MOBILITY 2016

The Sixth International Conference on Mobile Services, Resources, and Users

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MOBILITY 2016 Editors

Josef Noll, University of Oslo & Movation, Norway
Sofiane Hamrioui, University of Haute Alsace, France

MOBILITY 2016

Foreword

The Sixth International Conference on Mobile Services, Resources, and Users (MOBILITY 2016), held between May 22-26, 2016, in Valencia, Spain, continued a series of events dedicated to mobility-at-large, dealing with challenges raised by mobile services and applications considering user, device and service mobility.

Users increasingly rely on devices in different mobile scenarios and situations. "Everything is mobile", and mobility is now ubiquitous. Services are supported in mobile environments, through smart devices and enabling software. While there are well known mobile services, the extension to mobile communities and on-demand mobility requires appropriate mobile radios, middleware and interfacing. Mobility management becomes more complex, but is essential for every business. Mobile wireless communications, including vehicular technologies bring new requirements for ad hoc networking, topology control and interface standardization.

We take here the opportunity to warmly thank all the members of the MOBILITY 2016 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to MOBILITY 2016. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the MOBILITY 2016 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that MOBILITY 2016 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the areas of mobile services, resources and users.

We are convinced that the participants found the event useful and communications very open. We hope that Valencia provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

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A Real-Time Head-Tracking Android Application Using Inertial Sensors

Massimiliano Benedetto, Alessio Gagliardi
Università di Pisa, Pisa, Italy
{m.benedetto2, a.gagliardi3}@studenti.unipi.it

Pasquale Buonocunto, Giorgio Buttazzo
Scuola Superiore Sant'Anna, Pisa, Italy
{p.buonocunto, g.buttazzo}@sssup.it

***Abstract*—Several systems have been proposed in the literature to monitor head movements for different applications, including health care, tele-rehabilitation, sport, virtual reality, and gaming. Most of these systems are either expensive or not precise, and often require complex setup and calibration procedures. This paper presents a head-tracking monitoring system consisting of a 9-axis inertial unit that sends rotation data to an Android application that is in charge of recording and visualizing data in real time. Sensory data are sent to the smartphone via wireless channel, using the Bluetooth Low Energy communication standard. Data are then processed on the mobile device providing a realistic real-time 3D animation of the user head. Experimental results are presented to evaluate the end-to-end latency of the real-time representation.**

Keywords–Head Tracking; IMU; Real-time operating system; Multitasking application;

I. INTRODUCTION

A number of sensors using different technologies can be used today to track joint rotations. They include magnetic systems (like the Polhemus [1]), and visual-based systems, which use several cameras to triangulate the 3D position of a set of points detected, with the aid of markers attached to the body. For instance, the Vicon motion capture system [2] uses retro-reflective markers illuminated by infrared LEDs and tracked by infrared cameras. These systems can reach a precision in the range of millimeters, but are quite expensive, not portable, require a complex calibration procedure, and suffer from problems due to occlusions or missing markers.

A cheaper solution is represented by the Microsoft Kinect [3], which uses a camera and an infrared depth sensor to capture full-body 3D motion under any ambient light conditions. This system reaches a precision in the range of centimeters but, unfortunately, it is not portable and does not support a direct connection with tablets and smartphones.

Inertial measurements units (IMUs) represent an effective solution for tracking human joint trajectories in a compact and portable system. Several commercial tracking systems are available today, such as the Moven motion capture suite by Xsens [4], or a similar product by Intersense [5]. The main disadvantages of these solutions are their cost (in the range of 10K euros and beyond), and the use of proprietary wireless communication protocols that requires special hardware.

Several IMU-based tracking systems have been proposed in the literature for different purposes. For instance, Foxlin [6] presented a tracking system to measure the head movements relative to a moving simulator platform using differential inertial sensors. Avizzano et al. [7] developed a head tracking device based on accelerometers to provide a user interface for navigation in virtual environments and remote control. Keir et al. [8] proposed a head tracking device for robotics applications based on accelerometers. However, all these devices were developed to be integrated in a larger system and not to work as a stand-alone device for personal usage.

Zhou and Hu [9] developed a real-time monitoring system for human upper limb movements in post-stroke rehabilitation. This system is based on an Xsens MT9 inertial sensor acquired by a PC. Roetenberg at al. [10] presented an Xsense motion capture suit capable of reconstructing full-body human posture based on biomechanical models and sensor fusion algorithms. Although the system does not suffer from the problems typical of optical systems, wearing a suit is not so practical for monitoring everyday activities.

Other head tracking devices were proposed using different technologies. For example, Mulder, Jansen, and van Rhijn [11] developed an optical head tracking system, using two fixed FireWire iBOT cameras that recognize a dot pattern mounted onto shutter glasses. A similar system was developed by Lee [12] using a Wii Remote device, a Bluetooth receiver and IR LEDs. Wii Remote is a motion controller using an IR camera to track a number of IR LEDs placed on the user's head. Although the cost of these systems is more affordable, they are not portable and suffers from occlusion problems.

Other approaches developed for virtual reality and gaming are represented by the Google Cardboard [13], the OCULUS GEAR VR [14], or the Zeiss VR One [15], which exploit the motion sensors and the display of an Android smartphone mounted as mask visor. However, such solutions are quite invasive for the average user, since they require wearing a visor that prevents the view of the real world.

A body motion tracker for Android platforms having characteristics similar to the system presented in this paper is the Run-n-Read developed by Weartrons Labs [16]. The system, however, is specifically designed to support text reading on tablets or Ebook readers during dynamic activities and works by moving the image on the screen in sync with the motion detected by the sensor.

In summary, the solutions existing today are either too expensive, too complex to be used, not portable, or not easily connectable with mobile devices. To fill this gap, the system presented in this paper has been specifically designed for personal purposes (sport, tele-rehabilitation, training, or gaming), using low-cost components, and associated with an Android application developed for non expert users. A preliminary version of this paper has been presented as a poster [17].

Contribution of the work. The main contribution of this work is the development of a head tracking system integrating an 9-axis inertial sensing node with an Android application for storing and visualizing the head movements of the user in a graphic form. One of the major advantages of the proposed system is the easy calibration phase, which enables the system to be used by non expert people for a range of different applications domains.

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Organization of the paper. The remainder of this paper is organized as follows: Section II presents an overview of the system architecture and the general system functionality; Section III describes the kinematic model used for the 3D representation; Section IV illustrates the structure of the Android applications; Section V presents some performance measures carried out to evaluate the end-to-end latency of the representation process; and finally, Section VI states our conclusions and future work.

II. SYSTEM DESCRIPTION

The head tracking system consists of a head-mounted inertial sensor communicating via wireless channel to a smartphone running the Android operating system [18].

One of the most interesting features of this system is that the application does not require the user to mount the sensor in a very precise position on the head. This is achieved through a self-calibration routine executed at system initialization that allows the application to automatically compensate for different initial sensor positions.

More specifically, when the mobile device establishes the connection with the sensor, the first received quaternion is stored by the application as a *reference quaternion*, representing the zero position of the human head. From this point on, all head rotations are computed as a difference between the current quaternion (received in real-time from the sensor) and the initial reference quaternion. Such a simple feature acts as a very effective self-calibration method that solves all the problems resulting from the irregular morphology of the head and relieves the user from being too precise in positioning the sensor on its head. Thanks to this method, the system can easily and quickly be worn by anyone by hiding it inside a cap or fixing it at an elastic band around the head, as illustrated in Figure 1.

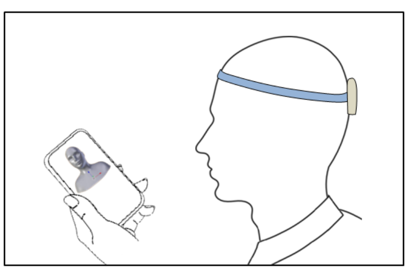


Figure 1. The head tracking system.

The application running on the smartphone has been developed in Java on Eclipse IDE (integrated development environment) using free and open source software components. The Java Development Kit 7 released by Oracle Corporation gives a preliminary class libraries and tools, such as compilers and debuggers, necessary for developing applications [19]. The Android SDK API 18 was used to provide the Bluetooth 4.0 Low Energy (BLE) support [20] for interfacing the smartphone with the inertial sensor.

As far as the graphic is concerned, the 3D design of the head model has been carried out using Blender [21], whereas the real-time manipulation of the model was implemented using Libgdx [22], a game-development application framework which includes some third-party libraries, as OpenGL, for the 3D rending and other functionalities.

A. The inertial sensor

Head movements are detected through a wireless inertial sensor developed at the RETIS Lab of the Scuola Superiore Sant'Anna of Pisa for limb tracking in telerehabilitation systems [23]. The sensor was specifically designed to reduce power consumption with respect to similar commercial devices, balancing lifetime with dimensions and incorporating the state-of-the-art IMU device to provide accurate orientation data.

The device dimensions are $4 * 3 * 0.8$ cm and it weights about 30 g. The sensor integrates the following components:

- a Nordic nRF51822 microcontroller with a 2.4 Ghz embedded transceiver [24];
- an InvenSense MPU-9150 9-axis inertial measurement unit (IMU);
- an integrated onboard chip-antenna with 20 m range indoor/80m range outdoor;
- a USB port;
- a microSD card for logging and debugging;
- some I/O devices (3 LEDs, 2 buttons and a buzzer);
- six configurable GPIO pins (that can be used for digital I/O or analog inputs), for expanding the board with other sensors, like ECG, EMG, etc.

Figure 2 illustrates the block diagram of the main logical components of the sensor node, whereas Figures 3(a) and 3(b) show the internal circuitry and the container, respectively.

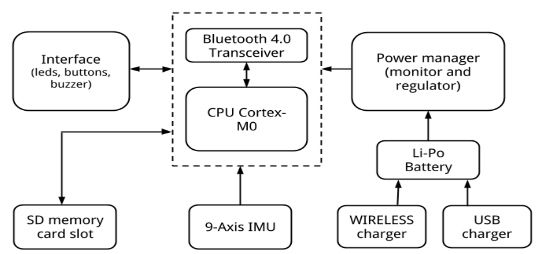
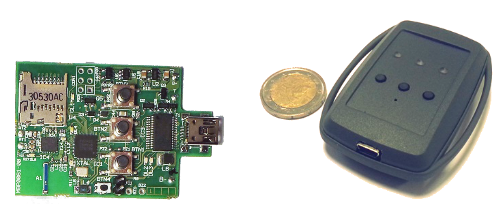


Figure 2. Block diagram of the main components of the sensory device.

