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GuardAnAngel

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Επιβλέπουσα: Μέμα Ρουσσοπούλου, Καθηγήτρια

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GuardAnAngel
An application for kidnapping prevention

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ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

GuardAnAngel
Μία εφαρμογή για την αποτροπή απαγωγών (παιδιών)

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ABSTRACT

The abduction of a child can destroy lots of lives, in many ways. Ideally, the ultimate goal of this work is the prevention of such malicious actions. From a software engineering perspective, the main aim of this thesis is to prove the feasibility of a service that notifies the people in a specific area about a missing child incident. An additional aim was the realization of geospatial queries on relational databases, a design feature that allows much smaller operational costs for such a service than the mainstream approaches.

The proof of concept was achieved through the development of an android application and the corresponding web services, which can be hosted in various cloud providers. Several experiments of different scenarios were conducted for the verification of the results. Moreover, a comparison on geospatial queries' execution between a relational database and a non-relational database took place, which showed that the relational database had better performance for a large number of records. Overall, the whole implementation reaches the desired outcome. Yet, whether and how this service, which is named GuardAnAngel, will have an impact in the real world is a broader discussion topic that needs further research.

SUBJECT AREA: Distributed Systems

KEYWORDS: kidnapping prevention, cloud, microservices, scalability, geospatial search, geolocation, geopositioning, smartphone application (Android)

ΠΕΡΙΛΗΨΗ

Η απαγωγή ενός παιδιού μπορεί να καταστρέψει πολλές ζωές, με πολλούς τρόπους. Ιδανικά, ο υπέρτατος στόχος και απώτερος σκοπός αυτής της δουλειάς είναι η αποτροπή τέτοιων κακόβουλων ενεργειών. Υπό το πρίσμα της πληροφορικής, ο κύριος στόχος αυτής της διπλωματικής εργασίας είναι να αποδείξει ότι είναι εφικτή η υλοποίηση μίας υπηρεσίας, η οποία ενημερώνει τον κόσμο σε μία συγκεκριμένη περιοχή για κάποιο περιστατικό εξαφάνισης παιδιού. Ένα ακόμα ζητούμενο είναι η πραγματοποίηση γεωγραφικών ερωτημάτων πάνω σε μια σχεσιακή βάση δεδομένων, ένα χαρακτηριστικό που καταλήγει σε πολύ μικρότερα λειτουργικά κόστη για μία τέτοια υπηρεσία.

Η δυνατότητα υλοποίησης αυτής της ιδέας αποδείχτηκε μέσω της ανάπτυξης μίας εφαρμογής για κινητά Android και των αντίστοιχων υπηρεσιών στο διαδίκτυο, οι οποίες μπορούν να φιλοξενηθούν σε διάφορους παρόχους cloud. Αρκετά πειράματα διαφορετικών σεναρίων διενεργήθηκαν για την επαλήθευση των αποτελεσμάτων. Επιπλέον, έλαβε χώρα μία σύγκριση πάνω στην εκτέλεση γεωγραφικών αναζητήσεων μεταξύ δυο βάσεων δεδομένων, μίας σχεσιακής και μίας μη σχεσιακής. Η σύγκριση αυτή παρουσίασε ότι η σχεσιακή είχε αισθητά καλύτερη απόδοση για μεγάλο αριθμό εγγράφων. Συνολικά, η υλοποίηση της εργασίας έχει επιτύχει το επιθυμητό αποτέλεσμα. Ωστόσο, αν μία τέτοια υπηρεσία, η οποία ονομάζεται GuardAnAngel, θα είναι αποδοτική έχοντας επίδραση στον πραγματικό κόσμο είναι ένα μεγαλύτερο θέμα συζήτησης που χρειάζεται περαιτέρω έρευνα.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: Κατανεμημένα Συστήματα

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: παρεμπόδιση απαγωγής, υπηρεσίες cloud, επεκτασιμότητα, γεωγραφική αναζήτηση, γεωτοποθέτηση, ανάπτυξη εφαρμογών

Στο φυλακα αγγελο μου

To my guardian angel

*“κάλλιον το προλαμβάνειν, παρά το θεραπεύειν”
Ιπποκράτης*

*“Prevention is better than cure”
Hippocrates*

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Finally, I reached my Ithaca! Some years ago, I took a decision and started an adventure that was questioned by many people, as the price was high. A 30-year-old software engineer with a demanding job and lots of responsibilities to start an HMMY postgraduate programme did not sound as a wise choice to people's ears. To people that care about me. On top of that, I wanted to complete it in my way, Fast and Furious, by taking almost all courses in one year. Ma neck, ma back ... were not very happy with that approach. The journey was hard but amazing. The journey matters the most based on Kavafis. The destination matters too though. After I reached it, I can say with certainty that the value of this journey was much higher than the price!

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Τελικά, έφτασα στην Ιθάκη μου! Πριν από μερικά χρόνια πήρα μια απόφαση και ξεκίνησα μια περιπέτεια που αμφισβητήθηκε από πολλούς ανθρώπους, καθώς το τίμημα ήταν υψηλό. Ένας 30χρονος μηχανικός λογισμικού με απαιτητική δουλειά και πολλές ευθύνες να ξεκινήσει ένα μεταπτυχιακό πρόγραμμα ΗΜΜΥ δεν ακούστηκε ως σοφή επιλογή στα αυτιά πολλών ανθρώπων. Κοντινών ανθρώπων που νοιάζονται για μένα. Επιπλέον, ήθελα να το ολοκληρώσω με τον δικό μου τρόπο, Fast and Furious, παρακολουθώντας σχεδόν όλα τα μαθήματα σε ένα χρόνο. Ο λαιμός και η πλάτη μου δεν χάρηκαν ιδιαίτερα με αυτήν την προσέγγιση. Ακόμα παραπονιούνται. Το ταξίδι ήταν δύσκολο αλλά καταπληκτικό. Το ταξίδι έχει τη μεγαλύτερη σημασία, σύμφωνα με τον Καβάφη. Ο προορισμός έχει επίσης σημασία όμως. Αφού τον έφτασα, μπορώ να πω με βεβαιότητα ότι η αξία αυτής της διαδρομής ήταν πολύ υψηλότερη από την τιμή!

Ως αναβαθμισμένη έκδοση του εαυτού μου, επίσημα πλέον, θα ήθελα να ευχαριστήσω όλους τους ανθρώπους που με συνόδευσαν σε αυτό το ταξίδι. Συγγενείς, φίλοι, σύντροφοι, συνάδελφοι, εργοδότες ... ήταν πολλοί και δεν μπορώ να τους κατονομάσω όλους. Μπορώ όμως να τους ευχαριστήσω όλους και να αναφέρω μερικούς.

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Σχετικά με τον Fast and Furious τρόπο παρακολούθησης, βρήκα ένα συμφοιτητή με παρόμοια νοοτροπία και μεγάλη ιπποδύναμη να τρέξει μαζί μου, τον Ευάγγελο Καραγεώργο. Πήραμε σχεδόν όλα τα μαθήματα και τις εργασίες μαζί. Θα ήθελα να ευχαριστήσω τον Βαγγέλη για τον χρόνο που περάσαμε μαζί, τις υπέροχες και παραγωγικές στιγμές, καθώς και τις γνώσεις που απέκτησα μαζί του.

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PREFACE

The present report is the outcome of my thesis for the Postgraduate Programme of Department of Informatics and Telecommunications of National and Kapodistrian University, Athens. As a subject, this thesis is mostly related to the fields of distributed systems and cloud computing.

The motivation and inspiration behind this work is a story I had heard as a child. According to this story, a little girl had been abducted from the playground and her parents were looking for her in collaboration with the police. A week later, the bell rang at the family's house, the mother opened it and found the little girl standing without eyes outside the door. True story or not, it affected me a lot.

More than 20 years later, I incidentally watched a TV show about investigating missing people cases. I recalled the story of that little girl, as well as several others with children or teenagers who disappeared, were abused or tortured horribly and irreparably, such as Myrto Papadomichelaki.

These thoughts did not let me sleep that night. If I could change all that, if I had a magic stick, I would do it right away. I am not able to change what is already done, but I can change the future. So, I began to consider how we could prevent such actions in the future with current technologies.

Having these thoughts in mind, I asked Professor Mema Roussopoulos if we could develop this application in the context of a thesis. Mrs. Roussopoulou is a professor with a lot of knowledge in the field of distributed systems. Apart from her academic background, she also has a unique personality, with the sensitivity of a good mom and the enthusiasm of a young and open-minded researcher. Although it was not a typical thesis, her response was positive and she became my tutor. The rest is history.

At the end of the day, the outcome and the impact of this proposal depends heavily on the high adoption of users, so that a sufficient number of message recipients exist in a given area.

ΠΡΟΛΟΓΟΣ

Η παρούσα αναφορά αποτελεί την καταγραφή της μελέτης που έγινε στα πλαίσια της διπλωματικής εργασίας για το μεταπτυχιακό πρόγραμμα του τμήματος Πληροφορικής και Τηλεπικοινωνιών του Εθνικού Καποδιστριακού Πανεπιστημίου Αθηνών. Η διπλωματική αυτή σχετίζεται κυρίως με τα πεδία των καταναμημενων συστημάτων και του cloud computing.

Το κίνητρο και η έμπνευση πίσω από αυτή την εργασία είναι μια ιστορία που είχα ακούσει μικρός. Σύμφωνα με αυτήν, κάποιος είχε απαγάγει ένα κοριτσάκι από την παιδική χαρά, το οποίο οι γονείς έψαχναν για μέρες μαζί με την αστυνομία. Μία εβδομάδα αργότερα, χτύπησε το κουδούνι στο σπίτι της οικογένειας, η μητέρα άνοιξε και βρήκε το κοριτσάκι να στέκεται χωρίς μάτια έξω από την πόρτα. Αληθινή ιστορία ή όχι, εμένα με επηρέασε πάρα πολύ.

Περισσότερα από 20 χρόνια αργότερα, γυρίζοντας από τη δουλειά μια μέρα, έτυχε να δω μια εκπομπή στην τηλεόραση, η οποία σχετίζεται με την ανευρεση εξαφανισμένων ανθρώπων. Θυμήθηκα αυτή την ιστορία, καθώς και αρκετές ακόμα με παιδάκια Η εφηβους που εξαφανίστηκαν, κακοποιήθηκαν Η βασανίστηκαν με φρικτό τρόπο και ανεπανόρθωτες συνέπειες, όπως η Μυρτω Παπαδομιχελακη.

Αυτές οι σκεψεις δεν με άφησαν να κοιμηθώ εκείνο το βραδυ. Αν μπορούσα να τα αλλάξω όλα αυτά, θα το έκανα άμεσα. Μπορεί να μην μπορώ να αλλάξω την ιστορία, αλλά μπορώ να αλλάξω το μέλλον. Για αυτό το λόγο, άρχισα να σκέφτομαι τι θα μπορούσαμε να κάνουμε για να αποτρέψουμε στο μέλλον τέτοιες ενέργειες με τις τωρινές τεχνολογιες.

