Audio Beacon Providing Location-Aware Content for Low-End Mobile Devices

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***Abstract*—Location Based Services can generate variety of new commercial applications and create new streams of revenue. However, there is currently no simple indoor positioning method for low-end devices which have no Wi-Fi or GPS capability. This paper presents a novel and simple audio-based localization system to provide location-aware content for low-end mobile devices, i.e., a location solution that uses acoustic waves to determine the position of the users and/or the content associated to it. In this solution, Audio Beacons send tones which are read by mobile devices for localization. These tones are generated in a barely audible frequency range, that can be hardly perceived by humans. The tones of the Audio Beacons are associated with an identification code that is linked to a location specific content. The solution requires no special hardware at the mobile device side, and a simple localization infrastructure, which can be deployed with low cost loudspeakers. Real experiments demonstrate the effectiveness of the proposed system, and show that the codes can be identified with distances as large as 20 m from the Audio Beacon.**

***Index Terms*—Context location, Audio Beacon, low cost devices, barely audible frequency range.**

I. Introduction

Location Based Services have received a lot of attention lately since that information about the user location can generate a variety of applications and, hence, it can aggregate new business value. Several new services can be created and some other can be improved with the user position knowledge. General information of environments such as restaurants and book stores, directions to a desired place, location-based audio guides in museums, these are simple examples of services that can be provided by the exploitation of the user location. Traffic and fleet management, and user/car/truck tracking are examples of advanced services making use of precise positioning systems.

Initially, the location-based services were thought especially for outdoor environments, becoming an important service extremely present in people's life. Usually, outdoor user positioning systems use GPS and/or cellular infrastructure to provide the location information. However, it was observed that interesting scenarios would be the indoor or the open wide places surrounded by buildings. These new environments brought new technical challenges for providing the user location. Besides, location-based services with seamless connection in different environments became something really important.

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In the last years, several indoor solutions can be found in the literature [1]–[5]. In general, indoor positioning systems present a trade-off between deployment burden and accuracy. Radio-frequency (RF) beacon-based approaches often rely on the wireless infrastructure and RF fingerprinting approach to provide user indoor positioning [1]–[3], [6]. RF fingerprint-based approaches generally need specialized RF surveys and wide infrastructure coverage to provide user positioning with high accuracy. Some recent systems [4]–[6] have incorporated methods using surveying by users, called "organic" or crowd-sourced systems, to reduce deployment efforts and costs, keeping the accuracy comparable to traditional approaches. Other systems employ images captured at mobile phone [7] and/or combine different signals from several technologies (802.11, Bluetooth, etc) [8] to provide the user location.

Most of the indoor positioning systems require mobile devices with special features, such as Bluetooth, WLAN, video cameras and inertial sensors. These requirements turn out to be a constraint that prevents the popularization of those systems as current low-end mobile devices do not have always such features. Therefore, a simple and cheap way to provide indoor positioning to low-end devices is needed. This should be done preferably without adding any extra hardware at the device side and using a low cost infrastructure to provide a frugal position.

In this context, audio-based indoor positioning techniques seem to be an interesting approach since all mobile devices have embedded microphones [9]–[11]. In [9] an indoor positioning system that senses ambient sound and other environment qualities (light, color, RF, as well the layout-induced user movement) is proposed. This sensing generates an environment fingerprint that is used to identify the user location. This approach is still not considered as a viable solution, mainly due to the meaningful deployment burden and large energy consumption from device side. In [10] a mobile phone plays a signal and uses the microphone to listen the room impulse response. By combining it to a room model, the user position is then determined. This approach requires individual learning phases for each environment to be located and its accuracy is strongly dependent to the quality of the audio systems built-in the devices. In [11] the mobile device plays a signal that is listened by microphones with known positions, and the microphones use the information of the received signal in order to determine the position of the mobile device. Although this is a simplified approach, it requires connectivity of the mobile device to the central infrastructure in order to obtain the position information.

This paper proposes a simple audio-based system for providing location-aware content for low-end mobile devices. The term "location-aware content" refers to an attribute of the system to determine the position of the user and/or the content (e.g., any digital information, such as a sound, video, text message, etc) associated to it. In order to be compliant to low-end mobile devices, the proposed approach was designed without including extra hardware at the mobile device side and requiring a low cost infrastructure to support it. In the proposed system, Audio Beacons (loudspeakers) scattered through a given environment send multiple tones in a barely audible frequency range (from 16 kHz to 20 kHz), yielding acoustic waves that are hardly perceived by people with normal hearing conditions. The strengths of these tones are determined by the mobile devices and are associated to any information (identification code). This code is compared to some data previously stored in the mobile device, which can represent a position and/or a content. Real experiments are performed to demonstrate that acoustic waves at barely audible frequency range can be used effectively to transmit information to mobile devices with no special hardware, using only its standard loudspeakers and microphones. It means that low-cost mobile devices are able to be contemplated with this approach since a very simple user interface (no maps) and no complex features (e.g., GPS, WLAN) are needed.

