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Positioning methods for future location-based services

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Abstract. In this paper we give an overview of the existing and upcoming positioning methods in the mobile environment. With the advent of mobile technologies, increased usage and expansion of mobile devices, mobile services and applications, among them also the so called location-based services, are gaining an increased amount of attention. The user context is an important element of personalization of future information retrieval systems, applications and services. We briefly present our scheme that could be deployed to obtain the user profile and context. An important factor for determination of the latter is an accurate positioning of a user in the environment which can be done by using different methods. Therefore, we have prepared a survey of the existing and upcoming possibilities. We present the state-of-the-art positioning methods and general ideas behind them, however comparisons among them are hard to make. It seems a method that will work well both in the indoor and in the outdoor environments does not exist. Positioning in the indoor areas is due to the nature of the environment namely harder to obtain and the needed precision is higher. Therefore, a combination of methods will be needed for accurate positioning for the future services and applications.

Keywords: positioning, location-based services, context, personalization

1 INTRODUCTION

Mobile communications have become the world's most widely available technology. From devices which initially complemented fixed-phone line calling, multimedia devices were developed. At the same time they contain a growing number of technologies for communication with others, such as Wi-Fi, worldwide interoperability for microwave access (WiMAX), infrared (IR), bluetooth, radio-frequency identification (RFID) and global positioning system (GPS). The nature and wide use of the mobile devices distinguish them from other multimedia systems. On the other hand, a mobile device is a user personal property and solely the owner uses it, which makes it very handy for user identification and personalization possibilities. If the user activities on a mobile are known, it can be claimed that the activities were performed by the device owner.

In the waste amount of data users receive they are not able to find the information which would be of their interest. Therefore researchers are struggling to find a way which would ease the user life. The user interests need to be obtained and gathered in a model, also called profile. Once the user profile is known, services and applications can use information from this model to offer personalized experience. If personalization is combined with contextualization, relevancy of the provided information is further improved. The context is defined by a number of parameters which can help us define the user situation. Namely, the user need for information varies from situation to situation.

In the last couple of years we have been witnessing a rapid development of mobile market. Service providers from the web are moving into the mobile environment, complementing their existing offers with new or adopted functionalities and using mobile operators as bit pipes. Although the traffic on the mobile networks has increased due to the growing usage of applications and services, this fact has not brought mobile operators any additional revenue. On the contrary, they have had to increase the capacity of their systems which has increased their expenses. One possibility of solving the discrepancy for them is to enter into competition or cooperation with the current application providers. The operators have enormous amounts of data about their subscribers which could be used to offer personalized and contextualized user experience. This could be achieved by offering their own applications or sharing the information with existing providers. The most promising seems to be location-based services (LBS) whose essential parameter is positioning of a user.

The interest in handheld positioning has grown with the arrival of the third-generation phones. The initial need for accurate terminal positioning has been motivated by the government authorities, mainly by the US FCC's E911 mandate for emergency services. In Europe, similar ideas have arisen but the primary interest is in commercial value-added services.

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In our paper we briefly present a conceptual design of a system that is gathering and processing data for formation of the user profile and context. The essential parameter of the user context is the user location on which is the focus of our writing. In Chapter 2 we first introduce the possible data sources for identifying the user profile and context. Chapter 3 contains a description of the conceptual design of our pilot. In Chapter 4 we present a sample of future location-based services and in Chapter 5 different positioning techniques. Each or combinations of them can be used for determination of the user location. In the last two chapters we provide some guidelines for further work and gather some concluding thoughts.

2 DATASET ABOUT THE MOBILE USERS

There are five major approaches to collect data about users [1]: questionnaires and user panels, monitoring of activities on end devices, deep packet inspection (DPI) at different points in the network, analysis of call detail records (CDR) and server-side measurements. Each method has its benefits and drawbacks. The decision about which method or combination of methods is best suited should be based on desired results and their accuracy, available sources and time frame of data collection.

Data-collection approaches can also be classified into the implicit and explicit ones. With the explicit data collection users manually notify the system of their activities. On the other hand, with the implicit way the user activities are to be resolved automatically from all collected data. By using both approaches we try to determine the user habits and interests, and the context a user is currently in. The user interests and habits build a user profile which is the basis for personalization of contents, services and applications. Knowing the user context or situation, makes it possible for finer filtering of the content that is relevant in a particular environment and at a particular time.

