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Measuring user-induced randomness to evaluate smart phone performance in real environments

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Abstract—**The radiated performance of a wireless device depends on its orientation and position relative to the user. In addition, the antenna performance is different on different devices and it depends on the device model. Hence, to understand the impact of the users behaviour on the device antenna and the resulting network performance an investigation of the device usage and signal quality is of high importance. This paper presents a first analysis of the orientation usage of wireless devices based on data gathered from 5 smart phones over a period of more than two months. The data was obtained from the built-in sensors in the phone, and includes angles of orientation, information about signal quality and the connected network. Some interesting trends regarding typical orientations of the phone are presented for both voice and data services. We believe that data of this type has the potential to be used for optimizing the device and the network performance, e.g., when the data is correlated with the experienced channel quality.**

I. INTRODUCTION

Over-The-Air (OTA) testing of wireless devices is standardized by, e.g., the CTIA and the 3GPP [1], [2]. An important part of these tests is the characterisation and modelling of the propagation environment [3]. In the so-called Line-of-Sight (LOS) environment there exists a dominant, direct signal path between transmit and receive antennas. In the opposite case, when the transmit signal reaches the receive antenna through various paths, the propagation environment is characterized as a multipath channel. Suitable test methods and emulating set-ups have been developed for both.

An anechoic chamber is the traditional test chamber emulating a LOS environment. It can be more generically referred to as Pure-Line-of-Sight, since only one wave is impinging on the receive antenna. On the other hand, the multipath propagation channel can be emulated in a reverberation chamber, and it is known as the Rich Isotropic Multipath (RIMP) environment [4]. Reverberation chambers have been successfully used to measure the radiation efficiency, the embedded element efficiency and the diversity gains of multi-port antennas, and during the last 5 years the throughput of LTE devices [4]–[6].

Small wireless devices do not have a directive beam, but rather a number of arbitrarily oriented lobes. The radiation pattern is also strongly affected by the orientation of the user and how he or she holds the device. By taking these statistical variations into account, the Pure-LOS environment can be more generically referred to as a Random-Line-of-Sight (RLOS) environment.

Currently, the randomness due to the user is not automatically included in OTA tests. However, it should be of interest to ensure good performance in real-life environments and especially in LOS, by incorporating realistic usage of wireless devices. Indeed, device performance affects overall network performance, i.e. a population of bad devices in the network will also affect the end-user perceived quality of experience. It will also affect the total capacity in the network since end-users with bad devices are often degraded to lower modulation and coding schemes.

Other type of applications where the RLOS performance is becoming of great importance is automotive communication. Here, self-driving, or autonomous, cars will be a reality in a few years. They will rely on communication via a direct signal path to neighbouring vehicles, and there is more probably a direct LOS to the base station than for human users inside or between buildings. The angle of arrival will depend on the orientation of the car and the road relative to the base station, thus appearing as RLOS. The RLOS can for this case be measured as proposed in [7].

In this paper we present a general description of the data logged by a smart phone application (app) to collect information related to the device usage, e.g., device orientation, position, type of service, etc. The empirical statistical distributions for the azimuth, pitch and roll orientations are presented for a single smart phone and for the aggregated data of up to 6 different smart phones for voice and data services gathered over a period of more than two months in a live network.

II. ADDRESSING REAL-LIFE ENVIRONMENTS

The RLOS and RIMP environments are edge or limit environments, which are rarely present in real-life. Real-life environments are somewhere in between RLOS and RIMP. They may not be rich (e.g., due to few incoming waves), and they will most likely show a mix of LOS conditions and Non-Line-of-Sight (NLOS) (i.e., no direct path between transmit and receive antenna). Furthermore, introducing the user randomness means that the LOS component can be characterized as a RLOS due to the user [7]. It means that the LOS experienced by a mobile device becomes completely random due to its random position and orientation w.r.t. the base station.

It is then practical to introduce the following real-life OTA hypothesis [8]: *If a wireless device is tested with good*

Fig. 1. Illustration of the random orientations of a wireless user device causing the user-random Pure-LOS, or briefly Random-LOS

performance in both RLOS and RIMP environments, it will also perform well in real-life environments and situations, in a statistical sense. This means that the radiated performance of a wireless device is best evaluated over a distribution of users in all the different propagation environments that have been defined or could appear in practice.