This paper makes the following contributions:

- We show that the simple audio-based system is able to provide location-aware content for low-end mobile devices, without any additional hardware at the mobile device side, and making use of a low-cost infrastructure to support it.
- We examine two audio tone detection thresholds, finding a good trade-off between computational complexity and detection accuracy.
- We demonstrate the effectiveness of the system through real experiments.

This paper is organized as follows. Sec. II presents the description of the proposed system. This system is evaluated in Sec. III with experimental results. Sec. IV closes the paper presenting the conclusions.

II. Audio Beacon Solution

A. General Description

This section describes a new indoor location solution that uses acoustic waves to determine the position of mobile users and/or a content associated to it. As already mentioned, the proposed solution is designed to low-end mobile devices in which only few wireless features and sensors are available. Besides, a low cost infrastructure (loudspeakers) and no extra hardware at the mobile device are required to support the whole indoor location solution.

Figure 1 shows a schematic overview on the necessary blocks for the Audio Beacon system. The transmit side is shown in Figure 1 (a), where the Audio Beacon creates a signal containing the beacon identification code (Id), and sends it through a loudspeaker. Figure 1 (b) presents the block diagram at the receive side. When receiving the Audio Beacon signal, the mobile device reads its microphone input and tries to detect if there is a valid Id being transmitted. In case an Id is detected, the information related to this Id is obtained in a location-specific content database. Once this information is identified, the mobile station takes the action related to it, that may be as simple as showing the current location on the screen, presenting information about the place, or storing information about the user.

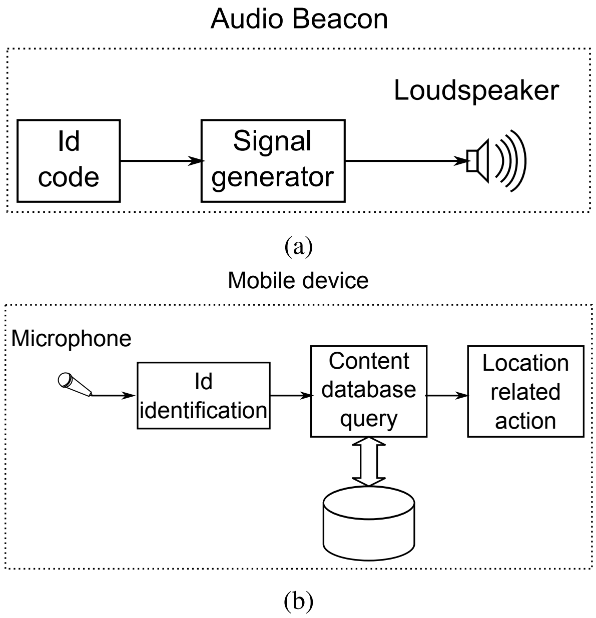


Fig. 1. Overview of the Audio Beacon localization system, with (a) the schematic overview of the transmit side, and (b) the schematic overview of the receive side.

The location-specific content database may be obtained by the user following one of two options. Firstly, the user may pre-store the data before using the system (offline approach). By using this option, the user would get the data from PC using a USB cable or from a web site using some wireless connection. Secondly, the user could use some online approach, like short message service or Internet to access the database.

In a real environment, the system could work as depicted in Figure 2. In this scenario, three loudspeakers transmit two different Ids: two loudspeakers are used for providing coverage for Room 1, transmitting the same Id code, while the third one is used for providing the identity code for the second room (Room 2). In another type of implementation, the Ids could be different even in the same room. However, they would be associated to some areas inside the room where different contents should be shown. In Figure 2 the mobile device is positioned closer to the Audio Beacons with identification code Id_1, which means that the location systems should point to the content C_1.

B. Implementation Aspects

This section presents aspects related to the implementation of the proposed system. These aspects are related to how the Audio Beacons are designed, and how to detect them in the mobile devices.

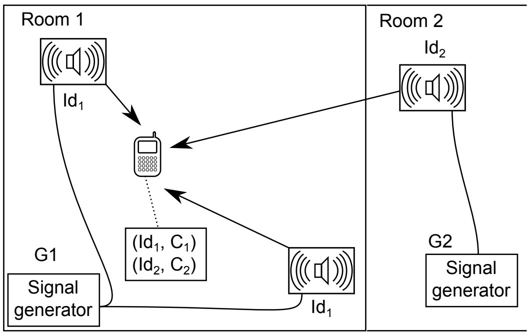


Fig. 2. Schematic overview of the received Ids with two rooms and three loudspeakers transmitting the room identification number Id_x and the location related content C_x.

