THE MOTIVE CONCEPT
Enabling Mobile Terminals to Act as Sensors

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Abstract: In a mobile telecommunications environment, the mobile terminal collects a variety of network performance related data that are subsequently used in order to perform basic networking functions, such as cell selection, handover or power control. Terminals' processing capabilities and the potentials derived through their integration with sensors, remain today mostly untapped. Taking advantage of these evolving sensing capabilities, the MOTIVE (MObile Terminal Information Value addEd Functionality) project intends to demonstrate the potential stemming from the exploitation of such information. The MOTIVE system comprises a terminal monitoring module (which operates in a user transparent mode) and a network module that collects the appropriate set of data and performs the proper processing. The paper examines the application of this concept in three key areas, related to integrated end-to-end user experience monitoring, ubiquitous terminal assisted positioning and anonymous mobile community services, taking into account the terminal functionality evolution as well as the network evolution towards a multi-access composite IP based network.

1 INTRODUCTION

Recent evolutions in mobile communications include both the widespread use of mobile terminals and the development of new technologies. Indeed, more than 2 billion people around the globe are mobile communications subscribers, and growth rates are considerably promising for the future. In addition, modern mobile terminals have become technologically sophisticated, encompassing increased functionality and a variety of extra features, such as cameras, multiple antennas, temperature sensors, and short range connectivity (e.g., Infrared and Bluetooth).

In parallel, the scientific community has recently shown a tremendous interest in the area of wireless sensor networks. Significant progress has been made, regarding sensors' hardware, operating systems, embedded software, and networking enabling technologies. As a result, modern wireless sensor networks have provided the means for developing innovative applications, targeted for environmental monitoring, motion monitoring as a form of condition-based maintenance (Culler et al, 2004), patient monitoring and assisting (Jovanov et al, 2001), inventory management, product quality monitoring and disaster areas monitoring. Hence, the use of wireless sensor networks is valuable for a variety of applications and is expected to grow further in the future.

In this paper, it is argued that the largest wireless sensor network existing today is the community of mobile terminals, which still remains unexploited. Indeed, mobile phones and sensors present a lot of similarities:

(a) relatively limited processing speed and storage capacity;

(b) substantial processing capability in the aggregate, but not individually; and

(c) wireless communication capability.

What is more, mobile terminals present a number of useful characteristics. Firstly, in contrast to sensor nodes, mobile phones have a global identification (ID), the Mobile Station International ISDN Number (MSISDN). Secondly, there are already a large number of devices scattered all over the world. Thirdly, the location of these devices can be estimated via a number of indoor and outdoor localisation methods (Muthukrishnan et al, 2005). Consequently, a "sensor network" consisting of mobile terminals can provide applications with geospatial data at a higher granularity and with greater coverage than previously possible.

The MOTIVE (MObile Terminal Information Value addEd Functionality) project introduces the aforementioned innovative idea, which has not yet been exploited. Mobile phones collect by default several measurements, concerning, for example, the bit error rate and the signal-to-noise ratio, which are subsequently used in order to perform basic networking functions, such as handover. These measurements are currently untapped, in the sense that they are not fully exploited. Moreover, mobile phones could be outfitted with several inexpensive sensors that provide enhanced capabilities.

Based on this idea, MOTIVE's vision is to build a powerful wireless sensor network. MOTIVE enabled terminals are expected to transparently store, pre-process and upload monitored data to the network, without, however, obstructing the user from utilising his device. In more detail, the MOTIVE project proposes the application of this innovative "sensor network" in three key areas, related to: (a) integrated end-to-end user experience monitoring; (b) ubiquitous terminal assisted positioning; and (c) anonymous mobile community services.

This paper describes the architecture of the MOTIVE concept and the proposed applications in the three key areas. Section 2 presents the proposed architecture regarding the terminal and the network side. Sections 3, 4 and 5 refer, in detail, to the three proposed applications, as well as the methods in which the capabilities of the underlying network can be exploited. Finally, Section 6 concludes the paper and identifies future research directions.