There are several elements and classifications of the user context. According to the classification in [2], elements form the environment, participants or activities. An environment consists of a location and orientation of objects, brightness, noise level, availability, physical properties, quality of devices and communication. Participants comprise the status of the user and other participants in the environment, their mental state, physical health, location and personal properties like age and education. Activities consist of tasks and goals of participants and events in the environment, such as time and weather. An accurate location information is among all the most crucial element for context determination and therefore it deserves to be paid a lot of attention.

To determine the user interests and context in the mobile environment from the mobile operator sources, the data of the mobile internet usage is very appealing. The usage of this service has grown exponentially in the last couple of years. It offers access to web contents and applications practically anytime and anywhere. The service enables internet connectivity to various types of devices, among them also mobile terminals. Analysis of this dataset might thus open new opportunities for personalization and contextualization which we are currently investigating.

3 CONCEPTUAL DESIGN AND TOOLS

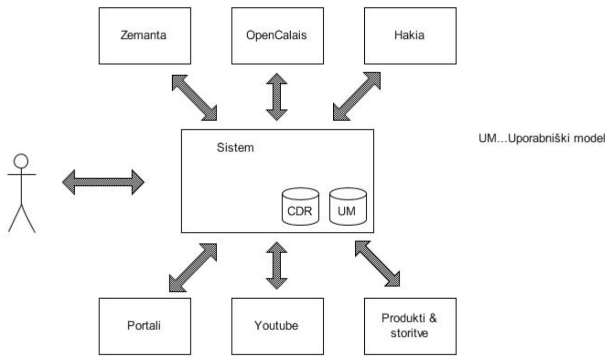

Figure 1. Sheme of the used semantic tools and data sources

The existing mobile services of the future use the data that is available on user terminals to exploit the user profile and context. In our design [3] shown in Fig 1, we focus on a concept which is easy to implement independently from the user mobile devices. We used two major components: CDRs as a source of the user activity and semantic tools for knowledge extraction.

On the Gi interface a billing centre recording CDR of the user activities on the URL level is used. The Gi interface is a standard Ethernet/IP interface from the gateway GPRS support node (GGSN) to internet and thus a variety of tools for traffic analysis is available. During the authentication process, when the system checks if an individual is entitled to a certain service, cell ID is passed over the RADIUS protocol to the billing centre. This is the currently used positioning method which is recorded together with the time of usage and visited URLs. The recorded data can on one hand be used for statistical processing and search of certain patterns. By employing semantic tools for knowledge extraction, such as OpenCalais [4], Zemanta [5] or Hakia [6], metadata about the consumed content can be obtained and thus the user interests can be determined which are essential for personalization. By assuming an individual user likes the consumed content, the user profile can be generated by combining semantic data of the consumed content. This is the basis for determination of the content a user will be willing or needs to consume. The user profiles can be used further for different deployments, such as recommendation systems, personalization of the content and services, personalization of mobile portals and mobile marketing.

On the other hand, the user context will be mainly determined with time and location. We strive to determine it on the general level, as for example the user is in the office or at home. However, together with geographic information system (GIS) and metadata of points of interest (POI) we hope to determine it on a narrower, more precise level. Combining this information with the knowledge about the user profile will hopefully result in identifying for example the user particular activity in his free time.

As the location is the main attribute of the user context, we are investigating more accurate positioning methods. Namely, precision of the user-context determination can not be higher than precison of positioning itself.

4 Future mobile services

Before exploring different mobile positioning methods, we present some of the solutions which indicate the development trend of future services. The main contextual information they use is the location. Application Google Maps [7] was initially used for orientation and location search. Upgraded with the service Latitude it displays friends locations and statuses. The mobile version of the Google browser offers location-based search. It returns physically close results. An enhanced version of a mobile search is presented in [8]. It helps the user by suggesting the key words and it neglects the results which are not relevant in a particular context. Instead of words it uses thesaurus concepts. Each concept is supplemented by an ontology which describes its properties. Once a user chooses a desired concept, the application offers further possibilities to fine-tune the search. The system also takes the explicitly and implicitly obtained user profile, geolocation and environment. Foursquare [9] has a growing number of users who mark the visited POIs and add their comments. Thus an enormous dataset of POIs is being built which users or developers can use when searching for a particular service. IYOUIT [10] senses, stores and uses the user-context information as an input parameter for other information services, for sharing with friends and for possible future use. It tries to recognize the user context based on the user previous and current activities which a user can input explicitly. It has a solid database of POIs which are suggested to a user based on the user physical location and type of activities which they offer. Future mobile services will include also aspects of augmented reality. Wikitude [11], as an example of a service of this kind, displays additional information about POIs on the top of a live picture from the mobile camera.