Κάπως έτσι, πρότεινα στην καθηγήτρια Μεμα Ρουσοπούλου να αναπτύξουμε αυτή την εφαρμογή στα πλαίσια της διπλωματικής εργασίας. Η κυρία Ρουσοπουλου είναι μια καθηγήτρια με πολλές γνώσεις στον τομέα των καταναμημενων συστημάτων. Πέρα από το ακαδημαϊκό της υπόβαθρο όμως, έχει και μια ιδιαίτερη προσωπικότητα, με βασικά χαρακτηριστικά την ευαισθησία μιας καλής μαμάς και τον ενθουσιασμό νεας και ανοιχτόμυαλης ερευνητριας. Εκ των υστέρων, συνειδητοποιώ ότι μπορεί να υπήρχε και μια έμμεση επίκληση στο συναίσθημα. Παρότι λοιπόν δεν ήταν η τυπική διπλωματική, η απάντηση της ήταν θετική και έτσι έγινε η επιβλέπουσα μου. Τα υπόλοιπα είναι ιστορία.

Στο τέλος της μέρας, το αποτελεσμα αυτής της πρότασης εξαρτάται σε μεγάλο βαθμό από την ευρεία αποδοχή των χρηστών, ώστε να υπάρχει η απαραίτητη συγκέντρωση παραληπτών του μηνύματος σε μία συγκεκριμένη περιοχή.

1. INTRODUCTION

1.1 Overview

In this thesis, a mobile application was implemented that prevents children's kidnapping, by informing people about a missing child incident in a precise manner. Most abductions occur in crowded places, like commercial centers, festivals or playgrounds. As soon as a child's parent, or its guardian, notices that the child is missing, he will be able to notify other people in that area, saving valuable time at a critical point for its finding.

As an example, imagine a mother sitting in a restaurant of a commercial center, with her daughter playing around. Moments later, the mother realizes that she has lost sight of her daughter. She looks around without being able to find her. She uses her application to report that her daughter disappeared in that location. At the beginning, all the people in the range of five hundred meters are informed about the incident. Their mobile devices receive a message that contains a photo and details about the girl, like name and height. After ten minutes, if the girl has not been found, the people in a broader area are informed, one kilometer away from the spot that the event took place. Twenty minutes later, the notification distance increases to two kilometers.

Hence, if someone has grabbed the child, he cannot easily leave the building unnoticed. The security control at the exits will be watchful, while many eyes of vigilant bystanders will be looking for the child. If there is no malicious action, the child will probably be found effortlessly and return to its mother safe. In both cases, the success rate of finding the child unharmed grows substantially.

Briefly, this notification service, named GuardAnAngel, aspires to inform people in surroundings immediately by avoiding bureaucracy and taking advantage of high smartphone penetration in various countries and cities. This instant action could be crucial for the recovery of the child safely. Regarding the false alarms and alert misuse, various rules could be applied to discourage a person from using this service without real reason, like being banned from the application or facing legal charges. The plan to avoid alert misuse is not in the scope of this thesis.

1.2 Scope

The objective of this thesis consists of two parts. First and foremost, our primary target is to prove the feasibility of a location-based notification service as a standalone. Additionally, the second part is the design of a low-cost architecture, by taking into consideration the main cloud service providers' schemas.

Regarding the main functionality, i.e., a user to be able to notify other people in a specific area, the service needs to know the location of these people, without them necessarily using the application at that moment. Moreover, for these people to be informed, server-to-client messaging must take place, which is contrary to the traditional client-to-server request-response communication that is initiated by the client. Given that direct access to smartphone applications is not allowed, for security reasons, many questions are probably raised. For example, how could the location of the people in a specific area become known to the service? How could they be informed about the missing child event, which took place near them? These questions will be answered in the Methods chapter.

Due to this service's nature, which is intended for non-profit society contribution, some extra criteria were added in its design, like minimizing the operational costs. A step of the whole process is the geographical queries. There are various databases, or data structure stores, realizing geospatial queries, such as MongoDB and Redis. However, the most popular cloud service providers have significantly higher charges for those add-ons, in comparison to the basic schemas with relational databases. Under most circumstances, the basic schemas are offered gratis. Therefore, a solution over relational database schema was conceived and implemented, equipping us with an equivalent alternative to the mainstream approach, in terms of performance and throughput. By applying Microservices Architecture principles, the geospatial queries' functionality was built as a separate service, the geosearch service, which allows us to scale out over several servers, or even several providers. Geosearch service could be characterized as provider agnostic, with all the advantages that such an attribute brings, such as more servers in the free tier.

1.3 Outline

Introduction

The main goal of this thesis is to minimize the number of missing children. Children are considered missing either because of kidnapping or for other reasons. In the first chapter, we briefly describe the implemented application and its importance, based on its potential impact and the existing gap in this field. The application was designed by taking into consideration three factors: the social or human side, the feasibility of the service and its low-cost maintainability. Although partially interconnected, the first factor is business-oriented, while the last two are interesting from a software engineering perspective. These three different aspects, with their challenges and their solutions, are examined and analyzed in the remaining chapters.

Background

In this chapter, we examine the problem and how it is handled right now. The strong points and the limitations of transferring such information via an established authority, like Amber Alert, are presented and are compared to our approach, especially for such a time-critical issue. Moreover, we quote some facts regarding the cloud market and explain some of our engineering decisions.

Methods

Due to the overall approach of the idea as a service, we faced various challenges in different aspects of our implementation. These problems and our decisions to overcome them are described in this chapter. Apart from the engineering puzzles, we managed to realize geographical queries in a traditional relational database, which is the main research topic in the results section.

Results

Various successful experiments were realized both in real and in simulation environments. The experimental results support our initial assertions and the final product acts as proof of concept. Additionally, we show that it is possible to use a relational database for geospatial queries. Not only can a relational database be used for geospatial queries, but it also performs better than schemaless databases with such features.

Conclusions

At the end of the day, the most important thing is that our research, design, and implementation prove the feasibility of such a service. However, the application can

have an impact only if it is uploaded on the mobile app stores. The desired level of functionality has not been reached yet and the application cannot be uploaded. Further work needs to be done in various fields. Possible extensions and improvement recommendations are discussed so that this service could be used in the real world and in a broad range. Integration with some organizations' services, like telecommunication providers and perhaps some social networks, would significantly increase the number of recipients and consequently the effectiveness of an alarm. Both social and engineering skills are required to cover the lack in these areas, which is out of this thesis's scope.

2. BACKGROUND

2.1 General Information

The national organizations against crime, like the FBI, keep records based on the reports of missing children. Based on NISMART [7], missing children are considered the children whose caretakers did not know their whereabouts and were alarmed for at least an hour while trying to locate them. Missing children are divided into two main categories. Those that have been lost and those that have been kidnapped. Unfortunately, since many children are never reported missing, there is no reliable way to determine the total number of children who are actually missing.

On the other hand, if a child runs away multiple times in a year, each instance would be entered separately and counted in the yearly total. Nearly 90% of missing children have simply misunderstood directions or miscommunicated their plans, are lost or have run away. The rest have been kidnapped. 9% are kidnapped by a family member in a custody dispute. 3% are abducted by non-family members, usually during the commission of a crime such as a robbery or sexual assault. The kidnapper is often someone the child knows. [6] Only about a fraction of 1% of children are kidnapped each year in the stereotypical stranger abductions you hear about in the news. About half of these children come home.

Based on the identity of the perpetrator, there are three distinct types of kidnapping: kidnapping by a relative of the victim or "family kidnapping" (49 percent), kidnapping by an acquaintance of the victim or "acquaintance kidnapping" (27 percent), and kidnapping by a stranger to the victim or "stranger kidnapping" (24 percent). Family kidnapping is committed primarily by parents, involves a larger percentage of female perpetrators (43 percent) than other types of kidnapping offenses, occurs more frequently to children under 6, equally victimizes juveniles of both sexes, and most often originates in the home. Acquaintance kidnapping involves a comparatively high percentage of juvenile perpetrators, has the largest percentage of female and teenage victims, is more often associated with other crimes (especially sexual and physical assault), occurs at homes and residences, and has the highest percentage of injured victims. Stranger kidnapping victimizes more females than males, occurs primarily at outdoor locations, victimizes both teenagers and school-age children, is associated with sexual assaults in the case of girl victims and robberies in the case of boy victims (although not exclusively so), and is the type of kidnapping most likely to involve the use of a firearm.

Only about one child out of each 10,000 missing children reported to the local police is not found alive. However, about 20 percent of the children reported to the National Center for Missing and Exploited Children in nonfamily abductions are not found alive.[3] In 80 percent of abductions by strangers, the first contact between the child and the abductor occurs within a quarter-mile of the child's home. Most potential abductors grab their victims on the street or try to lure them into their vehicles. About 74 percent of the victims of nonfamily child abduction are girls. Acting quickly is critical. Seventy-four percent of abducted children who are ultimately murdered are dead within three hours of the abduction. One in five children 10 to 17 years old receives unwanted sexual solicitations online.

In United States of America, every 40 seconds a child becomes missing or is abducted. In a 1998 study of parents' worries by pediatricians at the Mayo Clinic in Rochester, Minnesota, nearly three-quarters of parents said they feared their children might be abducted. One-third of parents said this was a frequent worry -- a degree of fear greater than that held for any other concern, including car accidents, sports injuries, or drug addiction.

2.2 Global Statistics

The lack of a common definition of "missing child," and a common response to the issue, results in few reliable statistics on the scope of the problem around the world.

Even with this challenge, we know that:

- In Australia, an estimated 20,000 children are reported missing every year. Australian Federal Police, National Coordination Centre.
- In Canada, an estimated 45,288 children are reported missing each year. Government of Canada, Canada's Missing – 2015 Fast Fact Sheet.
- In Germany, an estimated 100,000 children are reported missing each year. Initiative Vermisste Kinder.
- In India, an estimated 96,000 children go missing each year. Bachpan Bachao Andolan, Missing Children of India.
- In Jamaica, an estimated 1,984 children were reporting missing in 2015. Jamaica's Office of Children's Registry
- In Russia, an estimated 45,000 children were reported missing in 2015. Interview with Pavel Astakhov MIA "Russia Today", Apr. 4, 2016.

- In Spain, an estimated 20,000 children are reported missing every year. Spain Joins EU Hotline for Missing Children, Sep. 22, 2010.
- In the United Kingdom, an estimated 112,853 children are reported missing every year. National Crime Agency, UK Missing Persons Bureau.
- In the United States, an estimated 460,000 children are reported missing every year. Federal Bureau of Investigation, NCIC.

This, however, is only a snapshot of the problem. In many countries, statistics on missing children are not even available; and, unfortunately, even available statistics may be inaccurate due to: under-reporting/under-recognition; inflation; incorrect database entry of case information; and deletion of records once a case is closed.[5]

2.3 Notable Incidents

2.3.1 Adam Walsh

July 27, 1981 - 6-year-old Adam Walsh is abducted from a mall near his home in Hollywood, Florida. His mother had let him look in the toy department at Sears while she looked for a lamp. When she returned, Adam was missing. Two weeks after Adam disappeared, his severed head is discovered in a canal 120 miles away from the mall. The rest of his body is never recovered. His father, John Walsh, becomes an advocate for missing children, lobbying for legislation and nationwide alert systems, and hosting the television program, "America's Most Wanted."

2.3.2 Amber Hagerman

January 13, 1996 - 9-year-old Amber Hagerman is abducted as she rides her bike in a parking lot near the home of her grandparents in Arlington, Texas. January 17, 1996 - Hagerman's body is found near a creek about eight miles from where she was abducted. Her killer is never found and the case remains unsolved. Her abduction and murder led to the creation of the AMBER Alert system.

2.3.3 Shawn Hornbeck

October 2002 - 11-year-old Shawn Hornbeck is kidnapped while riding his bicycle to a friend's house near his home in Richwoods, Missouri.

January 2007 - The police find Hornbeck and another missing boy, 13-year-old Ben Ownby, who had been held for four days, in the Kirkwood, Missouri, apartment of Michael J. Devlin.