The random nature is a result of the randomness of the user orientation and device usage, causing a random angle of arrival and polarization as illustrated in Fig. 1. This makes it very different from any traditional LOS channel measurements. Therefore we need to find ways of characterizing the user randomness in terms of its cumulative distribution function (CDF) and corresponding effect on the throughput.

Next we address this challenge by presenting some initial results from collected user data. A sample analysis of the phone orientation as imposed by the user and insight into the typical use patterns is presented.

III. OTA MEASUREMENTS FROM SMART PHONES

In real-life, the randomness of the orientation of the device is not known, and it is not likely to be uniform. To investigate this, modern smart phones offer unique opportunities in their sensor capabilities. They all contain sensors which provide information about the phones orientation in 3D as well as sensing proximity to e.g. head. This orientation information together with information on location, signal level/quality and type of service offers valuable user statistics to understand and model device usage.

A. Reading sensor and measurement values with a smart phone application

Our measurement system consists of a smart phone app which is installed onto a number of phones, and a server which aggregates the data automatically into a searchable data base. This app records sensor values from the phone in the background while the smart phone is active, i.e. during a phone call or data session. The app collects samples approximately once per second. Tests have been carried out since July 2014. The app records data and settings in three categories according to the description provided in Table I. In this paper we present results only for the orientation of the device and type of service.

TABLE I
SENSORS AND VALUES RECORDED FROM SMART PHONES

3D sensors:	
Magnetic field	Measures magnetic field in μT
Acceleration	Linear acceleration, including gravity vector in m/s^2
Orientation (Rotation)	Derived from magnetic field and acceleration. Shows device rotation around the three axes in a global coordination system.
Gyroscope	Rotational acceleration in rad/s
Proximity	Senses proximity to the display side of the phone. Used to e.g. turn off screen if display is blocked by holding the phone to your ear.
Location	In latitude and longitude, either from GPS or network location.
Signal and network related measurements:	
Cellular technology	The mobile technology on which the terminal is connected: 2G (GSM), 3G (UMTS, HSPA) or 4G (LTE)
Signal strength and quality	The values depend on the system connection. The basic value is the 'Arbitrary Strength Unit' (ASU) as defined by the 3GPP. The signal strength in dBm is derived from this [9], [10], [11]. The range and conversion rule differs between 2G, 3G and 4G. The signal quality can be retrieved for LTE as the RSRQ value [11]
Cell information, serving operator	Cell ID and Location Area Code (LAC/TAC) for the cell which the phone is attached to. These are numbers defined by the operator. Together with the Mobile Network Code (MNC), these provide unique identification of the cell.
Neighbour cell list	Cell IDs, LACs/TACs and ASUs for neighbour cells.
Other phone settings and conditions:	
Service type (active connection)	Whether there is an active voice (phone) service or data service
Other radios on or off	Whether Wi-Fi or Bluetooth is activated.
Use of handsfree	Whether wired handsfree or Bluetooth handsfree is used.

B. Finding device orientation

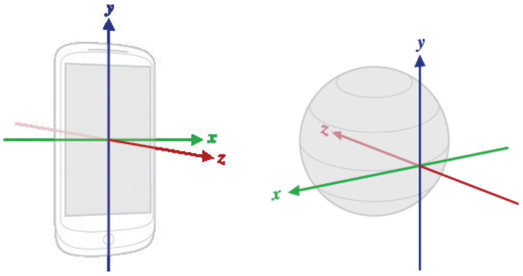
The orientation angles which are presented in this paper are not direct values from the sensors, but is found by combining readings from two hardware sensors [12] which are returning values in the *device coordinate system*, see Fig. 2a:

- The *magnetic field sensor* returns geo-magnetic field readings in the device coordinate system and gives orientation towards magnetic north.
- The *linear accelerometer* returns acceleration included gravity in the device coordinate system and gives orientation relative to earth perpendicular axis.

Values from these two sensors are combined to calculate the rotation matrix. The rotation matrix is used to calculate the orientation in an *inverted world coordinate system*, see Fig. 2b:

- Azimuth, rotation around the Z axis.
- Pitch, rotation around the X axis.
- Roll, rotation around the Y axis.