5 Positioning methods of mobile devices

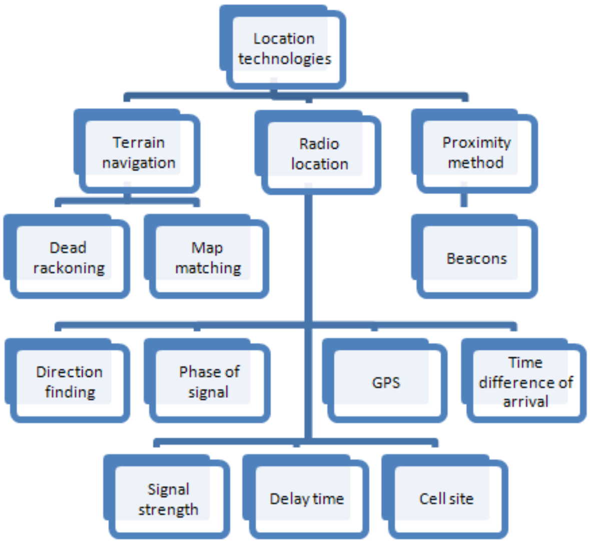

Figure 2. Classification of location techniques [12]

There are several ways of clustering positioning methods. One such example is shown in Fig 2. Another option is to classify all the methods into indoor and outdoor positioning. In both cases, this can be done either on the handheld, in the network or by using a hybrid solution. For a network-based or hybrid positioning a handheld might need to provide measurement data to the network. Therefore, it has to have an established bi-directional channel. In a call-related GSM system, a handheld is said to be in a dedicated mode while in the GPRS system a handheld is said to be in a ready mode. If positioning is required in a network-based method while the channel is not established, a mobile station must be forced to either a dedicated or a ready mode [13].

Positioning can be implemented in the user plane, as for example by assisted GPS (A-GPS) with a secure user plane (SUPL), or in the control plane by using the system carriers. Determination of the location can be done in real time or it takes a while to compute it. Furthermore, position and mobility management can be classified into in-session and idle mobility. The in-session mobility management refers to seamless handoffs for on-going sessions to new radio systems, while the idle mobility management requires continuous information about the location so as to keep track of movement of persons [14].

In our paper we clustered the presented positioning methods in outdoors and indoors solutions. However, we do acknowledge that also some outdoor positioning techniques are used in indoor areas and vice versa. Outdoor methods we further divided into mobile, satellite, wireless and hybrid solutions. The guiding principles known from the mobile environment are used also by other radio-frequency technologies.

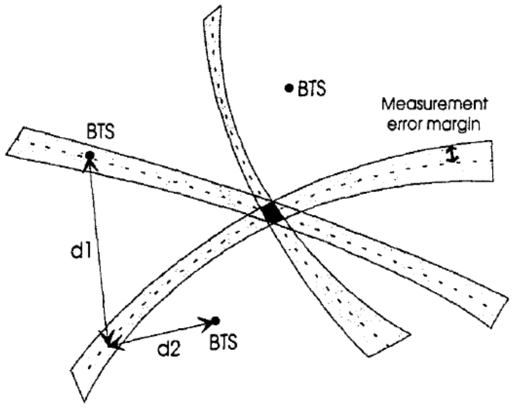

Figure 3. TDOA algorithm for positioning [17]

5.1 Mobile technologies

There are three main algorithms used in the positioning methods in the mobile environment [15]: angle of arrival (AOA), time of arrival (TOA) and time difference of arrival (TDOA), shown in Fig 3.