December 21, 2007 - Devlin receives 74 life sentences.

2.3.4 Madeleine McCann

May 3, 2007 - 4-year-old Madeleine Beth McCann disappeared in the evening from her bed in a holiday apartment at a resort in Praia da Luz, in the Algarve region of Portugal. The Daily Telegraph described the disappearance as "the most heavily reported missing-person case in modern history". Her whereabouts remain unknown, and German prosecutors in 2020 have stated that they assume that she is dead.

2.4 Child Abduction Alert Systems

2.4.1 Amber Alert

An amber alert (also AMBER alert) or a child abduction emergency alert is a message distributed by a child abduction alert system to ask the public for help in finding abducted children. [8] It originated in the United States in 1996. AMBER is a backronym for America's Missing: Broadcast Emergency Response. The alert was named after Amber Hagerman, a 9-year-old girl abducted and murdered in Arlington, Texas in 1996.

In the United States, amber alerts are distributed via commercial and public radio stations, Internet radio, satellite radio, television stations, text messages, and cable TV by the Emergency Alert System and NOAA Weather Radio. The alerts are also issued via e-mail, electronic traffic-condition signs, commercial electronic billboards, or through wireless device SMS text messages. AMBER Alert has also teamed up with Google, Bing, and Facebook to relay information regarding an AMBER Alert to an ever-growing demographic: AMBER Alerts are automatically displayed if citizens search or use map features on Google or Bing. With the Google Child Alert (also called Google AMBER Alert in some countries), citizens see an AMBER Alert if they search for related information in a particular location where a child has recently been abducted and an alert was issued. This is a component of the AMBER Alert system that is already active in the US (there are also developments in Europe). Those interested in subscribing to receive AMBER Alerts in their area via SMS messages can visit Wireless Amber Alerts, which are offered by law as free messages. In some states, the display scrollboards in front of lottery terminals are also used.

The decision to declare an AMBER Alert is made by each police organization that investigates each of the abductions, in many cases, the state police or highway patrol. Public information in an AMBER Alert usually consists of the name and description of

the abductee, a description of the suspected abductor, and a description and license plate number of the abductor's vehicle if available.

Activation Criteria

The alerts are broadcast using the Emergency Alert System, which had previously been used primarily for weather bulletins, civil emergencies, or national emergencies. In Canada, alerts are broadcast via Alert Ready, a Canadian emergency warning system. Alerts usually contain a description of the child and of the likely abductor. To avoid both false alarms and having alerts ignored as a "wolf cry", the criteria for issuing an alert are rather strict. Each state's or province's AMBER alert plan sets its own criteria for activation, meaning that there are differences between alerting agencies as to which incidents are considered to justify the use of the system. However, the U.S. Department of Justice issues the following "-", which most states are said to "adhere closely to" (in the U.S.):

1. Law enforcement must confirm that an abduction has taken place.
2. The child must be at risk of serious injury or death.
3. There must be sufficient descriptive information of the child, captor, or captor's vehicle to issue an alert.
4. The child must be under 17 years of age

Many law enforcement agencies have not used #2 as a criterion, resulting in many parental abductions triggering an Amber Alert, where the child is not known or assumed to be at risk of serious injury or death. In 2013, West Virginia passed Skylar's Law to eliminate #1 as a criterion for triggering an Amber Alert. It is recommended that AMBER Alert data immediately be entered into the Federal Bureau of Investigation (FBI) National Crime Information Center. Text information describing the circumstances surrounding the abduction of the child should be entered, and the case flagged as child abduction. The Royal Canadian Mounted Police's (RCMP) requirements in Canada are nearly identical to the above list, with the exception that the RCMP instead of the FBI is normally notified. One organization might notify the other if there is reason to suspect that the border may be crossed. When investigators believe that a child is in danger of being taken across the border to either Canada or Mexico, U.S. Customs and Border Protection, United States Border Patrol and the Canada Border Services Agency are notified and are expected to search every car coming through a border checkpoint. If

the child is suspected to be taken to Canada, a Canadian Amber Alert can also be issued, and pursuit by Canadian authorities usually follows.

2.4.2 AMBER Alert Europe

AMBER Alert Europe is an international non-profit organization with 32 members (law enforcement, ministries & NGOs) in 21 countries. Its Police Network consists of over 50 experts representing law enforcement from 19 European countries. The goals of AMBER Alert Europe are backed by 465 Members of the European Parliament: most successful Written Declaration since 2011. Therefore, AMBER Alert Europe suggests the following 5 key points to the European Commission and the European Parliament:

1. A bigger, stronger AMBER Alert network
2. More flexibility in issuing child alerts
3. Better cross-border information sharing
4. Better cross-border police cooperation
5. Improving the identification and protection of children at borders

In 2008, AMBER Alert Netherlands was launched. With a reach of more than 12 million Dutch citizens, AMBER Alert Netherlands quickly became an example of how citizen sourcing can work; in 94 percent of the cases, the child was successfully found. Inspired by the success of the Dutch AMBER Alert, the AMBER Alert Europe was founded in 2013 with the following goal:

1. To be a life-saving factor in abductions or disappearances of children throughout Europe.
2. To undertake any further actions necessary related to achieving or advancing the above-mentioned goal, in the broadest sense.

In 2014, AMBER Alert Europe launched the Police Expert Network on Missing Children. The goal of the network is to allow missing children police experts to quickly and informally contact their colleagues in other European member states and exchange best practices.

AMBER Alert Europe is a neutral platform. It operates either evidence-based, scientifically proven, or expert-based. All activities are executed with respect to the privacy of missing persons and data protection laws. According to AMBER Alert Europe, any child whose whereabouts is not known will be considered as missing until located,

and their well-being or otherwise confirmed. All cases should be assessed to determine the seriousness and immediacy of risk, which will indicate the response that is required.

Activation Criteria

Extensive US research, backed by UK findings, show that when a child is abducted and killed, in 76% of the cases the child was killed within three hours after the abduction. The AMBER Alert system was developed for these special 'life or death' cases.

Law enforcement agencies are responsible for issuing an AMBER Alert and use strict criteria. Below you can find the current criteria as recommended by the European Commission.

1. The victim is a minor (i.e. under 18 years of age).
2. It is a proven abduction, there are clear elements indicating that it could be a case of abduction.
3. The health or the life of the victim is at high risk.
4. Information is available which, once disseminated, will allow the victim to be located.
5. Publication of this information is not expected to add to the risk facing the victim.

2.4.3 AMBER Alert, Netherlands

The Dutch AMBER Alert was launched in 2008 by the Dutch National Police, the Dutch minister of Justice at the time, Ernst Hirsch Ballin, and social enterprise Netpresenter. On February 14, 2009, the first Dutch AMBER Alert was issued when a 4-year-old boy went missing in Rotterdam. He was found safe and sound after being recognized by a person who saw his picture on an electronic billboard in a fast-food restaurant. He was recovered so quickly, that the transmission of the AMBER Alert was halted before all recipients received it. Since 2008, the AMBER Alert system has been deployed for 29 AMBER Alerts and over 1000 Missing Child Alerts.

Currently, AMBER Alert has 3 million participants including thousands of large organizations. Indirectly, a Dutch AMBER Alert reaches more than 12 million Dutch citizens (89 percent of the Dutch population). With a success rate of 94 percent, the Dutch AMBER Alert system is an example of effective citizen sourcing.

An AMBER Alert is issued when a child is missing or abducted and the Dutch police fear that the life or health of the child is in imminent danger. The system enables the

police to immediately alert the press and public nationwide, by means of electronic highway signs, TV, radio, social media, PCs, large advertising screens (digital signage), email, text messages, apps, RSS news feeds, website banners and pop-ups. There are four key criteria in The Netherlands to be met before an AMBER Alert is issued:

- 1.The child is (very likely) abducted by an unknown person or persons or the child is missing and its life is in imminent danger
- 2.The victim is a minor (under 18 years of age);
- 3.There is enough information about the victim to increase the chances of the child being found by means of an AMBER Alert, such as a photo, information about the abductor or the vehicle used during the abduction.
- 4.The AMBER Alert is issued as soon as possible after the abduction or disappearance of the child.

Parts of the Dutch AMBER Alert system are being used for Missing Child Alerts. A Missing Child Alert is issued when there is an immediate and significant risk of harm for the missing child but the case does not reach the criteria for an AMBER Alert. The Dutch police can decide to publicize information and ask the help of citizens to recover the child.

2.4.4 NCMEC – CyberTipline

In 1984, John and Revé Walsh and other child advocates founded the National Center for Missing & Exploited Children as a private, non-profit organization to serve as the national clearinghouse and resource center for information about missing and exploited children. During the last 36 years, NCMEC’s national toll-free hotline has received more than 5 million calls. NCMEC has circulated billions of photos of missing children, assisted law enforcement in the recovery of more than 327,000 missing children and facilitated training for more than 367,000 law enforcement, criminal/juvenile justice, and healthcare professionals. NCMEC’s Team HOPE volunteers have provided resources and emotional support to more than 74,000 families of missing and exploited children.

In 2019 NCMEC assisted law enforcement and families with more than 29,000 cases of missing children. Of the nearly 26,300 runaways reported to NCMEC in 2019, 1 in 6 were likely victims of child sex trafficking.

NCMEC also participates in the AMBER Alert Program, a voluntary partnership between broadcasters, transportation agencies, law enforcement agencies, and the wireless

industry to activate an urgent bulletin in the most serious child abduction cases. NCMEC serves as the secondary distributor of these alerts. NCMEC's forensic artists have age-progressed more than 6,900 images of long-term missing children and created more than 575 facial reconstructions for unidentified deceased children. NCMEC is currently assisting with more than 691 cases of unidentified children's remains, and so far has assisted in 154 identifications.

Team Adam, which provides rapid, on-site assistance in cases of critically missing children, has deployed more than 1,200 times. The program was named after Adam Walsh, the abducted and murdered son of NCMEC co-founders John and Revé Walsh. Team Adam also provides technical assistance and outreach regarding long-term missing child cases and has assisted families, communities, criminal justice, and forensic professionals more than 10,900 times.

NCMEC has analyzed more than 17,600 attempted child abductions to identify trends and help develop safety tips for families. NCMEC operates the CyberTipline, a national mechanism for the public and electronic service providers to report instances of suspected child sexual exploitation. In 2019 the CyberTipline received more than 16.9 million reports, most of which related to:

- Apparent child sexual abuse material.
- Online enticement, including "sextortion."
- Child sex trafficking.
- Child sexual molestation

Since its inception, the CyberTipline has received more than 71 million reports. To further NCMEC's mission and help reduce proliferation, NCMEC has sent more than 311,000 notifications to electronic service providers regarding publicly accessible websites (URLs) on which suspected child sexual abuse material appeared.

2.4.5 Child Alert Foundation (CAF)

The Child Alert Foundation (CAF) is a private, non-profit organization that was established in the state of Pennsylvania in 1998. Operating strictly from donations and fundraising, CAF is dedicated to assisting federal and local law enforcement agencies in the recovery of missing and abducted children and elderly individuals. The Child Alert Foundation helps law enforcement notify their surrounding communities with their copyrighted Abduction Central Alert (ACA) community alert notification system.

The Child Alert Foundation was the first organization to ever create a fully automated implementation of the Amber Plan outlined in 1997 in Dallas, Texas, which has since become the AMBER Alert. The original Amber Plan (1997) was a faxed based procedure where law enforcement agencies were required to prepare information for public distribution and then fax that information to a list of designated primary radio stations. This was a manual procedure and time-consuming process.