All values given in radians counter-clockwise. The orientation angles are defined as shown in Fig. 3. The *reference orientation*, i.e. when all angles are '0' (zero) is shown in Fig. 3 in



(a) (b)

Fig. 2. Device (a) and inverted world (b) coordinate systems [12]

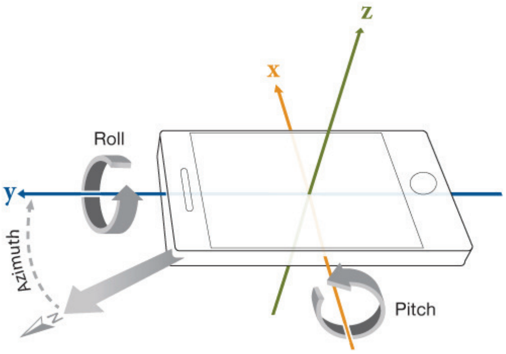


Fig. 3. Definitions of orientation angles [13]

which the device is placed on the horizontal plane (xy-plane) with the display facing upwards (along the z-axis) and the top edge of the device pointing towards the magnetic north (along the y-axis).

C. Error sources and sensor accuracy

Smart phones are not high grade measurement equipment and sensors and reported values may have limited accuracy. General studies on the accuracy of such sensors are scarce, however there are a few studies related to the use of sensors in, e.g., augmented reality applications. One quite comprehensive study has been reported in [14] where the accuracy of location estimates and the orientation capabilities have been evaluated. In this paper the orientation estimates are inferred from magnetometer readings. As shown in the next section, the magnetic field vector is part of the total smart phone orientation vector. Magnetic field sensors are not very accurate, e.g., [14] reports mean compass errors around 10-30°, which obviously affects the accuracy of the orientation angles.

Another source of error is the method used to calculate the rotation matrix from the acceleration and magnetic field values. The method assumes that the acceleration is equal to the gravity vector, which is generally not true unless the phone is standing still or moving with constant speed in a straight line. Improving the data quality can be done, e.g., by using a technique called *sensor fusion* devised in [15]. This method includes values from the gyroscope sensor to mitigate errors in the acceleration vector as well as removing noise.

IV. RESULT ANALYSIS AND DISCUSSION

In this section we present a simplified analysis of the orientation angles extracted from logged data. The main objective is to provide a first insight of the usage of smart phones by looking at the probability distribution functions (pdfs) of the pitch, the roll and the azimuth orientation angles. Two main use cases have been analysed: i) *data service* and ii) *voice service*. We believe there might be marked differences between the two user situations.

The data service means all types of communication except cellular voice, which is recorded as voice service. The data service also includes possible Over-the-Top (OTT) voice-services like Skype, Viber etc. It is worthwile to note that smart phones also generate a lot of background data traffic due to, e.g., app updates, location services etc., due to the *always on* nature of mobile phones.

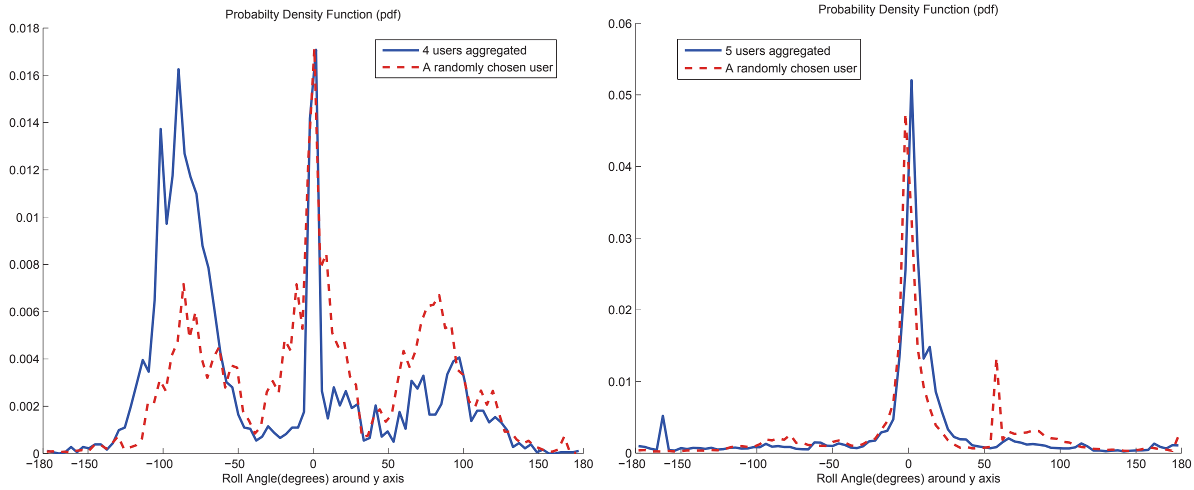
It has been possible to filter the data with respect to the use of a wired handsfree set or not. For the voice service case, it was expected that the use of handsfree would make a big difference, and we have selected the case in which handsfree has not been used for the current analysis. This means that the user must hold the phone to the ear. The samples for the data service usage includes both cases. We have collected the samples from the users which have provided a reasonable amount of samples, and we have truncated the number per user to be the same in order to avoid that heavy users are given more weight in the common statistics. The number of data samples are generally much higher than for voice. For the voice service, samples from 4 users have been analysed, with 1144 samples per user. For the data service, samples from 5 users with 16683 samples per user have been analysed.