1) Environment Mapping Stage: Each place and/or content of an environment is represented in our system by a binary code. The code size (in terms of number of digits) should accommodate the number of places and/or contents to be represented, i.e., for an environment of 10 places to be mapped, a 4-digit code is suitable (2^4 = 16 combinations of code). Table I shows an example of how an environment with 10 different places is mapped using a 4-digit code.

TABLE I
ENVIRONMENT MAPPING

Id Code	**Place**	**Content**	**Active Tones**
0000	Can not be used	-	-
0001	Meeting Room 1	sound01.mp3	f_4
0010	Meeting Room 2	sound02.mp3	f_3
0011	Meeting Room 3	sound03.mp3	f_3 and f_4
0100	None place defined	-	f_2
0101	None place defined	-	f_2 and f_4
0110	None place defined	-	f_2 and f_3
0111	None place defined	-	f_2, f_3 and f_4
1000	None place defined	-	f_1
1001	Laboratory 1	sound05.mp3	f_1 and f_4
1010	Laboratory 2	sound06.mp3	f_1 and f_3
1011	Laboratory 3	sound07.mp3	f_1, f_3 and f_4
1100	Laboratory 4	sound08.mp3	f_1 and f_2
1101	Main lobby	sound09.mp3	f_1, f_2 and f_4
1110	Corridor	sound10.mp3	f_1, f_2 and f_3
1111	None place defined	-	f_1, f_2, f_3 and f_4

A physical Audio Beacon should be associated to a single place. However, several ones can be located at the same place. As an example, multiple Audio Beacons at the same place may be transmitting a single Id code to provide better coverage, as already shown in Figure 2, or Audio Beacons at distant positions may reuse the same Id code to improve the capacity of the environment mapping stage, in terms of number of locations that can be mapped with the same code size.

The number of possible codes is limited by the bandwidth were the tones are concentrated, and by the desired time latency for detection. If more codes are desired, it is possible to include more tones in the transmission scheme. However, the observation period for detecting these tones will be larger, as the time window for distinguishing among different tones needs to be bigger.

2) Transmission Stage: This stage is referred to the step in which the Id code is transmitted by using acoustic waves. Each digit of the Id code is associated to a single tone. If an environment is represented using a 4-digit code, 4 independent tones are required to map it, i.e. the tones at frequency f_1, f_2, f_3, and f_4 to map the code digits 1, 2, 3, and 4, respectively. The tone spacing α is a parameter that can be optimized to improve the overall system detection performance. In our approach, a code digit with the binary value equal to '1' means that the associated tone should be active, otherwise not. Figure 3 shows the transmission scheme of a four-digit code '1011' by 4 acoustical tones. In this figure, the tone at carrier f_2 is inactive because its associated code digit is '0'.

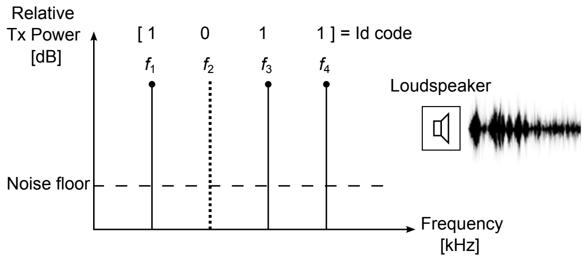


Fig. 3. Transmission Scheme for the four-digit code '1011'

The Audio Beacon may be deployed in 4 different ways, as shown in Figure 4. In the first implementation shown in Figure 4 (a), a single loudspeaker is previously being driven by a computer for transmitting music (or other type of advertisement used in commercial facilities). In this type of implementation, no hardware investment is needed, only requiring the installation of a software in this computer for generating the Id codes.

The second type of implementation is shown in Figure 4 (b), where a special device is manufactured with a loudspeaker and hardware capable of generating the Id codes. This hardware implementation would have reduced manufacturing costs, since the frequency range where the Id code is sent is so high that humans can barely hear the localization signals. This implies that low accuracy at low frequencies is needed for these loudspeakers. Additionally, the power levels are small, so neither large batteries nor power amplification system is needed. Hence it is expected that this type of implementation would be done with a small portable battery driven device, that just needs to be turned on, and stuck to a wall.

For larger commercial sites, it is expected that pre-existing audio equipment is present, and several loudspeakers are connected to the same computer, or audio amplifier. In that case 2 options may be available. In Figure 4 (c) one computer controls all the loudspeakers, sending at the same time music and an Id code signal used for localization. This implementation implies that the same Id code is sent for all loudspeakers, or at least the same Id code is sent for all loudspeakers sharing the same audio channel. This approach can be easily deployed with software installed at the computer, as in the implementation of Figure 4 (a).