2 THE MOTIVE ARCHITECTURE

2.1 Network Architecture

A high level presentation of MOTIVE's proposed architecture is depicted in Figure 1.

As can be observed, two main entities comprise the overall system: (a) the data capturing devices; and (b) the network server. Communication and data transferring between these entities is carried out by exploiting a composite radio network infrastructure, consisting of diverse, heterogeneous networks.

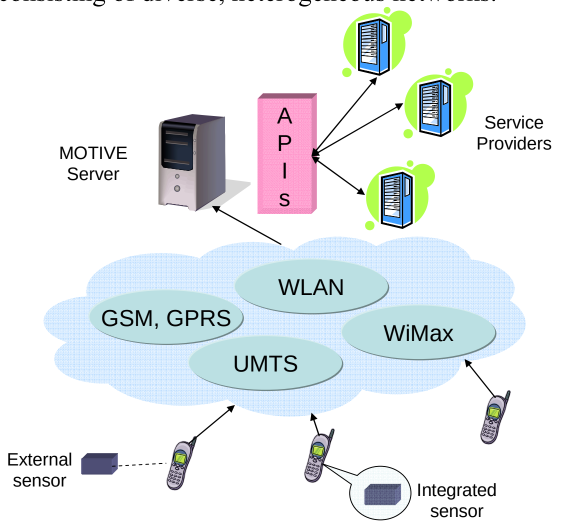

Figure 1: MOTIVE high-level architecture

The data capturing devices fall into three categories: (a) external sensors communicating with the mobile terminal and transferring the collected data to it through a short-range technology (e.g., Bluetooth); (b) sensors integrated to the mobile terminal; and (c) the mobile terminals, acting as sensors themselves.

Regarding (a), external sensors are devices equipped with simple networking functionality and able to sense different environmental parameters. Their size or power consumption, however, does not permit their integration to the mobile terminal. A typical example of this type of sensors is the gas sensors (Schmidt et al, 2001). These sensors require a significant amount of time for heating up, accompanied by excessive energy consumption (often around 1W for 1 minute).

Pertaining to (b), there are sensors that their energy demand, processing requirements and size render their integration to the mobile terminal

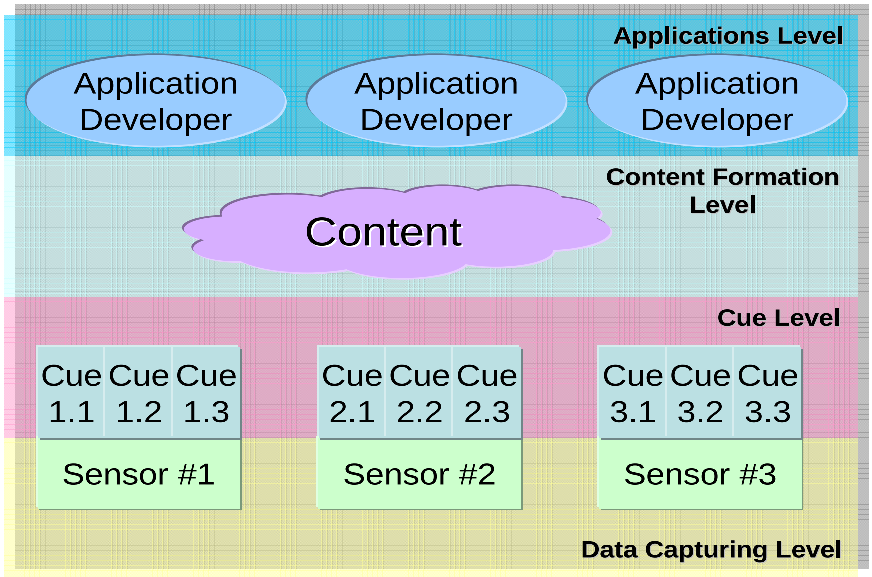

Figure 2: Functional layers of the MOTIVE architecture

feasible. In fact, a number of mobile devices already implement such sensing abilities. For example, microphones can provide valuable information, even when using minimal processing power. Calculations on a microcontroller with less than 200 bytes of RAM proves to contribute useful information, such as the noise level and the type of input (noisy, music, speaking).