The node is powered by a single cell LiPo battery that guarantees more than 20 hours of continuous usage at the maximum frequency (100 Hz) and can be charged via USB or through a wireless recharge device. The device communicates with the tablet through the BLE protocol [20] intended for strongly energy-constrained applications, such as sensors or disposable devices. Compared to the standard Bluetooth or to WiFi communication, the BLE data transmission is performed



(a) Interior of the node (b) Sensor container

Figure 3. The sensor node.

at a reduced speed [25] (approximately 1 Mbit/s) that was found to be appropriate for the implemented head tracking system, allowing us to exploit the other advantages of the BLE protocol, such as lower power consumption, better immunity to interference, and compatibility with widespread mobile devices.

In summary, the main advantages of this sensor with respect to similar commercial products available on the market are briefly summarized below:

- Low cost (in the range of 50 Euros);
- Precision of joint angle measurements below 1 deg;
- Low-energy consumption (a battery can last for a week in typical conditions and for two days in continuous transmission at the maximum frequency of 100 Hz);
- Standard wireless BLE protocol for connecting to tablet and smartphones;
- light weight (30 g);
- Simple initialization and calibration procedure.

III. 3D MODEL

The 3D model used for the graphics animation of the user's head was built to represent the upper part of a human being, including the head, the neck, the shoulders and a portion of the chest. They are represented by a set of vertices connected with line segments to form a polygonal mesh. Such a 3D model was created in Blender to provide the structure for the animation.

To recreate the natural movement of the head, the model requires the definition of virtual bones, used as a skeleton structure for expressing rotations around their joints. Such a virtual skeleton, referred to as the *armature*, consists of a set of bones associated with the geometry of the mesh. Each bone affects a specific portion of the mesh, so that its movements will change the geometry of the corresponding area of influence. A careful positioning and dimensioning of the armature is crucial to achieve a realistic head animation, since small position errors of the armature inside the mesh may cause incorrect rotations of the whole model.

The skeleton structure used in this application consists of three bones, one for the bust (*RootBone*), one for the neck (*NeckBone*), and one for the head (*HeadBone*), and is illustrated in Figure 4. Clearly, a higher number of bones allows achieving a better accuracy of the movements, which reflects in a more realistic head motion, but increases the computational complexity, both in terms of memory and processing power. After testing different solutions for the armature, we observed that the selected three-bone structure represents a reasonable trade-off to balance realistic motion with computational complexity.

In general, the bones of the armature form a hierarchical chain of links, where each link is connected to a parent (except for the root link). Then, the rotation of each link can be computed as a kinematic transformation relative to its parent. The whole armature has a rotation, scale, and translation with respect to a fixed reference frame. In this way, the animation requires solving a series of kinematic transformations over a period of time. The complete model with graphic rendering is illustrated in Figure 5.

In this application, the rotation detected by the head-mounted sensor is associated with the *HeadBone* segment. The kinematic transformation performed by the Android application on the 3D model is then triggered by the reception of the quaternion, periodically transmitted by the IMU every 20 milliseconds.

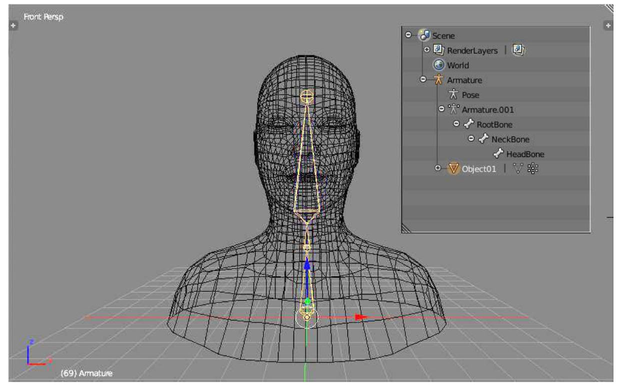


Figure 4. Basic 3D head model with mesh and armature.

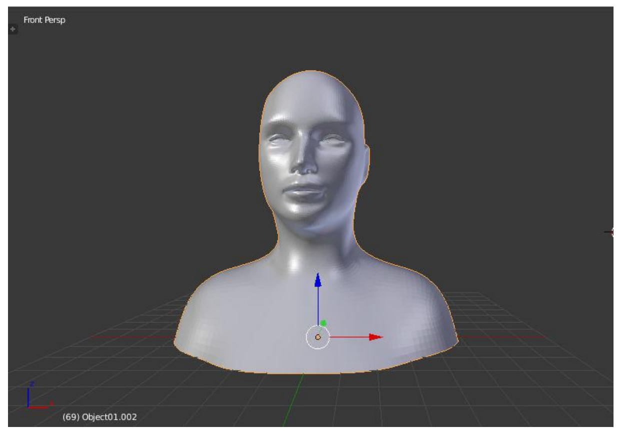


Figure 5. Complete 3D head model with graphic rendering.

Note that the model generated by Blender (exported in a .fbx file format) had to be converted into a format suitable for rendering on LibGDX, which can only import .g3dj and .g3db formats, because they are smaller and faster to load. Since the fbx file does not include texture information, a simple pink texture in .jpg format was created to wrap the 3D model and simulate the human skin. The sequence of operations described above to integrate the model into the Eclipse IDE is illustrated in Figure 6. Note that the Headtracking package containing all the folders and dependencies required by the LibGDX library has been generated by the LibGDX project setup.

IV. APPLICATION STRUCTURE

The application has been developed using the LibGDX library [22], which is an open source Java framework for game development. The main advantage if this library is that it provides APIs for multiple platforms, such as Linux, Mac, Windows, Android, iOS, BlackBerry, and HTML5. This is possible thanks to the presence of multiple project folders in its layout. In particular,

- Core project: it contains all the application code, except the so called starter classes. All the other projects link to this project.

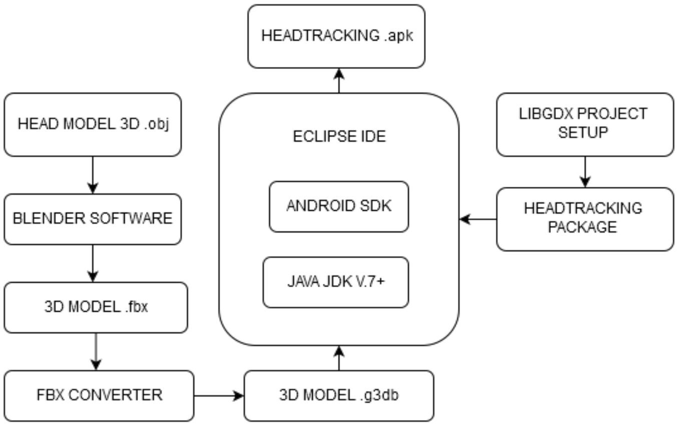


Figure 6. Block diagram of the main software components.

- Android project: it contains the starter class and other necessary files to run the application on Android. The assets/ folder stores the assets of the application for all platforms.
- Desktop project: it contains the starter class to run the application on the desktop. It links to the Android project's assets/ folder and to the core project.
- HTML5 project: it contains the starter class and other necessary files to run the application as a native HTML5 application. It links to the Android project's assets/ folder (see gwt.xml file) and to the core project.
- iOS RoboVM project: it contains the starter classes and other necessary files to run the application on iOS through RoboVM. It links to the Android project's assets folder (see robovm.xml) and to the core project.

For the head tracking application, only the Core and Android project folders have been used. The Android project contains the functions responsible for the Bluetooth communication and the user interface, whereas the "Core project" contains the functions responsible for rendering the model and change its parameters. The data received from the sensor are sent to the classes of the Android project and are processed by the classes of the Core project. For this reason, both folders contain specific code for exchanging data between them. The structure of the application is shown in Figure 7.

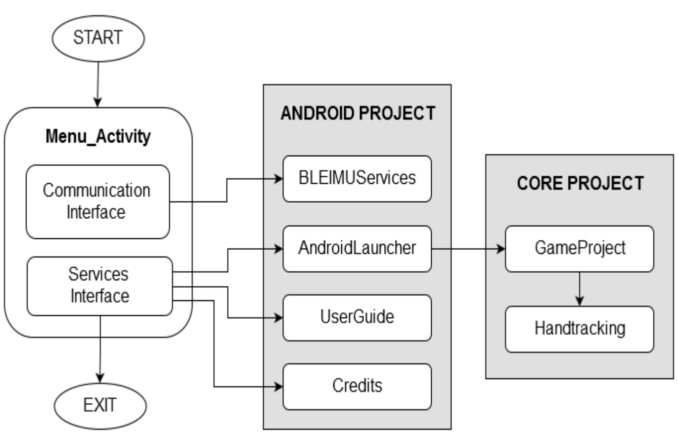


Figure 7. Application Structure.

The main menu of the application provides a *Communication Interface* responsible for managing the Bluetooth protocol (BLEIMUServices) and a *Services Interface* for selecting of the offered services. A screenshot of the main menu is shown in Figure 8.

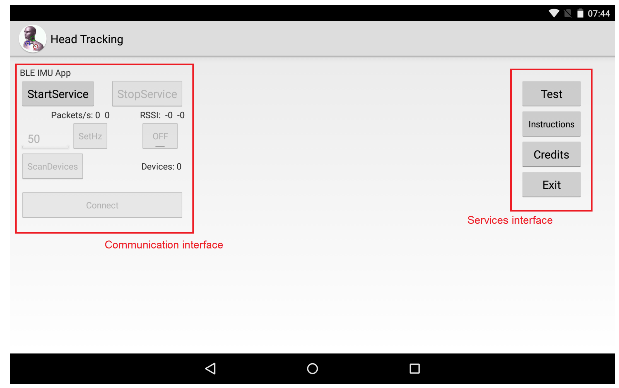


Figure 8. The main menu.

A. Communication interface

Using the Communication Interface the user can start or stop the Bluetooth communication between the sensor and the application, set the baud rate, scan the available devices and even monitor the arrival of incoming packets. The *StartService* and *StopService* buttons are used to start or stop the communication service, respectively. The *setHz* button allows setting the transmission frequency, whereas *ScanDevices* is used to start searching for available sensors. The *Connect* and *Disconnect* buttons allow starting and stopping the connection and, finally, the *ON/OFF* button can start/stop data acquisition from the connected devices.

In particular, when the ON button is pressed, the first received quaternion is used as a reference for all the subsequent data coming from the sensor, in the sense that all head rotation angles are computed as a difference between the current quaternion and the initial reference. In this way, the preliminary phase of positioning the sensor on the user head is not crucial, since any initial misalignment with respect to the ideal fixed frame is compensated by the differential computation with the initial quaternion. Such a calibration phase can be triggered by the user at any time by interacting with the control panel.

B. Services interface

The Services Interface allows the user to start other activities, such as testing the system, checking for the credentials, accessing the app manual, and turning the system off by pressing the *Exit* button.

Pressing the *Test* button the system displays the menu illustrated in Figure 9, which offers two different operational modes. The *Sensor Mode* provides a real-time animation of the 3D model, whose angles are updated every 20 milliseconds based on the data coming from the sensor.

