

Miscellaneous Service Delivery to Modern Mobile Devices

Guest Editors: Ondrej Krejcar, Peter Brida, and Stavros Kotsopoulos





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Editorial

Miscellaneous Service Delivery to Modern Mobile Devices

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This special issue comprises some selected and specific peer-reviewed research papers on miscellaneous service delivery to modern mobile devices. Within the framework of wireless telecommunications technology convergence issues, the ability of current mobile devices to support new services is practically limitless. The philosophy in this case is to provide to the users the option for supporting total service continuity based on seamless transfer mode from one network to another. The new era in modern service provision from the user's point of view is to offer the "always connected option" in indoor and outdoor environments. The new communication services will be based on specific communication platforms, by taking into account input information from embedded sensors (i.e., accelerometers, proximity, GPS, etc.). The hardware and software complexity of these devices is estimated to be very high. This led us to devise utilization issues, not only from communication point of view but also for device smartness purposes. Modern mobile devices can be used in the health care sector (e.g., home care service) and in the transportation sector (e.g., vehicle telemetry services). Multimedia services form very interesting segment of the services.

A variety of wireless telecommunication services need the position information for real-time service operation; for this reason either almost all modern devices are equipped with GPS sensor or alternative positioning solutions can be implemented if GPS signal is not presented or its corresponding received signal strength level is too low. Hostile wireless mobile environment impacts on the delivering of the services. Each service is sensitive to the immediate status of radio channel in different ways. The limitation of the facts as well as the services design is very important. Each service should be

characterized by specific Quality of Service (QoS) levels. The specific QoS parameters like localization accuracy, delay, and so forth define corresponding QoS levels. For some services, those parameters are not well defined.

This special issue is addressed to researchers and engineers in both academia and industry sectors to take advantage of ideas, shared experiences, and reported original works about all aspects of the above-stated philosophy, which is covered in five selected papers for this special issue.

The paper entitled "*Real-time communications in autonomous networks: system implementation and performance evaluation*" by C. Tselios et al. focuses on the design and prototype implementation of a communication platform aiming to provide voice and video communication in a distributed networking environment. Performance considerations and network characteristics have also been taken into account in order to provide the set of properties dictated by the sensitive nature and the real-time characteristics of the targeted application scenarios. The achieved results show that the proposed platform operates seamlessly in two hops, while in the four hops scenario, audio and video are delivered with marginal distortion.

The paper entitled "*Impact of used communication technology on the navigation system for hybrid environment*" by J. Machaj et al. deals with navigation of mobile device in outdoor and indoor environments by only navigation system or application. The navigation system is proposed in the light of seamless navigation service. Main parts of the system from the positioning point of view are based on GPS and WifiLOC system. WifiLOC is an indoor positioning system based on Wi-Fi technology. The system is implemented at the

University of Zilina as a pilot noncommercial project; therefore it is called University Mobile Navigation System (UMNS). The navigation system can be characterized as a real-time system; that is, the system operations cannot be significantly delayed, since delay of the system depends significantly on communication platform used for map information downloading or communication with the localization server. We decided to investigate an impact of the used communication platform on the time needs for some of the functions implemented in the navigation system. Measurements were performed in the real-world application.

The paper entitled “*The concept of the remote devices content management*” by M. Behan and O. Krejcar presents a concept of customizable interface of remote device management which takes into account mobile devices and their content. The concept is suitable not only for Apple iOS or Google Android, but also it covers all mobile platforms as well as the sensors capabilities of mobile devices which can turn such mobile smart device to smart and mobile sensor concentrator.

The paper entitled “*Open personal identity as a service*” by M. Behan focuses on Open Personal Identity as an independent service which is gathering available identity resources and provides unified person identities. The service enables to resolve current mobile device problematic around multiplicities, backup or change management of person identification where multiple devices replication is an option.

The paper entitled “*Troubleshooting assistance services in community wireless networks*” by P. Kriz and F. Maly proposes troubleshooting assistance services which will assist the users during solution of communication problems, gathering data for expert analysis, informing the user about the state of the network (including outages), and so forth. Network administrators will be provided with a unique tool supporting the network analysis, operation, and development. We have mainly focused on the use cases and prerequisites—the problem of topology discovery.

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Research Article

Open Personal Identity as a Service

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The mobile computing established communication environment where personal identification is a key factor which influence usability of mobile application. Open personal identity is a partial service which enables crowd resource identifications processing in online distributive unified form over secured communication channel. The service provides current fresh personal identifiers which are essential in communication process.

1. Introduction

Do you remember the situation when you have changed your phone number and you had to tell this change to all of your friends, relatives, and even workmates? That time is over with the Open Person Identity as a Service. Imagine worldwide Internet service which provides online personal information such as mobile numbers, current living address, or current friend's cross different social media. There are many advantages of usage of such a kind of service. We would like to introduce some of them in more details.