By measuring AOA of the transmitted signal at the two or more base stations (BS), the mobile handheld position is determined by triangulation. Especially suitable for calculation of the angle of arrival is the antenna array. In the TOA method, the propagation time from the mobile to BS (or via versa) is measured. The mobile bounces the signal back to BS which calculates it. The use of two-way signalling just for time measurement is not efficient which is the main drawback of this method besides accuracy. The most significant challenges in the CDMA networks with the TOA method are due to interferences [16]. As the BSs normally operate in the same frequency band, there is in-band interference for any signal. The effect is mostly noticeable when a mobile terminal near BS it is connected to tries to perform measurements from the neighbouring BSs. In order to mitigate this challenge, BS the mobile terminal is connected to is turned off for a short period of time and the handheld takes the measurement in this so called idle period. TDOA uses three or more BSs to gather positioning information. A mobile unit sends a signal to all BSs within the range. The latter measure the time between signal reception and transmission. The time differences have to be very accurate, requiring all BSs to be in synchronization. The CDMA networks are already synchronized by default which makes them suitable for this method. The accuracy of this solution comes to some 50 meters in urban areas and 150 meters in rural settings.

The cell global identity (CGI) is the most simplistic and cost-effective network-based method [18]. The location is determined by the cell a handheld is using. The location of a cell is fixed with the position of a base station. This method lacks accuracy which depends on the type of the area and density of BSs. The user precise position within a cell is impossible to resolve. Its deviation typically ranges from 1 to 2 km which is good enough for a general idea of the user location, but not sufficient to provide navigation or tracking services. However, the accuracy can be improved by dividing cells into sections, by using AOA or by combining CGI with a technique called timing advance (TA) which corresponds to the amount of time a signal takes to reach BS from a mobile. Thus, an approximate distance of a user from BS can be estimated. Unfortunately, TA information can hardly be obtained with no access to the mobile positioning centre (MPC) which is a system in an operator network that serves the location-based services with the user location information. The accuracy obtained with a combination of CGI and TA normally ranges between 100 to 200 meters.

In the UMTS networks, the TA method from the GSM world corresponds to the round trip time (RTT) which is possible to measure in an active mode only on a downlink dedicated physical channel (DPCH) transmitted from the NodeB - base station in the UMTS network - and an uplink dedicated physical data channel received in the same NodeB. Based on the RTT measurement, the distance between NodeB and handheld is calculated. Together with the cell ID it ensures an accuracy of less than 50 meters.

Uplink TDOA (U-TDOA) is a network-based method that determines a mobile phone location by comparing the times at which a cell signal reaches multiple location measurement units (LMU) installed at the operator BSs. The accuracy is determined with the network layout and deployment density of LMUs to BSs. Enhanced observed time difference (E-OTD) works in a similar way as U-TDOA with the major difference being that also the handset makes the time measurements. The method relies on measuring the time at two geographically dispersed locations: mobile terminals and LMUs. For this method to work, BSs have to transmit a precise clock time. All signals have to be sent at the same time and here LMU comes into play. It provides an accurate timing source for the measurements. During the measurement process, a handheld records time differences of a signal from at least three BSs. Triangulation for obtaining the handheld position uses measurements from terminals and LMUs and can be performed on the handheld or in the network. The results are typically accurate within 50 to 100 meters. For the UMTS FDD networks the observed time difference of the arrival (OTDOA) method is suitable [19]. For the calculation, the timing offset of the common pilot channel (CPICH) is used.

In the mobile environment the received signal strengths and locations of femto cells are interesting too. Positioning with signal strength analysis requires either a very good radio-frequency propagation model or an empirical base of the measured signal strengths in the desired area. Authors in [20] reported highly accurate results with this method which is also used by Google Maps. Femto cells are small cellular BSs, typically covering the area of a house. As it is an end-user equipment which a user has to connect to the service provider network via a broadband connection, its location is by default not known. However, there are at least two scenarios how its location can be obtained: manually by a customer when purchasing the equipment or automatically by sniffing its location using radio or IP. Once location of the femto cell is known, the handheld location precision is defined by the coverage area of the femto cell.

For the next-generation mobile technology, known as long term evolution (LTE), three positioning methods are specified [21]: uplink and downlink cell coverage-based positioning methods, OTDOA and assisted global navigation satellite system-based positioning methods. The first one is basically an enhanced CGI method while the last one lets the choice of the used satellite system. A hybrid solution using multiple options from the presented methods is also supported.