Concerning (c), mobile terminals can act as sensors without any extra enhancements. In other words, the mobile terminal can record and upload measurements of parameters related to its operation, as, for instance, the perceived signal strength. This information can later be used in a plethora of applications, like location based services.

In order for these captured data to be efficiently exploited, their further processing is required. Initially, the data collected are pre-processed at the mobile terminal. The pre-processed data are then uploaded to the MOTIVE application server through the radio access interface used by the terminal. The scheduling of the transmissions and the cost of transferring the data are matters that need to be carefully examined before deploying the corresponding services. The main volume of the required processing is conducted by the MOTIVE server. Appropriate functionality for retrieving, indexing and storing the collected information is in place in this entity. Service providers should be able to retrieve the necessary information through suitable Application Programming Interfaces.

2.2 Definition of Functional Layers

In what follows, a layered architecture is presented, serving as the basis for the development of a simple, yet efficient, system aiming at the provision of enhanced, context-aware applications. The four layers comprising the proposed architecture are depicted in Figure 2. For further comprehension of the system's functionality, the role of every layer will be discussed, and a representative application will be investigated.

The lower level consists of the data capturing devices, namely the three abovementioned types of sensors. These components are responsible for collecting the required measurements from their surroundings and, in the case of the external sensors, transmitting them to the mobile terminals.

The next level involves the formation of cues. By using the term cue (Schmidt et al, 2001), we refer to information that has been submitted to a pre-processing procedure. The concept of cues has proven to be very useful, since it provides a level of abstraction from the hardware components and renders their modification transparent to the higher layers. In this way, if new sensing devices are included in the system, only changes to the corresponding cues must be adapted. Cues can be realized by using appropriate statistical functions. Thus, the collected data are either summarized or processed at a basic level. Typical examples of cues that are usually investigated are the average value, the standard derivation and the first derivative. It is noteworthy that each cue is dependent on one single sensor, but, by using the data of one sensor, multiple cues can be calculated.

The next level involves the formation of content, that is the main processing and indexing of the collected information into organised structures. The result of this level's processing leads to data forms that can be directly exploited by the application providers of the higher level.

Finally, at the top of the proposed architecture lies the application level. All possible context-aware applications utilizing the collected information can be included in this level.

Taking into account the processing capabilities of the mobile terminals, the power consumption limitations raised, as well as the network load provoked, the following mapping of the functional entities described above to the network entities of Figure 1 can be deduced: Data retrieval from sensing devices and cue development can be integrated in the terminal-side. More precisely, the MOTIVE terminals will gather the desired information and proceed in its statistical pre-processing. This information will afterwards be uploaded to the MOTIVE server, where it will be submitted to the content formation procedures. The content created by these procedures will then become available to application developers through the appropriate interfaces.

In what follows, a simple, yet enlightening, application will be presented, through which the functionality of the involved entities will be clarified. This application is launched by a service provider who desires to deploy a service providing temperature information over a large city. Firstly, at the lowest level, mobile terminals, integrating the temperature measurement functionality, will record temperature values, perceived at their current positions. These measurements will then be pre-processed by the mobile terminal, in order to form the corresponding cues. Useful and exploitable parameters would be, for example, the average temperature and the corresponding changing rate. The time window during which the measurements should be taken is a matter of further study. The results are then uploaded to the MOTIVE server. At this point, they are combined with measurements originating from other terminals, and the main volume of processing takes place. A useful piece of information, resulting from this level, would be, for example, the categorization of the perceived temperatures, according to the specific time and place they were measured. Finally, at the higher level, the application provider would exploit this formatted content, in order to create maps of the area under consideration, where measured temperatures would be depicted in a user-friendly way (e.g., different colours indicating different climate conditions).

