CHILD LOSS PREVENTION:
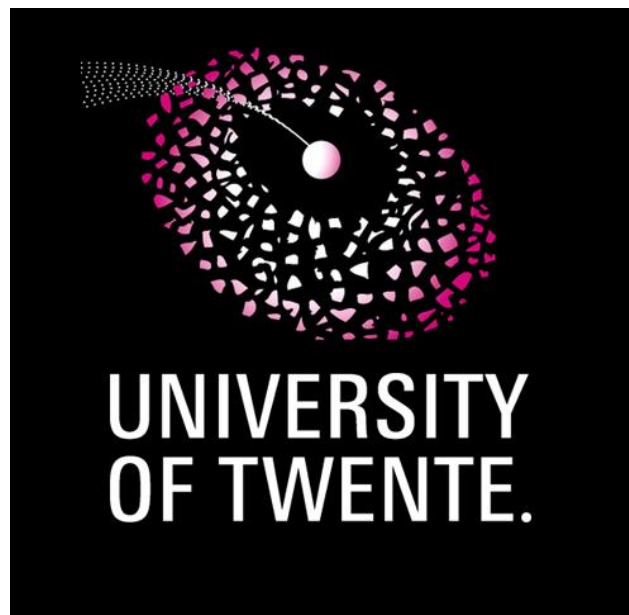# *A WiFi BASED ASSISTANT IN A PREDETERMINED DOMAIN*

Creative **Te**chnology

Graduation Project

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Critical observer: Hans Scholten

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ACKNOWLEDGEMENTS

ABSTRACT

This project tries to plan and implement a solution to assist parents in keeping their child close and locating them once lost, in a public venue setting such as a museum. The creative technology design process was used as a methodical guiding principle; this includes reviewing related work, user interviews, ideation, specification, and evaluation phases.

Non-functional requirements of the system include reliability, reusability, transparency.

Functional requirements include an Early Alarm, Local Ranging/Positioning, and Information Privacy/Security.

To answer the research questions a system was developed. The system consists of 3 main components, the Child Node, the Sentinel and the Smartphone Application.

The Child Node is responsible for emitting a wireless beacon from the Child's position. The Sentinel is a monitoring sensor which can be placed by business owners over various parts of the venue. The Smartphone Application serves as interaction with the parents.

Positioning/Ranging using the Sentinels was not fully possible due to sampling performance limitations explained in the realization and evaluation phase.

The Early Alarm showed potential by alerting on time, however it requires further testing and evaluation to be fine-tuned for reliability.

1 INTRODUCTION

1.1 BACKGROUND

As soon as toddlers learn to walk they start exploring; this is the natural way they develop, which means that most of the time they need adult supervision, or they will do something random and potentially unsafe. They are too young to know better.

Keeping an eye on the child puts a large burden on the parents. In public both the parents and child are more likely to be distracted than at home. The burden becomes even greater and the parent's task becomes harder, while they are dealing with various external stimuli. The short line of sight in an indoor venue or crowd, means that the child might be out of sight and outside the 'circle of safety' offered by their parents within seconds. The issue can be due to the child running away and the parent not focusing. Inadequate oversight due to distraction is a risk taken by parents in busy public venues.

The Louvre in Paris is 72 735m2 [1]. This is a huge space, in which looking for a lost child is like finding a needle in a haystack. In the worst case scenario, the lost child is never reunited with their parents. They could be never seen again. This is one of parent's greatest fears.

1.2 PROBLEM STATEMENT

The child needs to be monitored even when the parents are distracted.

A momentary lack in parental supervision should be combated with an appropriate IT solution in context. The child needs to stay generally within the line of sight. It is necessary for the proposed system to alert the parents when the child walks too far away and outside the 'circle of safety' (generally the parents' line of vision), even if the parents are distracted.

If the child does go missing, the aid of technology can increase efficiency and decrease the time necessary to locate the child.
The child needs to be located, only at the will of the authorized persons (the parents). Once there is data available about the location of the missing child, this data needs to be displayed as information that the parents can easily understand and use.

1.2.1 CHALLENGES

Information privacy: Keep the sensitive information about the child secure in terms of digital privacy.

Indoor and (outdoor) context challenge: The alarm and locator system should provide both indoor and outdoor functionality. Indoor positioning systems are not commonly used; they are usually expensive and tailored for a specific custom use case.

Hardware and Software: Design the alarm and locator system, selecting suitable wireless hardware and software solutions to (a) tag the mobile child and (b) form an infrastructure in context.

1.3 RESEARCH QUESTION:

What secure solution helps parents keep their child nearby, and aids them in the locating process?

SUB-QUESTIONS:

How is the problem handled without technology?

What are the components of a suitable positioning method?

What is necessary for processing the received data into information?

How can privacy concerns be eliminated?

What is a suitable output format & interface?

2 STATE OF THE ART

This chapter will discuss existing solutions.

2.1 SCENARIO: APPROACH NOT MEDIATED BY IT

The child walks away, and the parents notice that their child is no longer in their range of sight. In this scenario the parents' reaction will then be rather predictable. Their realistic options are: go looking for the child, contact the venue employees, or call the police. The parents will probably split tasks. One will look for the child nearby, while the other attempts to reach venue officials using the fastest method available (for example, the reception desk or a hotline phone number) to find out what else can be done.

Venue officials will likely send security guards, check cameras and ask other employees. These employees go looking for the child using a description of their physical appearance and their last known location. When these methods are not successful, the police are involved. This is a common human approach to solving this problem.

2.2 BACKGROUND: TERMS AND TECHNOLOGIES

2.2.1 TECHNICAL TERMS

RFID – Radio Frequency Identification

Access Point (AP) – The broadcast of a WiFi wireless hotspot that clients can see and connect to

RSSI – Received Signal Strength Indicator (dB)

FSPL – Free Space Path Loss

Trilateration – A positioning method; when a signal is picked up from at least 3 antennas, the intersection of their radii (signal strength) defines one point relative to these 3 antennas.

2.3 RELATED WORK

[2] "CHILD MONITORING SYSTEM" – US PATENT 6396403 B1

Context: The system works in a predetermined domain. A wearable monitoring system is embedded into children's clothing. Since the method of wireless data transmission is not specified, the system is incomplete and hypothetical. The patent inventor is Lenora A. Haner.

The system's main aspects

1. An audible alarm which is activated when a child or object has gone beyond a predetermined area or range.
2. Two-way communication; speaker & microphone which allows for direct communication with the child, and
3. Frontal camera
4. Bracelet transmitting assembly & GPS receiver

Advantage: In-context design.

Disadvantage: Vague. Lack of wireless transmission details limit usage to hypothetical scenarios.
Since GPS alone does not provide accurate data for indoor positioning, the system's application would be limited to a predetermined outdoor area, such as a theme park.
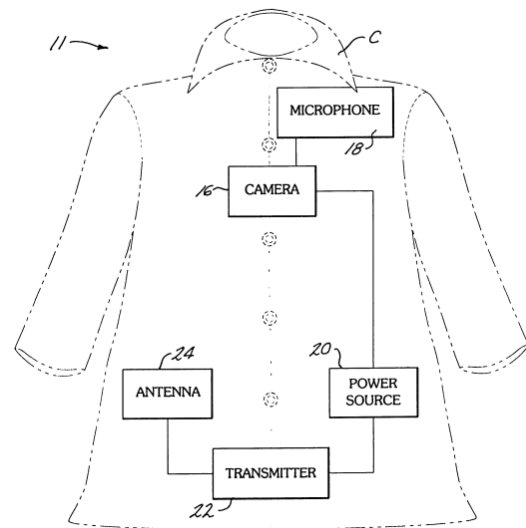
Fig. 1 – Wearable monitoring system **[2]**

[3] "Child protection system" – US Patent 7164354 B1

Context: Monitoring whether a child is still inside the building or predetermined domain. The patent inventor is Justin Panzer.

"Upon [the child] crossing a monitoring point, an alarm is triggered to alert parents". [3]

RFID tags are registered when they cross an RFID sensing gate or 'monitoring point' located at main entrance and exit points of a building.

A good solution when there are not many entrance/exit points, such as a building. Leaving via a non-monitored exit point should not b be possible, the location should be contained.

Advantage: This is a fairly reliable way of monitoring whether a child is still inside the building (assuming that the child is not wilfully acting against being monitored).

Disadvantage: The issue of positioning the child is not dealt with. Effectivity can decrease with an outdoor location (containment).
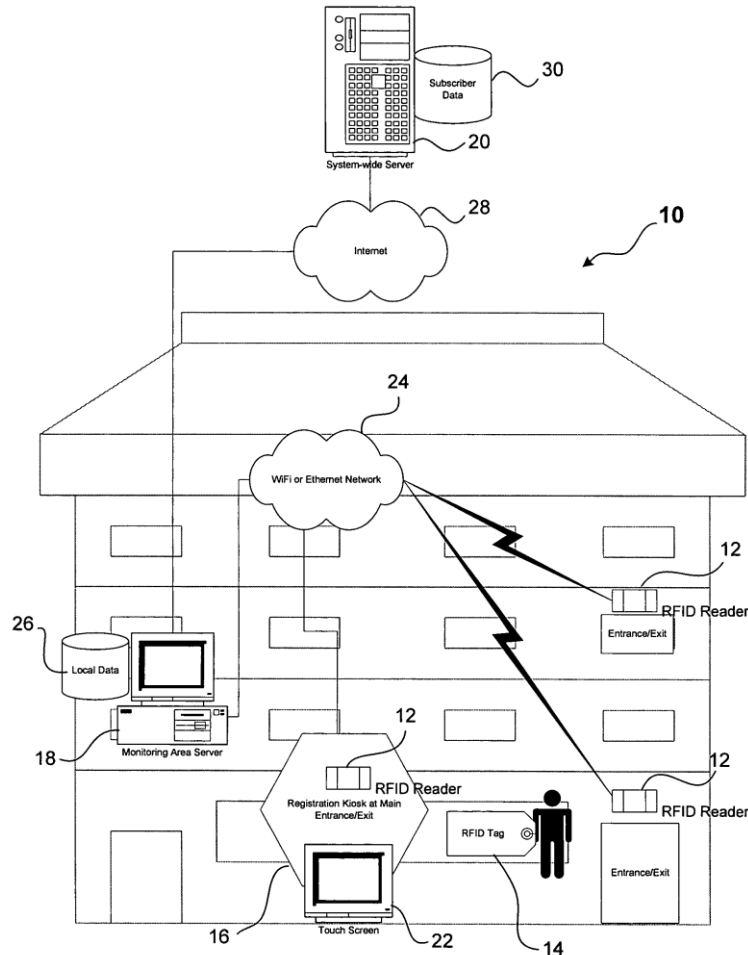
Fig. 2 – RFID monitoring point layout [3]

[4] "Child loss prevention system and method of use" – US Patent 5423574 A

Context: A wristband identification system to verify that the child leaves with the same parent that they arrived with.

Just like the RFID Gate [3] system, entrance and exit points are monitored points. Upon arrival the parent and child are given a random unique identifier, which is verified by a machine when leaving the venue.

Advantages: Simple. The system will possibly deter kidnappers.