5.2 Satellite technologies

The GPS system is the most popular satellite device-based positioning technology being used today [22]. It uses 24 satellites orbiting 20,000 km from the Earth in six different planes which send a reliable location and timing information to GPS-enabled receivers which communicate with three to four satellites at any single point of time. Over the past several years, the size, power consumption and price of GPS modules have decreased which has made them appealing for use in mobile environment. This method can be very accurate, depending on the GPS type and surrounding environment. The device measures the amount of time it takes for the satellite signal to reach it. The calculation of the user coordinates can be performed directly on the device or it sends the measurement results to a network server for processing. The precision of the position estimation is between 5 and 40 meters which refer to the basic L1 code signal. The GPS system is currently being upgraded. Thus, current satellite updates have already started to transmit a second open service signal known as L2. It is stronger than L1 which allows a lower power consumption in reception which is suitable for the mobile environment. If both carriers are used, ionospheric effects can be mitigated and the accuracy improved towards five meters. Later on a third, an even more powerful frequency will be added which will further contribute to the accuracy gain and extend coverage in indoor areas. The drawbacks of this solution are the need for line-of-sight condition, inability to penetrate in the buildings, not neglectable power consumption of GPS modules and needed time for positioning in a range of one minute.

In Europe, a separate navigation system - global navigation satellite system (GLONASS) was developed in Russia in the 70's. Currently it has 21 operational satellites in circular 19,100 km orbits and offers a slightly worse accuracy than GPS. Europe has however decided to develop a new system, called Galileo. By offering two frequencies as standard, it will deliver the real-time positioning accuracy down to a meter range and it will be interoperable with GPS and GLONASS. Thus a user receiver will be able to calculate its position from any of the satellites in any combination. It will also notify users of a satellite failure in a matter of seconds which makes it suitable for applications where safety is crucial. A fully working system will consist of 27 operational satellites, orbiting at 23,222 km above the Earth. Galileo will be also the only system which will provide feedback to the user and five levels of services with a guaranteed quality [23].

Navigation satellite systems are complemented with satellite-based augmentation systems, such as European geostationary navigation overlay service (EGNOS) for Europe. It combines GPS and GLONASS to provide an improved service: accuracy of the location to within three metres and better availability [24].

5.3 Hybrid technologies

Time-delay and line-of-sight issues of GPS positioning can be overcome with A-GPS, a representative of hybrid methods [25]. A-GPS handset receives GPS signals and sends its recordings to a network server. The latter knows locations of BSs and it has a great deal of the computation power. Thus, it can calculate the position of a handheld and sends the calculated position over to the handheld. An accurate information about the BS sites enables better judgement on conditions affecting the GPS signal which further contributes to the position-calculation precision. On the other hand, the network server can provide the GPS receiver with a precise time and orbital data of GPS satellites in sight. These features make the position estimation possible within 20 seconds and the system to work also in not perfect line-of-sight conditions which has practically been proven in [18]. In order to further improve the accuracy of positioning to provide geolocation services, GIS can be used to provide a complete topographic view of an area. At the same time, the assisted Galileo is in the process of consideration in the 3GPP standards and is likely to be very similar in implementation to the GPS equivalent.

5.4 Wireless technologies

Mobile devices are no longer using only mobile technologies to be constantly connected. Thus also wireless technologies can be used for positioning. Wi-Fi modules are part of all the newer smart phones and some of them include also the WiMAX technology. The first is moving from the local area networks to metropolitan areas. It offers an inexpensive connection for users and traffic off-load to mobile operators. WiMAX on the other hand is among technologies of the fourth generation and can cover all types of areas: indoor, residential and rural, similar to mobile technologies. Both technologies can use methods known from the mobile environment: CGI, triangulation based on the signal strength and similar. Especially in indoor environments, where reflections, attenuation of different materials on the way and multi-path play a significant role, RF fingerprinting becomes very suitable. Access points use RF fingerprinting to collect information via a site survey which creates a grid of values identifying how any part of an area in question looks to all access points from a signal strength perspective.