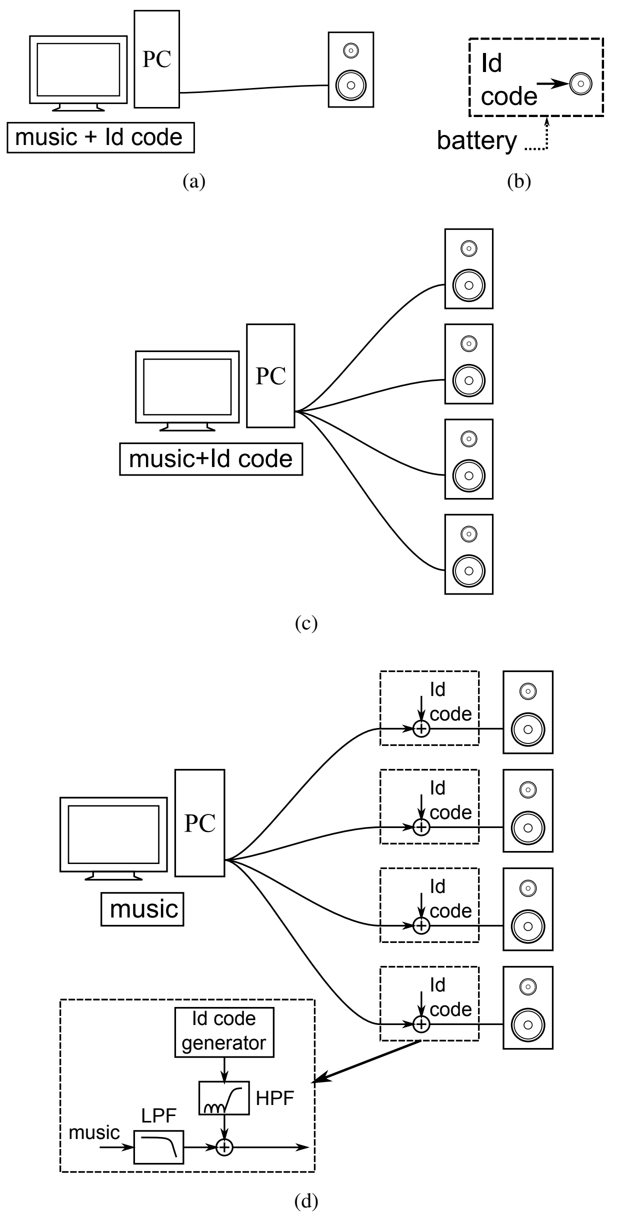


Fig. 4. Schematic implementation of the Audio Beacon at the localization infrastructure (LI) with (a) one computer feeding music and the Id code for a single loudspeaker; (b) one portable hardware implementation, with an Id code generator connected directly to a loudspeaker; (c) one computer feeding music and Id code for several loudspeakers simultaneously; (d) one computer feeding music for several loudspeakers, were each loudspeaker has a component connected to them for generating the Id codes.

If the implemented system requires that a unique Id code is sent by each loudspeaker, and that a pre-existing audio system with multiple loudspeakers is reused for localization, the system shown in Figure 4 (d) can be used. In this implementation, a device for generating the Id code and for summing it to the music that is being transmitted to the loudspeaker is used. In this system, it is desirable that active loudspeakers are used, i.e. loudspeakers that contain their own amplifier. The reason for this requirement is that it would be expensive to build one of such devices that adds the Id code to a power signal that is being sent to the loudspeaker. With this simplifying assumption, the costs related to this hardware implementation would be bounded to a couple of operational amplifiers, and the Id code generation digital circuit. At this device the incoming musical signal coming from the computer would be connected at its input, and the outgoing signal with music and the Id code would be connected to the loudspeaker.

3) Reception Stage: This stage is responsible for detecting the identification codes from acoustic waves. As each tone and its associated digit are independent from each other, two basic power detection thresholds are proposed to classify if a specific tone is active or not, as follows:

$$PDT_1(dB) = (NF + M); \tag{1}$$

$$PDT_2(dB) = max(NF + M, \frac{NF + max(Rx(f_n))}{2}); \tag{2}$$

where PDT_1 is the power detection threshold #1, PDT_2 is the power detection threshold #2, NF is the environment noise floor in dB (estimated at a specific frequency, e.g., 17.5 kHz), M is a safety margin in dB and $max(Rx(f_n))$ is the highest received power from all received n tones. If a specific tone is received with a signal strength above the selected power detection threshold, the tone is considered as active and its associated code digit as '1', otherwise, the tone is assumed as a non-active one and its code digit as '0'.

III. Evaluation

A trial was implemented for evaluating the performance of the Id code detection based on the description of the solution of Section II. The information query related to this code is not covered by this trial. Hence, three main issues were covered in this evaluation, namely

- The analysis of the background noise in a noisy environment;
- The beacon detection algorithm in noisy conditions;
- The influence of the mobile device distance to the beacon in a realistic environment.