3 END-TO-END USER EXPERIENCE MONITORING

As has already been noted, in a mobile telecommunications environment, the mobile terminal collects a variety of network performance data that are subsequently used in order to perform basic networking functions, such as cell selection, handover or power control. Terminal collected data constitute a valuable, but untapped yet, source of information. By properly exploiting them, mobile terminals can turn into ubiquitous super-sensors, providing information about end-to-end user experience.

In more detail, the integration of a monitoring agent will enable mobile terminals to monitor several Key Performance Indicators (KPIs), related to: (a) the efficiency of the user interface; (b) the efficiency of the protocol stack during communication; and (c) the network's performance.

Regarding (a), the time it takes to find and trigger an application through the user interface, as well as how often an application is used, can be assessed. Pertaining to (b), several parameters, including the receiver quality, the voice quality and the IP protocol performance, can be utilized. Both of the aforementioned issues are currently addressed via terminal testing, which lacks in scalability. MOTIVE's monitoring agents can complement to the task of terminal evaluation, helping terminal manufacturers to improve their products.

Concerning (c), the contribution of network performance to user experience can also be assessed at the level of the mobile terminal, by measuring primarily air-interface parameters related to coverage quality and air-interface performance, including the bit error rate and the signal-to-noise ratio. By acting, in this way, as sensors and relaying the aforementioned measurements back to the network side, possibly after some filtering or pre-processing (e.g., calculation of the average value), mobile terminals can provide significant feedback to mobile network operators, in issues such as radio planning and customer care. Currently, to resolve these issues, mobile network operators rely on network verification surveys, KPIs derived from the

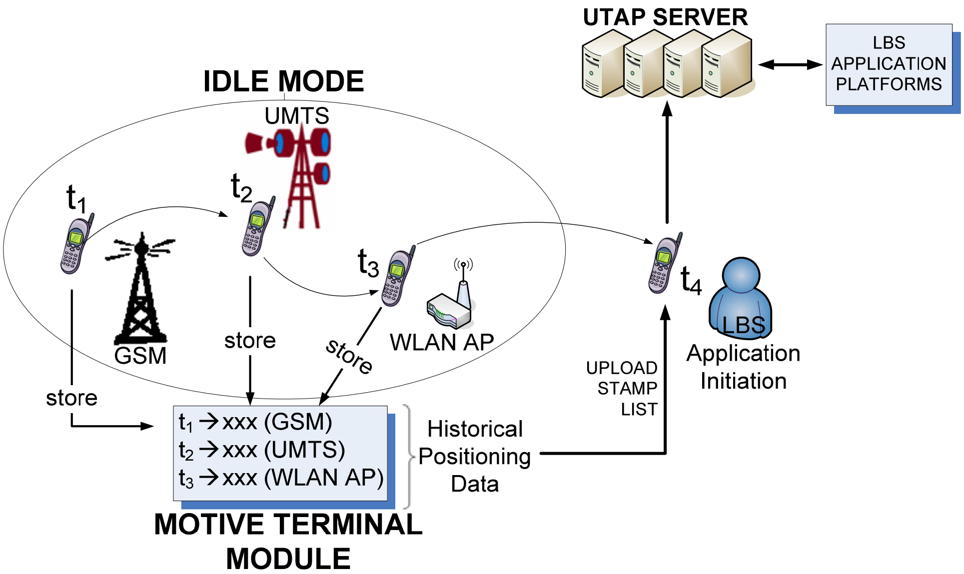

Figure 3: The UTAP architecture

Network Management Systems (e.g., blocked or dropped calls), or measurements from special terminal implementations, such as Ericsson TEMS and Nokia Traffica. The MOTIVE approach is able to outperform the state-of-the-art, as it is far more scalable and collects measurements from the actual end users.