The ACA system created by Child Alert is a totally automated procedure that was designed from the very beginning to exceed the original Amber Plan requirements. Rather than limit the alert to the radio, CAF expanded coverage to include television and news organizations as well as other law enforcement agencies for notification. In addition to sending faxes as the original plan required, the ACA system sends emails, alert pagers, send text messaging, build automatic web pages, posters and more. The ACA system also provides full circle notifications by issuing closure alerts when an incident is terminated. Since its original implementation in 1998, the ACA system has been further expanded to assist law enforcement with notifying the community when a Silver Alert is issued for missing elderly individuals.

With their collective backgrounds in computer technology, applications development and telecommunications, the founders of CAF collaborated and created a new Alert Notification System (ANS) that was called Abduction Central Alert (ACA) in honor of all missing children across the nation. With the ACA system, an alert area of one hundred (100) miles is centered around the initial abduction location and establishes a "zone of influence" for the notification area. Since the first hour of any abduction is critical and an abduction vehicle can travel over 60 miles an hour, one minute can equal a mile and this was the reason why the 100-mile radius distance was selected. The alert "zone of influence" represents a virtual network that can cross state and local boundaries and provides law enforcement with a greater advantage of apprehending a perpetrator in that first hour. This system can immediately notify a variety of agencies and organizations of missing and/or abducted individuals in a matter of seconds of being activated.

In May 2001, the Child Alert Foundation released their infrared digital fingerprinting services program called the ACA Child Identification Poster System (ACA CHIPS). This program automated the old Polaroid photograph and ink fingerprint concept of providing child identification services and stored information digitally on a disk that could easily be retrieved and imported into the automated Abduction Central Alert (ACA) community

alert notification system. The CHIPS program interfaces with a digital video camera to take real-time video snapshots and an infrared fingerprint scanner to capture digital impressions of a child's fingerprints. This information is saved in various digital formats on a disk or flash drive and given only to parents and guardians to access in case of an emergency. In the unfortunate event that a child is reported missing and/or abducted, the digital information can immediately be reloaded into an alert notification system (ANS) program like Abduction Central Alert so that an Amber Alert can be immediately activated by law enforcement.

With the introduction of the digital ACA CHIPS program (2001), the Child Alert Foundation became the first organization to offer full circle alert coverage to law enforcement and their communities. Law enforcement could use ACA CHIPS to provide parents and guardians with child identification disks as a community service. Parents in turn could provide the CHIPS disks back to law enforcement in the case of an emergency so that an expedited Amber Alert could be activated using the ACA system to notify their surrounding community of a missing child.

2.4.6 Wireless Emergency Alerts

Wireless Emergency Alerts (WEA, formerly known as the Commercial Mobile Alert System (CMAS), and prior to that as the Personal Localized Alerting Network (PLAN)), is an alerting network in the United States designed to disseminate emergency alerts to mobile devices such as cell phones and pagers. Organizations are able to disseminate and coordinate emergency alerts and warning messages through WEA and other public systems by means of the Integrated Public Alert and Warning System.

The government issues three types of alerts through this system:

- Alerts issued by the President of the United States.
- Alerts involving imminent threats to safety of life, issued in two different categories: extreme threats and severe threats.
- AMBER Alerts

2.4.7 GuardAnAngel contribution

The main conclusion is that acting quickly is critical. The historical data show that looser activation criteria result in a higher safe-recovery ratio. In an alternative interpretation of the proverb "better safe than sorry", the GuardAnAngel application has been developed based on the theory that false positives are preferable to delayed positives. The

evidence indicates that GuardAnAngel moves in the right direction. A balance between immediate action and invalid information transfer is achieved by employing a maximum broadcast range, relatively short.

Compared to the existing systems, the GuardAnAngel service could be described as an enhanced modern alert notification system, combining most of the other systems' features. Additionally, it makes use of the high smartphone penetration in many countries. Closer to the Dutch Amber Alert' and CAF's philosophy, GuardAnAngel fills the current gap on the instant reaction of a missing child incident, counteracting the slow response that gives the kidnapper an advantage. Moreover, it provides a citizen sourcing mechanism for tackling abduction attempts to countries, which have not developed such systems already. Most of the aforementioned systems and organizations operate in the USA only.

3. METHODS

3.1 Main Scenario

In this chapter, we will analyze the aspects of the main scenario from an engineering perspective. First, we will describe the main scenario, and then, we will present the most difficult or important problems and their solutions.

In our main scenario, the guardian of a child wants to inform the people in that area about a missing child, either because he witnessed the abduction of the child or because he has lost it from his sight for a long time and cannot find it, considering that the child is in danger. By keeping a recent photo with some details on the child's appearance in his GuardAnAngel application, he reports the disappearance of the child through the application to the corresponding service.

Immediately, the people in the range of five hundred meters distance will receive a notification about a missing child. We should note here that for someone to be informed, he needs to retain our application on his smartphone. In our scenarios and examples, we will assume that a large number of people have downloaded the application and have given all the required permissions.

After ten minutes, if the child has not been found, the broadcast range increases to one kilometer. Of course, without sending another notification to those persons that have received it already. In twenty minutes, people in a broader area are informed, two kilometers away from the incident. In thirty minutes, the broadcast range reaches its maximum value, which is five kilometers. After half an hour, if the child has not been found, an official authority should be contacted. After that time and in a longer distance, the missing child broadcast loses its effect on immediate action. In this case, police and established platforms, like Amber Alert, would provide a more efficient action plan and valuable advice.

Moreover, due to the easiness of reporting such incidents, there is a high risk for a significant number of false alarms that could possibly damage the service's reputation and credibility. Therefore, the service should have a sophisticated limit on the broadcast range, so that the information is conveyed only in the critical area. In that way, we hope that we will prevent a turn of GuardAnAngel into a "cry wolf" service that people would ignore.

In the figure below, there is a visual representation of how the information will be conveyed after an incident is reported.

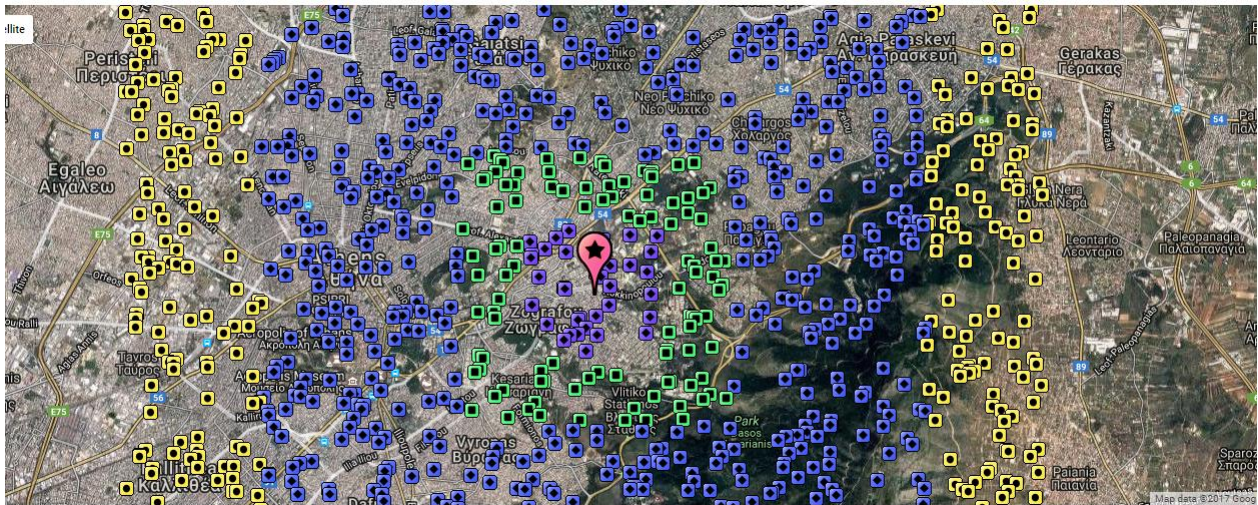


Figure 1: Visual representation of alert notifications

3.2 Overall design

In this section, we describe the main concepts of our design, we present some of the alternatives that were considered during the analysis phase, their limitations, and explain how and why we ended up in our solution.

At the first and current stage, the service operates as a standalone and was designed as such. This fact implies that only the service users can be notified of a missing child incident, at least for the moment. Having that in mind, one thought would be that the smartphone application could be used as an active component of the service, utilizing mobile resources and offering a distributed approach for our service.

In this case, the server could send to all the users just one message, containing the coordinates and the rest information about the missing child report. By receiving that information, each device would be able to determine if its user should be notified or not, based on the distance, the report time, etc. Those calculations would be realized by the smartphones and the server's computation load would be minimized.

However, such an approach is not possible due to the security constraints of most phones' operating systems. The direct application messaging is not allowed, especially for an application that either runs in the background or does not run at all. The service can contact a smartphone device only via the notification system of each platform, Android or iOS. After the user opens the received message, the corresponding

application is launched. Therefore, the service needs to be very precise to avoid becoming disturbing. These factors necessitated server-side processing.

The filtering of the users based on their position can occur only if the service knows their location. Considering that a search could take place at any moment, the service needs to keep track of them, almost constantly and in real-time. A discrete and energy-efficient manner of location reporting is a prerequisite for the success of this service. Such a way was found, by implementing a backoff algorithm of location posting, similarly to TCP congestion-avoidance algorithm. The location tracking is crucial for the reliable operation of this service and is elaborated in the following sections. With the users' locations given, a geographical query can take place at any moment and filter the people in a specific area. After that, the service uses the provided notification system to inform these people, based on the result-set.

3.2.1 Server client communication

The most important parts of the server-client communication are two. First, by chronological order, the server needs to ask the location of a mobile device. Second, the server needs to notify the people in a specific area. In both cases, the server has to initiate the communication with the client and possibly a sequence of actions. Traditionally, the client starts the communication by sending a request to the server. The main techniques for server-client communication are WebSockets and polling. Both applied mostly on internet browser cases, with an already opened page, like a chat or live score. On the contrary, our case is a smartphone application that is not even open. Moreover, it should be noted that WebSockets is a very energy-consuming technique. Especially for a mobile application, it cannot be adopted.

Regarding the location reporting, a polling technique was used. In our Android prototype, a background service sends periodically a POST request to the corresponding URI. The request contains the coordinates and the unique identifier of the device, which is used by the notification system to inform that specific device. Moreover, the background Android service sends the location to the server regardless of the application status, if it is open or not.

About the messaging of people in a specific area, the notification system is employed, in our case the Firebase Cloud Messaging on Android. After having collected the coordinates and the notification identifiers, the server is able to filter first the devices in a specific area and then send a notification alert to these devices. Actually, the server

makes an API call to the Firebase platform, for all those identifiers. Then, Firebase contacts the devices with the message that the GuardAnAngel server has defined. The end-user will receive a notification, similarly to WhatsApp or Messenger messages.

3.2.2 Efficient battery consumption polling (backoff algorithm)

A background service that causes fast battery drainage is a serious drawback for an application. Spotting its location is an expensive action for a mobile device. It consumes a lot of energy. The effect of frequent location actions is apparent on the battery energy bar.

Therefore, a backoff algorithm was developed for consumption efficiency, likewise the Transmission Control Protocol (TCP) uses a slow start scheme for network congestion-avoidance. In that way, the application's impact on the battery is negligible.

