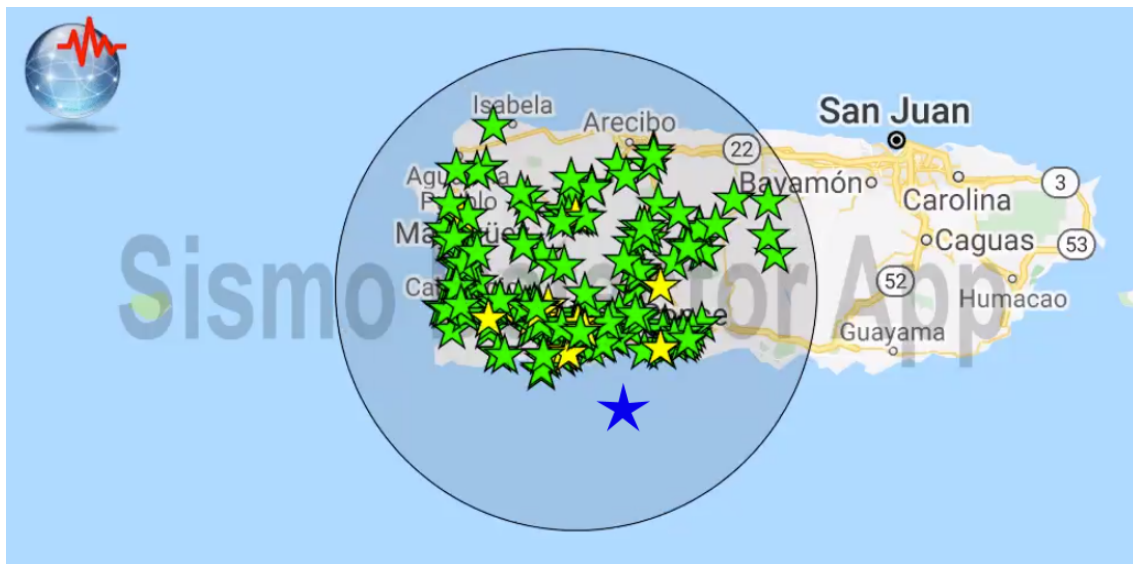


## 5 USER FELT REPORTS

141 By simply pushing a button in the app interface, users can report the impact of an earthquake they just felt.  
 142 Spatial coordinates of the smartphone are automatically sent with the felt report. Contrary to a questionnaire,  
 143 the app is designed in such a way that the report is sent as fast as possible to the server and the app interface  
 144 (see Figure 3) only allows for 3 levels of impact: mild (only perceived), strong (fall of objects) and very  
 145 strong (building collapse).

146 If many reports are received from the same area at around the same time, a notification is sent to the  
 147 smartphone users using FCM. In general, users first receive the early warning alert triggered by smartphones  
 148 and within one minute they receive the notification triggered by users. By clicking on the notification, the  
 149 user is redirected to a map showing all felt reports. As an example, Figure 2 depicts the reports collected  
 150 in Puerto Rico within 60 seconds after a 3.6 magnitude earthquake. Before any official information was  
 151 released, app users were aware that the impact of the earthquake was negligible. In general, this kind of  
 152 information may be useful for civil protection agencies and first responders in order to identify areas where  
 153 the earthquake had the highest impact on people and things.

154 Additionally, reports collected in the first few seconds/minutes after the earthquake are useful for  
 155 providing preliminary estimates of earthquake parameters such as magnitude and depth. Finazzi (2020)  
 156 shows how a space-time statistical model is trained to provide estimates of the above parameters, uncertainty  
 157 included, and to update those estimates while new felt report are collected by the server. The statistical  
 158 model accounts for an information content of the felt reports which increases with time and for the  
 159 heterogeneity in the people's response across the globe. It is usually the case that people living in low  
 160 seismicity countries tend to report a strong earthquake despite it is small in magnitude and despite the  
 161 actual impact is not the one selected through the app user interface.



**Figure 2.** Felt reports sent by users of the Earthquake Network app after a 3.6 magnitude earthquake in Puerto Rico on 26 January 2020, 01:59:26 UTC (EMSC catalog ID 823242) within 60 seconds from origin time. Blue star is the earthquake epicentre. Green (mild) and yellow (strong) stars are felt reports localised using smartphone spatial coordinates.