The *Manual Mode* displays six screen buttons that can be used to manually change the pitch, roll, and yaw angles of the head, individually. The *Reset* button allows setting the head in the starting position. In both modes, orientation and zoom of the avatar can be controlled by the user via touch screen during the real-time animation.

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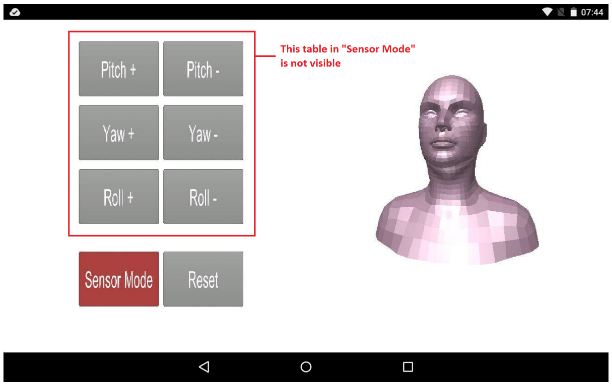

Figure 9. The Test Activity.

Finally, pressing the *Instructions* button the system displays the user manual, which reports the application features and explains the user interface.

V. EXPERIMENTAL RESULTS

This section presents some experimental results carried out to evaluate the effectiveness of the developed system in measuring head orientations and providing timely data.

A. Orientation accuracy

The orientation errors of the sensor node was evaluated with respect to a reference given by a Polhemus Patriot system [1], which provides the position and orientation of a mobile probe with respect to a fixed reference. In particular, the fixed reference emits a tuned electromagnetic field that is measured by the mobile probe. This procedure avoids performing hybrid data merging via software. The resulting resolution is about 0.03 mm and 0.01 degrees, whereas the static accuracy is of 1.5 mm RMS for the X, Y, and Z position and 0.4 degrees RMS for the orientation.

In the performed test, both the Polhemus and the head sensor have been mounted on a rotating link, as illustrated in Figure 10, to avoid any measurement error caused by misalignments.

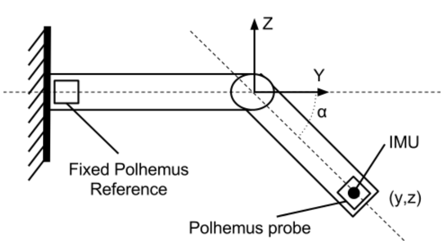

Figure 10. Experimental setup used to evaluate the accuracy.

The orientation accuracy of the sensor node was measured by converting quaternions to Euler angles and directly comparing them to the ones given by the Polhemus. Only the angles around X and Y axes were measured, because rotations around the Z-axis relies on the magnetometer, which is strongly affected by the magnetic field generated by the Polhemus.

Figure 11 shows the IMU measurement error distribution with respect to the Polhemus reference. Note that the error mean is 0.8685 degrees and its RMS is 0.9871 degrees. Considering the lower cost of the head sensor with respect to the Polhemus (i.e., tens of euros compared to thousands of euros) the achieved results are quite satisfactory.

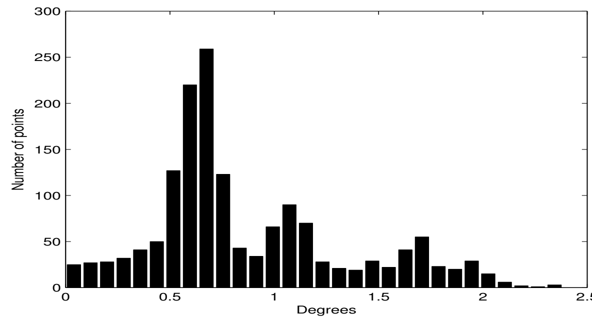

Figure 11. Distribution of the angular error.

B. Processing time and communication delay

Another specific test has been carried out to evaluate the computation time spent by the sensor node to process the data coming from the IMU and the end-to-end delay of data transmission, also taking into account the graphic representation performed by the tablet.

Processing times on the sensor node were measured by switching a GPIO pin at the beginning and at the end of the computation, and capturing them by a multi-channel logic analyzer. In particular, the following times have been captured on the sensor node:

- arrival times of the interrupts from the IMU device;
- duration of the packet read procedure from the I^2C bus;
- duration of data processing.

The results of this experiment are shown in Table I, which reports the execution time statistics for the I^2C read routine and the CPU processing time, that is, the time measured from the instant the packet is read from the I^2C bus to the time it is sent to the radio transceiver.

TABLE I. EXECUTION TIMES (ms)

Time (ms)	Mean	RMS	Std Dev.	Variance
$I2Cread$	2.409	2.416	0.1833	0.0335
$computation$	0.218	0.228	0.0660	0.0043

Unfortunately, GPIO switching cannot be used for measuring the communication delay between sensor and tablet. In fact, tablets do not allow the user to change a GPIO pin state in a simple way, as in microcontrollers, and there is no access to the internals of the BLE stack.

For these reasons, the message delay was estimated by measuring the interval of time from the instant at which the data packet is transmitted by the sensor to the time at which the Android application reacts to it by changing the color of a rectangular area of the screen. The color change (from black to white and viceversa) has been measured by a photoresistor attached to the screen. With the setup described above, data have been acquired at a sampling frequency of 20 Hz by a Nexus 7 tablet for 60 seconds.

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The results of this test are shown in Figure 12, which reports the measured delay distribution. Note that the end-to-end delay of data processing and representation varies from 3 ms to 30 ms, with an average value of 14.85 ms, leading to a smooth and reactive the 3D head animation. Table II reports the delay statistics of radio transmitting times and the overall delay from the time the packet is sent by the sensor to the time it is processed and displayed on the screen by the Android application. The high variance observed in the end-to-end delay measurements is due to a number of reasons, among which the transmission variability of the BLE protocol, the lack in the Android framework of a structured support for managing time constraints at the application and communication layer, and the complexity of the video rendering subsystem, which is optimized to improve the average user experience rather than a predictable timing behavior of data representation.

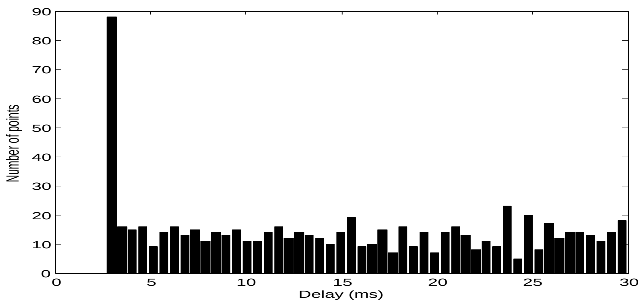

Figure 12. Distribution of communication delay, including the processing time of the Android application.

TABLE II. DELAY TIMES (ms).

Delay(ms)	Mean	RMS	Std Dev.	Variance
$BLEsend$	2.627	2.634	0.197	0.039
$display$	14.8523	17.1974	8.6754	75.2621

VI. CONCLUSIONS

This paper presented a low-cost, portable head-tracking device that works in combination with an Android application in charge of recording and visualizing head rotation data in real time. Sensory data produced by a 9-axis inertial unit are sent to a smartphone using the BLE communication protocol and then reconstructed to produce a realistic real-time 3D animation of the user head. The tests performed on the device to measure the end-to-end delay show that all the sensory data packets are processed and displayed within 30 ms, with an average delay of 14 ms, making the proposed system very competitive with respect to other (more expensive) commercial solutions, and attractive for a large number of applications, including rehabilitation, sport, gaming, and virtual reality. As a future work we plan to integrate the presented tracking device in a more complete monitoring system for detecting driver distractions to improve road traffic safety.

REFERENCES

[1] Polhemus. Polhemus Patriot Product Specification. [Online]. Available: http://polhemus.com/support/product-manuals/ [retrieved: March, 2016]

[2] Vicon. Mx hardware reference manual. [Online]. Available: http://www.udel.edu/PT/Research/MAL/ [retrieved: March, 2016]

[3] Microsoft Corp. Kinect. [Online]. Available: http://www.xbox.com/en-US/xbox-360/accessories/kinect [retrieved: March, 2016]

[4] Xsens Technologies. Mti technical documentation. [Online]. Available: https://www.xsens.com/wp-content/uploads/2013/12/MTi-User-Manual.pdf [retrieved: March, 2016]

[5] InterSense Inc. Inertiacube2+ manual. [Online]. Available: http://www.intersense.com/pages/33/142/ [retrieved: March, 2016]

[6] E. Foxlin, "Head-tracking relative to a moving vehicle or simulator platform using differential inertial sensors," in Proceedings of the AeroSense Symposium on Helmet and Head-Mounted Displays V, SPIE Vol. 4021, Orlando, FL, April 24-25, 2000.

[7] C. Avizzano, P. Sorace, D. Checcacci, and M. Bergamasco, "A navigation interface based on head tracking by accelerometers," in Proc. of the 13th IEEE Int. Workshop on Robot and Human Interactive Communication (ROMAN 2004), Kurashiki, Japan, Sept. 20-22, 2004.

[8] M. Keir, C. Hann, G. Chase, and X. Chen, "Accelerometer-based Orientation Sensing for Head Tracking in AR & Robotics," in Proc. of the 2nd International Conference on Sensing Technology (ICST 2007), Palmerston North, New Zealand, November 26-28, 2007.

[9] H. Zhou and H. Hu, "Inertial motion tracking of human arm movements in home-based rehabilitation," in Proc. of IEEE Int. Conference on Mechatronics and Automation, Niagara Falls, Canada, July 2005.

[10] D. Roetenberg, H. Luinge, and P. Slycke, "Xsens mvn: Full 6dof human motion tracking using miniature inertial sensors," Xsens Motion Technologies BV, Tech. Rep, Tech. Rep., April 2013.

[11] J. D. Mulder, J. Jansen, and A. van Rhijn, "An affordable optical head tracking system for desktop vr/ar systems," in Proc. of the 7th International Immersive Projection Technologies Workshop (9th Eurographics Workshop on Virtual Environments), 2003.

[12] J. C. Lee. Head-tracking for desktop VR displays using the Wii remote. [Online]. Available: http://www.cs.cmu.edu/~johnny/projects/wii/ [retrieved: March, 2016]

[13] Google. Google cardboard. [Online]. Available: http://www.google.com/get/cardboard/ [retrieved: March, 2016]

[14] O. V. LLC. Oculus gear vr. [Online]. Available: http://www.oculus.com/en-us/gear-vr/ [retrieved: March, 2016]

[15] Z. VR. Zeiss vr one. [Online]. Available: http://zeissvrone.tumblr.com/ [retrieved: March, 2016]

[16] W. Labs. Run-n-read. [Online]. Available: http://weartrons.com/ [retrieved: March, 2016]

[17] M. Benedetto, A. Gagliardi, P. Buonocunto, and G. Buttazzo, "An android application for head tracking (poster paper)," in Proceedings of the 31st ACM Symposium on Applied Computing (SAC 2016), Pisa, Italy, April 4-8 2016.