Under normal conditions, the application reports its location every 5 minutes. If the device has not been moved significantly, the application sends a location report after 10 minutes. Then after 20 minutes and at the end the period increases to 30 minutes. As long as the location has not changed, the reporting period remains at 30 minutes. The distance threshold that sets a location to "Changed" is 100 meters.

This approach affects the vast majority of the users. Most people remain in a place for a long time, like people at work or people at home. Hence, it was considered a necessity. A similar approach could be followed for people that travel and are not in the target group to inform. For example, someone that has moved more than 25km in 30 minutes could report every 30 minutes. However, this case needs extra analysis and was skipped.

Geolocation Sampling

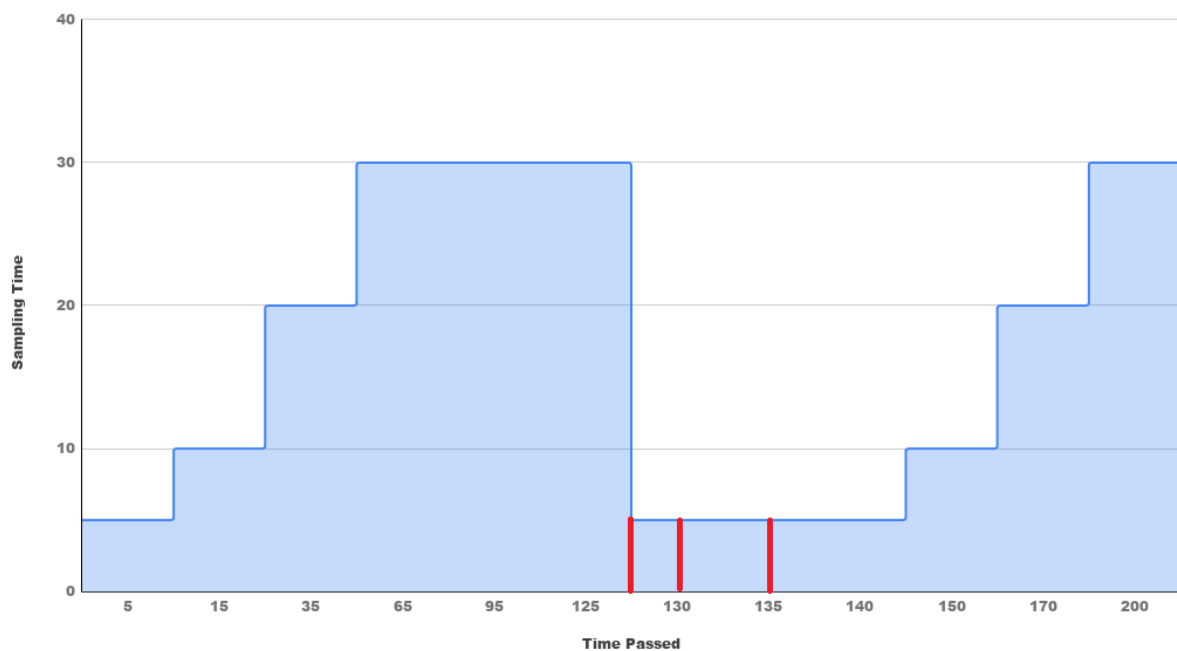


Figure 2: Location reporting algorithm representation (red spikes denote location change)

3.2.3 Geographical position

For location tracking, the most prevalent options are:

- the Global Positioning System (GPS), based on satellites
- the cellular triangulation, based on cellular network antennas, and
- the WiFi positioning, based on routers.

WiFi positioning allows great accuracy with small energy consumption and is widely used in indoor navigation systems. However, it is not very suitable for the GuardAnAngel application overall, thus the other two alternatives will be examined. Moreover, Android provides positioning only via GPS or cellular network.

GPS uses satellites to locate an object. Theoretically and experimentally, GPS takes significantly more time to locate a device than cellular triangulation. Especially, when the mobile phone is in a building, where the signal is weaker, the GPS positioning could take even 15 minutes. Moreover, GPS consumes more energy.

On the contrary, triangulation uses cellular antennas to locate an object. Comparing to GPS, triangulation lacks in accuracy, in general. In the rural areas though, triangulation becomes even less accurate. However, due to the larger number of incidents in the cities, the GuardAnAngel application is mostly targeted at urban areas, where the

density of antennas is high. For all the reasons above, the cellular alternative was selected.

3.3 Design Analysis

The GuardAnAngel service was designed by taking into consideration the following factors: performance, scalability, adaptability, and operational cost.

Regarding performance, response time and throughput were our metrics. About these two metrics, the main concern was that the final choice would not be inferior to the alternatives. After all, it was at least equivalent.

About scalability, the ability of a system to handle a growing amount of work by adding resources, the service was designed to handle the increased load by scaling out. Scaling out is adding more components in parallel to spread out a load. Scaling up is making a component bigger or faster so that it can handle more load. Scaling up is more expensive.

Concerning adaptability, the ability of a system to adjust to changes, there are two parts. First, the changes in conditions on load and system needs are covered in scalability. The second part is the changes in the real world, cost changes, cloud and hosting providers changes. Briefly, the metric would be how easily the service can be moved from one provider to another.

Finally, the operational cost for a nonprofit, social benefit service is a very important issue. It could determine the service's survival. Market research on cloud and hosting providers has showed that for basic schemes and demands, the cloud choice is preferable. However, very careful design and management are needed to avoid extra costs, which are not obvious.

Overall, the service design was based on the paradigm of microservices. In that way and with diligent searching and decision making, the reached outcome satisfies the above criteria. The service consists of two main domains: administrative actions and geographical search. Thus, the web application was split into two microservices, the administration and the geosearch. The corresponding architecture is depicted in *figure4*.

There is no real need to elaborate on the administration service. It handles all those user actions that need to pass via an authority or need authorization, like user registration, account details editing, and missing child report. These requests are a small percentage of the total requests. Consequently, it is unlikely that this module will need to scale.

On the other hand, the greatest number of requests are sent to the Geosearch service. All the location report requests, while all the search requests too, are sent to this service. The simplicity and decoupling of this service allow its hosting even in different providers. The Geosearch service can scale-out not only over the same provider's virtual machines but also over different providers. In this way, the combination of several free tiers of cloud services is possible to serve a larger number of users. The orchestration of these instances over different providers is not in the scope of this thesis and will not be covered here. Although, it is a straightforward issue to handle.

All in all, the GuardAnAngel service could be described as provider agnostic. Such a characteristic was achieved by avoiding the use of specialized technologies and specific features of providers, like a storage service, but instead developing the architecture based on common features for all providers, mostly fundamental and inexpensive. For example, all cloud providers' free tier contains a relational database, like PostgreSQL or MySQL. Various NoSQL databases or in-memory data stores that provide geospatial functionality, like MongoDB or Redis respectively, are expensive modules to add in cloud schemes.

Therefore, the Geosearch service was implemented on top of its own relational database, by assigning the calculations and transformations to the business service layer (Appendix I). The geospatial queries end up to simple SQL queries on longitude and latitude, which can be materialized by any relational database. By comparing just numbers, basic indexes could be used to improve performance. The experimental results proved our hypotheses.

The screenshot displays the AWS Free Tier details page. At the top, there are navigation links for 'AWS Free Tier', 'Overview', 'FAQs', and 'Terms and Conditions'. The main heading is 'Free Tier details'. Below this, there is a 'Filter by:' section with a search bar and a 'Clear all filters' link. The filters are organized into two sections: 'Tier Type' and 'Product Categories'. The 'Tier Type' section includes options for 'Featured', '12 Months Free', 'Always Free', and 'Trials'. The 'Product Categories' section includes options for 'Analytics', 'Application Integration', 'Business Productivity', 'Compute', 'Customer Engagement', 'Database', and 'Developer tools'. The main content area shows three service cards: 'COMPUTE' featuring Amazon EC2 with 750 Hours per month; 'STORAGE' featuring Amazon S3 with 5 GB of standard storage; and 'DATABASE' featuring Amazon RDS with 750 Hours per month of db.t2.micro database usage. Each card also indicates 'Free Tier' and '12 MONTHS FREE'.