Disadvantages: If the identifier can be simply read from the wristband, there is a possibility that it can be used to impersonate the parent. The system doesn't deal with positioning or loss prevention.
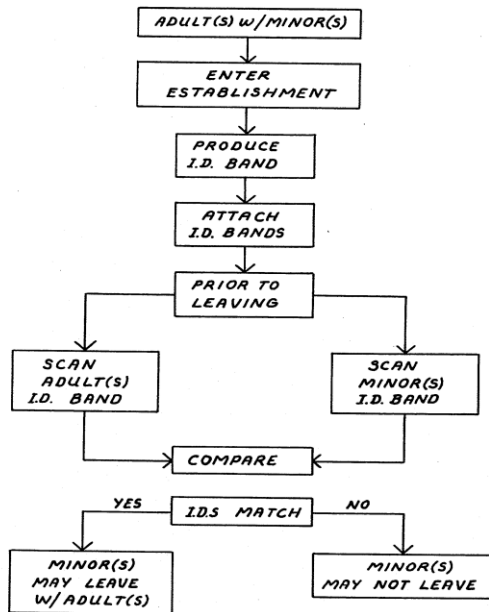
Fig. 3 – Event Plan [4]
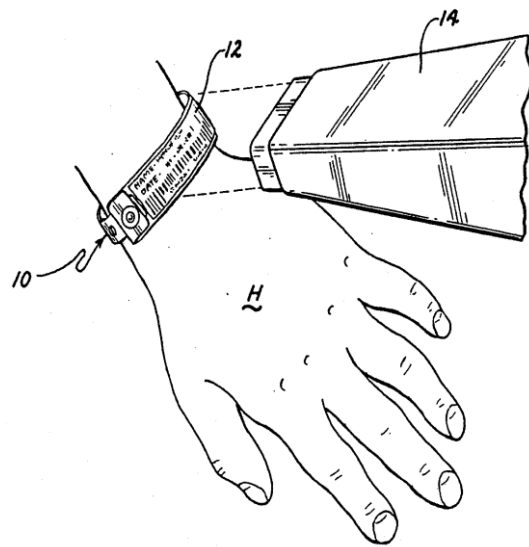
Fig. 4 – ID Bracelet [4]

[5] "CHILD POSITION MONITORING AND LOCATING DEVICE" – US PATENT 5289163A

Context: Early Alarm: In and outdoor wireless tether/leash

The system "…monitors the position of a child by detecting the signal strength of a radio frequency carrier from a transmitter attached to the child. If the signal of the radio frequency carrier is too weak, the child is too far away from the adult who has the child position monitoring device. When this happens, the adult is informed..."[5]

The system uses a directional antenna. The compass-like LED display is functional but such an outdated interface is a limitation in displaying information today. (Fig. 5)

Despite the lack of absolute position data means this system is still applicable for keeping the child in the 'circle of safety' around the parents. The application works both in and outdoors. When used indoors walls will limit and decrease the working range of this solution.

Advantage: Simple straightforward concept.

Disadvantage: Doesn't deal with positioning.
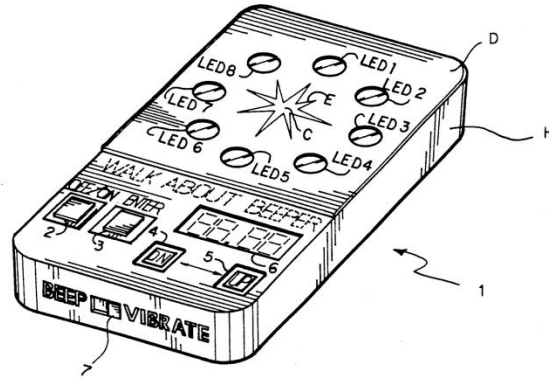
Fig. 5 – The Monitoring Device [5]

[6] ZACK SCHOLLZ – "FIND: HIGH-PRECISION INDOOR POSITIONING FRAMEWORK"

Context: Positioning software solution for WiFi devices (trilateration)

This open source framework determines the position of a client. Samples of WiFi fingerprints are captured and stored, this is called 'training a location'. As shown on the figure below; different colours represent the signals of different access points. By learning the strength of the different signals at specific locations, the client is then able to trilaterate itself. Using signal strength as an indicator for distance to an AP, the database of fingerprints can be used for estimating the client's position.
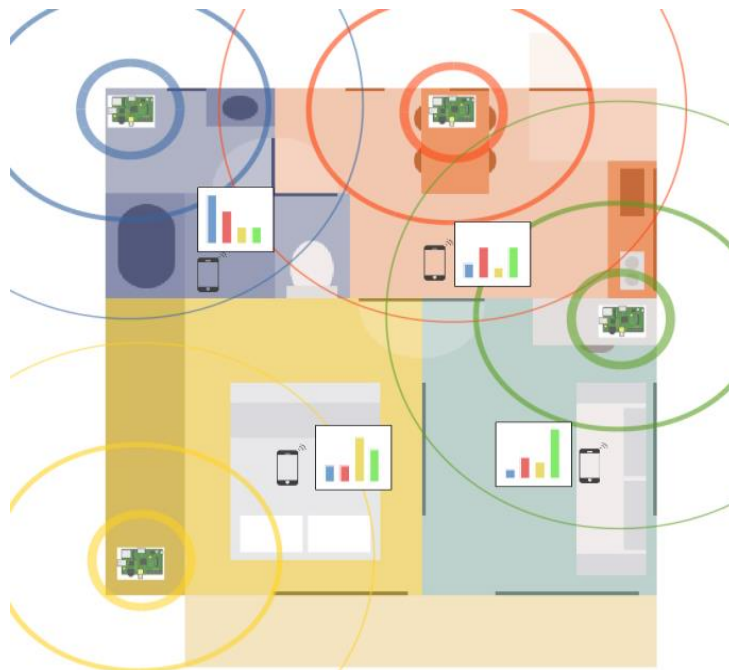
Fig. 6 – AP signal strength layout [6]

Advantage: Open source and software based positioning. Uses existing infrastructure to function indoors, and works in multi-level buildings.

Disadvantages: Positioning accuracy depends on the density of WiFi access points in range.

[7] FRANK LAMMERS – "BLUETOOTH LOST CHILD LOCATOR"
Context: Smartphone application for positioning in a predetermined domain

Guests of the venue are asked to download an application onto their smartphone. The application (Fig. 7 blue) uses the device to actively look for Bluetooth tags marked missing (Fig. 7 yellow). "When a tag is scanned, the current location of the phone is saved for 15 minutes. If the child is reported missing during this time, the phone will send the location with a timestamp to a server, which will relay this information to the parents."

The positioning relies on the smartphone's ability to obtain longitude and latitude coordinates. This happens through GPS and Assisted-GPS. When used indoors, the accuracy of the position can suffer.
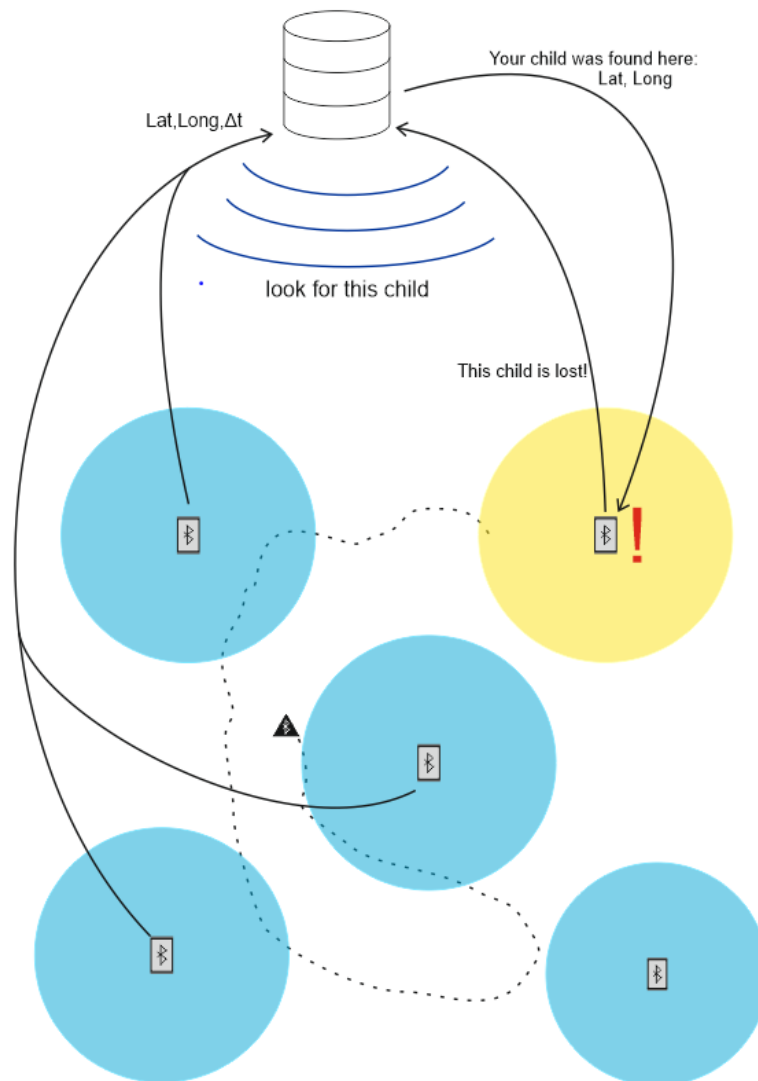
Fig. 7 – Smartphone mesh [7]

Advantage: The system's main advantage is the lack of investment necessary for hardware, and the opportunities this provides for certain scenarios. Outdoors the GPS should be accurate.

Disadvantage: Indoor position accuracy. Bluetooth has lower range compared to WiFi. For the system to function guests in the museum need to have the software running on their devices.

[10] KiGo Watch

Context: Smartwatch tracker

The KiGO watch is a device given to a child with many features, including location tracking and basic communication. The watch is capable of providing a location on demand to the parents, through a smartphone application. The indoor/outdoor location data is acquired using GPS and WiFi access point scanning. The watch features a sim-on-chip and communicates via a 2G/3G data connection.

Fig. 8 – KiGO Kid watcher [10]

Advantage: A very polished and in-context user friendly design from both the parents' (smartphone application) and the child's (watch) point of view. The device will accurately position the child outdoors with use of GPS. Possible 2-way communication with the child can be very helpful in emergencies.

Disadvantage: The indoor location data is acquired from nearby WiFi access points and compared to their proprietary database. The user is not given information about the validity, accuracy and the currentness of this database; there is valid concern for the accuracy of this indoor position data.

2.4 Related Work: Table Comparison

The related works have been compiled to Table 1, ideas and concepts of interest are highlighted.

Related work reference #	Circle of safety Early monitor	Positioning	Indoor / Outdoor	New necessary infrastructure?	Privacy concerned?
[2]	yes	outdoor only	both (unsp.)	unspecified	unspecified
[3]	no	monitored area	both (indoor)	yes	unspecified
[4]	no	no	both	yes	no
[5]	yes	no	both	irrelevant	unspecified
[6]	potentially	yes	both	no	irrelevant
[7]	no	yes	both (outdoor)	no	yes
[10]	yes	yes	both (outdoor)	no	yes

Table 1

3 METHOD

The methods and techniques used in this project will be explained in this chapter.

3.1 STAKEHOLDER ANALYSIS

A stakeholder analysis allows for the identification of the most important stakeholders within this project.

The relevant stakeholders are people and organizations affected by this project. Stakeholders are categorized in the following manner:

Primary stakeholders:

The primary stakeholders are the stakeholders who are directly affected by this project. For example: the parents and child.

Secondary stakeholders:

The stakeholders who are indirectly affected by this project. For example: The business owners.