[18] Android. Android operating system. [Online]. Available: http://www.android.com [retrieved: March, 2016]

[19] Oracle. Java se documentatio. [Online]. Available: http://www.oracle.com/technetwork/java/javase/documentation/index.html [retrieved: March, 2016]

[20] Google. Bluetooth low energy. [Online]. Available: http://developer.android.com/guide/topics/connectivity/bluetooth-le.html [retrieved: March, 2016]

[21] Blender. Fbx file format specification. [Online]. Available: http://code.blender.org/2013/08/fbx-binary-file-format-specification/ [retrieved: March, 2016]

[22] LibGDX. Libgdx. [Online]. Available: http://libgdx.badlogicgames.com/ [retrieved: March, 2016]

[23] P. Buonocunto and M. Marinoni, "Tracking limbs motion using a wireless network of inertial measurement units," in Proc. of the 9th IEEE Int. Symp. on Industrial Embedded Systems (SIES 2014), Pisa, Italy, June 18-20, 2014.

[24] N. Semiconductor. nrf51822 product specification v1.3. [Online]. Available: http://www.nordicsemi.com/eng/Products/Bluetooth-Smart-Bluetooth-low-energy/nRF51822 [retrieved: March, 2016]

[25] Bluetooth. The low energy technology behind bluetooth smart. [Online]. Available: http://www.bluetooth.com/Pages/low-energy-tech-info.aspx [retrieved: March, 2016]

Internationalization Testing for a Multilingual Based Wireless Response System: A Case Study

Abduladim Ali
School of Computing and Engineering
University of Huddersfield
Huddersfield, United Kingdom
Email: Abuladim.ali@gmail.Com

Joan Lu
School of Computing and Engineering
University of Huddersfield
Huddersfield, United Kingdom
Email: j.lu@hud.ac.uk

***Abstract*— Recently, wireless technologies have had a tremendous influence on various advanced technology areas through e-learning environments such as the use of smart devices to engage learners and encourage them to interact effectively. Wireless communication technologies are being widely adopted within the education sector in order to deliver the best education support both virtually and globally. Today, introducing a multilingual Wireless Response System (WRS) application is not only an enormous challenge but also a complex one. The aim of this paper is to implement an internationalization-testing strategy using a WRS case study for multilingual speakers of Arabic, Chinese, French, German, Romanian, Spanish and Turkish. It also aims to evaluate the internationalization testing results as well as localization and cultural testing impacts. This paper also attempts to identify the various challenges that are associated with internationalization and localization testing based on smart devices, as well as introducing a globalization testing model for a multilingual system that includes each language's specific features, for instance: the direction of writing for some languages such as right language (Arabic and Urdu), and word spaces translating.**

Keywords*— *Mobile learning; WRS; Internationalization*; *Globalization Testing; Usability testing.

I. INTRODUCTION

In recent years, there has been continuous growth of mobile applications in various areas, from leisure to providing business needs. This is due to the tremendous growth in the diversity of smart devices. Therefore, advanced mobile application response systems have grown rapidly and this has led to intense attention on these applications by researchers and developers. In fact, various advanced technologies have been introduced for the users to facilitate and improve the effectiveness of teaching and learning [1]. The extensive everyday use of these applications has led to higher demands when it comes to quality and stability. Specifically, users of smart devices are more interested in utilizing easily accessible applications. These applications are required to be more scalable and to support various languages that is, they are supposed to be multilingual. According to John [2] fixing internationalization bugs costs 30 times more than other issues.

Mobile Learning (M-Learning) has had a significant impact on teaching and education sectors where M-learning is defined as learning across multiple contexts, through social and content interaction, using personal electronic devices [4]. One such benefit has been that students are more attracted to expanding the boundaries of higher education into an "anytime/anywhere" experience [3]. Therefore, a WRS in M-learning is necessary for students and teachers to interact with each other. The WRS as an M-learning application based on multilingual use has been developed by the XML Database and Information Retrieval (XDIR) research group at the University of Huddersfield in the UK [4]. WRS enables students and teachers to collaborate with each other by means of smart devices.

The WRS like many M-learning applications is based on advanced technology in order to operate on smart devices across a wide range of platforms [5] including: PCs, laptops, tablets, and smart phones.

This paper attempts to highlight several challenges , which are associated with the internationalization testing of mobile applications. This paper will also describe the effectiveness of the test strategy to evaluate the localization process testing with the help of a WRS mobile app case study. The internationalization testing was conducted for multilingual use in Arabic, Chinese, French, German, Romanian, Spanish and Turkish.

Though sample sizes larger than 30 and less than 500 are appropriate for most research studies [6], throughout this study a relatively small sample size has been considered as this parameter is not as significant compared with the respondents' interface and interaction with the investigated system. Thus, when a user with a particular language employs this system, he/she may find that customized text space is insufficient; this would of course be the result for all respondents in this language [7].

This paper is organized as follows: Section 2 presents the internationalization background of mobile applications. Section 3 presents works related to globalization testing. Section 4 presents the experimental methods of WRS. Section 5 presents the discussion and evaluation of the experiment result with statistical results for each language. Finally, conclusions and suggestions for future work are given.

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II. BACKGROUND

This section highlights issues such as the state of worldwide mobile applications including the internationalization testing process, internationalization testing challenges, globalization testing, the definition of GUI testing, and cultural testing.

A. *The state of worldwide mobile applications*

According to Sandrini [8] and Buck et al. [9], in 2013 alone, twenty one billion mobile apps were downloaded globally. The profits through the sale of mobile applications are expected to be more than $330 billion by 2015 [10]. Therefore, every year the usage of mobile applications is rapidly increasing. Lu [11] stated that more than 15% of global internet traffic is expected to be from mobile users by 2015 as compared to desktop users. Hence, wireless smart devices play a key role in accessing a wide range of services and becoming an essential part of users' daily lives for banking, shopping, healthcare, education and games.

B. *Globalization Testing*

Internationalization and localization are subsets of globalization (abbreviated g11n). Globalization testing is the process of assessing the mobile application in order to identify the application's performance within specific culture and language input and output conditions [4]. As depicted in Figure 1, globalization has been categorized into three phases including: feature to be tested, localization testing, and local awareness testing [12].

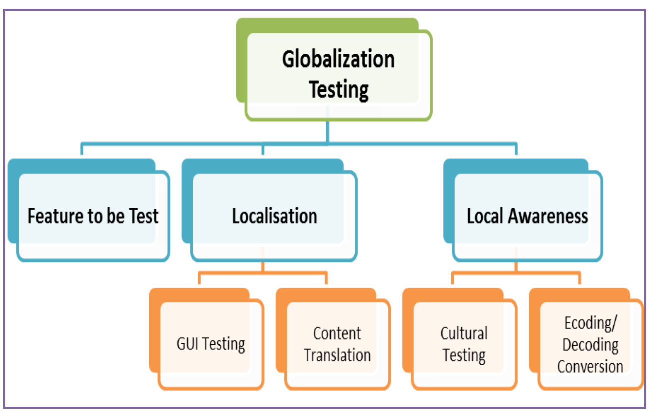

Figure 1. Globalization Testing Sub-tree

a) *Internationalization Testing*

Internationalization (abbreviated "i18n") organizes smart apps to make them easier for localization. Internationalization testing on the other hand is the process of evaluation for a single country, local, language, or culture [2].

i. ***Internationalization Testing Challenges***

The internationalization testing challenges consist of issues and concerns related to the native users in different countries. Theses are in terms of language and culture specifications as depicted in table 1.

TABLE I. GLOBALIZATION TESTING ATTRIBUTES AND CHALLENGES.

Attributes	Challenges
Screen Size Limitation	Flexible layout to avoid expansion and contraction of text.
Screen Direction Layout	(RTL) and vertical text direction e.g. for Hebrew, Arabic, or Persian
Platform	Different OS IOS and Android
Context and Special Characters	The characters, symbols, labels, icons and buttons from language to language e.g., English to Chinese.
Data Handling	How the app handles data, warring messages and navigation
Regional Standards	Date, month and time e.g. Arabic or USA format (١٢ كانون الثاني ٢٠١٤).
Text Translation and Abbreviation	Space handling, e.g. content translated into German can take up to 30% more space than English
Culture Specification	Colour and image according to culture specifications.

ii. ***Internationalization Testing Process***

The internationalization testing process consists of globalization testing with feature based testing, localization testing and local awareness testing as depicted in Figure 1.

iii. ***Feature Based Testing***

Feature based testing is a process used to identify features of a product available in specific languages that have different content as compared to other languages and cultures. In fact, it is important to ensure that these features are turned on or off as required while switching locales [13].

b) *Localization Testing*

Localization testing is language verification testing, which is mainly focused on the appropriateness of the translation [14]. It is a process of asset verification within the application's user interface for the specific language contents and for the functionality state of the application, including: keyboard and mouse events, different GUI components e.g., menu bars, toolbars, dialogs, buttons, edit fields, and rich text [15]. In fact, 80% to 90% of localization issues are based on text translation quality issues, for example grammar mistakes, spellings, syntax, corrupted text, wrongly translated text, wrong language, and missing audio/text [16]. Moreover, linguistic accuracy is essential in globalization testing in order to identify those issues that have been introduced during the localization process.

c) *Local Awareness*

Local awareness testing is the process of detecting the translating formats of specific languages and cultures, for instance Arabic formats from right to left (e.g, ٠،١،٢،٣،٤،٥،٦،٧،٨،٩), as well as date, month, year, and time (e.g, ١٢ كانون الثاني ٢٠١٤). In fact, it is essential for each global mobile application to consider storing and retrieving documents containing locale-sensitive data such as changing the logic of all the formatting functions such as: date, time, currency, numeric, etc. It must also follow the language specification formats in terms of text, number and image formats [17].

III. RELATED WORK

Many studies have examined several factors of internationalization testing such John [2], Meng and Lu [3], Lu [5], and Sekaran [6] though each of the studies has it is own contributions and limitations. Since 2007 when the first mobile application was released in app stores [6], countless technologies have been introduced to facilitate and improve the effectiveness of wireless response systems. Therefore, the internationalization of M-learning apps is essential for students and teachers to collaborate with each other, and to remotely enhance students' performance. Simkova et al. cited in Bastien [18] emphasized that M-Learning is certainly an interesting approach to learning, but is unfortunately still an unknown concept in many countries where it has not yet caught on.

Web course (WebCT) is an M-learning application which was criticized by Haller [19] due to the complexity of the application, which was contributed to by its complex architecture. Another example of an app that is challenging to use is the IELTS exam. This app has several individual applications as depicted in Figure 2, which consist of: the IELTS Reading app, IELTS Writing app, IELTS Speaking app and IELTS Grammar app. However, the individual apps are not useable by students. Because the apps are not all integrated into one application, students have to download each part of the English exam individually. In fact, these apps are suffering from a lack of a responsive approach.