In Figs 4, 5 and 6 we show the pdfs for voice service and data service for roll, pitch and azimuth angles. Each graph shows one curve with common statistics for a number of users, and the statistics for one randomly chosen user. The reason is to show a common trend and to see single user diverging behaviour.

The most immediate observation from the roll and pitch angle statistics shown in Figs. 4 and 5, is the high peak around zero degrees especially for the data service. This means that the phone is lying horizontally eith the display side up, e.g., on a table when many samples are collected. For data service this was expected since phones do a lot of background data traffic without user interaction, and in these cases, the phone is often lying on a table or another horizontal surface.

Further, the sample statistics from the voice service shows a distinct maximum for negative roll angles, and a weaker one for positive angles as shown in Fig. 4(a). On the other hand for the pitch angle the data is more concentrated on the negative side as shown in Fig. 5(a). This might be an indication of a typical ear-holding talk position, on either left or right side. The asymmetry in the roll angle may indicate that one side is dominant in the analysed samples.

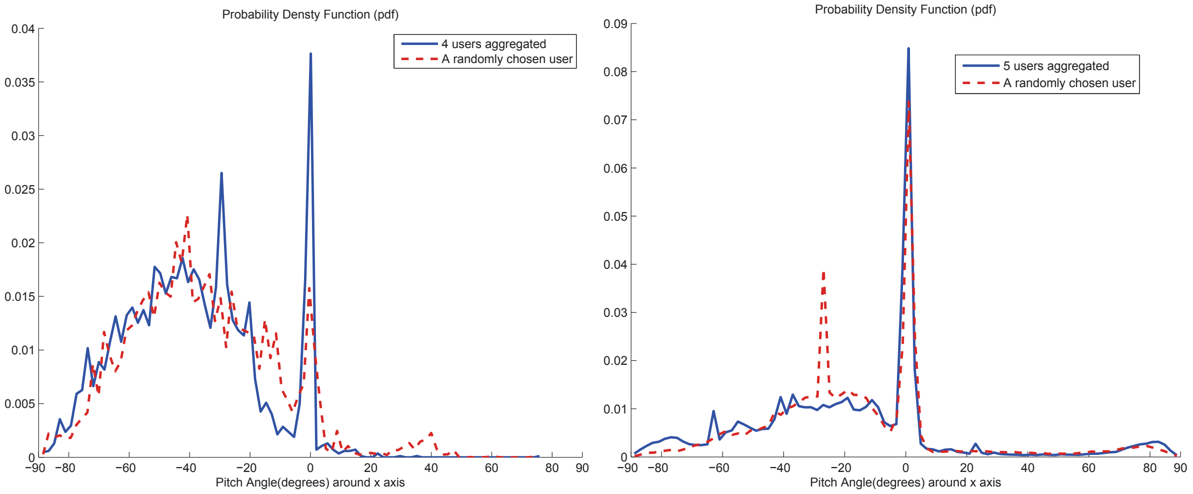
The data service samples show a weak maximum for negative pitch angles as shown in Fig. 5(b), but none for the