These categories provide an outline of the stakeholders' function. In order to fully understand the significant reach of this project the stakeholders are identified by importance. Stakeholders are given a value of **interest** and **influence**. The data can then be graphed or shown in a matrix.

The definition of the **interest** variable is how much the stakeholder cares about whether the outcome is functioning as intended and secondarily whether the research produced is methodically true and accurate. The definition of the **influence** variable is how much power the stakeholder has to affect design decisions and affect the direction of the project.
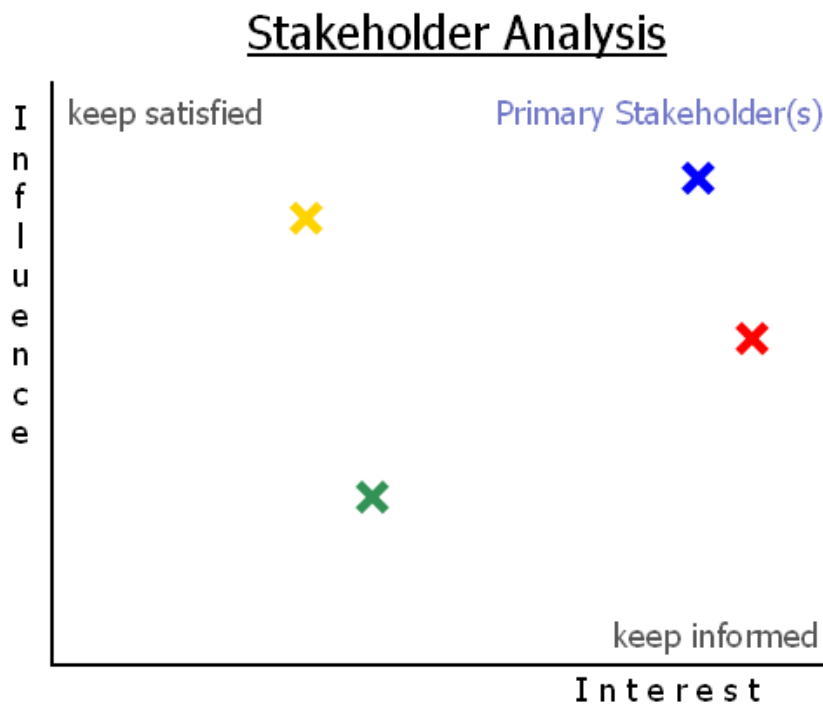

Fig. 9 – Stakeholder Analysis Example

3.2 PRIMARY STAKEHOLDER REQUIREMENTS / USER NEEDS: SEMI STRUCTURED INTERVIEWS

Semi-structured interviews are conducted with the **primary** stakeholders. This way the primary user needs can be identified. A storyboard and scenario description helps demonstrate the idea and parents are able to better understand the concept of the project.

Their answers are written on paper and then summarised below in section 4.1.2 (Ideation).

Semi-structured interviews differ from structured interviews in the sense that they allow for a more open discussion regarding the question or topic, and allow for an understanding from the stakeholder's point of view. New ideas can be brought up by the interviewees easily as a result of discussion.

3.3 MoSCoW METHOD

The stakeholders ask for a list of requirements which need to be categorized (prioritized). The MoSCoW method was developed by Dai Clegg [11]. The method uses the following categories to prioritize the stakeholder requirements:

- **Must have**: This requirement is key to the project, if it is not met the product is considered a failure
- **Should have**: This requirement is important to the project, but if it is not met, the system can still function.
- **Could have**: The implementation of this requirement is desirable, but not vital. This requirement is only fulfilled if there is/are extra time or resources.
- **Won't have**: This requirement is not expected to be fulfilled in this iteration, but can serve as recommendations for further development outside of this project.

3.4 CREATIVE TECHNOLOGY DESIGN PROCESS

The process starts with a **design question** in the form of creative inspiration, which is acquired from the **user needs** and available **technology**. **Tinkering** plays a part in bridging the gap between the **creative idea** and **technology** by helping to identify uses for existing or new technology. Creative thinking methods and related works help to generate a **creative idea** which eventually becomes a **product idea**. The **user needs** are explored through interviews with the help of sketches and mockups. This first phase is called **Ideation**.

Phase 2 is called **Specification**. It involves the exploration of the design space with the specification of the possible scenarios and concepts. Early prototypes are the product of the functional and experience specification, such as use scenarios. A **product specification** is born, through the specification of interaction, experience, service and business.

Phase 3 is the **Realisation** of the overall **product specification**. The different specifications are integrated into a main **product prototype**.
The evaluation within this phase has to address whether the final product meets the outlined product specifications.
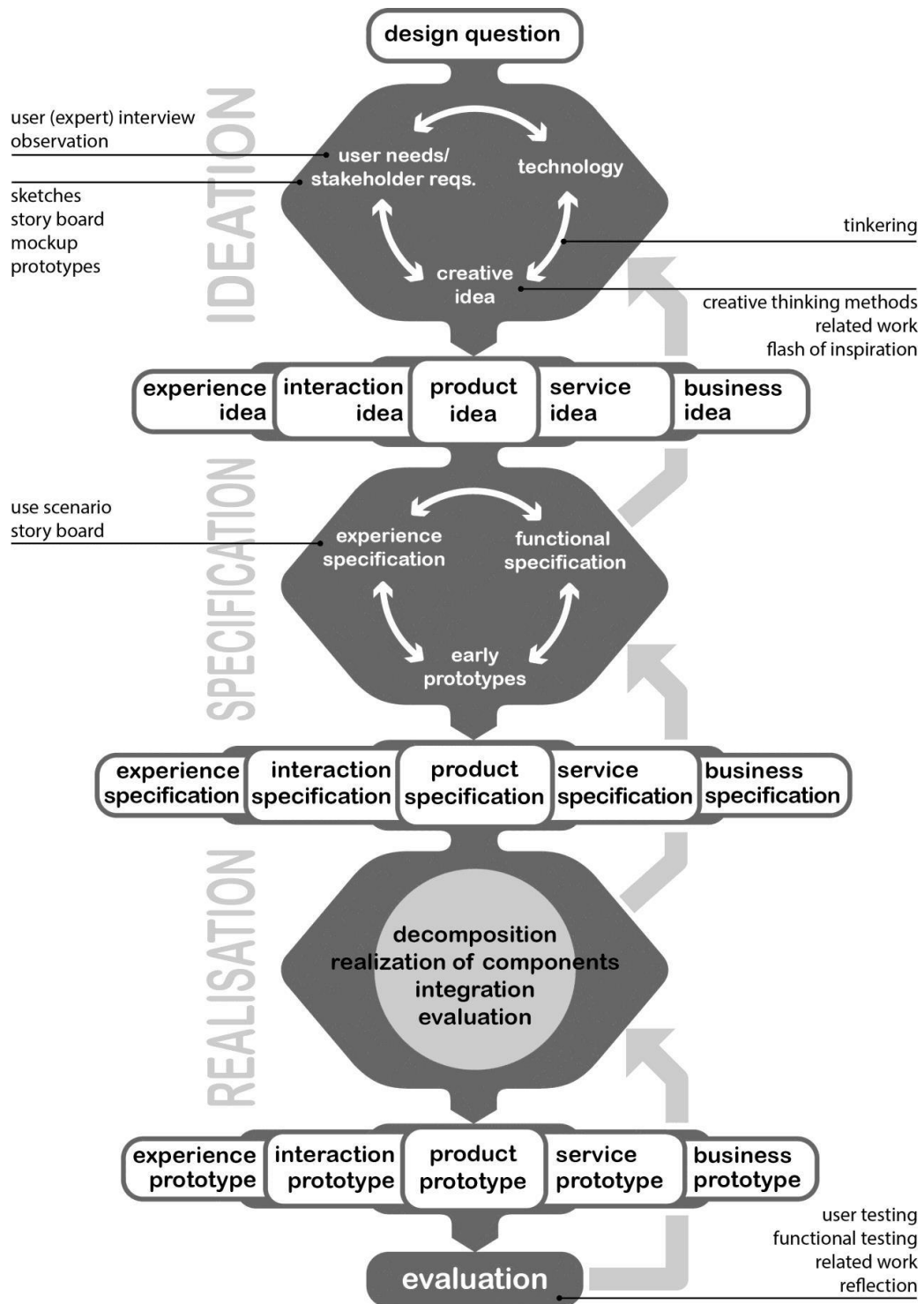
Fig. 10 – The Creative Technology Design Process [9]

4 IDEATION

4.1 STAKEHOLDER ANALYSIS

The parents are the **primary** stakeholders; they need to be the most involved. They have both the highest **influence** and **interest** within the project. They are directly affected by the outcome of the project.

The other 3 stakeholders are **secondary** stakeholders; they are indirectly affected. The child and the business owners need to be kept satisfied, while they do not have much interest in the details of the project. Creative Technology needs to be kept informed; they do not have much power in the outcome.

The 4 stakeholders were only graphed on the **interest** variable, due to the ambiguity of the **influence** in this context. Quantifying the **influence** of CreaTe, Business Owners and the Child proves subjective and hard to justify. It can be argued that these 3 stakeholders have similar levels of influence while the Parents have the highest.
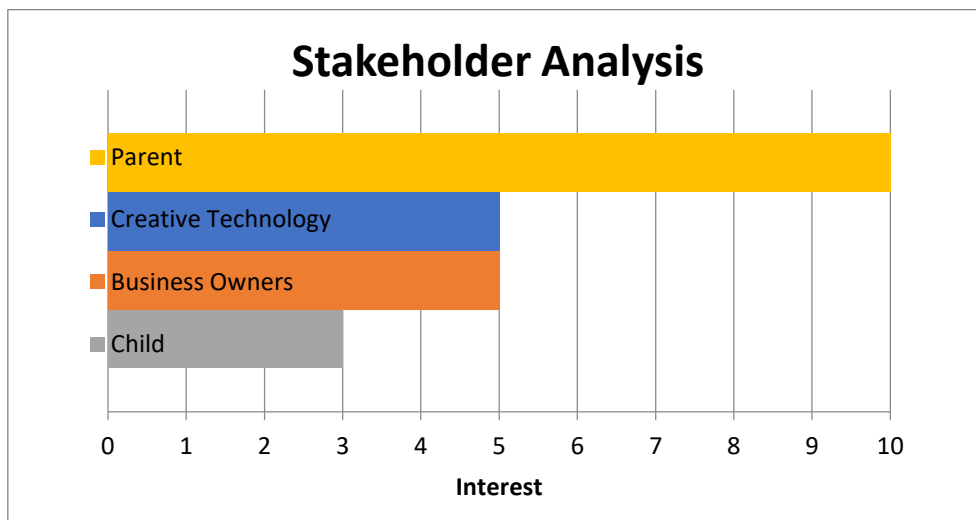
Fig. 11 – Stakeholder Analysis

4.1.1 REQUIREMENTS BRAINSTORM

Brainstorming was done to identify possible user needs. The following concept features are necessary to combat the issues identified in the problem statement 1.2 and challenges 1.2.1.