Figure 2. IELTS Exam Mobile Application adopted from [7]

Moreover, Dhingra, cited in Haller [19] discussed various challenges that are associated with the localization and testing of mobile applications. He also described several elements and recommended that each element should be equipped with an effective test strategy for localization testing. He also stated that mobile localization should not just include translation, but should also include the user interface, and an adaptation of graphics based on locale or culture differences. [20].

IV. WRS METHOD OF EXPERIMENT

The proposed method for this research is based on the WRS case study and the eight identified attributes of internationalization testing requirements. It also takes into consideration several challenges of each attribute within each individual language that have been utilized in the WRS application. Translating the terms of the WRS application was based on an independent professional translating firm as professional translators.

The translated terms of every language were applied to localise the application by using Adobe Flex Builder 4.6 for the teacher phase, and Adobe Action Script® for the student phase. The WRS app was programmed in PHP and MySQL was used to retrieve the data.

For each language, there were 10 participants who carried out the globalization testing to evaluate the application based on their language attributes. The WRS testing was divided into two phases: student testing was the first phase, and the second phase assessed the teacher interface. Then the teacher and students interfaces were evaluated to understand how they experienced this application.

V. DISCUSSION AND EVALUATION

Internationalization testing for the WRS was carried out for seven languages: Arabic, Chinese, French, German, Romanian, Spanish, and Turkish. The calculation method for each language was: a number of questions were asked and the participants' answers were based on five evaluation matrices: excellent, poor, above average, below average, and average.

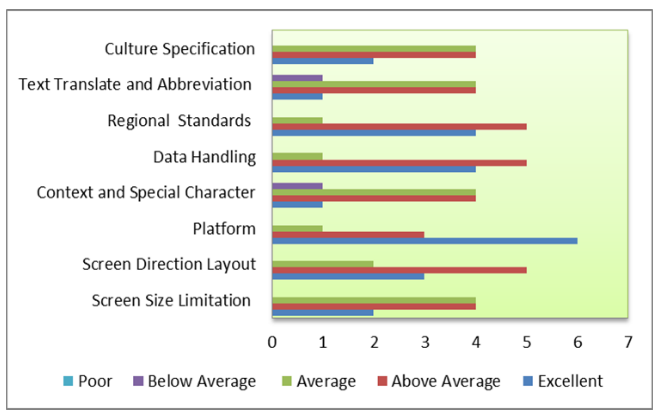

Figure 3. WRS Internationalization Test attribute for Arabic language

According to the test results, the internationalization testing for the Arabic language as depicted in Figure 3 highlights that 6 participants evaluated the WRS app as excellent for platform scalability, whereas 4 participants evaluated the app as above average in terms of text translation. 5 participants evaluated the WRS app as above average in terms of regional standards, data handling, and screen direction. 4 participants evaluated the app as average as compared to only 2 participants who evaluated the app as below average.

The Chinese language was the second to undergo internationalization testing of the WRS as depicted in Figure 4. 5 participants evaluated the WRS app as excellent for platform scalability, whereas 4 participants evaluated the app as average in terms of culture specification and regional standard. In addition, 3 participants evaluated the app as above average compared to only 2 participants who evaluated the app as below average in terms of context and special characters. 1 participant evaluated the WRS app as poor in terms of text translation, context and special characters.

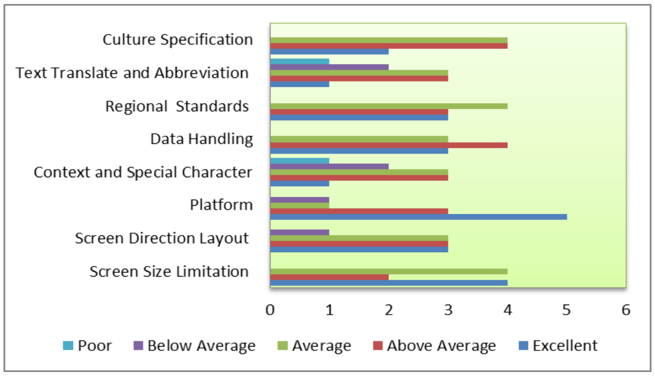

Figure 4. WRS internationalization Test attributes for Chinese language

The third language to undergo internationalization testing was the French language as depicted in Figure 5. Here, 7 participants evaluated the WRS app as above average for platform scalability, whereas 5 participants evaluated the app as excellent in terms of screen size limitation.

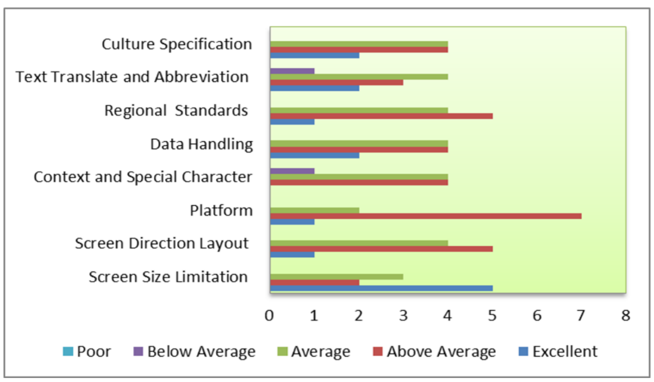

Figure 5. WRS Internationalization Test Attributes for French Language

4 participants evaluated the app as above average as compared to only 1 participant who evaluated the app as below average. Only 1 participant evaluated the WRS app as below average in terms of context and special characters.

Internationalization testing has also been carried out for the German language as depicted in Figure 6.

In this test, 6 participants evaluated the WRS app as above average for platform scalability, whereas 6 participants evaluated the app as above average in terms of culture specification.

4 participants evaluated the app as above average, as compared to only 2 participants who evaluated the app as below average in terms of context and special characters. Only 1 participant evaluated the WRS app as poor in terms of text translation, context and special characters.

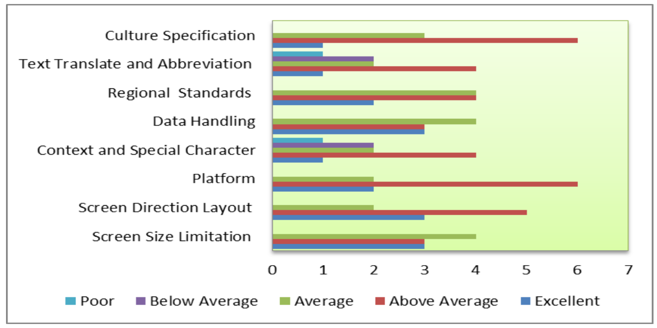

Figure 6. WRS Internationalization Test Attributes for German Language

The fifth internationalization testing was carried out for the Romanian language as depicted in Figure 7.

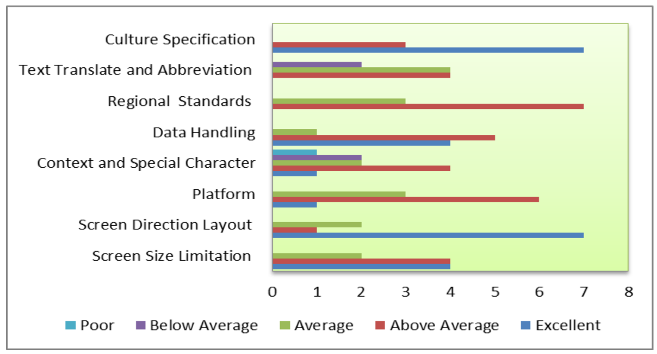

Figure 7. WRS Internationalization Test Attributes for Romanian Language

The majority of the participants evaluated the WRS app as excellent in terms of screen direction and culture specification; whereas 4 participants evaluated the app as above average in terms of text translation, context and special characters. 4 participants evaluated the app as excellent, 5 participants evaluated the app as above average, and only 1 participant evaluated the WRS app as average in terms of data handling.

The internationalization testing was carried out for the Spanish language as depicted in Figure 8.

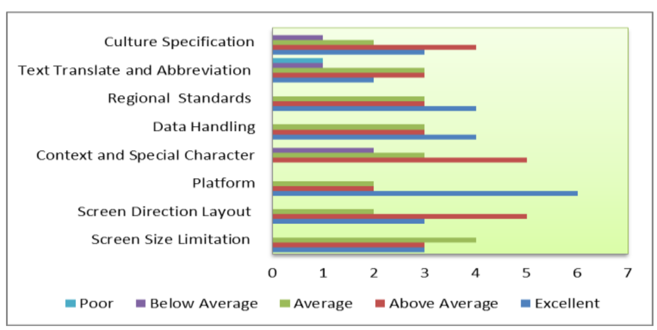

Figure 8. WRS Internationalization Test Attributes for Spanish Language

6 participants rated the WRS as excellent in terms of platform scalability. Whereas 5 participants evaluated the WRS app as above average in terms of context, special characters and screen direction layout. 4 participants evaluated the WRS app as excellent in terms of data handling, as compared to the other 4 participants who evaluated the WRS app as below average for context, special characters, text translation and culture specification.

The Turkish language has also been tested as depicted in Figure 9. 6 participants evaluated the WRS app as excellent in terms of platform scalability, and 5 participants evaluated the WRS as excellent for the screen limitation, screen direction and culture specification.

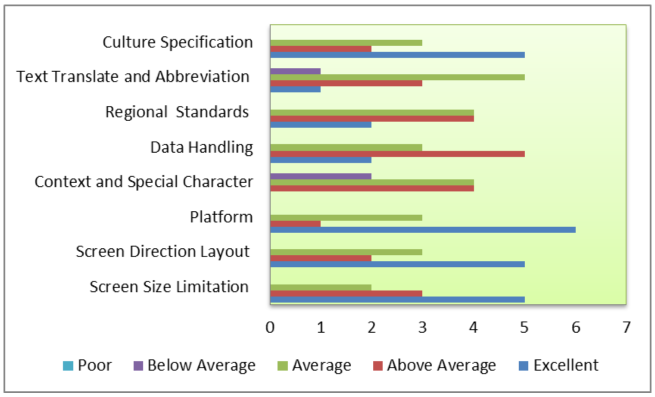

Figure 9. WRS Internationalization Test Attributes for Turkish Language

4 participants evaluated the WRS as average for regional standard, 3 participants evaluated the WRS as below average scale for context, special characters and text translation.

From the above analysis it is clear that the researcher dealt with 70 participants through seven different languages; the ratio of trust these participants gave to the application according to the offered attributes is depicted in the table below.

From the below table it is clear that the attributes that best won the confidence of the participants and were above average are Platform (70.8%), followed by Screen Direction Layout (70.3%) and Data Handling (70.3%), respectively.