(a) Voice service

(b) Data service

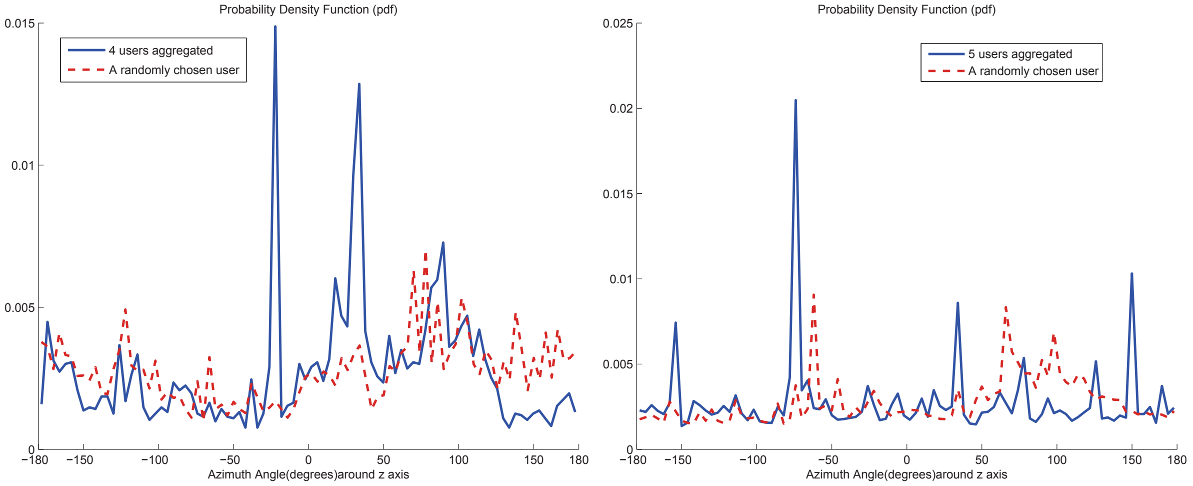
Fig. 4. Evaluation of the *roll* angle for voice service without handsfree recorded from 4 smart phones and data service recorded from 5 smart phones. The number of samples for voice service was 1144 per device, and the number of samples for data service was 16683 per device.



(a) Voice service

(b) Data service

Fig. 5. Evaluation of the *pitch* angle for voice service without handsfree recorded from 4 smart phones and data service recorded from 5 smart phones. The number of samples for voice service was 1144 per device, and the number of samples for data service was 16683 per device.



(a) Voice service

(b) Data service

Fig. 6. Evaluation of the *azimuth* angle for voice service without handsfree recorded from 4 smart phones and data service recorded from 5 smart phones. The number of samples for voice service was 1144 per device, and the number of samples for data service was 16683 per device.

roll angle, Fig. 4(b). This might indicate a portrait handling screen view mode with light tilting of the screen towards the user.

The azimuth angles shown in Fig. 6 represents a more random picture, reflecting that there is no preferred direction in the horizontal plane, neither for voice or data usage.

In general, all graphs show some distinct and random peaks, which clearly indicates that the number of samples are to few.

V. CONCLUSION AND FUTURE WORK

These early measurements of smart phone orientation in normal usage shows the potential of collecting data to better understand how users handle their smart phones. The analysis shows that the samples are indicating some trends, but more data from more users are needed together with more in-depth analyses before firm conclusions can be drawn.

The data collected in the project includes other type of data than the orientation angles. The future analysis will focus, among other things, on the following tasks:

- To acquire an in-depth understanding of the difference between voice and data usage.
- To define some typical user handling modes, like left-ear, right-ear, screen view, table, etc.
- To find out whether there is a correlation between handset orientation and signal quality.
- To determine the influence of the proximity to body (or other objects) and performance (proximity is detected on the display side of the phone, which does not provide the complete picture)
- To be able to differentiate the performance between different brands and models as a tool for network performance optimization.

As touched upon in section III-C there is also an obvious need to work on understanding and improving the data quality. Also, the fact that smart phones do a lot of background communications without any user interaction makes the analysis of the data service mode especially challenging. This clearly contributes to the high zero-peak in the pdfs. A better approach to analysing the angles in the 3D space is also planned.

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