Functional Requirements:

- Notification system
- Secure Personal Information (Privacy & Encryption)
- Local Ranging/Positioning (Within the domain of the venue)

Non-functional requirements:

- Reliability
- Scalability

4.1.2 PRIMARY STAKEHOLDER REQUIREMENTS / USER NEEDS

A semi-structured interview was conducted with parents at the University of Twente. Office workers in the Zilverling building were asked to participate. 8 participants shared their opinions by answering 10 questions. Their answers provide an insight into the necessities deemed important by the users. The main requirements in the interview are identified & concluded below:

- **Notification**
  - Parents want to be notified when their child is too far away from them.
  - Sensitivity: The alarm sensitivity should be adjusted by the parent; this is preferred to a fixed alarm sensitivity setting. Example: At a public outdoor beach where the water is close and there are no walls or obstructions, the alarm needs to be triggered earlier.
- **Trustworthiness / Reliability**
  - False positives should be minimized
  - The timing of the notification directly affects how the effectivity of the system is perceived.
- **Security / Privacy**
  - Encryption of data
  - Any personal data should be deleted as soon as the child is found by the parents; alternatively interviewees suggested data may be stored for up to 24h.
- **Navigation**
  - Parents want the fastest route to their child.
  - Interviewees prefer to be guided by either voice or map navigation. Generally a map was preferred however two users preferred a car-like voice navigation.
- **Fastened / Secure device**
  - Interviewees suggested for the device on the child to be difficult to remove
    - The device should be attractive to the child (colourful design).Possibly serve with an alternative function that will keep the child engaged.
    - Alternatively the device should be embedded in clothing or somehow locked to the child.

4.1.3 DEFINED REQUIREMENTS: MoSCoW

The results of the brainstorm 4.1.1 and the interview answers in 4.1.2 are compiled and defined in terms of the MoSCoW model and separated into functional and non-functional requirements.

Functional Requirements:

Must Have:

- Early Alarm notification to help keep child in range
  - Variable sensitivity

Should Have:

- Local Ranging/Positioning (Within the domain of the venue)
- Information Privacy / Encryption

Could Have:

- Child Node with child friendly design

Won't Have:

- Voice/Other Navigation
- Child Node with alternative function to engage/interest the child
- Child Node embedded into clothing or locked to child
- Absolute (Outdoor GPS style) positioning

Non-Functional Requirements:

Must Have:

- Reliability
- Transparency
- Reusability

Should Have:

- Performance
- Energy efficiency
- Scalability

4.2 PRODUCT IDEA OUTLINE

The defined requirements of 4.1.3 are used to make a product idea. Ideas are compiled into possible solutions. The main features in the product idea outline need to adhere to the scope defined in 4.1.3.

4.2.1 EARLY ALARM

Related work [5] has one of the most important concepts that is necessary to solve the issue of alerting the parents before the child is lost. The concept monitors the signal strength between the parent and the child. This can be achieved by emitting a beacon from the position of the child (using a node on the child such as a WiFi enabled device), which is then picked up by a device in the hands of the parent (smartphone). This feature serves as the early alarm warning system, the **signal strength** is a precursor to the **distance** between the child and the parent. A notification alarm can be set to alert before the signal is completely lost. The goal is to notify the parent after the child has crossed a certain distance and has left their parents' line of sight or 'circle of safety'.

In the case that the absolute positions of both the parents and the child are known, the distance (difference) between the two positions can easily be calculated. For example: In an outdoor environment this would be possible with GPS. Using this method the **Early Alarm** could also be triggered, however GPS is not a viable application for this project due to its limitations.

4.2.2 LOCAL RANGING/POSITIONING

GPS is a common and available technology; however it is unreliable and should not be expected to work for indoor applications. Outdoor coverage is expected almost everywhere without a roof; but indoor accuracy suffers if coverage is available at all.

It is possible to estimate the relative position of a child using only software & the WiFi landscape. Related work [6] allows a WiFi enabled device to estimate its own position. The potential of this technology is extensive. However the database of the latest WiFi landscape has to be kept updated for the positioning to work accurately. The application of such software on the child node means positioning could work indoors as well as outdoors.

The system uses existing infrastructure; the WiFi access points that the technology uses to locate itself are quite common. Costs are lowered for stakeholders in the sense that less hardware is required. However that is not to say that coverage will be exclusively guaranteed everywhere. The needed dense coverage is most likely available inside modern buildings.

Related work [3] uses RFID gates to monitor designated areas such as entrances and exits. These "monitoring points" can be effective however the RFID working range limits them. The child has to pass through the gate at close proximity for the signal to be picked up. Just like theft alarm gate systems in shops.

WiFi can be used to substitute RFID technology to create **monitoring points**; WiFi has the benefit of having a larger working range. **Sentinels** are nodes responsible for scanning the WiFi devices that pass through a monitoring point. While the child is emitting a WiFi beacon and happens to walk past a **Sentinel**, this beacon can be sent to and displayed on the parents' smartphone. Since the position of the sentinel is known, the position of the child is known as a radius around the **Sentinel** (ranging).

If the beacon is picked up by at least 3 **Sentinels**, the **Child Node**'s position can be trilaterated relative to the fixed position of the **Sentinels** (Fig. 18).

4.2.3 INFORMATION PRIVACY

Personally identifiable information can never be explicitly shared without obscuration (encryption). The **Child Node** identifier needs to be passed to the sentinel since it acts as another pair of eyes and needs to know what to look for. This data exchange tunnel needs to be encrypted. A public/private key scheme can be used, where keys are given to both sentinel and smartphone app. (Fig. 15)

An issue with Fig. 15 is that Public and Private keys need to be distributed; hence an additional authentication server might be necessary. This server would be responsible for handing out the keys, as well as the list of available sentinels and their corresponding addresses.

4.2.4 CONCLUSION

In summary the product idea consists of 3 main system components defined in 5.1.

5 SPECIFICATION

5.1 SYSTEM SPECIFICATION

5.1.1 CHILD NODE

The **Child Node** is a small piece of wearable technology, such as a bracelet. It should be physically small and should not interfere with the everyday tasks that the child might do.

The **Child Node** has one main function: emitting the beacon that will be picked up by the **Smartphone Application** and the **Sentinel**(s). The beacon will be emitted from the child's position which is assumed to be constantly changing.

The **Child Node** needs to have an identifier that the parents can enter into the **Smartphone Application**.
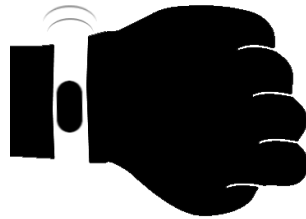
Fig. 12 – Child Node illustration

5.1.2 SENTINEL

The **Sentinel** is a node with a fixed position within the local domain. This position is vital information; it is used to calculate the position (range) of the **Child Node** relative to the position of the **Sentinel**(s).

The function of the **Sentinel** is scanning for beacons in a designated area. The **Sentinel**(s) need to communicate with the **Smartphone Application**. This 'data exchange' includes the **Child Node** identifier (to know what to scan for) and the corresponding sighting data.

Fig. 13 – Sentinel illustration

5.1.3 SMARTPHONE APPLICATION

The **Smartphone Application** is responsible for the interaction with the user. The **Child Node** identifier needs to be selected by the parents through the **Smartphone Application**.

Just like the **Sentinel**, the **Smartphone Application** is also responsible for scanning for beacons of the selected **Child Node**. The 'circle of safety' or this monitored area around the parents is used to sound the **Early Alarm**. When the beacon is lost or out of the specified range (sensitivity) the **Early Alarm** sounds.

The data exchange with the **Sentinel**(s) involves relaying the selected **Child Node** identifier, and receiving sighting data. This data is displayed as information to the parents.

The parents specify the sensitivity for the **Early Alarm** within the **Smartphone Application**. This sensitivity should be presented in a user friendly unit of measurement, preferably other than signal strength.

Fig. 14 – Smartphone Application illustration

5.1.4 SECURITY SPECIFICATION

The **Smartphone Application** interacts with the **Sentinel**(s).This data exchange needs to be secured to make sure that in case of a man-in-the-middle attack, the data is obscured. A public-private key encryption scheme can be used as shown below in Fig. 15.
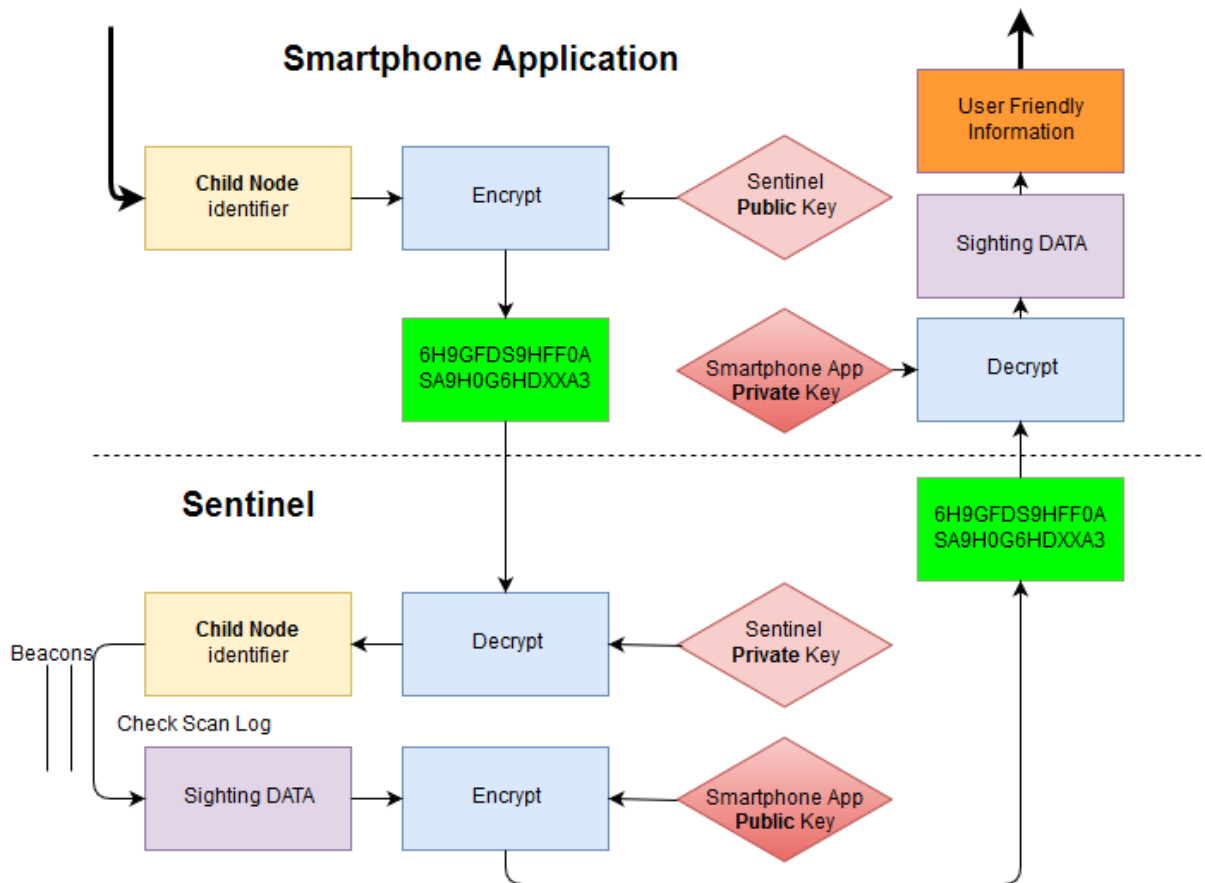
Fig. 15 – Public/Private key scheme between the Smartphone App and the Sentinel