These issues resulted in three experiments, which are used to optimize the Audio Beacon detection system.

A. Trial Implementation

The transmission was implemented in a straightforward way, with a music player connected to a portable loudspeaker. In this transmitter a pre-recorded Id code is played in a loop in the music player.

At the receiver side, the challenge is to identity the tones that are above the detection thresholds presented in Section II-B3. A Nokia N900 mobile device running Maemo Linux with QT4 and C++ was used. In the receiver implementation, the microphone samples are processed with an FFT to obtain the frequency energy at each beacon frequency. The FFT was implemented using the FFTW library [12] with parameters shown in Table II. Once the FFT is obtained, the energy of each tone is calculated based on the energy average of 33 frames. Then, the threshold calculation and code detection is calculated as in Section II-B3. Finally, the detected code is shown in the user interface.

TABLE II
FTTW PARAMETERS

Parameter	Value
Sample Rate	44.1 kHz
Sample Size	2048
Frames per Seconds	33

B. Noise Floor Evaluation

In this section the noise floor behavior is evaluated in order to quantify its magnitude in a chaotic environment. The data collection was carried out at a subway station in the Brasília city (Brazil) using the parameters defined in Table III. Figure 5 shows a snapshot of this subway station.

TABLE III
PARAMETERS OF THE NOISE FLOOR EXPERIMENTS

Parameter	Value
Mobile device	Nokia 900
	17.5 kHz
	18.0 kHz
Noise floor estimated at	18.5 kHz
	19.0 kHz
	19.5 kHz

Fig. 5. Brasília's Subway Station (Brazil).

This experiment has considered four different cases as follows:

1) Center of the station, while the station is empty;
2) Center of the station, while the station is crowded;
3) Center of the station, while the station is crowded and the subway train is arriving and leaving in only one direction;
4) Center of the station, while the station is crowded and the subway train is arriving and leaving at both directions.

Table IV shows the results obtained for the considered scenarios. In these results, the amount of energy in the observed frequency band is directly related to the amount of people in the station, and to the passage of the subway train. Additionally, the noise floor presents similar time variation for all the frequencies under analysis, as shown in Figure 6. As expected, the higher the frequency, the lower the received signal strength. Thus the energy at 17.5 kHz represents a conservative estimation of the noise floor at the analyzed frequency band, as can be observed in Figure 6. Hence, our initial approach for the beacon detection uses an estimation of the noise floor at 17.5 kHz, since it provides us a worst case estimative.

TABLE IV
RELATIVE NOISE SIGNAL STRENGTH [dB]

Case	@17.5kHz	@18.0kHz	@18.5kHz	@19.0kHz	@19.5kHz
1	64.9±1.5	64.3±1.4	63.6±1.6	62.7±1.8	61.4±1.9
2	69.6±2.9	68.6±2.7	67.0±2.6	66.2±2.8	65.5±3.1
3	72.0±2.8	70.3±2.6	69.0±2.9	68.1±3.2	67.1±3.6
4	73.4±3.2	72.7±2.9	71.9±2.6	71.2±2.6	71.0±2.7

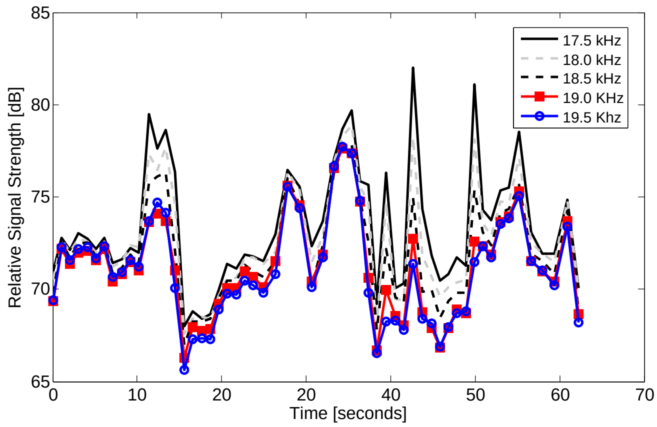


Fig. 6. Temporal variation of the noise (case 4).

C. Evaluation of the Detection Thresholds

This Section compares the approaches for power detection thresholds described in Section II-B3. In this experiment, the following methodology was used:

- A mobile device and a loudspeaker were placed over a table inside a meeting room;
- The loudspeaker was used to transmit acoustic tones through audio files stored in a PC connected to it. The Audio Beacon signals were created using a 4-digit code;
- Two distances and four microphone positions sets were assumed for the data collection, as shown in Figure 7;
- A computer was used to play the audio files at full power (100% of volume).

Table V defines the parameters considered in the experiments.