Figure 3: Cloud services provider free tier

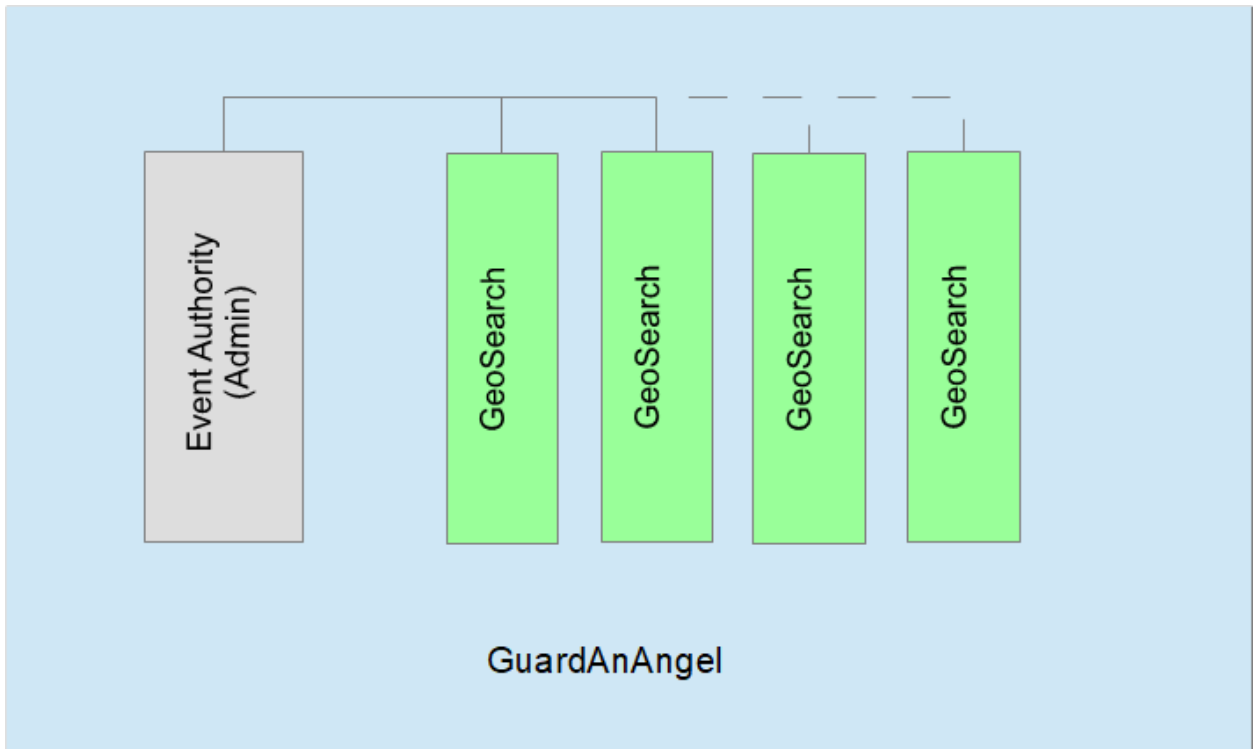


Figure 4: GuardAnAngel Service Architecture

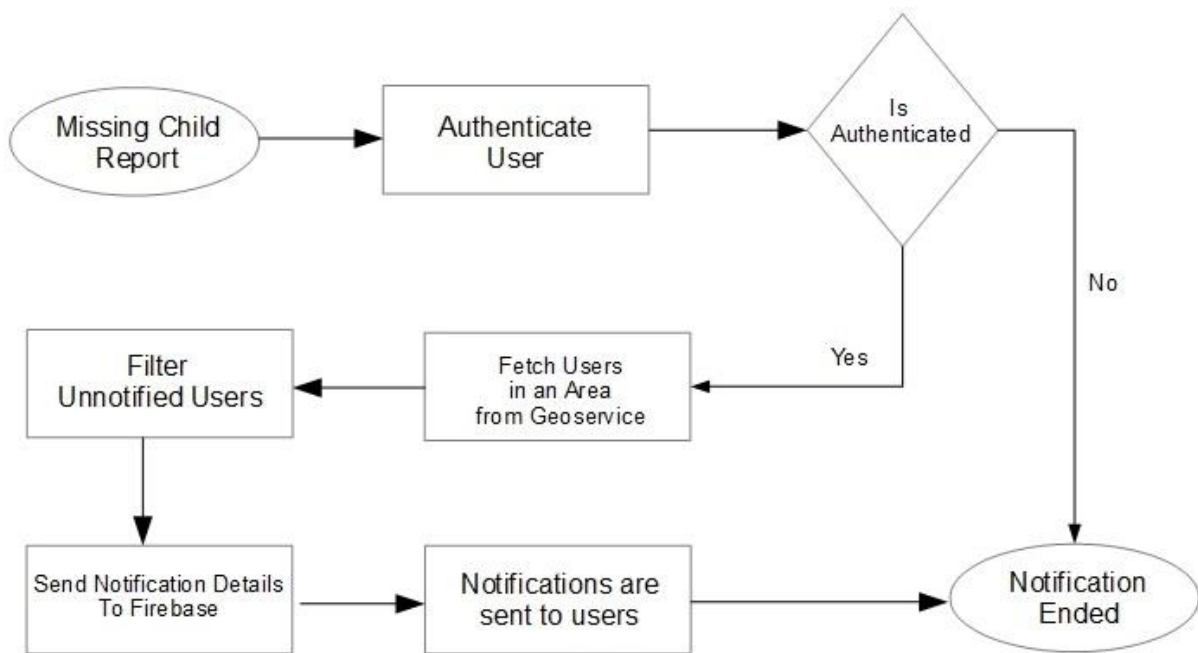


Figure 5: Missing Child Report FlowChart

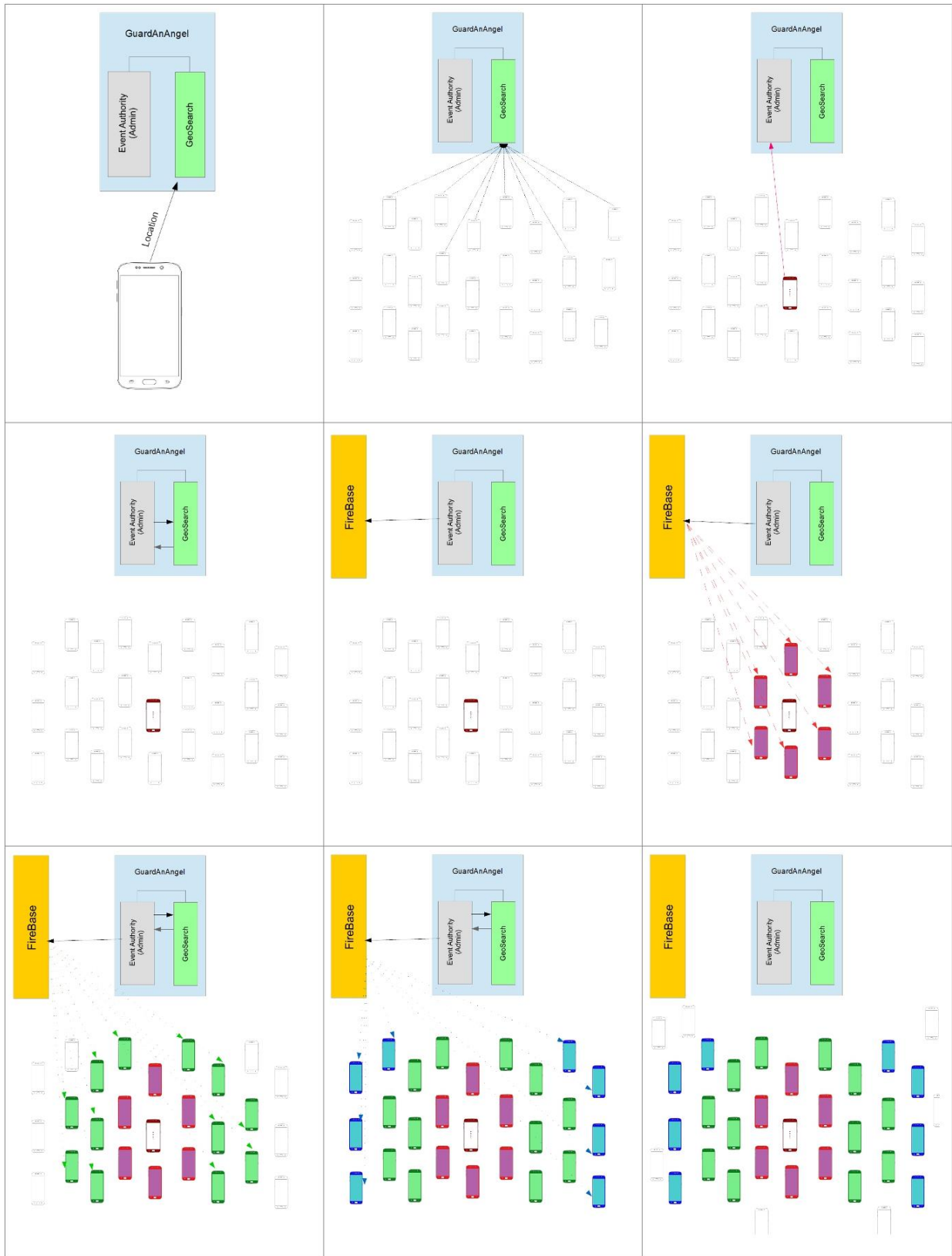


Figure 6: Missing Child Report Scenario

3.4 Technical Overview

In the previous section, the design and architecture of GuardAnAngel Service were described at a higher level. In this section, some more technical details are provided to give the reader a better grasp of the implementation.

In figure 4, the illustration of the architecture shows us the two microservices that constitute the GuardAnAngel Service and how the geosearch service could scale out as more users are added. Geosearch service has its own database. Each service instance keeps a separate database, the same schema with different data. In this way, a distributed data store without a replication factor could be achieved over various physical or virtual servers. When a geographical query needs to be executed, each instance runs the query on its data, returns the result-set and the final result-set is formed by the individual result-sets combined.

The database schema mainly consists of one table that holds the locations of the registered devices. The table “location_spot”. Other tables could also be included, like the “event_users_notified”, which is used for filtering out already informed users. Such tables could exist either in the geosearch database or in the authority service database. The geosearch database is preferable because it decreases the network traffic by avoiding redundant information transfer. However, we will not elaborate on these auxiliary tables.

The table location_spot contains three fields: id, longitude, and latitude. The table’s definition and the field datatypes are provided in codeblock 1. Regarding the field id, it could be used as an indexed identification field to improve the updates’ time. Indexes could be used on fields longitude or latitude to speed up the query execution. The query is given in codeblock 2. At this point, it should be noted that in-memory databases or data structures could be used to store these records too. However, it is considered unnecessary to use such an expensive measure, like memory, to implement the geosearch service, while the queries rarely occur.

```
CREATE TABLE public.location_spot
(
    id bigint NOT NULL,
    latitude integer,
    longitude integer,
    CONSTRAINT location_spot_pkey PRIMARY KEY (id)
)
```

CodeBlock 1: LocationSpot database table

```
SELECT id, latitude, longitude  
  
FROM location_spot  
  
WHERE longitude>longitude_MIN_VALUE AND longitude<longitude_MAX_VALUE AND  
latitude>latitude_MIN_VALUE AND latitude<latitude_MAX_VALUE
```

CodeBlock 2: Geosearch query

In case of an incident, the actions of the flow chart in figure 5 will take place. The step “Fetch Users in an Area” is basically the query in codeblock 2. The result-set would be empty or wrong if the records in location_spots table were not updated properly. The devices inform the geosearch service as mentioned above.

More precisely, a device will call the geosearch service by making an HTTP POST request. The body of the request contains a JSON object with three fields: id, longitude, latitude. In figure 6, the first two images demonstrate these calls. The location update is a repetitive, background task for a device. An increased number of subscribers means an increased number of requests to the geosearch service and a larger database.

At the third image of figure 6, a Missing Child Report request occurs, which is also the start of the flow chart in figure 5. This event is the most important and initiates a series of actions. This request is also a POST HTTP request, which due to its criticality, has some security constraints, like user authentication. The HTTP request body contains a JSON object that includes information about the child and the coordinates of the device, which reports the Missing Child Event.

In the next step, the Event Authority service calls the Geosearch service to fetch the devices in a specific area, by making an HTTP POST request containing the coordinates of the Missing Child incident and the desired distance. The Authority service creates three scheduled tasks to run after the specified times. These tasks will repeat this step and the following actions for a different distance. Meanwhile, if the Authority service receives a “Child Found” event, the scheduled tasks will be cancelled. The already notified users about the missing child incident should be informed accordingly by another message.

After receiving the response with the users to notify, the Authority service will retrieve the corresponding notification tokens and send them to Firebase, accompanied by the “Missing Child” message. Firebase will send this information to the specified devices. These users will receive an alert notification about a missing child. By opening it, they will be able to read more in GuardAnAngel application.

The last three images in figure6 are the results after the corresponding scheduled tasks are executed. As more time passes, the distance increases up to a maximum. Then, the “Missing Child” event is archived. If the Authority service receives a “Child Found” event, the notified users will be informed.

4. RESULTS

The “Results” chapter consists of two sections, according to the experiments that were conducted. The first section focuses on the feasibility of such a service, as a proof of concept. The second one presents the results of the comparison between two different approaches, by using a relational database and by using a NoSQL database with geospatial functionality.

4.1 Service feasibility

In this section, the verification process of GuardAnAngel service functionality will be described, along with some observations that arose during this process. Various aspects of the application and the service were monitored and examined.

First of all, the main items of the experiments were a mobile device with Android OS and the service, Postgres database and 2 Tomcat servers running on a computer in a local network, connected to the internet and having access to Firebase. In some experiments, the Android application ran in debug mode, so that some of its operations were controlled and investigated by us, like the GPS vs Cellular location spotting, or the background location service operation, while some others were monitored through logging.

At the beginning, we confirmed that the Android device was reporting its location to the server while the application was closed. Moreover, the gradually backoff behavior was also confirmed when the location remained unchanged. A significant observation should be noted though. The longer the period of an application not in use, the less important its background services become for Android OS, resulting in lower priority and infrequent location posting. This fact should not discourage us at this phase, but it should be recorded for future work. By having assured the location reporting, we could proceed to the main scenarios.

First and foremost, various tests took place to prove the desired functionality and outcome. Having the Android device as a neighbor with a specific and known location, we used Google Map to extract coordinates for spots in a determined range and then reported a Missing Child Incident via Postman. Indeed, after the expected time period, the device was receiving the notification. Additionally, no notification was repeated for the same incident, while the device was receiving more than one notification due to reports for different incidents, as it should.

In the second approach, the Android device was reporting the Missing Child incident, as it would be the normal case. The neighbors had been set manually, with fixed positions around the incident location. These neighbors did not include a Notification Identifier for the Firebase platform. Thus, the server did not send any message to the Firebase and the Quality Assurance step was materialized via the logs. Furthermore, the Android device did not receive any notification because it was the reporter.