TABLE II. THE RATIO OF TRUST GIVEN TO THE APPLICATION BY THE PARTICIPANTS, ACCORDING TO THE SPECIFIED ATTRIBUTES.

The Attributes	Average %	Total (N)
Screen Size Limitation	60.7	N = 70
Screen Direction Layout	70.3	
Platform	70.8	
Context and Special Characters	40.6	
Data Handling	70.3	
Regional Standards	60.7	
Text Translation and Abbreviation	40.5	
Culture Specification	70.0	

However, Context and Special Characters (40.6%) were below average. This is perhaps due to the difference in the size of the words and the number of characters per word for each language. Additionally, Text Translation and Abbreviation (40.5%) was lower than the average, this has been attributed to the translators failing to arrive at a precise and uniform translation for some of the terms, this is because each languages' words carry many meanings, and the translators can detect errors only when the application is used.

The ratio of trust that the participants gave to the application according to each language is in the following table:

TABLE III., THE RATIO OF TRUST GIVEN TO THE APPLICATION BY THE PARTICIPANTS ACCORDING TO EACH LANGUAGE.

The Languages	Average %	Total (N)
Arabic	70.1	N = 10 for each Language
Chinese	50.9	
French	60.0	
German	60.4	
Romanian	70.3	
Spanish	60.6	
Turkish	60.3	

From the above table it is clear that the best languages that won the confidence of the participants and performed above average were the Romanian language which achieved (70.3%), followed by Arabic (70.1%), Spanish (60.6%) and German (60.4%). The French Language (60.0 %) and Chinese language (50.9%) came in last, possibly due to the same reasons mentioned above.

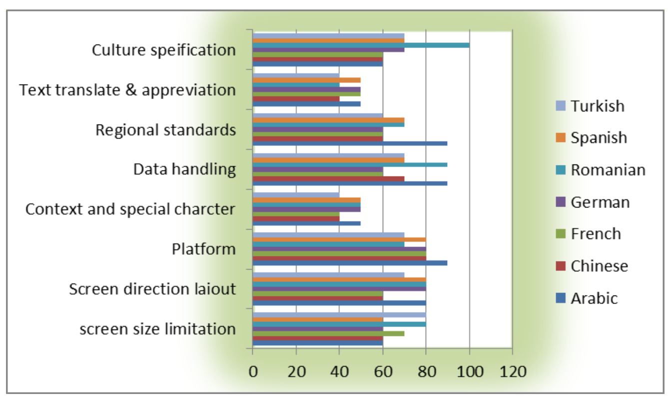

Figure 10. WRS Internationalization Test Attributes For All Languages

From figure 10 above, it is clear that there are some problems in the attributes (Context and Special Characters) as well as Text Translation and Abbreviation. The causes of these problems have been explained previously in the second and third tables.

VI. CONCLUSION AND FUTURE WORK

The aim of this research was to investigate two areas: firstly, it demonstrated the concept of the internationalization testing process, and secondly, it established a comprehensive method for internationalization testing techniques for a Wireless Response System (WRS) application in multilingual use. However, based on our literature study we can highlight that international testing is a challenging task for mobile applications because it has a great impact on the quality of the mobile application in terms of globalization attributes. Our experiments were based on a holistic view of how to influence the WRS testing strategy for multilingual apps by identifying the challenges. In addition to this, we identified some of the key attributes and demonstrated the careful design of an internationalization testing strategy to overcome these challenges and develop solutions for performing localization testing of mobile applications.

In this paper we presented the globalization testing techniques including the internationalization and localization testing for the WRS case study evaluating globalization-testing issues, specifically within WRS apps. Our aim was to discover issues and errors in the selected languages. We also intended to focus on the key attributes for each language. Each language's attributes have been tested by native speakers of the selected languages in order to identify and highlight the drawbacks of WRS, as well as to help conduct different approaches for target audiences with varied cultures, regions, or screen direction.

For future work, we will attempt to use the internationalization testing approach in further validation experiments for more languages, followed by comparing the internationalization attributes in each of the languages in terms of complexity.

REFERENCES

[1] D. Banks, *Audience Response Systems in Higher Education: Applications and Cases: Applications and Cases*: IGI Global, 2006.

[2] S. K. T. John. *Localisation Testing, Build a Great Team.* Available: http://www.ministryoftesting.com/2014/08/localisation-testing-build-great-team/, 2014

[3] Z. Meng and J. Lu, "'Implementing the Emerging Mobile Technologies in Facilitating Mobile Exam System," in *2011 2nd International Conference on Networking and Information Technology, IPCSIT*, pp. 80-88 2011,

[4] J. Lu, R. P. Pein, G. Hansen, K. L. Nielsen, and J. B. Stav, "User Centred Mobile Aided Learning System: Student Response System (SRS)," in *Computer and Information Technology (CIT), 2010 IEEE 10th International Conference on*, pp. 2970-2975. 2010,

[5] Lu, Zhongyu Joan, ed. "Learning with Mobile Technologies, Handheld Devices, and Smart Phones: Innovative Methods: Innovative Methods." *IGI Global*, 2012.

[6] U. Sekaran, "Research methods for business: a skill building approach," *Journal of Education for Business*, vol. 68, pp. 316-317, 2003.

[7] B. Esselink, *A practical guide to localization* vol. 4: John Benjamins Publishing, 2000.

[8] P. Sandrini, "Website localization and translation," in *EU-High-Level Scientific Conference Series MuTra*, 2005.

[9] C. Buck, C. Horbel, T. Kessler, and C. Christian, "Mobile Consumer Apps: Big Data Brother is Watching You," *Marketing Review St.Gallen*, vol. 31, pp. 26-35, 2014.

[10] J. Gao, X. Bai, W.-T. Tsai, and T. Uehara, "Mobile Application Testing: A Tutorial," *Computer*, vol. 47, pp. 46-55, 2014.

[11] J. Lu, "Student Response System (SRS)/Wireless Response System (WRS)–a Next-Generation Student Response System for Academia and Industry," 2011.

[12] B. Amen, M. Sardasht, and J. Lu. "Mobile Application Testing Matrix and Challenges", in *Fifth International conference on Computer Science and Information Technology* Sydney, Australia, 2015 pp. 27-40

[13] M. Kompf, "Usability and internationalization of information technology," *Education and Information Technologies*, vol. 11, pp. 187-189, 2006.

[14] M. Fetaji and Z. Dika, "Usability testing and evaluation of a mobile software solution: a case study," in *30th International Conference on Information Technology Interfaces*, 2008 ,pp. 501-506,

[15] V. Rajappa, A. Biradar, and S. Panda. "Efficient software test case generation using genetic algorithm based graph theory." 2008 First International Conference on Emerging Trends in Engineering and Technology, July 2008, pp. 298-303.

[16]Bernal-Merino, Miguel Á. "Globalization and Co-Creation: Trends in International Game Production" in A. Esser, M. Á. Bernal Merino and I.R. Smith *Media Across Borders: Localising TV, Film and Video Games* , 2016

[17] N. Albalooshi, N. Mohamed, and J. Al-Jaroodi, "The challenges of Arabic language use on the Internet" in *2011 International Conference for Internet Technology and Secured Transactions (ICITST)*, , 2011, pp. 378-382.

[18] J. C. Bastien, "Usability testing: a review of some methodological and technical aspects of the method," *International Journal of Medical Informatics*, vol. 79, pp. e18-e23, 2010.

[19] K. Haller, "Mobile Testing," *ACM SIGSOFT Software Engineering Notes*, vol. 38, pp. 1-8, 2013.

[20] J. Lei and J. Zhang, "Challenges and Future Directions in Sinic Education," in Y. Zhao (ed) *Handbook of Asian Education: A Cultural Perspective*, p. 134-156, 2010.

Basic Internet Access: Capacity and Traffic Shaping

Elin Sundby Boysen
University of Oslo/UNIK
Kjeller, Norway
email: elinsbo@ifi.uio.no

Iñaki Garitano
Enginering Faculty
Mondragon Unibertsitatea
Mondragon, Spain
email: igaritano@garitano.org

Josef Noll
Basic Internet Foundation
University of Oslo/UNIK
Kjeller, Norway
email: josef@unik.no

***Abstract*—This paper analyzes economical and technological aspects for service provisioning on varying networks. Though mobile networks are continuously evolving, the use of mobile broadband is and will be limited. Availability and affordability are two aspects, which are addressed in this paper through the introduction of basic information and *low capacity (LC)* services. The paper addresses how information provisioning and network-aware applications work together to achieve a digital society including everyone, rather than enhancing the digital gap. Initiatives like Facebook's Free Basic and the Basic Internet Foundation and their approaches on LC-service and information provisioning are addressed. The second focus is on a proactive approach for mobile applications (apps), adjusting to the network capacity and bandwidth limitations. The main results are recommendations towards a low-capacity Internet for everyone, supported by examples of LC-service provisioning, as well as network-aware apps.**

***Keywords*–Internet; Basic Internet; broadband; devices; network; information; developing economies; availability; affordability.**

I. INTRODUCTION

The Internet now links several billion devices worldwide together, and consists of a multitude of networks with local or global scope, private or public connected to a broad array of networking technologies [1]. In the 1990s, the Internet had developed into a usable and efficient service that changed the economy. Today, around 46% of the world's households have access to Internet through either fixed or mobile subscriptions [2]. However, the gap between developed and developing countries is still wide. According to ITU [2], by the end of 2015, 34% of households in developing countries had Internet access, compared with more than 80% in developed countries. In the least developed countries, only 7% of households have Internet access. In this same set of countries, 12 of 100 inhabitants have active mobile broadband subscriptions, whereas less than 1 of 100 inhabitants have fixed broadband subscriptions.

Higher penetration of Internet access in these areas is important for three main stakeholders:

i) for local governments, as digital inclusion is vital for six key sectors: health, education, financial services, retail, government and agriculture [3]. In the latter Internet access is an important premise for harvesting benefits that lie in the use of IoT-technologies that can automate labor-intensive and health-hazardous industrial and agronomic work [4].

ii) for the inhabitants themselves to gain access to information related to education and healthcare, and thus providing a possibility to provide better care for themselves and their families.

iii) for companies that realize the market potential behind this vast number of people currently without access to Internet. This may not be in terms of the purchasing power of each inhabitant, but as a result of the mere number of people. Serving such a number of customers - often residing in rural areas - will only be possible through Internet instead of physical presence.