TABLE V
PARAMETERS FOR THE THRESHOLD VERIFICATION EXPERIMENT

Parameter	Value
Mobile device	Nokia 900
Loudspeaker	Philips SPA2201
Id code	0101
Tone f_1 at	18.0 kHz
Tone f_2 at	18.5 kHz
Tone f_3 at	19.0 kHz
Tone f_4 at	19.5 kHz
Noise floor estimation frequency	17.5 kHz
M	4 dB

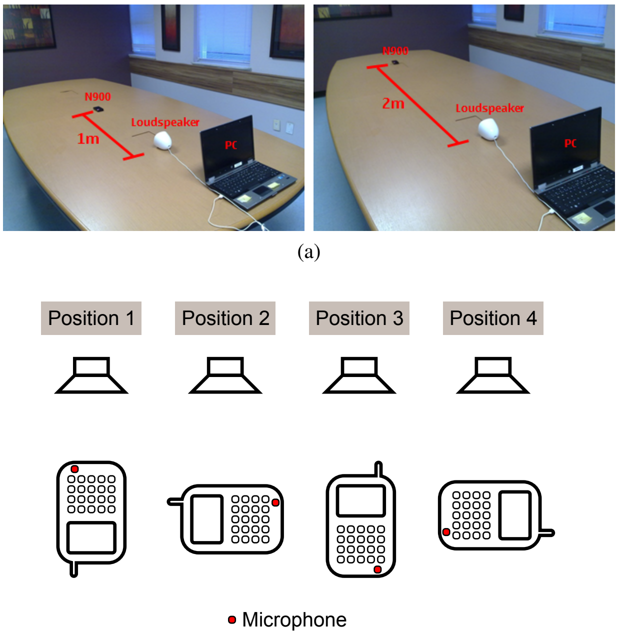


Fig. 7. Test setup for the optimization of the beacon detection thresholds. (a) Picture showing the setup with loudspeaker and mobile device placement; (b) Microphone relative positions.

Table VI shows the beacon detection hit-rate when using equation 1 for the Id code '0101'. These results show that equation 1 preforms poorly even if the mobile device distance is small and the environment noise is low. This shows that equation 1 has many limitations, since it depends on the safety margin M, and is subject to false-positives. Table VII shows that a significant hit-rate improvement is obtained when this experiment is repeated using the threshold in equation 2. However, the tone f_4 presents some false-negatives, which are explained by the loudspeaker/microphone frequency responses. At frequencies close to 20 kHz, low-cost microphones and loudspeakers have some attenuation, which limits the performance of the beacon detection. Hence, this behavior shows that it is recommendable to avoid using the frequency tone at 19.5 kHz in order to improve the system performance.

TABLE VI
HIT-RATE FOR POWER DETECTION ALGORITHM USING THRESHOLD 1 IN EQUATION 1

Id Code	Microph. Position	F1 Hit-rate [%]	F2 Hit-rate [%]	F3 Hit-rate [%]	F4 Hit-rate [%]
		Distance = 1m			
0101	1	41.9	**100**	37.2	**100**
	2	47.7	**100**	84.1	**100**
	3	17.2	**100**	22.4	**96.6**
	4	29	**100**	32.3	**100**
		Distance = 2m			
0101	1	33.3	**100**	24.4	**100**
	2	80.6	**100**	90.3	**96.8**
	3	88.4	**100**	86	**95.3**
	4	81.1	**100**	73	**100**

TABLE VII
HIT-RATE FOR POWER DETECTION ALGORITHM USING THRESHOLD 2 IN EQUATION 2

Id Code	Microph. Position	F1 Hit-rate [%]	F2 Hit-rate [%]	F3 Hit-rate [%]	F4 Hit-rate [%]
		Distance = 1m			
0101	1	100	**100**	100	**100**
	2	100	**100**	100	**100**
	3	100	**100**	100	**0**
	4	100	**100**	100	**100**
		Distance = 2m			
0101	1	100	**100**	100	**100**
	2	100	**100**	100	**41.9**
	3	100	**100**	100	**39.5**
	4	100	**100**	100	**29.7**

It is important to mention that although the results had been shown only for the Id code '0101', the same conclusions are extended for the other codes.

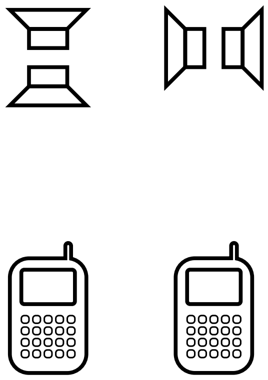
D. *Office environment case study*

This section describes a real-life experiment at an office environment. The environment layout is depicted in Figure 8, which consists of a large office room. In the measurement position, the desks are separated by 1.40 m high wooden walls, with 76 cm high desks. In all the experiments described in this section, the measurements were performed with an Audio Beacon positioned at the top of a wooden wall at the position shown in Figure 8, and measurement positions at the line bellow the Audio Beacon. A pair of loudspeakers was used for implementing the Audio Beacon, where the loudspeakers where placed with 180^o angle between each other. The frequencies used were changed from previous trials because of the false positives in Table VII, with updated values described in Table VIII. This office room was populated by people working normally during the experiment, and no subjected reported to perceive the presence of the Audio Beacon tone.