5.5 *Indoor positioning*

In indoor environments there are two major constraints: the mobile and satellite signal do not cover all areas and, moreover, a much better precision is required. For example, to provide a targeted marketing based on a location in shopping centres, a precise customer position is required in order not to spam him. Several options can complement technologies for outdoor positioning. Wi-Fi was already mentioned. Another option for mobile devices is bluetooth. It is possible to define the user location based only on the access point a user is connected to or by means of the signal strength received which makes the calculated results more precise. As authors in [26] have shown, it is possible to determine the user location down to four meters of accuracy. On the other hand, it is possible to use IR beacons. This requires that users aim at the infrared port of their devices to location beacons. User dependency is not necessarily a drawback, since automatic detection of location information (without user participation) may cause nuisance. An example, a user while seeing an offer from the shop he is currently in could be bothered by the offers of the shops next doors. The conclusion could be that also user participation may be in some cases more advantageous [27]. For indoor, but also outdoor positioning, the RFID technology can be used. RFID tags can be placed around the indoor environment and when a user passes them, the system knows the user position. The accuracy of the system depends above all on the density of used tags. Nowadays, a growing number of smart phones contain accelerometers and digital compasses. They can be used to determine the user position, the speed and direction of his movement. If the user entrance point into the indoor environment which can be determined in an example with GPS is combined with trajectory of the user movement indoors, estimated based on information from device compass and accelerometer, the user position can be predicted.

A lot of simulations and measurements were made to compare different methods which often yield contradictory results due to signal propagation sensitivity to the surrounding environment. Roughly some of the methods are compared in Fig 4. Here, only two parameters are used for comparison, namely the precision of location estimation and time to fix. However, other important factors, too, should be considered, such as easiness of implementation and cost. There is not one perfect solution and the several presented methods will need to be combined to offer a reliable and accurate positioning.

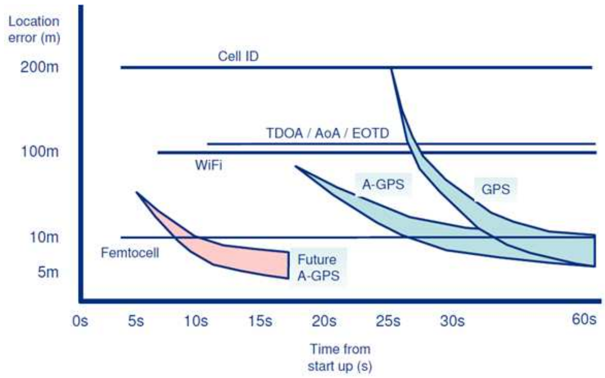

Figure 4. Comparison of different positioning methods [23]

6 FURTHER WORK

As the next step, practical investigation in more precise location determination needs to be done. We will evaluate if any of the presented methods is feasible in our mobile network and how it could be used in the briefly presented pilot system which is the main motivation of our work. We will focus on the precision improvement of mobile technologies based on the cell ID, the reason being that they cover both the outdoor and indoor environments, and that they can be obtained rather easily. We foresee to achieve improvements by applying precise knowledge of our own mobile network. This method will be complemented with satellite or/and hybrid methods wherever signal reception will allow it. All the method precision will be assessed by comparing position determination results with the actual location of test users.

7 CONCLUSIONS

Mobile devices are the most used consumer devices. Developers have acknowledged them and are thus offering numerous applications. Among them LBSs seem a very promising field. LBS considers the context of the service use, above all the location as its major element. Accurate positioning methods are enablers for this type of services and are therefore gaining in importance. If operators decide to enter the mobile service market either by cooperating with service providers or by competing with them, implementation of a positioning system is a step in this direction. The presented methods are not equally good and not suitable for every operator. The factors affecting the choice are the desired accuracy and coverage, existing and desired infrastructure, investment thresholds and a driver for implementing it in the first place. The methods based on the mobile technologies offer a base for positioning which will be improved with other methods presented in the paper.

As with any other personal information, privacy issues have to be considered also with location information. Therefore, users have to opt in and an environment where the location information is not misused or even abused has to be established.

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Matevž Pogačnik graduated in 1997 and defended his Ph. D. thesis in 2004 in the field of telecommunication and informatics at the University of Ljubljana. His research and scientific work is focused on development of interactive multimedia services for different devices with a special emphasis on development of systems for user-adapted content choice (personalization). Lately he’s been involved in development of interactive services on all devices in the fields of e-learning and IPTV systems using different interaction modalities. He has participated in numerous European projects in the field of interactive digital television, e-learning, e-tourism and P2P systems. He is also a member of the international organization IEEE.