After all these experiments, the verdict was that the implementation of the GuardAnAngel application as a proof of concept was successful. It is possible for such an application to be created and operate properly. Also, it should be noted that the impact on the battery was imperceptible, after hours and days of the application background service running.

However, the current trends indicate that most people would not download another application. Especially an application that they would not use often and would keep it mostly as a subscriber. Further research needs to be done on how the application would be more meaningful and effective in the real world.

4.2 Databases comparison on Geospatial queries

In this section, the results of the comparison between a relational and a schemaless database on geospatial queries are demonstrated. The relational database was PostgreSQL and the schemaless was MongoDB. All the rest of the infrastructure was remaining unchanged. The same test cases and scenarios were materialized by changing the database and calling the corresponding APIs.

The time measurements are presented in the table below. It should be mentioned that the displayed values are the average from a series of measurements. Specifically, the average of 20 values. Moreover, any value with a large deviation was removed and spikes did not affect the final results. In that way, data credibility was ensured.

Table 1: Databases' execution times in milliseconds

NoOfRecords	Postgres		MongoDB	
	SavingTime	QueryTime	SavingTime	QueryTime
1000	4	15.04	3	23.91
5000	3.6	41.43	2	94.65
10000	5.5	56.68	1.1	137.7
50000	5.8	215.74	1.3	582
100000	5.1	338.92	2.5	1422.41
500000	3.2	2445.07	1.5	6835.4
1000000	1.54	3344.31	1.4	13630.89
3000000	1.85	15581.3	0.8	54279.43

These results prove our initial assumptions. Indeed, the execution time of a geospatial query in a relational database is at least equal to a schemaless database query. Actually, Postgres has achieved better execution time than MongoDB. Moreover, as the number of records increases, the performance gain gets bigger.

Query Performance

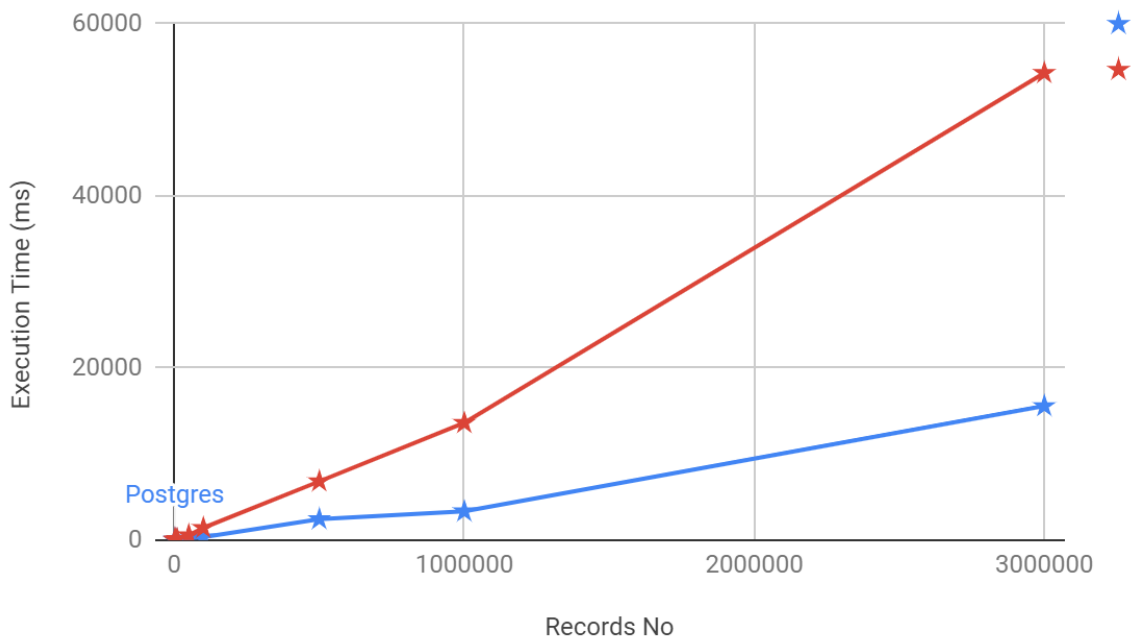


Figure 7: Geospatial queries' processing time (Blue:PostgreSQL, Red:MongoDB)

Record Saving Time

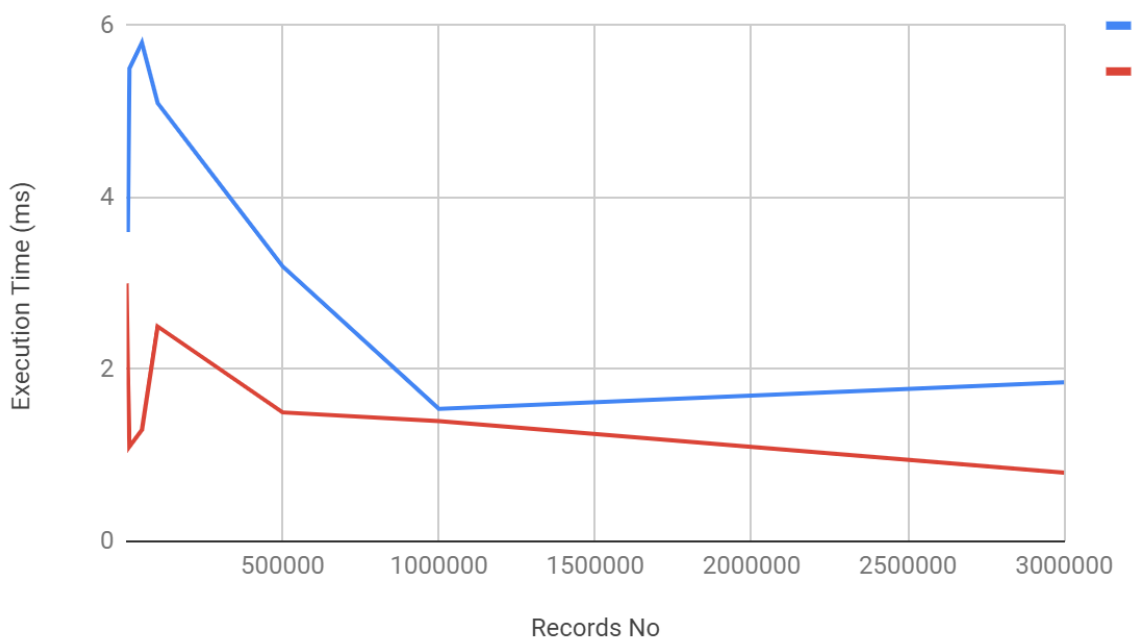


Figure 8: Record saving time (Blue:PostgreSQL, Red:MongoDB)

The query time metric is our main metric, the most important one. It denotes the response time of the system in case of an incident. Write time is also an important factor in the comparison of databases. Thus, it was included in this benchmark. However, in our case it is not that critical. Apart from the fact that the difference is insignificant, there are techniques to decrease the write time per record and control the load on the database. For example, by using queues and batches. Therefore, the use of a relational database is a clear favorite. The behaviors of the examined databases are illustrated in Figure 7 (Read Time) and Figure 8 (Write time).

These two metrics are mostly used for comparison between the two databases. The actual values are not so important. They could differ based on the environment that the experiments are conducted. In this specific case, the measured time was the duration of an application search. Network latency did not affect because the server and the database were running on the same computer. The delays of the application loading the records from the database are identical. Therefore, the measurements result in a fair comparison of the two databases.

4.3 Results analysis

The experimental results are not surprising. Many benchmarks show that Postgres is significantly faster than MongoDB for most query types. Especially about aggregation queries and analytics, theory and empirical observations state that Postgres is better. Although some official benchmarks do not demonstrate big differences, while there are even some cases in favor of MongoDB, the context in these benchmarks is not quite clear and the theoretical indications are regarded as valid.

Document-oriented databases, like MongoDB, and NoSQL in general, are known to struggle when the dataset is larger than the memory. Relational databases perform better in these cases. Moreover, relational databases are considered faster and more efficient at retrieving records from the disk.

Furthermore, the schema is defined in our case. The fixed-length fields and tuples could allow a more sophisticated approach to mature technologies, such as relational databases, than a document scan that occurs in MongoDB. Postgres could take advantage of tuples' specific memory space and even handle comparisons in a bitwise manner. These gains add up when the number of records increases.

All these factors explain why Postgres performs much better as the dataset and the load increase. Our query seems to fall into the category of aggregation queries because a

potentially whole table processing is required. The multitude of processed and returned records neutralize any effect of indexes.

It is worth mentioning that some additional experiments were conducted, in order for us to investigate the database operation and the behavior of our queries. By running a Query Analyzer and studying its output, we noticed that indexes were skipped. The reason is the number of records returned. After decreasing the size of the area so that few records were returned, we managed to make the query optimizer choose a query plan using an index. The two query plans are presented in figure 9. Query A makes use of the index on field longitude while query B does not. The application's real scenarios would affect lots of users and indexes would be skipped. Therefore, any elaboration on indexes' use and the demonstration of the related measurements were omitted.

However, MongoDB uses indexes by default for geospatial storage and searches. A custom, enhanced R-tree approach is used for indexing the geospatial data. Such an approach is an excellent fit for steady objects that are not moving. When the saved objects change their locations often and re-indexing is needed, various complications and performance issues could emerge, especially when these operations happen at scale. We did not examine the updates of records in these experiments. It could be added as an item for future work.

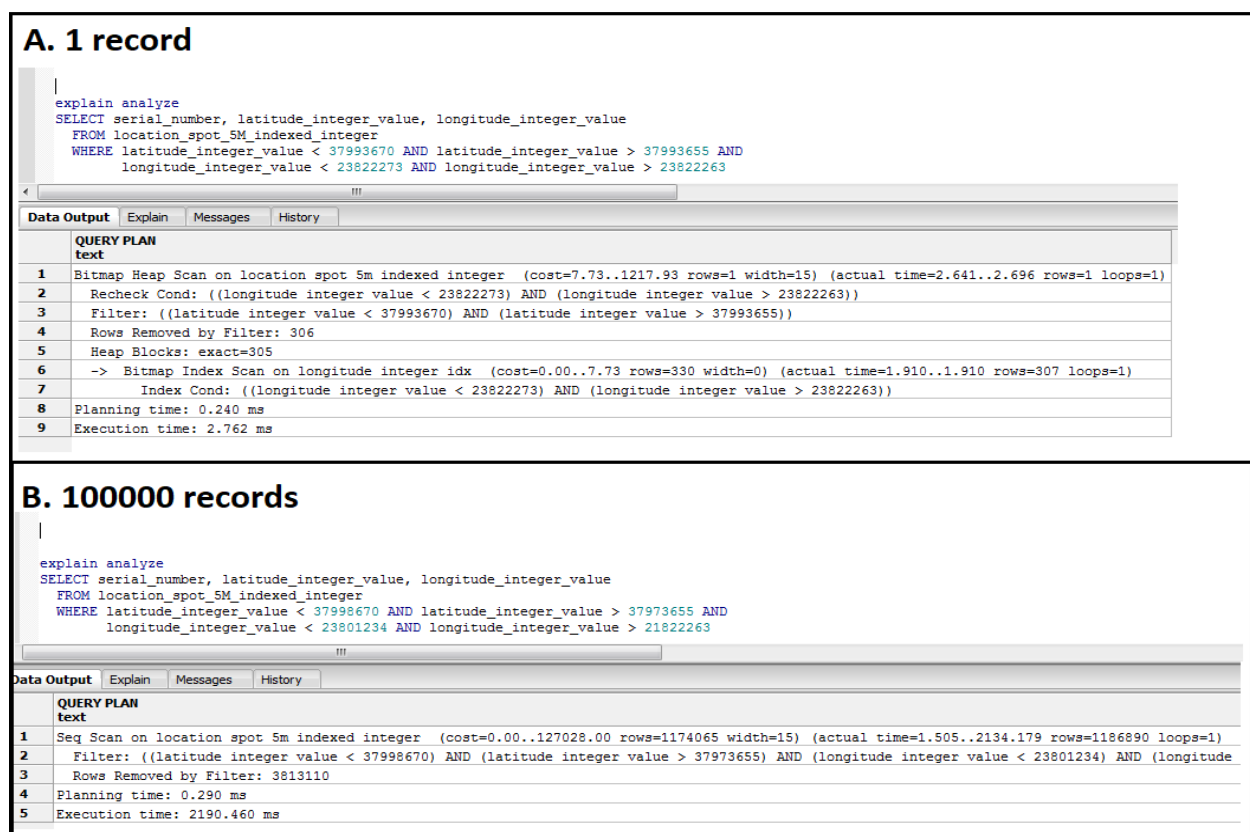


Figure 9: The query plans for the geosearch query

4.4 Outcome

MongoDB could be more suitable in other use cases, where the stored objects would have a loose schema definition, with different extra information involved, while their location does not change. For example, geographical searches of restaurants that have a play area for children, offer tacos and souvlakia, and are located in the center of Athens, would utilize MongoDB's features and capabilities, highlighting its strengths.