Access to mobile networks and feature phones have already increased drastically over the last 15 years, where the proportion of the worldwide population covered by a 2G mobile-cellular network grew from 58% in 2001 to 95% in 2015 [4]. A similar growth in access to mobile Internet access is envisioned, but relies on overcoming the main challenges for adoption:

i) *pricing of phones*. Many in these regions cannot afford to buy smart phones and seldom use their mobile phones for more than the occasional voice call. Companies such as Micromax, Xiami, Google and Mozilla are however trying to meet the challenge of expensive phones by developing low cost handsets targeting these markets' needs [4].

ii) *availability and affordability of data traffic*. GSMA has pointed out that by the end of 2014 around 77% of the developing world only had access to no (59%) or narrowband (18%) [5]. Though operators plan for cheaper networks with wider coverage, there will still be a substantial amount of people in the developing world not being able to connect.

iii) *traffic speed*. When connections with less than 2Mbit/s are the normal situation, access to widely used web sites and services, and downloading necessary information becomes cumbersome and sometimes even impossible due to time-outs.

iv) *lack of local content* that is relevant for inhabitants in the region, in their local languages, and which also embraces the challenges of traffic speeds in the region.

The Basic Internet Foundation has been established to provide Basic Access to Information to inhabitants addressing these challenges. Free access to low-capacity information is seen as a minor extra cost for the network operator, being either an ISP or a mobile operator. In this paper we address the Basic Internet solution and how it relates to other solutions with similar goals. Further we describe the main technological challenges of content delivery for capacity-limited networks, being traffic shaping on the server side and selected access on the mobile client side. The main contributions of this paper are solutions for traffic shaping and better matching of content to capacity. These solutions are vital in providing access to basic information, but will also be relevant and applicable for other implementations and usage scenarios.

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The paper is organized as follows: Section II presents solutions from companies with similar goals. Section III presents the technology challenges, and Section IV addresses first results from pilot implementations. Section V concludes the paper.

II. RELATED INITIATIVES

In this section, we provide an overview of existing solutions for Internet distribution in areas with economic issues, and discuss some of their limitation. We then give a brief introduction to our solution and its main technical challenges. Initiatives like ConnectTheWorld [6] and Digial Impact Alliance (DIAL [7]) form the political and societal platforms for digital inclusion. From the technical point of view, this paper concentrates on the approaches by Free Basics, Mozilla, and the Basic Internet Foundation.

A. Free Basics from Facebook

Internet.org is a partnership between Facebook and several companies to bring affordable access to Internet services. The initiative targets both areas where access is non-existent and areas that have a mobile infrastructure. Non-existent access is provided through local Internet Service Providers (ISPs) using Wifi Express. In areas with mobile coverage, zero-rated content is offered to mobile operators. Zero-rated content are web pages and apps, which are provided free-of-charge to the end customer. *Free Basics by Facebook* is launched in 39 countries provides an open platform for providers of apps, websites or services an open platform. These can be added to Free Basics as long as they abide by Facebook's participation guidelines that shall ensure acceptable performance on older phones and slower network connections. The idea is that the free access will help people understand what Internet is and what it can be used for, and thus, that paying for further access to the broader internet is worth the cost. Internet.org estimates that 50% of people who use Free Basics will pay for data and access the broader internet within 30 days.

A similar platform, Airtel Zero, offers free access to certain mobile applications and services [8]. Developers and service providers who pay Airtel a fixed fee for the cost of data transfer can offer their apps free to end customers.

Both Free Basics and Airtel Zero has been criticized for violating net neutrality [9] as their approach creates a walled garden around information their users can access. Lately Free Basics has published technical guidelines for efficiency and size [10], and has thus transferred the evaluation of apps and web sites to objective measures.

B. Free access paid by ads

Mozilla has targeted the challenge of high prices on handsets by developing a low-cost handset with their own Firefox OS. In Bangladesh and several African countries they have teamed up with local mobile operators such as Grameenphone and Orange. In Bangladesh, Grameenphone offers the users 20MB of free data per day given that they visit the phones marketplace where users are exposed to advertisements that fund the access. Orange offers buyers of Mozilla's smart phone unlimited free Internet for a set period of time in several African countries.

C. Basic Internet Foundation

The Basic Internet Foundation started its activities back in 2010 for developing Internet access in Africa, following the idea that *information* should be accessible to everyone. A series of pilots were established in 2011, amongst others the Internet access for the region and the University of Lisala (DRC). Experiences from these pilots showed that the bandwidth limited and costly satellite link was the biggest hurdle for affordable Internet access.

Basic Internet thus introduced *compressed text and pictures* as the core elements for Basic Information. Information is seen as social, economic, political and cultural content depending on the background of the reader, and its importance will vary accordingly. Hence, non-discriminating access to Basic Information and net neutrality are fundamental for the Basic Internet solution. The solution allows any Internet provider, being it a mobile or an ISP operator, to set up a system where they can provide each user with free access to Basic Information. Voucher sales covers operating costs and allows end users to buy access to more data traffic. As opposed to the solutions described in Section II-B, the Basic Internet solution is not dependent on specific operating systems or apps on the users' phones.

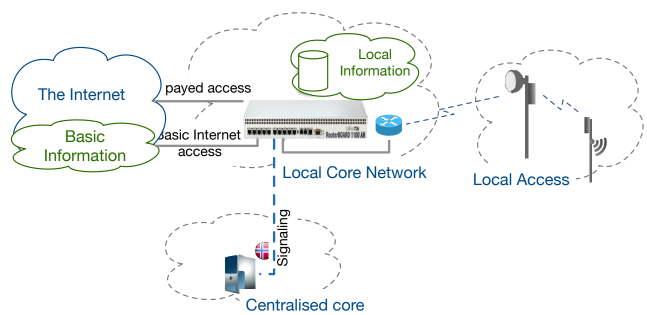

Figure 1. The cost-effective Basic Internet Architecture

As data costs constitute a barrier from accessing mobile data, the main focus of the Foundation is getting as much information as possible through a bandwidth-limited link. Some examples of such low-availability links are satellite links and congested mobile networks. The Foundation has implemented a network architecture (see Figure 1) answering the need of a low-cost local infrastructure and rapid deployment.

The Basic Internet network contains in its complete form: a local core network with local information, a local network, a centralised core, and the backhaul network/network termination. In areas where no Internet connection is available, the network termination can be achieved through either a radio link or a satellite connection. The solution provides high capacity access to local content, payed access for Internet services, and *free access* to Basic Information. Further elaborations on the business models are given in section IV.

The next section describes the major challenges related to information provisioning and traffic shaping that allows for Basic Internet access.

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III. Technology Challenges

Currently, the technological department of the Basic Internet Foundation is focused on solving two main challenges related to capacity optimization and traffic shaping: *(i)* the notification of information and *(ii)* traffic recommendation.

The *first challenge* is related to information provisioning and the way information is best presented in bandwidth-limited systems. Thus, we try to characterize information content related to the amount of bits being used in the communication. Instead of restricting content, we suggest to restrict content types, e.g., to allow text and pictures, but dismiss videos. However, both definition and technological implementations are not straight forward. Taking the example of the resolution and the size of a picture. Depending on the content of a picture, a certain resolution and size is required to provide meaningful information. This part of capacity optimization takes place in the back-end of the Basic Internet system.

The http archive provides various measures of content of web pages [11]. An average Web page has doubled in size from 2012 to 2015, being 1.09 MB in 2012, and 2.1 MB in 2015. The space used by scripts on web pages is between 15 and 19%, while images account to slightly more than 60%. The raise of video is documented first time in 2015, accounting for 10% of the web size.

TABLE I. WEB SITE GROWTH AND CONTENT

	1Jul2012	1Jul2013	1Jul2014	1Jul2015
av. web site [kB]	1090	1485	1829	2135
Images [kB]	684	909	1159	1348
Scripts [kB]	210	225	293	344
Video [kB]				204

Though the total size has doubled, there are remarkable differences in size. Google.com uses only 90 kB, while Wikipedia uses around 300 kB, both substantially lower than the 3.3 MB used by the NYTimes.com. On thin lines, e.g., a satellite link of 1 Mbps, a web page of 2.1 MB would load in 20 s, and block the satellite capacity for other users.

Thus affordability requires reduction of information, which can be achieved through removing content, content elements, resizing images and compression of the whole web page. Opera Mini is one of the best examples of a browser designed primarily for mobile phones, smartphones and personal digital assistants that can provide a maximum of information, even though it has limited capacity in the network [12]. Statistics from Opera point to an average of 340 pages/user, resulting in an average of 4 MByte per month for users in Nairobi [13].

The *second challenge* is related to providing a better foundation for app developers to make their apps adhere to changing network conditions and the users' limited data plans by providing a *traffic recommender*. Basic Internet will be delivered to end users via WiFi hot spots or mobile broadband. Most smart phones allow the users to limit the apps from transferring large amounts of data when using mobile data. However, when WiFi is available, these apps usually do not consider the amount of data transferred, the end-to-end throughput, or allow for limited traffic profiles. This easily results in high bandwidth usage and poor user experience. The needs for better capacity usage in Basic Internet access networks is one application area. Addressing the bandwidth limitations is a second application area for the traffic recommender, as shown in these two scenarios:

A) The mobile unit perceives the WiFi as a high-capacity link when indeed the back end is a low-capacity 2G or satellite link limiting traffic (see Figure 2).

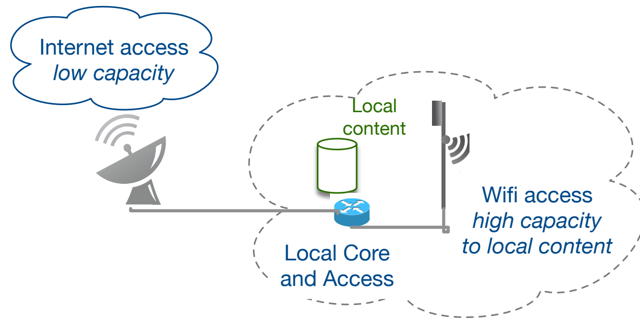

Figure 2. Bandwidth is limited by the low-capacity backhaul.

B) The WiFi AP and backhaul does indeed allow for high traffic, but the payment plan sets limitations. In the latter case, a misguided app can end up downloading unnecessary data worth a month's quota unless it is informed that access to WiFi is not the same as "send as much as you like". (see Figure 3).

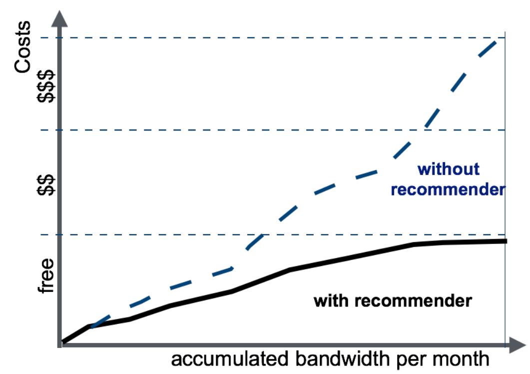

Figure 3. Free/low-cost use up to a certain data amount, and then experience full stop or high prices

A recent report by Morgan Stanley Research [14] describes that more than 50% of network traffic was initiated from web browsers. However, the report also show that users spend more than 80% of screen time in apps. These numbers indicate first of all that the browsers still constitute an important source of traffic, and that much network traffic can be reduced through adapting the browser. Secondly, there are large network traffic savings due to better guiding of apps.