## 6 SOCIAL NETWORK

Earthquake Network is also the first social network about earthquakes. With chatrooms in 10 languages, users can share information soon after an earthquake, either in the public space or with private messages. In the public space, order is maintained by chat moderators whose role is to keep the discussion focused on important matters and to block users who behave against the rules. Although secondary with respect to the mission of Earthquake Network, chatrooms actually help people during what can be a shocking experience and, according to their comments, having someone to discuss with is useful to reduce anxiety and the fear of new earthquakes. Moreover, users who join the chatrooms are those who keep the app installed for longer periods, from months to years. User retention is a common problem of citizen science projects and encouraging interaction with the app and other users may increase the user lifetime value.

Earthquake Network is also on popular social networks such as Facebook<sup>2</sup>, with nearly 90k people engaged, and Twitter<sup>3</sup>, with around 82k followers. When an early warning is issued or users report an earthquake, information are published in real time on Facebook and Twitter in order to reach people without the app installed and who will likely join the project.

## 7 SEARCH AND RESCUE AID

When a strong earthquake hit and causes extensive damage, smartphone technology can be helpful in search and rescue operations allowing missing people to be localised. Earthquake Network is currently testing two strategies for helping localise missing people, one based on statistical modelling of people location and one based on the smartphone geolocation capabilities. Both strategies assume that people and smartphone are located in the same place, which is usually the case.

### 7.1 Statistical model of people location

The Earthquake Network app periodically sends the smartphone location to the server. This information is exploited, on the one hand, for earthquake detection, and on the other, to first alert people close to the epicentre when an earthquake is detected.

Considering all the locations sent by a smartphone during an extended period, a statistical model (Finazzi and Paci, 2019) can be trained to learn the spatio-temporal pattern of the user location along a typical week. Indeed, people tend to exhibit cyclical patterns and to be in the same place at a given time of a given day of the week. If a person is missing after a strong earthquake, the statistical model can provide the expected location(s), uncertainty included, at the time of the earthquake.

### 7.2 Real time geolocation

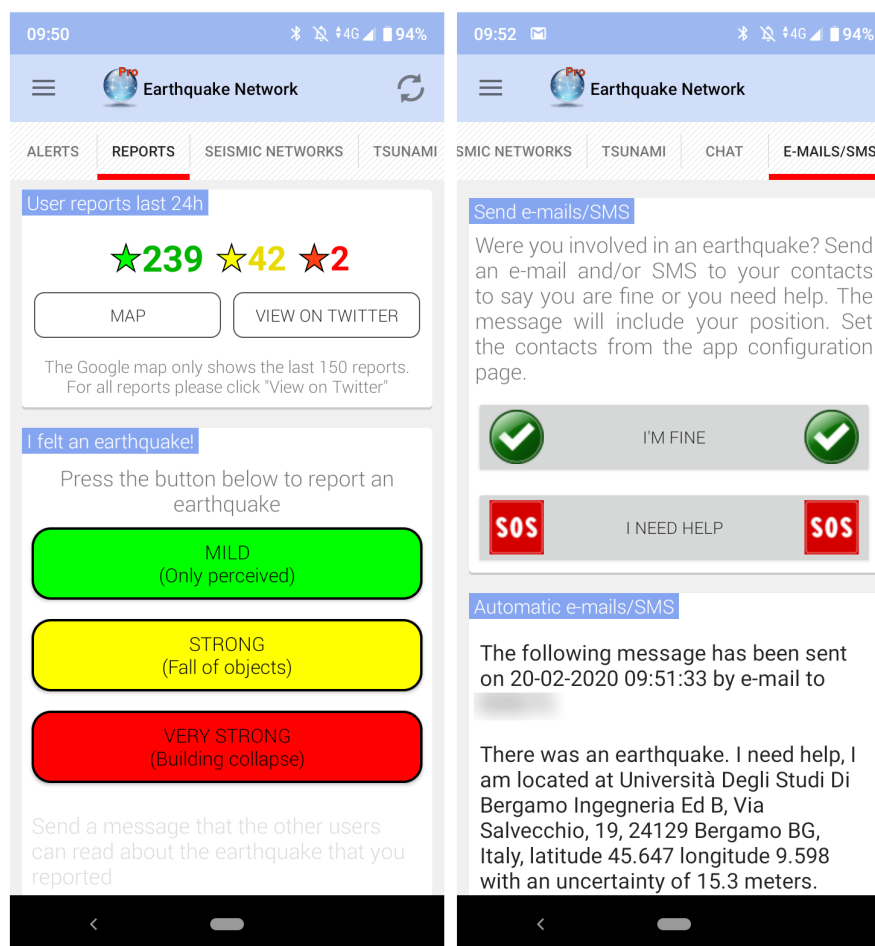
The second strategy implemented by the Earthquake Network app is to send the smartphone coordinates by e-mail or SMS to a list of trusted contacts when an alert is received. The idea is that, even in the case of catastrophic earthquakes, the alert is received before the shaking starts and the e-mail/SMS is sent before Internet and/or the phone network are compromised. This solution is more appealing since the uncertainty on the user location is usually much lower if compared with the previous strategy. However, it requires the smartphone to be on at the time of the earthquake.