The ease of use for a distributed database that MongoDB offers is not really needed in our scenario. Moreover, the distribution is achieved in another way, by moving the control and routing to the service layer.

Overall, not only did we manage to implement a solution with geospatial searches over a traditional relational database, but we achieved a better performance as well. We proved that relational databases could also be adopted for geospatial queries for various use cases, although such choice is not the mainstream approach. By analyzing the needs of each application, implementations over relational databases could take place and save a considerable amount of money (operational costs) to a potential service provider.

5. CONCLUSIONS

5.1 Overview

The developed application in this thesis acts as a proof of concept. Much additional work needs to be done to make this application releasable to the public. In the case of a standalone application, the extra work could be considered trivial, because the most difficult and fundamental part has been implemented. In brief, the foundation has been built. Styling, decoration, additional functionality needs to be added but the core has been developed. Based on Pareto's law, the result of this thesis is 20% of the total implementation, which provides 80% of usage.

From a software engineering perspective, many tricky issues have been solved and an operating service has been delivered. Creating an application is one thing though and making an application successful is another. In general, a mediocre design and poor performance lead to a bad experience that results in a service abandonment by the user. Usually, he stops using the service and hardly ever comes back. Therefore, software design is very important. But, in order for someone to leave a service because of a bad experience, he first needs to start using it.

Current mobile industry trends indicate that a small percentage of people would download our application. Lots of people avoid downloading applications to their phones, let alone, an application that would be rarely used. Only some parents would consider downloading it, most probably by having doubts about the real effect of a missing child report, resulting in low engagement. Without a sufficient number of people, acting as listeners, the service would lack effectiveness. Further research in alternatives needs to take place as future work.

Some important facts that could dictate future decisions should be reviewed. 51% of US smartphone users do not download apps. Around 13% of mobile device users in the US download one app per month. Data on the average app downloads per month shows that just 5% of users download eight or more apps during the same period, while 51% of all US smartphone owners do not download any apps. 81% of mobile users have Facebook installed on their device. Facebook is the app we are most likely to have installed on our phones. 68% of mobile users have Facebook Messenger installed on their device. Facebook's Messenger app holds the third spot on the app popularity list. According to these mobile app download statistics, users who have the basic app may not care as much about its messaging features. The most popular app categories for 2019 seem to remain unchanged for the foreseeable future.

5.2 Future work

The optimal way to broadcast a missing child notification event would be through SMS. By sending the details to the mobile network operators, the operators would be able to filter their subscribers in a specific area and inform them accordingly. It is a very convenient solution, but an onerous approach with a small chance of success nevertheless, due to bureaucracy and the reasonable hesitation from operators' side. This approach should definitely be inspected though.

Based on the statistics, the best way to expand the target audience without any agreement with telecommunication providers is via social media. Particularly, the Facebook platform would be a serious candidate for further research and development, as the most downloaded and frequently used application. Perhaps, the application could be converted to a "game" for the Games Area in Facebook. In that way, users would not need to download an extra application to their mobile. Another approach would be by using a Messenger Bot, which would take advantage of the Facebook Messenger, allowing users to be subscribers without downloading the GuardAnAngel application.

5.3 Extensions

Some possible extensions for the application would be the notification for elderly people and pets. Although the first idea was about children, which is a more sensitive case and most people would allow being interrupted with such alarm, a broader notification system would attract more people and consequently more subscribers. After some market research, which cannot be considered necessarily indicative, it seems that pet owners are more nervous and aware of a pet's disappearance than many people are about a child's disappearance. By allowing preferences on what notifications a user would like to receive, like Children, Elderly, Pets, etc., the application makes the user responsible for the content he receives. In that way, the user can filter out any information that he considers as noise, and the likelihood of remaining a subscriber is increased.

Another extension could be the construction of special IoT bracelets, which would be combined with the application to provide better service quality. Evidence from empirical studies suggests that improved service quality increases profitability and long-term economic competitiveness. Features, like maximum distance between a child and its guardian, reminders for the child to declare "safe", and much more could be developed, contributing to the value growth of the service. Apparently, extensive research is required in the following fields: Internet of Things, hardware design, product design.

Perhaps, the most appealing extension for parents could be the GuardAnAngel Academy, an educational unit that would focus on the child's development and would be part of the application. GuardAnAngel Academy would provide advice and tips to the parents based on the child's age, especially for the early stages of development. There would also be fairytales, quizzes, riddles, games, and courses to enhance the training and education of older children in an entertaining way. In such a way, users would be more active and engaged.

5.4 Epilogue

At the end of the day, the feasibility of a fine and discreet notification service was proved. The character of a child is tender and sensitive. A seriously unpleasant event, like an abduction, could affect someone for the rest of his life, let alone a child. The pain for the family is unbearable, especially in cases of no happy ending, while fear dominates their thoughts and lives. Let us hope there will never be any missing child incidents in the future. Let us hope that this application will never be used! Not because it failed, but because the sick minds of this world would not even dare to touch a child. Evil is strong. But Good is stronger! And from today, we have an extra weapon against evil.

Amen

ABBREVIATIONS – ACRONYMS

AMBER	America's Missing: Broadcast Emergency Response
FBI	Federal Bureau of Investigation
TCP/IP	Transmission Control Protocol/ Internet Protocol
NISMART	National Incidence Studies of Missing, Abducted, Runaway and Thrownaway Children
NCMEC	National Center for Missing & Exploited Children
NCIC	National Crime Information Center
CAF	Child Alert Foundation
ACA	Abduction Central Alert
PLAN	Personal Localized Alerting Network
CMAS	Commercial Mobile Alert System
ANS	Alert Notification System
WEA	Wireless Emergency Alerts
GPS	Global Positioning System
IoT	Internet of Things

APPENDIX I

Distance calculation code

```
public double distanceBetweenTwoPoints(double latitude1, double longitude1,
double latitude2, double longitude2, double earthRadius) {
    double dLat = Math.toRadians(latitude2 - latitude1);
    double dLng = Math.toRadians(longitude2 - longitude1);
    double sindLat = Math.sin(dLat / 2);
    double sindLng = Math.sin(dLng / 2);
    double a = Math.pow(sindLat, 2)
        + Math.pow(sindLng, 2)
        * Math.cos(Math.toRadians(latitude1))
        * Math.cos(Math.toRadians(latitude2));

    double c = 2 * Math.atan2(Math.sqrt(a), Math.sqrt(1 - a));
    double dist = earthRadius * c;

    return dist;
}
```

Find Location Spot by Distance and Direction

```
public LocationSpot findGeoPoint(double latitude, double longitude, double
distance, double earthRadius, double bearing) {
    double brngRad = Math.toRadians(bearing);
    double latRad = Math.toRadians(latitude);
    double lonRad = Math.toRadians(longitude);
    double distFrac = distance / earthRadius;

    double latitudeResult =
        Math.asin(Math.sin(latRad) * Math.cos(distFrac) +
            Math.cos(latRad) * Math.sin(distFrac) * Math.cos(brngRad));

    double a =
        Math.atan2(Math.sin(brngRad) * Math.sin(distFrac) * Math.cos(latRad),
            Math.cos(distFrac) - Math.sin(latRad) * Math.sin(latitudeResult));

    double longitudeResult =(lonRad + a + 3*Math.PI) % (2*Math.PI) - Math.PI;

    return new LocationSpot(
        Math.toDegrees(latitudeResult),
        Math.toDegrees(longitudeResult)
    );
}
```

Area Determination by coordinates

```

public List<LocationSpot> findByCoordinatesNear(double eventLatitude, double
eventLongitude, double distanceInKilometers) {

    LocationSpot eventLocationSpot =
        new LocationSpot(eventLatitude, eventLongitude);
    eventLocationSpot.initNumericValues();

    LocationSpot northLocationSpot = geoCoordinateHelper.
    findNorthGeoPointInKiloMeters(eventLatitude, eventLongitude,
    distanceInKilometers);

    LocationSpot southLocationSpot = geoCoordinateHelper.
    findSouthGeoPointInKiloMeters(eventLatitude, eventLongitude,
    distanceInKilometers);

    LocationSpot eastLocationSpot = geoCoordinateHelper.
    findEastGeoPointInKiloMeters(eventLatitude, eventLongitude,
    distanceInKilometers);

    LocationSpot westLocationSpot = geoCoordinateHelper.
    findWestGeoPointInKiloMeters(eventLatitude, eventLongitude,
    distanceInKilometers);

        northLocationSpot.initNumericValues();
        southLocationSpot.initNumericValues();
        eastLocationSpot.initNumericValues();
        westLocationSpot.initNumericValues();

    int minLatitude = Math.min(northLocationSpot.getLatitudeIntegerValue(),
    southLocationSpot.getLatitudeIntegerValue());

    int maxLatitude = Math.max(northLocationSpot.getLatitudeIntegerValue(),
    southLocationSpot.getLatitudeIntegerValue());

    int minLongitude = Math.min(eastLocationSpot.getLongitudeIntegerValue(),
    westLocationSpot.getLongitudeIntegerValue());

    int maxLongitude = Math.max(eastLocationSpot.getLongitudeIntegerValue(),
    westLocationSpot.getLongitudeIntegerValue());

    return locationSpotRepository.findByAreaBorders(minLatitude, maxLatitude,
    minLongitude, maxLongitude);
}

```

```
public interface LocationSpotRepository extends CrudRepository<LocationSpot,
Long> {

    @Query(
        "SELECT spot
        FROM LocationSpot spot
        WHERE (:minLatitude)<=latitudeIntegerValue AND
        latitudeIntegerValue<=(maxLatitude) AND
        (:minLongitude)<=longitudeIntegerValue AND
        longitudeIntegerValue<=(maxLongitude)")

        List<LocationSpot> findByAreaBorders(@Param("minLatitude")int minLatitude,
        @Param("maxLatitude")int maxLatitude,
        @Param("minLongitude")int minLongitude,
        @Param("maxLongitude")int maxLongitude);

}
```

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