TABLE VIII
PARAMETERS OF THE OFFICE ENVIRONMENT CASE STUDY

Parameter	Value
Mobile device	Nokia 900
Loudspeaker	Philips SPA2201
Id code	0101
Tone f_1 at	17.5 kHz
Tone f_2 at	18.0 kHz
Tone f_3 at	18.5 kHz
Tone f_4 at	19.0 kHz
Noise floor estimated at	17.0 kHz
M	4 dB

The first set of measurements was performed with mobile devices positioned at the top of wooden walls. These positions were chosen in order to have line-of-sight (LOS) between the Audio Beacon and the microphones of the mobile devices. Two different loudspeaker angles were chosen, as described in Figure 9. In Figure 9 (a) a loudspeaker points directly to the mobile device, while in Figure 9 (b) both loudspeakers have a 90^o angle with the mobile device.



(a) (b)

Fig. 9. Loudspeaker position for (a) 0^o angle and (b) 90^o angle.

The results in LOS condition are shown in Figure 10. The LOS results with 0^o show that the proposed technique works with almost 100% hit-rate when the mobile device is closer than 20 m to the Audio Beacon. Additionally, an angle rotation of 90^o of the Audio Beacon decreases significantly the operation distance of the system, since the hit-rate is only larger than 80% when the distance is smaller than 8 m. Hence, the chosen loudspeaker is very directive in the chosen frequency range. Moreover, since the reverberation usually has a low-pass characteristic, the wall reflections above 17 kHz are attenuated, and will not change much the directionality of the loudspeaker.

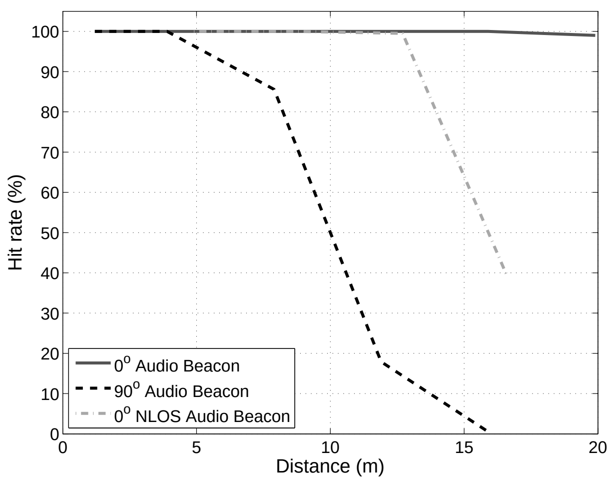


Fig. 10. Office case study results in line-of-sight conditions with 0^o and 90^o angle of the loudspeaker, and non-line-of-sight measurement.

The second set of experiments include non-line-of-sight (NLOS) conditions. In these results, the measurements were performed in the green triangles of Figure 8, with the mobile device located at 95 cm from the floor. This distance measurement height was chosen as a typical hight where a mobile device is held. Additionally, at this height the Audio beacon would be partially blocked by the wooden walls.

The NLOS results are shown in Figure 10. In the chosen conditions, the system operates with small error when the distance is smaller than 15 m. When comparing the NLOS results to the ones of 0^o LOS, the coverage of the Audio Beacon is reduced in the presence of obstacles. This result shows that Audio Beacons placed at different rooms do not interfere with each other. Additionally, the acoustic wave diffraction also enables the coverage of places blocked by obstacles. The small walls of office environment used in this experiment may resemble the obstacles commonly found in department stores, or other commercial rooms, which shows the applicability of this concept in these cases.

IV. Conclusions

This paper presents a new audio-based localization system. Although this system is originally designed for low-end mobile devices, it can be applied in any kind of mobile devices (e.g., from low-end to smart ones), or any other devices with embedded microphones. The solution is based on acoustic waves transmitted through multi-tones operating in a barely audible frequency range (from 16 kHz to 20 kHz). The transmitted audio tones are associated to an identification code (Id code), which represent a position and/or content associated to it. The signal levels received from these tones at the receiver side are used to decode the Id code and then associate it to some location-specific content previously stored in the mobile device. The whole solution requires a low-cost infrastructure, with the Audio Beacons (signal generators, like music players, and loudspeakers) and without extra hardware at the mobile device side.