In addition to the benefits for terminal manufacturers and mobile network operators, the MOTIVE enabled terminals can prove to be valuable for context radio systems. Cognitive radio systems can be defined as systems capable of sensing the RF environment and easily adjusting to current conditions, by making intelligent decisions about how to best utilize spectrum. In this context, mobile terminals can act as sensors, in order to properly "sniff" the RF environment and detect spectrum holes, i.e. RF bands where the interference level is below a certain threshold, rendering them usable for communication. The collection of measurements for this purpose and the use of a feedback channel, so as to transfer them to the network side, can facilitate the latter to select the most suitable configuration, at any given time.

4 UBIQUITOUS TERMINAL ASSISTED POSITIONING

Various research activities are ongoing in the field of Location Based Services (LBS), a type of services that is expected to give a boost to mobile communications. The provision of such services assumes that the position of the client is known. Hence, localisation proves to be of paramount importance for their development.

Several techniques have been proposed for addressing the localisation problem. These techniques can be classified according to several characteristics (Muthukrishnan et al, 2005):

- Outdoor vs. Indoor, depending on the position area.
- Network based vs. Terminal based, depending on the side of the implementation (terminal or network).
- Terrestrial-radio-based vs. Satellite-based vs. Standalone depending on the use of a terrestrial radio signal, a satellite signal or no use of signal for positioning.
- According to the location estimation technique used, namely Global Positioning System (GPS), Assisted GPS (A-GPS), Observed Time Difference (OTD), Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), Multipath Fingerprinting, Timing Advance (TA), Enhanced Forward Link Triangulation (E-FLT) and Received Signal Strength (RSS).

All of the aforementioned positioning methods rely on signal measurements. In some cases, the measurements are collected by a mobile device acting as a sensor, while in other cases by a specialised sensor network that may or may not cooperate with a mobile device. Regarding the specialised sensor networks, several techniques have been proposed so far, based on Bluetooth (Forno et al, 2005), Ultra Wide Band (UWB) (Bocquet et al, 2005), Infrared (Lee et al, 2004), Ultrasonic (Holm et al, 2005), GPS (Zhao, 2002), or force measuring sensors (Orr at al, 2000).

All of these techniques can easily be integrated in the Ubiquitous Terminal Assisted Positioning (UTAP) concept, which is illustrated in Figure 3.

The main characteristics of the UTAP concept are:

- It is functional in a B3G environment, where a variety of network technologies (GSM, GPRS, UMTS, WLANs, short range radio interfaces, etc.) are present.
- It can use any of the existing positioning methods and techniques, either as a stand-alone or as a hybrid scheme.
- The use of A-GPS is proposed for positioning in RF-shadowed environments. The basic idea of assisted GPS (Zhao, 2002) is to establish a GPS reference network whose receivers have clear views of the sky and can operate continuously. The most important contribution of a reference network to handset GPS receivers is the reduction of the frequency uncertainty of satellite signals.
- The Statistical Terminal Assisted Mobile Positioning (STAMP) (Markoulidakis et al, 2006) approach can utilize the terminal's historical positioning data, in order to improve the terminal positioning accuracy. STAMP exploits the measurements that the mobile terminal periodically collects while in idle mode. Firstly, standard positioning techniques are applied on the collected measurements to provide estimations of the terminal's positions in successive time moments. Then, statistical filtering (e.g., Kalman filter) is applied on the latter estimations, in order to accurately infer the terminal's current position.
- It allows the concurrent estimation of the mobile terminal's speed and direction, enabling the timely provision of advanced LBS applications.
- It requires only an additional software module on the terminal side, while the impact on the terminal operation is minimal (e.g., through the exploitation of parameters which terminals anyhow measure as part of their standard operation).

Based on these characteristics, the UTAP concept intends to provide location estimation under any circumstances and with high precision. Further research and real experiments for evaluation purposes are ongoing under the MOTIVE project.