5.1.5 FUNCTIONAL OVERVIEW
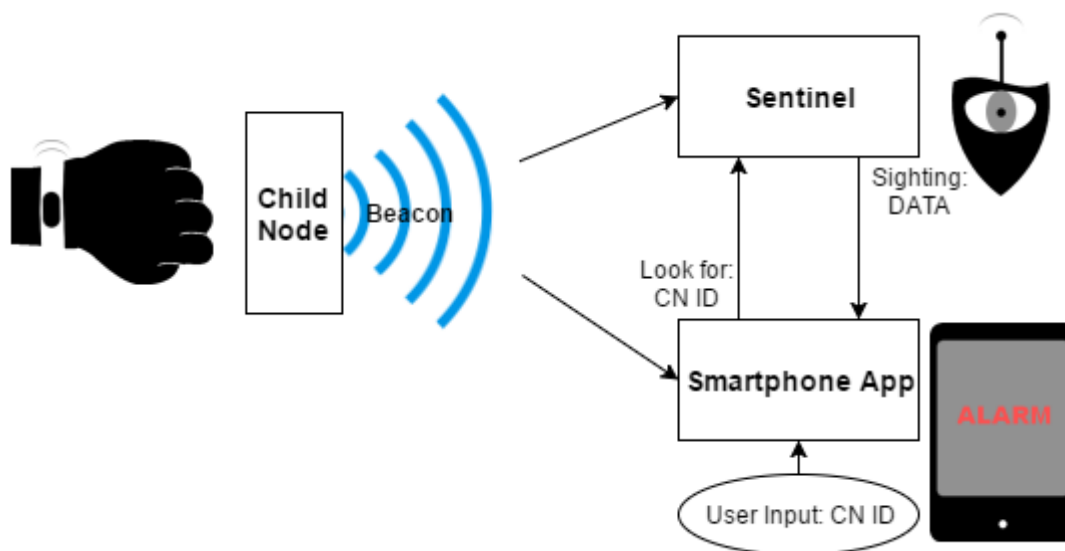
Fig. 16 – System: Functional overview
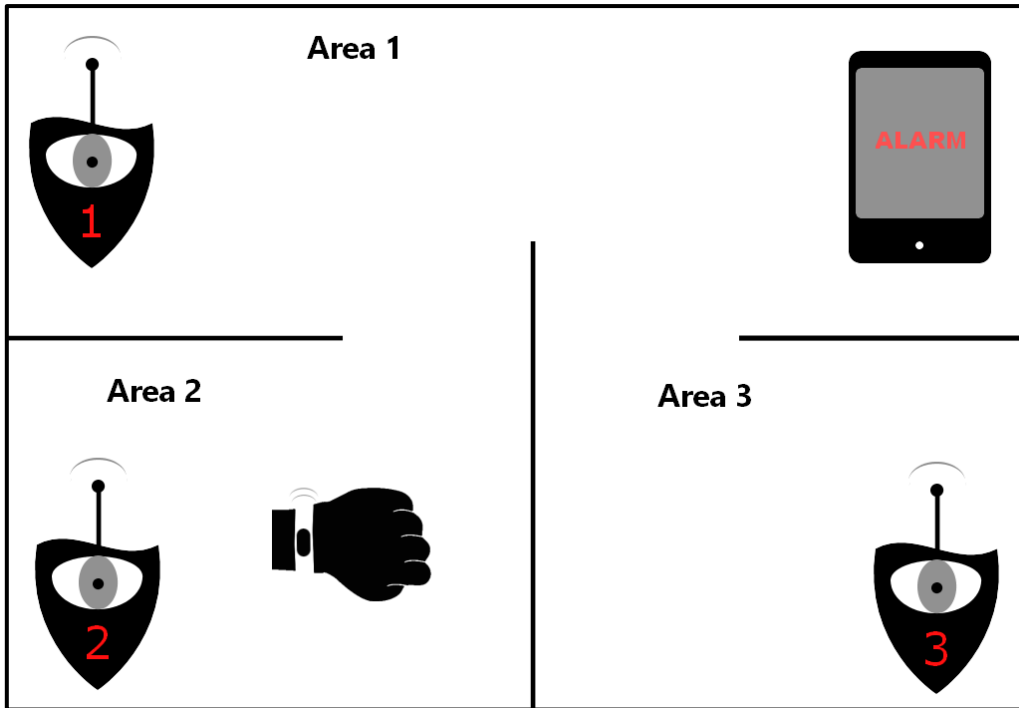
Fig. 17 – System: Top-Down Map Demonstration

In Fig. 17 the **Child Node** can be found in Area 2, which means that the beacon emitted by the **Child Node** will be picked up by **Sentinel** 2. In the case that the beacon is also picked up by Sentinels 1 & 3, trilateration can be used to position the **Child Node**. The radii around 2 **Sentinels** intersect at 2 possible points, and the radii around 3 **Sentinels** only intersect at one point. This is shown below in Fig. 18.
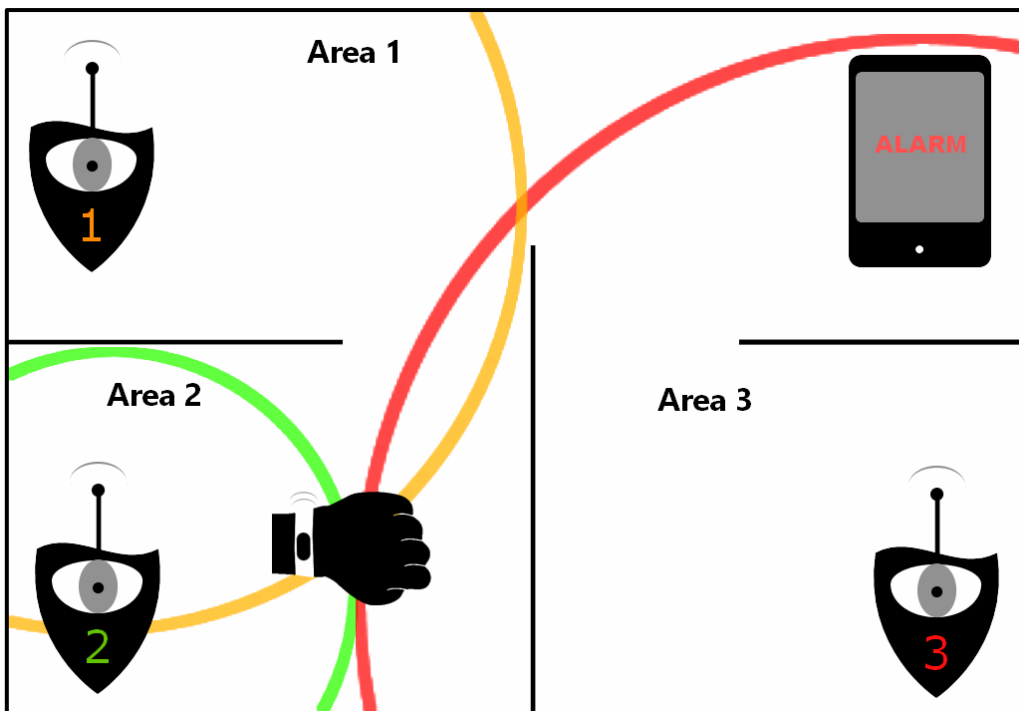
Fig. 18 – System: Top-down map demonstration with trilateration

5.2 INTERACTION & EXPERIENCE SCENARIO

Parents Michael and Sophie decide to spend the weekend at a nearby city, where they have not been before. They enjoy being tourists and seeing what the city has to offer. They have a 6 year old who is impatient and wants to see the dinosaurs in the renowned local natural history museum.

The family arrives at the entrance of the museum and little Jimmy is flourishing in excitement. He cannot wait to see how big dinosaurs actually were. At the entrance is a queue with a wait time of about 15mins.

"Not too bad" Michael thinks to himself. There are warnings not to touch the exhibits and warnings reminding parents to keep their children and valuables under close supervision.

One sign explains how there is a system in place for monitoring your child within the museum. The supervision system enables the parents to know when their child is at a close proximity and receive a notification on their smartphone if the child has left this circle of safety. The child needs to wear a device which emits a beacon. This beacon is also picked up around the museum by other monitoring devices called 'sentinels'. If the child is lost and out of sight, and the parents cannot find him/her; then the parents are able to request the position of where the beacon was last picked up. Sophie also sees the sign and they decide to ask for the device to make sure Jimmy doesn't get lost.

At the counter they are given the beacon emitting bracelet, which they give to Jimmy while explaining the purpose and not to take it off. On the inside of the bracelet is an identifier code, which Michael types into his smartphone; the monitoring application is available for download which only takes a few seconds.

They step inside the museum, it is spectacularly old and large building; there is a crowd, not too dense. But as they move closer to the T-Rex skeletons, there are more and more people.

Michael checks at his smartphone, which displays the distance to Jimmy; the number updates every second or so. He has enabled the alarm to go off at the sensitivity he thinks is necessary. This sensitivity can be adjusted and is based on the distance value to Jimmy.

They walk past exhibits of cavemen and prehistoric animals.

Michael and Sophie exhausted, sit down on a bench looking at tigers, while Jimmy is excited and running around from dinosaur to dinosaur with the bracelet on his leg. There are a lot of people between them and the line of sight to Jimmy is not clear. The alarm goes off.

This is when Sophie decides to go toward the direction where Jimmy was playing. She makes her way through the crowd, past the huge skeletons. She thought he would be there. She keeps walking through the crowd into the jungle section of the museum; thankfully Jimmy is there looking at the interactive moving dinosaurs.

"They're real!" he exclaims when he sees his mother.

Sophie frustrated, tells Jimmy to follow her back to the bench where they will get ice cream to calm him down. He hesitates for a second but then takes her hand and they walk through the crowd back to the bench where Michael is waiting nervously. He has his smartphone out and was ready to request the last seen location of Jimmy.

6 REALIZATION

6.1 CHILD NODE

A device called Raspberry Pi Zero W was used, powered by a 1Ah Lithium-ion battery with a charge/discharge module. This linux device was chosen for its compact form factor and its onboard WiFi radio. It runs Raspbian; a Debian based linux operating system.