The proposed solution was calibrated and validated with real experiments in complex scenarios in which localization could be easily applied, such as a subway station and an office environment. In these experiments, four tones were chosen and used for the mobile devices to detect their strength levels. Results have shown how the tone detection procedure could be improved, with an enhanced detection threshold. Additionally, the frequency operation limits of typical low-cost microphones pose a limitation on the maximum frequency range in which the frequency operates. Also, the Audio Beacon position impacts the percentage of hit-rate, while the reflections do not affect the solution like in RF systems. Hence, Audio Beacons placed at different rooms probably would not interfere with each other, due to the large attenuation caused by walls. At last, results showed that acoustic waves can be used effectively to transmit information to mobile devices with no special additional hardware.

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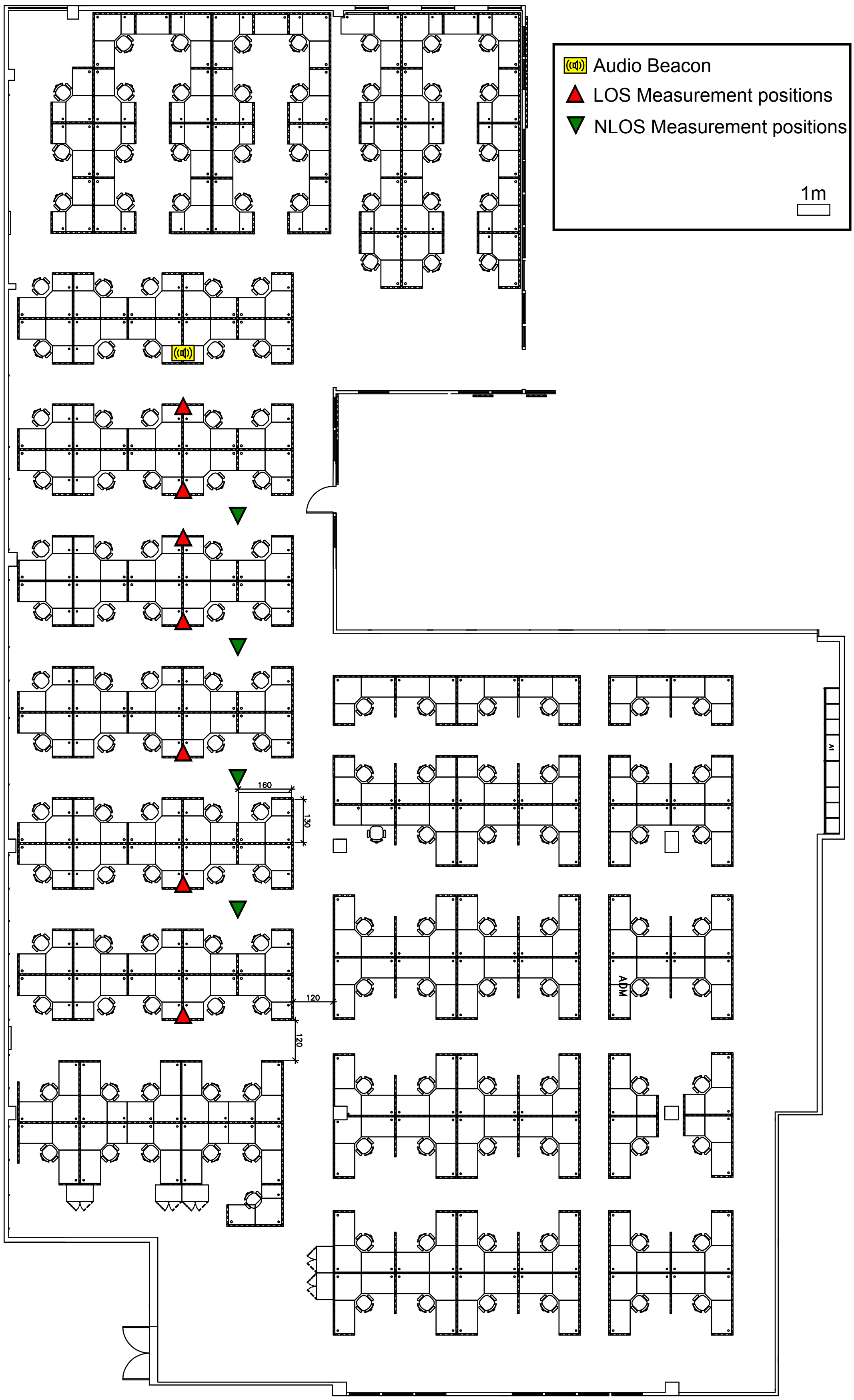

Fig. 8. Office environment layout. This layout shows the position of the desks, the Audio Beacon position, and how the mobile device was placed for the beacon detection. The desks are separated by 1.40 m high wooden walls.