5 ANONYMOUS MOBILE COMMUNITY SERVICES

The MOTIVE concept allows for the definition of a new, innovative type of services, the Anonymous Mobile Community (AMC) services, which exploit the capability of the terminals to act as sensors, i.e. collect information, and present it to the network whenever required.

Figure 4 depicts the concept of MOTIVE AMC services. According to this notion, the service requestor may be either a third-party application server or a mobile terminal. The MOTIVE AMC server receives and validates the request, and produces a response. Depending on the type of service, there are two alternatives for generating the appropriate response: (a) the real-time approach; and (b) the non real-time approach.

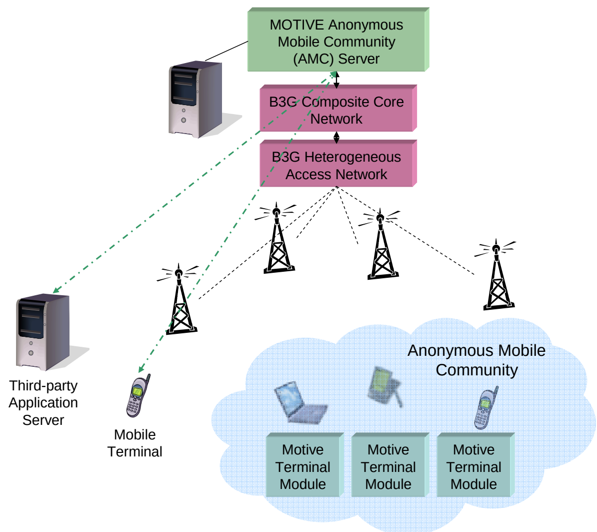

Figure 4: The concept of MOTIVE Anonymous Mobile Community Services

In (a), information is collected from the community of terminals immediately after validating the service request. Then, this information is processed, and the appropriate result is sent back to the requestor. In (b), the MOTIVE AMC server generates a response on the basis of the data that have already been collected from the community of terminals. In all cases, user anonymity and privacy should be respected. Privacy considerations are of high importance, and the relevant requirements, as specified in (3GPP, 2002) and (3GPP, 2005), must be satisfied.

Viewing an anonymous community of mobile terminals as a grid of active sensors offers the ability to construct a group of useful, innovative services on top of it. Representative examples of interesting services are depicted in the following.

(a) Environmental services. In this case, each terminal belonging to the anonymous community will provide information about the current temperature and the weather in its position. Requestors (either third-party application servers or terminals that are members of the community) can be informed about the average temperature and climate conditions in the area of their interest.

(b) End-user experience monitoring. As described in Section 3, the anonymous community of terminals can be used to sense KPIs, such as the bit error rate and the signal-to-noise ratio. Mobile network operators act in this case as requestors.

(c) Electromagnetic field monitoring. In a similar way to (b), terminals belonging to an anonymous community may be utilized to measure the value of the electromagnetic field in the used frequency bands. Special non-profit organizations will act as requestors, and generate reports about whether safety levels are met or not.

(d) Traffic conditions monitoring. The retrieval of road traffic conditions from fellow drivers (determined by the terminal velocity in that area), who are subscribers to the corresponding anonymous community, can prove to be extensively valuable in modern cities. Third-party application servers or terminals that are members of the corresponding community can act as requestors.

In general, provided that privacy requirements are satisfied in an uncompromised manner, this type of services is expected to become more and more popular in the future.

6 CONCLUSIONS

In this paper, the concept of enabling mobile terminals to act as sensors, by collecting data from their RF and physical environment, was evolved. The exploitation of such information in three key areas, related to integrated end-to-end user experience monitoring, ubiquitous terminal assisted positioning and anonymous mobile community services, was established.

Further research activities include the detailed specifications and development of the corresponding applications, as well as the conduction of trials for the evaluation of the system's functionality. The trials will be performed using commercially available mobile terminals in two different sites, Athens and Paris, employing several diverse radio access networks.

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