During the boot sequence the linux command "create_ap -n wlan0 Pi1 SecurePassword123" is loaded. With this command, a secured 'dumb' access point is created. [12]

The SSID of the access point running on the **Child Node** is the **Child Node** identifier that the parents need to know. In this case: "Pi1".
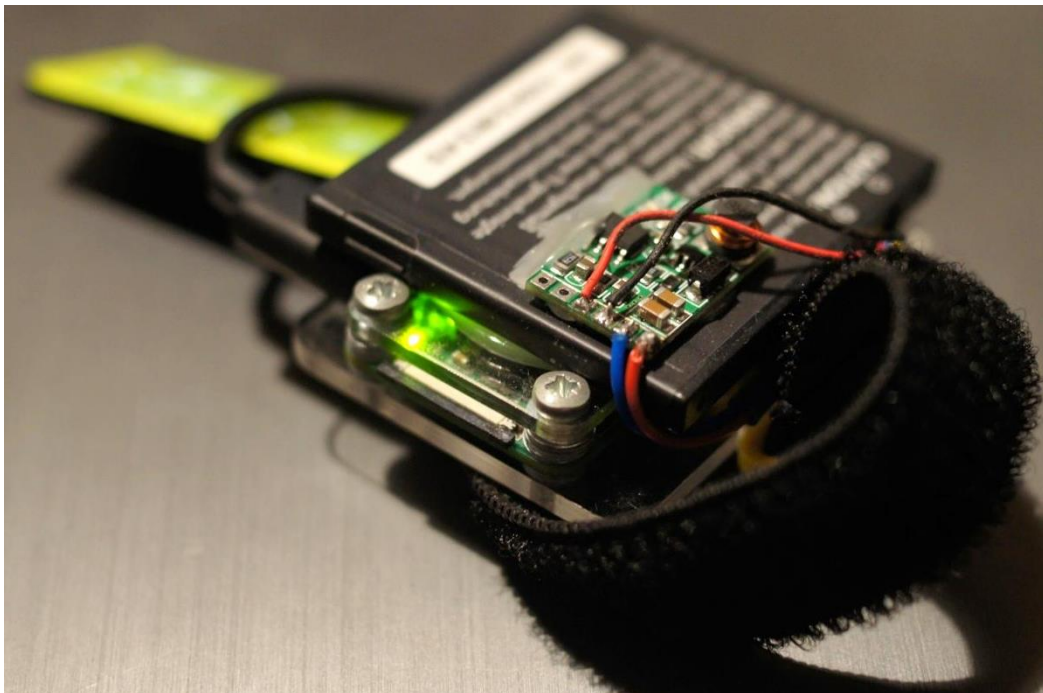
Fig. 19 – Child Node prototype

6.2 SENTINEL

The device used for the **Sentinel** is a regular non-wireless Raspberry Pi Zero. An external usb WiFi 'D-Link DWL-G122' dongle was used.

6.2.1 PYTHON SCRIPT

The Python language was used to create a script which logs necessary information; such as the SSID and RSSI (see 10.2.1 for code). To achieve this, a dependency called 'wifi' was used [13].

6.2.2 AIRODUMP-NG

Aircrack-ng is a utility toolset which includes Airodump-ng [14]. This utility captures raw WiFi frames and displays a list of detected access points. The utility can be configured to ouptut the captured data in csv format. Functionally it does the same as the 6.2.1 Python script, but is standalone (optimized) software.

Limitation:

The Airodump-ng utility requires the WiFi radio to be run in monitor 'sniffing' mode. This means that the radio listens to and captures all wireless WiFi frames. In this mode the **Sentinel** is not be able to communicate with the **Smartphone Application** over the WiFi network. (cont'd evaluation 7.2.2)

6.3 SMARTPHONE APPLICATION

Android Studio was used (an integrated development environment for the Android operating system) to create the **Smartphone Application**.

The application scans for nearby access points and stores them in a list. The list is presented on the interface and the user is allowed to choose which access point to monitor. In the background this list is updated at the interval, that the devices allows. The RSSI is presented to the user, who can use a slider to specify the sensitivity of the **Early Alarm**. Since this RSSI value is an obscure value that that user will not be familiar with, an estimation of distance was implemented using the Free Space Path Loss formula (FSPL). However there exists is no standardized relationship of any particular physical parameter to RSSI.

6.3.1 THE FSPL EQUATION

$$\text{Distance in meters} = 10^{\frac{(27.55 - (20 \times \log_{10} \textbf{frequency}) + \textbf{RSSI})}{10}} \quad [15]$$

The Free Space Path Loss calculation is idealistic and not accurate in real world scenarios. It assumes a perfectly clear line-of-sight between the 2 antennas with no walls or obstacles. Hence FSPL is rarely used by itself but rather as part of the Friis transmission equation which is more accurate at estimating distance as it includes the gain of antennas in the model. [16]

The calculated distance value in meters becomes more positively inaccurate as the RSSI increases

6.3.2 INTERFACE

The interface presents the user with the necessary information on a single home screen. The distance in meters is calculated once an access point has been selected; post selection, the frequency and RSSI is input into the FSPL formula and a physical parameter in meters is calculated and displayed.
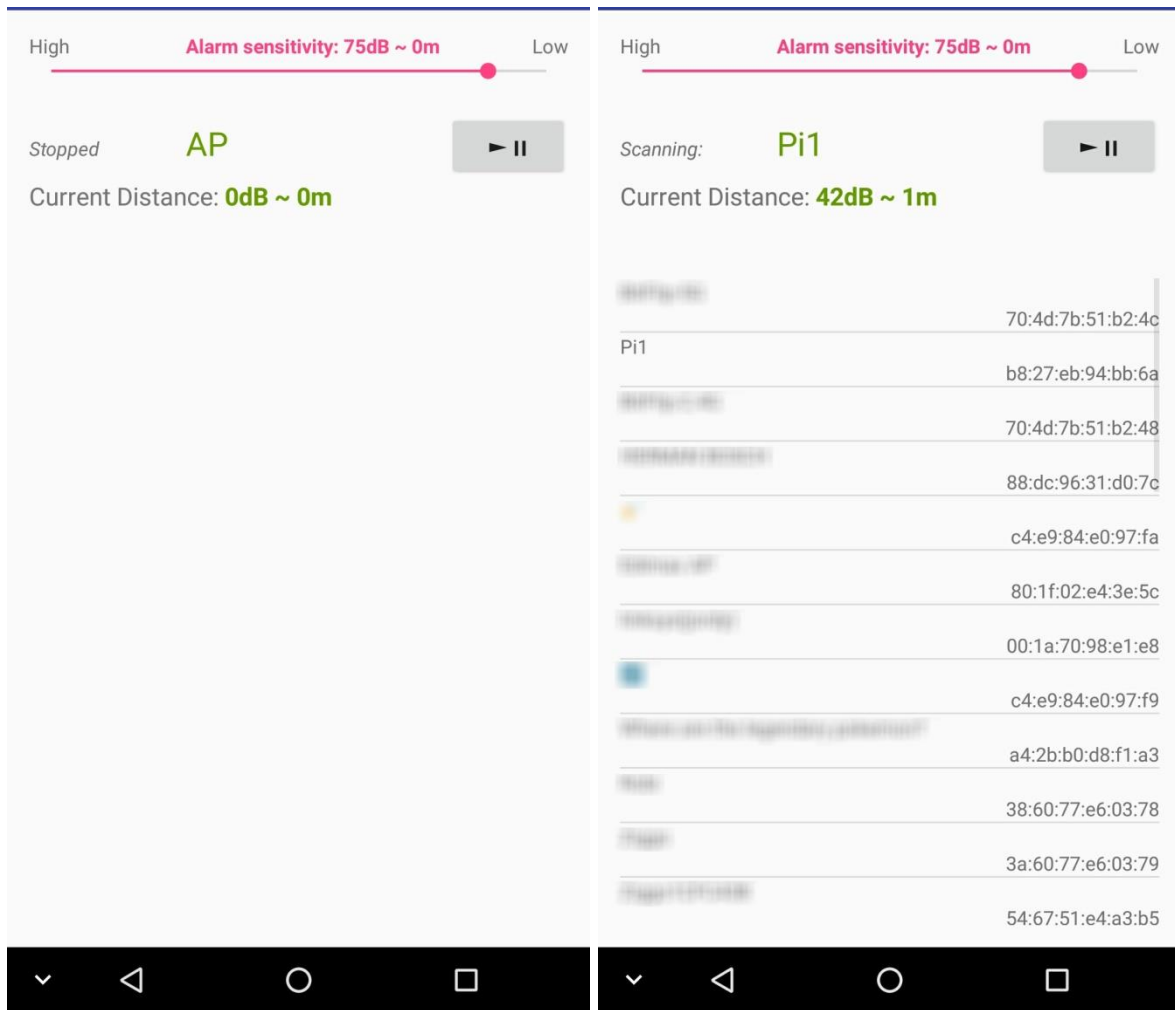
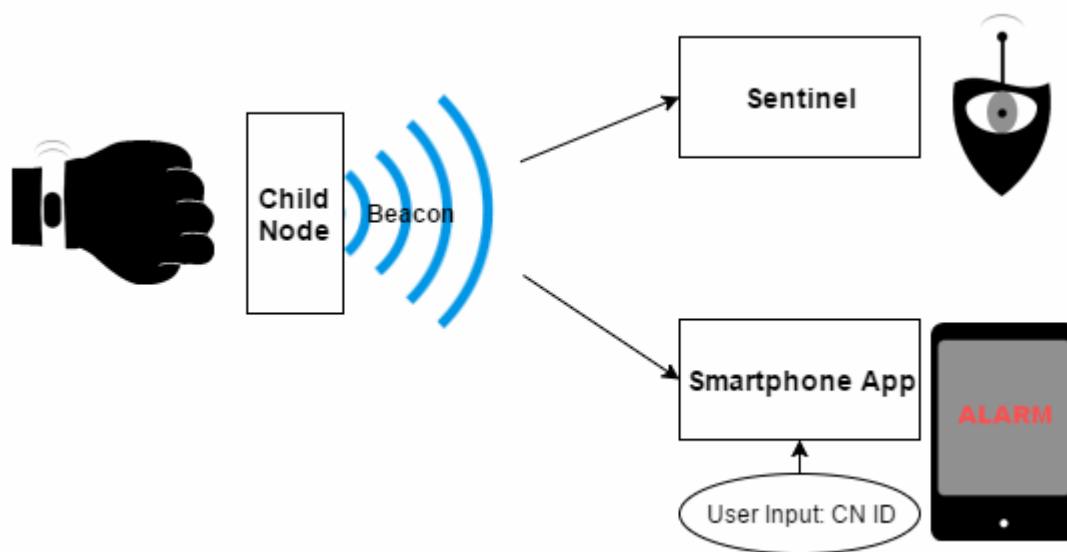**Fig. 20** – Smartphone Application screenshots

Fig. 21 – Realized System overview

7 EVALUATION

7.1 CHILD NODE

The system was evaluated with the 'Raspberry Pi Zero W' as the **Child Node**. It should be noted that with different hardware, the performance will likely differ. A different WiFi radio with a different antenna will not have the same characteristics as the onboard radio of the Raspberry Pi Zero W.

The battery powers the Raspberry Pi for 2.5-3 hours.

7.2 SENTINEL

7.2.1 PYTHON SCRIPT

The Sentinel was tested at a large indoor hall (SmartXP, University of Twente). During this testing it demonstrated unsatisfactory performance as a result of its sampling speed. The RSSI sampling interval of a specified access point constantly exceeded 15s. This leaves a large window of time where not enough data is being gathered and an opportunity for a child to potentially enter and leave a monitoring area without the beacon being captured.

The SmartXP has a large number of wireless IoT devices which potentially create interference, hindering the performance of the **Sentinel**. This is a stress test for the system straining it under difficult conditions. Further testing of the **Sentinel** should be carried out under different circumstances in different environments. The lack of variation in testing for this system component is a weakness of the component's evaluation.

The Raspberry Pi's weak CPU was constantly utilized at 100% while running the Python script.

7.2.2 AIRODUMP-NG

Airodump-ng operated in monitor mode showed improved sampling performance. However if Airodump-ng were to be used, another method of communication such as an Ethernet connection to the local network (which the smartphone is connected to) would be necessary.

Another solution is to use other high performance hardware which is capable of operating in monitor mode and communicating to the local WiFi network at the same time.

A system with dual WiFi radios; one listening in monitor mode and the other operating in standard mode connected to the local WiFi network could also be possible.

Airodump-ng outputs data in csv format and parsing this as input into a Python script utilizes the Raspberry Pi's CPU heavily. Reading and parsing the standard I/O streams of Airodump-ng's console output in Python was not possible.