In popular apps like Facebook and YouTube, further specification of bandwidth usage is available for defining whether videos should be started automatically or not, and in which quality. However, these settings require that users are aware that they *can* change these settings and also that they actually *use* that opportunity. With an average of 26 apps per mobile phone [15], we argue that the average users will not change

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these settings dynamically enough to a) limit their bandwidth usage as much as needed when on restricted networks nor b) get the full experience when connected to a higher-capacity access point without restrictions on bandwidth or cost. Table II shows typical bandwidth usage with different app types. Our proposal of a traffic recommender can pave the way for a more automated compliance with bandwidth restrictions.

TABLE II. NORMAL BANDWIDTH USAGE FOR TYPICAL APPILCATIONS

Service	Traffic
Web browsing	2.5 MB/min
Social Networks (1 Hour)	90MB
Video Streaming(i.e.YouTube) (1 Hour)	1125MB (720p)
Online Music, i.e. Spotify, 1 h	43.2MB (96kbps)
Mobile MMS with Video	100KB
Mobile SMS (1 message)	0.13KB

IV. Results and Impact

Section I summarised the main challenges for information provisioning to everyone. This section will focus on how information provisioning and network-aware applications work together to achieve the a digital society including everyone, rather than enhancing the digital gap.

Results of a simplified model for providing information over a satellite link are provided in Table III. For simplification, the costs per user are based only on the operational costs of the satellite link. The numbers are based on a 1 Mbit/s (Mbps) satellite link to Africa, with costs of 2000 US$/month, 12 h duty time, and a simplified linear distribution of the traffic. Table I in the previous section clearly shows the effect of basic information and compression, allowing to provide information at a satellite cost of half a dollar per month, given the average use of compressed 4 MByte per user and month. In comparison, a video transmission of 8 min, accounting to 50 MByte, would cost roughly 6 US$. Using a radio link or a mobile network termination will significantly reduce the cost, and can drop the Basic Internet provision to lower than 0.1 US$/month.

TABLE III. INFORMATION PROVISIONING COSTS

Usage [MB]	Users/1 Mbps	costs/user [US$/month]
4	3996	0.5
20	799	3
50	320	6

The Basic Internet Core Network (Figure 4) is the one responsible for the information optimization and supports traffic shaping, traffic balancing, free access to basic information and voucher-based access to full Internet including video and gaming.

The enhanced infrastructure, as piloted in Kinshasa (DRC), provides free access to Wikipedia and other educational sides from Cedesurk [16]. The customer infrastructure includes a local server, adding free-of-charge educational videos and content. The pilot had 5 phases (I-V), where phases I to III had the focus on integration of the centralised and the local core, the access to local information, and the provision of vouchers for the payed Internet access.

The major goal of the pilot was to bring the students up to Internet users (see Figure 5), allowing them to use their

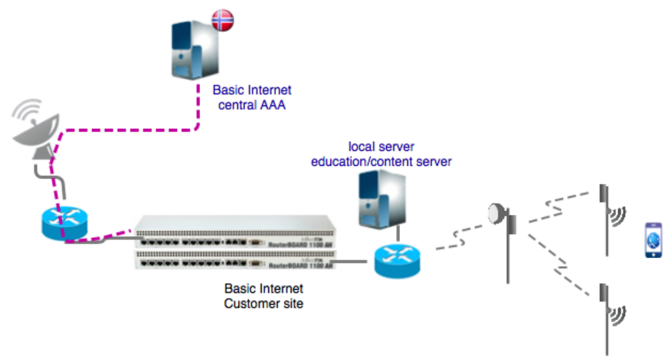

Figure 4. The Basic Internet central AAA and the Customer Equipment

own devices to search and use relevant content. The final goal is to leverage 90% of the students to be able to use the local content. An additional goal is to get students become creator of digital content, and digital services providers.

At the time of writing (March 2016) the first phases were concluded, and the conversion into an operational and self-sustainable network operation is ongoing. This self-sustainable network operation consists of *(i)* voucher sales for access to Internet, and *(ii)* the provision of free access to Basic Information. This free access is financed by license fees, where a certain percentage of the sold Internet capacity is used for ordering bandwidth for Basic Internet.

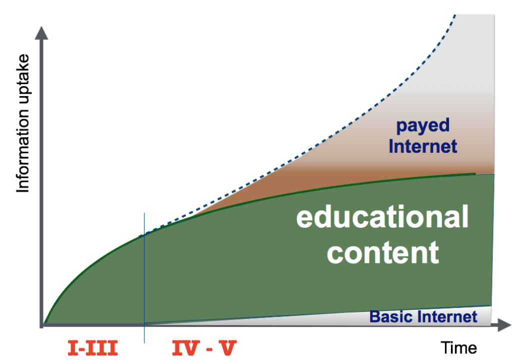

Figure 5. The expected update of Internet access

The results of the pilot implementations verify that

- A cost-effective Internet distribution is possible, providing a local core for roughly 400 US$, and of-the-shelf access points.
- The deployment leverage of students, using their own devices for free access to (local) educational content.
- Through the Basic Internet Infrastructure students can become creators of digital content, and digital service providers.
- The service offer is complementary to conventional telecom services, providing services to people who cannot afford the access to the basic information.

Other actors like Google have dedicated resources for building and helping the development of running wireless

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networks in emerging markets for connecting more people to the Internet [17]. The main concepts being provided by the Basic Internet Foundation and others are services reaching those who cannot access or cannot afford wireless Internet services. In that way, the access provision is complimentary to conventional Telecom services. Current activities include the marketing trial in Kinshasa to address potential scalability issues. Upcoming steps are pilots in selected African countries in order to address the ecosystem for digital education. Further steps include global alliances to reach out to countries seeing the need for digital inclusion.

V. Conclusion

In this paper, we addressed the needs for digital inclusion, both in developing and developed economies. Findings related to digital societies indicate that developing economies need to address digitisation as the driver of economical growth. What is common in both approaches is the need for an information infrastructure. Such an information infrastructure consists of *low capacity (LC)* services as a basic service for their inhabitants, as well as network-aware applications.

A LC-service offer can be provided as part of a public digital infrastructure, and through wireless as well as mobile networks. They will provide an always on-line experience, and thus reduce the digital gap. The LC-infrastructure is accompanied with a pro-active recommender, using the mobile device as decision maker. The recommender addresses technological aspects like actual bandwidth and economical aspects like individual capacity limits. Examples are provided how services can be adjusted to bandwith-limited systems like LC-networks, to individual data planes, and to combinations including network-availability forecast and personal information needs.

The paper further presents the results from the pilot implementation of LC-service provisioning in the Democratic Republic of Congo (DRC). The pilot proved the technical viability of LC-service provisioning, and is transferred into commercial operation following a novel business model.

References

[1] IETF - Internet Engineering Task Force. (1989, October) RFC 1122 - Requirements for Internet Hosts - Communication Layers, 1.1.2 Architectural Assumptions. Accessed 01Apr2016. [Online]. Available: https://tools.ietf.org/html/rfc1122

[2] International Telecommunication Union - ICT Data and Statistics Division, "ICT Facts & Figures," May 2015, accessed 03Apr2016. [Online]. Available: https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2015.pdf

[3] J. Manyika, A. Cabral, L. Moodley, S. Moraje, S. Yeboah-Amankwah, M. Chui, and J. Anthonyrajah, "Lions go digital: The Internets transformative potential in Africa," November 2013, accessed 01Apr2016. [Online]. Available: http://www.mckinsey.com/industries/high-tech/our-insights/lions-go-digital-the-internets-transformative-potential-in-africa

[4] GSMA, "The Mobile Economy report 2015 - Global," 2015, accessed 03Apr2016. [Online]. Available: http://www.gsmamobileeconomy.com/GSMA_Global_Mobile_Economy_Report_2015.pdf

[5] B. A. Lucini and D. Evans, "Mobile internet usage challenges in Asia — awareness, literacy and local content," July 2015, accessed 30Mar2016. [Online]. Available: https://gsmaintelligence.com/research/2015/07/mobile-internet-usage-challenges-in-asia-awareness-literacy-and-local-content/513/

[6] "Connect the world," 2016, accessed 02Apr2016. [Online]. Available: http://connecttheworld.one.org/

[7] "Digital impact alliance," accessed 01Apr2016. [Online]. Available: http://digitalimpactalliance.org

[8] Airtel Media Centre, "Airtel launches airtel zero: A win-win platform for customers and marketers," 02 2015, accessed 02Apr2016. [Online]. Available: http://www.airtel.in/about-bharti/media-centre/bharti-airtel-news/corporate/airtel+launches+-+airtel+zero-+a+win-win+platform+for+customers+and+marketers

[9] P. Doval, "Airtel Zero, Internet.org against net neutrality," *The Times of India*, May 23 2015, accessed 03Apr2016. [Online]. Available: http://timesofindia.indiatimes.com/tech/tech-news/Airtel-Zero-Internet-org-against-net-neutrality/articleshow/47391729.cms

[10] Internet.org, "Participation guidelines," accessed 01Apr2016. [Online]. Available: https://developers.facebook.com/docs/internet-org/participation-guidelines

[11] "http archive," accessed 03Apr2016. [Online]. Available: http://httparchive.org/interesting.php?a=All&l=Jul\%201\%202015

[12] G. Duncan. (2006, 01) Opera mini officially brings web to mobiles. Accessed 03Apr2016. [Online]. Available: http://www.digitaltrends.com/mobile/opera-mini-officially-brings-web-to-mobiles/

[13] Opera Software, "State of the mobile web report," Online, 06 2011, accessed 03Apr2016. [Online]. Available: http://techloy.com/wp-content/uploads/2011/07/opera-state-of-the-mobile-web-report-june-2011.pdf

[14] Morgan Stanley Research, "Google: There's an App for that...the Browser," Online, September 2015, accessed 02Apr2016.

[15] Z. Fox, "The Average Smartphone User Downloads 25 Apps," *Mashable*, Sept 2013, accessed 29Mar2016. [Online]. Available: http://mashable.com/2013/09/05/most-apps-download-countries/\#9aqOLOcy6Zqo

[16] "CEDESURK, Centre de documentation de l'enseignement superieur, universitaire et recherche a Kinshasa," accessed 01Apr2016. [Online]. Available: http://cedesurk.cd/

[17] A. Efrati, "Google to Fund, Develop Wireless Networks in Emerging Markets," The Wall Street Journal, Tech. Rep., 05 2013, accessed 02Mar2016. [Online]. Available: http://www.wsj.com/articles/SB10001424127887323975004578503350402434918