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<sup>2</sup> <https://www.facebook.com/earthquakenetwork>

<sup>3</sup> <https://twitter.com/SismoDetector>

196 After the e-mail/SMS is sent, users can update their status by sending a “I’m fine” or “I need help”  
 197 message to the same contacts. This is done by simply pressing a button in the user interface of the app.  
 198 The right panel of Figure 3 shows the user interface for sending messages to contacts and an example of  
 199 message which is sent by pressing the “I need help” button. Users can opt-in and opt-out this service at any  
 200 time from the app configuration page, where e-mail addresses and phone numbers of the trusted contacts  
 201 are also set.



**Figure 3.** User interface of the Earthquake Network app for sending felt reports (left) and for asking help if involved in an earthquake (right).

## 8 IMPLEMENTATION AND OPERATIONAL COSTS

202 Assessing the implementation costs of an EEW system developed over more than seven years is not an  
 203 easy task. Nonetheless, the magnitude of some costs can be provided.

204 Assuming to know all system specifications, developing an app similar to Earthquake Network (for  
 205 Android and iOS) costs around 40 thousand Euros. Implementing the server architecture (hosted by an  
 206 Internet provider) for the real time detection and able to handle up to one million active users costs around  
 207 50 thousand Euros. Operational costs, on the other hand, are relatively small. Assuming that the system  
 208 is stable and does not need major updates, average operational costs are around 250 Euros/month and no



human intervention is needed. Currently, these costs are covered by in-app advertising, meaning that the Earthquake Network project is self-sustainable.

Finally, scaling the EEW system requires around 2 thousand Euros per million active users. However, smartphone technology may not be the most efficient option for distributing a real time alert to a very large number of people and this cost is meaningful only up to 10 million users globally.

## 9 USER PRIVACY

Collecting and handling user locations opens some privacy issues. Despite this information is collected anonymously, the user must have a way to delete all personal data (chat messages included) stored on the server. Earthquake Network is compliant with the General Data Protection Regulation on data protection and privacy in the European Union and the European Economic Area. This means that Earthquake Network has a data protection officer who is responsible for handling and deleting personal data upon user request.

## 10 OPEN PROBLEMS AND CONCLUSIONS

Earthquake Network is widely appreciated in many seismic countries where EEW systems are not available or not yet operational. Despite it releases very preliminary information, it helps to rapidly fulfill the need for information arising among the population soon after an earthquake.

Current main limit of the EEW system implemented by Earthquake Network is that the warning is sent without an accurate information of the earthquake intensity. This means that warnings may also be triggered by mild earthquakes that do not require a warning to be sent. As a consequence, some users may receive the warning but not experiencing any shaking. Although the smartphone is measuring an acceleration, the smartphone acceleration is not easily related to the ground acceleration. Indeed, the smartphone is an object with a relatively small mass that is free to move. Especially during a strong earthquake, the recorded acceleration may be much higher than the ground acceleration. Also, in general, the recorded acceleration may depend on unknown factors such as the object above which the smartphone is located, the floor within the building and so on.

Another intrinsic limit of Earthquake Network is that smartphones are located where people are and the geometry of the network is not necessarily optimised with respect to the known faults. Therefore, it may be useful to integrate the smartphone network data with measurements coming from seismometers.

Thanks to TURNkey<sup>4</sup> and RISE<sup>5</sup> projects financed by the Horizon 2020 programme of the European Commission, Earthquake Network will see improvements both on the real time detection side and on the real time integration of data coming from classing seismic networks. In particular, a statistical approach will be adopted to explore acceleration-free methods for estimating and updating the earthquake intensity/magnitude in near real time, completing the information provided to the population through the Earthquake Network app and through social networks.

## CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

<sup>4</sup> <https://earthquake-turnkey.eu>

<sup>5</sup> <http://rise-eu.org>

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