7.2.3 SENTINEL LIMITATIONS: RANGING/POSITIONING & DATA EXCHANGE

Due to the sampling performance limitations and time constraints, reliable **Sentinel** ranging and trilateration positioning is not possible. Subsequently the data exchange between the **Sentinel** and the **Smartphone Application** was not implemented [Fig. 21].

7.3 SMARTPHONE APPLICATION

7.3.1 RUNAWAY BEACON PROBLEM

When the RSSI value on the smartphone is above 80 dB, and the child is assumed to be walking away from the parent, another beacon reading should not be expected with confidence. When the signal is this weak, it may drop out and not register again. To notify the parents reliably, precautions need to be taken.

The weakest setting for the **Early Alarm** sensitivity slider should be limited to 85 dB. When the signal strength is this low (in the range of 85-100dB), sampling confidence is weak and the system is unreliable.

Another proposed solution in case of a 'runaway beacon': A **Runaway Alarm** should sound in the case that the last beacon was weaker than 75dB and no other beacon has been received in the past 20 seconds (Fig. 22).
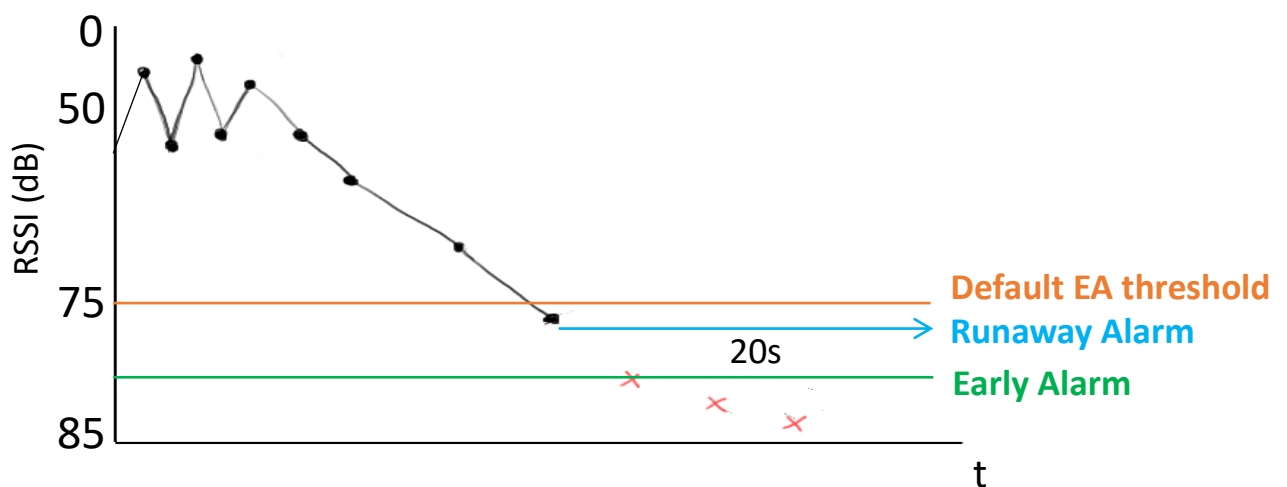
Fig. 22 – Runaway Alarm graph
The red crosses indicate unregistered beacons

7.3.2 ALARM TESTING

Indoor and outdoor environments were tested.

The outdoor test consisted of a straight-line pre-marked path down a street of 25m and 100m. The **Child Node** was left stationary while the **Smartphone Application** was displaced along the path at varying walking velocity.

The indoor test consisted of the **Child Node** placed in a room at one end of a house and the **Smartphone** displaced out of the room, along a hallway to the front door, also at varying walking velocity.

The displacement was recorded in meters at the moment the alarm sounded, based off a measure, using real-world markers.
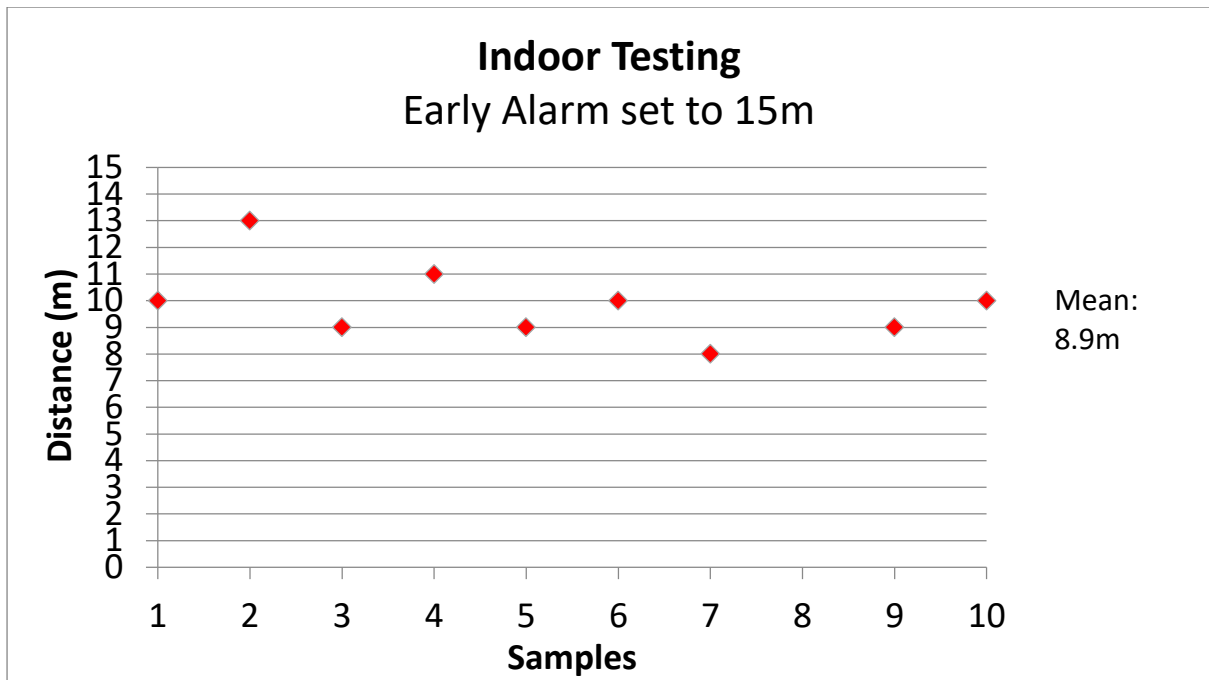
Fig. 23 – Early Alarm indoor test results

The results of the testing are as expected. The Early Alarm goes off before the configured distance due to the idealistic FSPL distance calculation (see 6.3.1) and the nature of RSSI.

Indoor circumstances mean that close range signal dropout should be expected more than with outdoor circumstances. This can be seen as an anomaly on Fig.22 (sample #8). Signal dropout occurred while the last received beacon was not weaker than the Runaway Alarm threshold and hence neither the Early Alarm nor the Runaway Alarm were activated.

Fig. 24 – Early Alarm outdoor test results

The **Runaway Alarm** was activated in 3 out of the 5 cases. It is an important feature that prevents false negatives, improving reliability and complementing the **Early Alarm**.

The difference between the mean activated distance and the **Early Alarm** setting for indoors 15m, outdoors 25m and outdoors 100m is **6.1**m, **6.2**m and **14**m respectively. Thes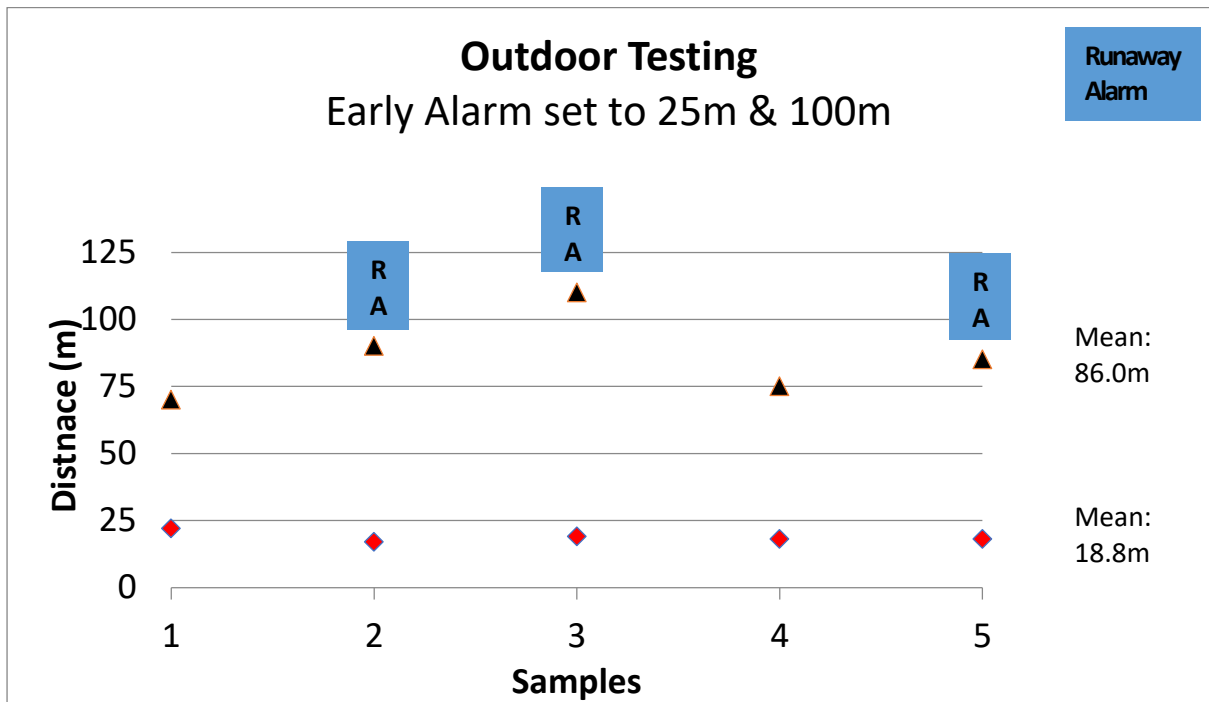e values show how much earlier the alarm activated compared to the real distance. These values needs to be adjusted so the different tests can be compared. Each value is divided by its total distance (eg. 6.1 ÷ 15 = 0.4067)

The results are **0.4067**, **0.2480** and **0.1400** respectively. These results show that relative to each other, the indoor test activated the most early (probably due to wall interference). The outdoor tests suffered from less interference which shows in the results, they activated less early. The **Runaway Alarm** might have skewed the data when it only activated after the timer completed and the person kept walking, possibly achieving a farther distance.

7.3.3 INTERFACE

The interface has only a single home screen which contains a lot of information. User friendliness could be potentially improved by using multiple screens and guiding the user through the process of first enabling scanning, selecting an access point and finally setting the alarm. A wizard like interface could be more user friendly to first time users, however due to time constraints this was not implemented.

"The simpler the better; interface designs with the least amount of information load happen to be the fastest and most effective ones" [8].

8 CONCLUSION & FUTURE WORK

The sampling interval directly defines how much data is gathered. The more data is available, the higher the quality of the conclusions that can be drawn from it. This translates directly to the non-functional requirement of reliability.

Fine tuning the Runaway Alarm should be done by performing more thorough testing in different environments to minimize false positives.

Improving the RSSI to physical parameter conversion can be done by using the Friis transmission equation and incorporating the antenna transmit power. This means the software needs to be hardware specific.

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10 APPENDIX

10.1 STAKEHOLDER REQUIREMENT INTERVIEW RESPONSES

1. **Have you ever heard of such a system?**
No one has heard of such a system specific to a public venue such as a museum. (8x)

2. **Have you ever used such a system? If so, can you please give details?**
No (7x)
Interviewees have used applications such as live location sharing. (1x)

3. **In your opinion, for what ages is such a system necessary?**
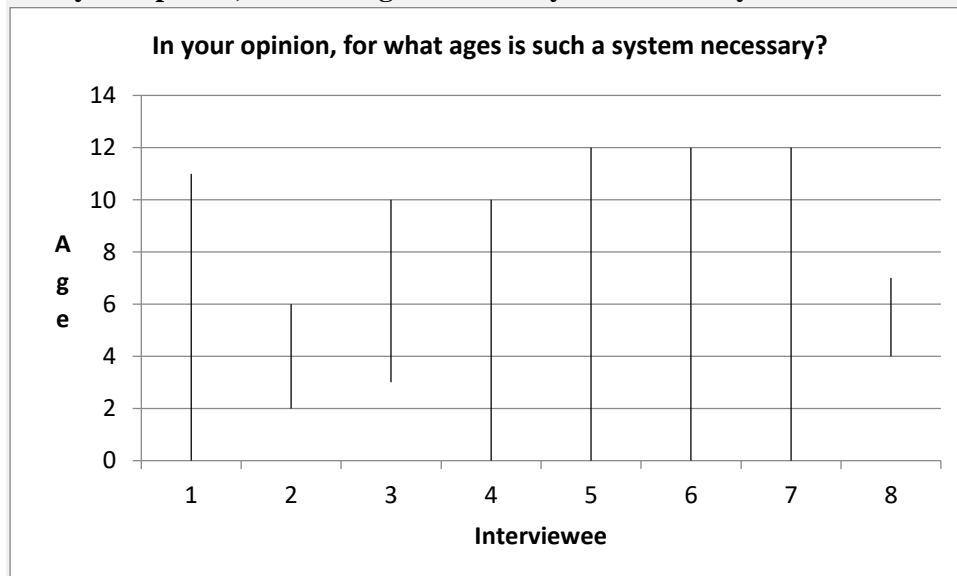
0-11
2-6
3-10
>10
>12 (3x)
4-7

4. **What features would you like?(eg. in a Smartphone application)?**
Work without internet access
Give the fastest route to the child

Be privacy concerned
Guide by Voice nav
Guide by Map (2x)

5. **The system should act after... (first notification)**
6-7 meters (2x)
10mins
When the child is out of sight (2x)
When contact with child is lost
User set custom range (early alarm sensitivity)

6. **What should happen right after the child is lost.**
Notification message (4x)
Start of 2-way comm
Like a car (map) nav (2x)
Voice nav

7. **What makes the system trutworthy?**
Security (2x), encryption
Speed (3x)-When the system notifies the parents asap
Difficult to remove, no need for working wifi, no need for battery
No false positives, reliability, correct directions to the child (2x)
When it has proven its efficiency

8. **How long can the data be kept?**
24h (3x)
Until the child has been found (5x)

9. **Would the child try to remove the device?**
Its possible (6x)
No (2x)

a. **What are ways of preventing this?**
Lock (2x)
Unremoveable (2x)
Appeal to child, design colour etc (2x)
Explain purpose of device (2x)

10.2 CODE

10.2.1 SENTINEL: PYTHON SCRIPT

```
import wifi
import time


while 1:
    wifilist = []
#   cells = wifi.Cell.all('mon0')        #use when in monitored mode
    cells = wifi.Cell.all('wlan0')       #use when in regular mode
    for cell in cells:
        wifilist.append(cell)
        print(str(cell.signal) + "  " + cell.frequency + "  " + cell.ssid)
#   time.sleep(10)
    print(' ')
```

10.2.2 SMARTPHONE APPLICATION: ANDROID STUDIO CODE

```
package nl.adamk.wifitest;

import android.Manifest;
import android.app.Activity;
import android.content.BroadcastReceiver;
import android.content.Context;
import android.content.Intent;
import android.content.IntentFilter;
import android.content.pm.PackageManager;
import android.media.MediaPlayer;
import android.net.wifi.ScanResult;
import android.net.wifi.WifiManager;
import android.os.Build;
import android.os.Bundle;
//import android.util.Log;
import android.os.CountDownTimer;
import android.util.Log;
import android.view.View;
import android.widget.AdapterView;
import android.widget.Button;
import android.widget.ListView;
import android.widget.SeekBar;
import android.widget.SimpleAdapter;
import android.widget.TextView;
import android.widget.Toast;

import java.util.ArrayList;
import java.util.HashMap;
import java.util.List;


public class WiFiDemo extends Activity implements View.OnClickListener {
    boolean scanning = false;
    WifiManager wifi;
    ListView lv;
```

```java
    TextView textStatus;
    TextView currentAP;
    Button buttonScan;
    TextView sensitivity;
    SeekBar seekbar;
    int sens = 75;             //default alarm sensitivity value
    int rssi = 0;              //rssi init
    TextView metersDisplay;
    TextView sensmetersDisplay;
    String SSID_KEY = "ssid_key";
    String BSSID_KEY = "bssid_key";
    ArrayList<HashMap<String, String>> arraylist = new ArrayList<>();
    SimpleAdapter adapter;
    private TextView signal;
    private String tracking = "";
    public CountDownTimer timer;
    public int freq = 0;

    /* Called when the activity is first created. */
    @Override
    public void onCreate(Bundle savedInstanceState)
    {

        final MediaPlayer alarmSound = MediaPlayer.create(this,
R.raw.alarm);          //create alarm media player
        timer = new CountDownTimer(22000,1000){
            public void onTick(long millisUntilFinished){

            }
            public void onFinish(){
                alarmSound.start();
            }
        };
        super.onCreate(savedInstanceState);
        setContentView(R.layout.activity_main);

        if(Build.VERSION.SDK_INT >= Build.VERSION_CODES.M){
            requestPermissions(new
String[]{Manifest.permission.ACCESS_WIFI_STATE,
Manifest.permission.ACCESS_COARSE_LOCATION}, 1);
        }
        currentAP = (TextView) findViewById(R.id.displayAP);
        textStatus = (TextView) findViewById(R.id.textStatus);
        signal = (TextView) findViewById(R.id.signal);
        buttonScan = (Button) findViewById(R.id.buttonScan);
        lv = (ListView)findViewById(R.id.list);
        metersDisplay = (TextView) findViewById(R.id.meters);

        buttonScan.setOnClickListener(this);

        wifi = (WifiManager)
getApplicationContext().getSystemService(WIFI_SERVICE);
        if (!wifi.isWifiEnabled())
```

```
        {
            Toast.makeText(getApplicationContext(), "wifi is
disabled..making it enabled", Toast.LENGTH_SHORT).show();
            wifi.setWifiEnabled(true);
        }
        this.adapter = new SimpleAdapter(WiFiDemo.this, arraylist,
R.layout.row, new String[] { SSID_KEY, BSSID_KEY, }, new int[] {
R.id.ssid_value, R.id.bssid_value });
        lv.setAdapter(this.adapter);
        lv.setOnItemClickListener(new AdapterView.OnItemClickListener(){
            @Override
            public void onItemClick(AdapterView<?> parent, View view, int
position, long id){
                HashMap<String, String> item = (HashMap<String, String>)
parent.getItemAtPosition(position);
                currentAP.setText(item.get(SSID_KEY));
                tracking = item.get(BSSID_KEY);    //set tracked bssid
            }
        });

        registerReceiver(new BroadcastReceiver()
        {
            @Override
            public void onReceive(Context c, Intent intent)
            {
                if (!scanning) return;
                arraylist.clear();
                List<ScanResult> results = wifi.getScanResults();

                for (ScanResult result : results)
                {
                    HashMap<String, String> item = new HashMap<>();
                    item.put(SSID_KEY, result.SSID);
                    item.put(BSSID_KEY, result.BSSID);
                    arraylist.add(item);
                    if (tracking.equals(result.BSSID)) //check scanresult
for tracked BSSID
                    {   freq = result.frequency;
//Log.d(WiFiDemo.class.getSimpleName(),String.valueOf(freq));
                        rssi = Math.abs(result.level); //save result level,
math.abs to remove (-)
//Toast.makeText(getApplicationContext(), String.valueOf(rssi),
Toast.LENGTH_LONG).show();
                        if (rssi >= 70 ){
                            timer.cancel();
                            timer.start();
                        }
                    }
                }
                if (rssi >= sens){
//Log.d(WiFiDemo.class.getSimpleName(), String.valueOf(rssi) + " is more
than " + String.valueOf(sens));
```

```
//Toast.makeText(getApplicationContext(), "ALARM" ,
Toast.LENGTH_SHORT).show();
                    alarmSound.start();
                }
//else {
//Log.d(WiFiDemo.class.getSimpleName(), String.valueOf(rssi) + " is less
than " + String.valueOf(sens));
//Toast.makeText(getApplicationContext(), String.valueOf(rssi) + " is more
than " + String.valueOf(sens) , Toast.LENGTH_SHORT).show();
//}

                signal.setText(String.valueOf(rssi)+"dB ~ ");
//set signal textbox to rssi

metersDisplay.setText(String.valueOf(calculateDistance(rssi,freq))+"m");
                adapter.notifyDataSetChanged();
                wifi.startScan();
            }
        }, new IntentFilter(WifiManager.SCAN_RESULTS_AVAILABLE_ACTION));

        sensitivity = (TextView) findViewById(R.id.sensitivity);
        sensmetersDisplay = (TextView) findViewById(R.id.sensmeters);
        seekbar = (SeekBar) findViewById(R.id.slider);        //SeekBar
        seekbar.setMax(85);
        seekbar.setProgress(sens);        //set slider to default sens value
        sensitivity.setText("Alarm sensitivity: " + (String.valueOf(sens))
+ "dB ~ ");             //write sens to to TextView

        seekbar.setOnSeekBarChangeListener(new
SeekBar.OnSeekBarChangeListener() {
            @Override
            public void onProgressChanged(SeekBar seekBar, int i, boolean
b) {
                sens = i;
                sensitivity.setText("Alarm sensitivity: " +
(String.valueOf(sens)) + "dB ~ ");    //write sens to to TextView

sensmetersDisplay.setText(String.valueOf(calculateDistance(sens,freq))+"m")
;
            }

            @Override
            public void onStartTrackingTouch(SeekBar seekBar) {

            }
            @Override
            public void onStopTrackingTouch(SeekBar seekBar) {

            }
        });

    }
```

```java
    public int calculateDistance(int signalLevelInDb, int freqInMHz) {
        double exp = (27.55 - (20 * Math.log10(freqInMHz)) +
Math.abs(signalLevelInDb)) / 20.0;
        return (int) Math.pow(10.0, exp);
    }


    public void onClick(View view){
        scanning = !scanning;
        if (scanning) wifi.startScan();
        else timer.cancel();
        textStatus.setText(scanning ? "Scanning: " : "Stopped");
    }


    @Override
    public void onRequestPermissionsResult(int requestCode, String[]
permissions, int[] grantResults) {
        if (requestCode == 1 && grantResults[0] ==
PackageManager.PERMISSION_GRANTED) {
            Toast.makeText(getApplicationContext(), "WiFi permission
acquired" , Toast.LENGTH_SHORT).show();
        }
    }
}
```