The modern knowledge society produces much more information than we are able to consume and therefore the utilization or clarity of information is more than convenient. Only those kinds of services which are not complicated or confusing would be accepted by many and the strength of intuitive factors for applications or services behaviour will increase in time. That is why social media have such power of influence because they are gathering information from many sources in easy and comprehensive personal way. The problem is when you have more social media than the amount of time to spend on scanning or posting personal information into the different sources is not efficient. The case is about to find an open solution which consolidates all media in one place and basically provides personal social connector as a convenient user-friendly solution with an easy and comprehensive user interface.

2. Problem Definition

The amount of social media networks, multiplicity of personal identity [1], and the inconvenient way of handling the important personal information leads us to think that there are some better ways of how to make our lives a little bit easier. That's why we start to think about the problem in terms of usability in current available online social technologies [2, 3].

We started to ask how to solve our daily life common problems and we summarized them in the following questions. What if we have more than one mobile device but each one of them has a different content? Or if we have just one mobile device but we lost it? Could we exchange mobile device platforms without any inconveniences? Do we have to notify everyone when we change our mobile number or even when we do not use it anymore as an identity? When we answered positively to some of those questions, we considered us in correct problem definition [4, 5].

That was just a brief overview of a complex task to solve. In this paper we are focusing on personal identity service which is used for virtual personal identification and enables communication between people over modern technologies; nevertheless we consider that kind of service as open and as an independent concept where commercial influences are minimized. At first we describe communication process between two or more sides where communication could be established if there is an existing compatible informational

data flow exchange between mobile device clients. To start the process at first we need to know the identity of the persons with whom we would like to communicate. The identification of personal identity consists of our tacit knowledge where the identity is located in available informational resources and how is the identity knowledge externalized by visualization in comprehensive form. After correct identification of required person, the communication process can start.

As a current personal identification mainly used in mobile devices we assume a phone contact list where identities are expressed by names, personal pictures, or associated phone numbers. That kind of establishment was made by mobile providers over the world. Another personal identity used in mobile device communication that we recognize are the instant messaging systems where identities are commonly defined by user name coded by sequence of characters. We consider these types of identification as obsolete and we propose a new concept in chapter New Design.

Also we define the environment as an online with unlimited access to the Internet according to the fact that the increasing mobile device online connectivity is arising. We announce the offline mode of Internet connectivity as temporary state which is identified by status of not connected client and which would be changed by user interaction or predefined settings device behaviour to online mode and proceeds in delayed tasks. We considered online Internet access to mobile device in terms of synchronization of contact list with the Open Person Identity Service (OPIS) over message-based client-server where changes are only made by authorized identity owner. In those terms of change management we defined following concept of the Front-End and Back-End.

Front-End. All clients which are accessing over the Internet to service by message-based communication and perform user's actions corresponding to the correct content within associated devices and also can perform data merge operation with current device content (Figure 1).

Back-End. The server provides service based on client-server type of connection and background resource processing which interacts with social media as automated direct resource connector (Figure 2).

Next chapter highlighted the solution concept which can solve our defined problematic by changing establishment and by exploiting today's technologically innovated environment surrounding us with an increasing mobile Internet connectivity.

3. Related Works

Today's personal identities are stored mostly in mobile device as a contact list saved on a local storage. Synchronization with other devices or with desktop applications is normally made over USB or Bluetooth which is connected directly to a personal computer. For instance we just highlight some of software solutions: Apple iTunes, Nokia PC suite,

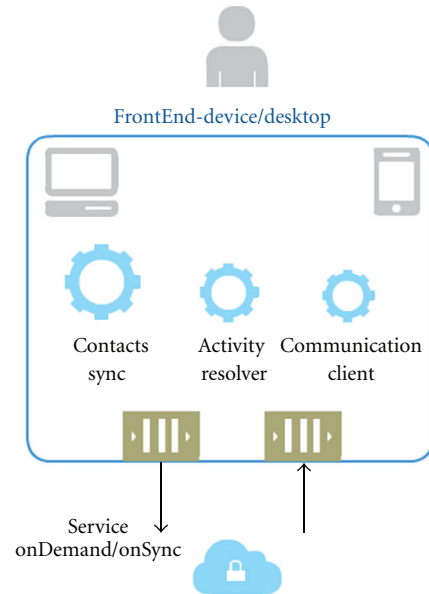


FIGURE 1: Service design: client.

and Microsoft Phone Data Manager. These mentioned software solutions have some disadvantages. The installation requires dedicated computer where all data are placed and managed. Supported mobile devices are basically only with corresponding platform or manufacturer in terms of single-content management or in case of mobile device lost or exchange.

Those disadvantages of current local data management software of mobile devices led us to propose remote data management solution, so one part in this paper is covering a solution for personal identities service based on a contact list embedded in mobile devices, which could be manageable from device itself or from web interface from Internet [6, 7].

The reason why we considered such solution is a usability of mobile devices due to its limitations in editing the contact where small screen and lower maturity level of a user's input interface is provided in comparison with common desktop. The other reason is a possibility of data replication to other different types of mobile devices. In short, it is to create an independent platform for mobile phone users who have more than one device. It is also useful for an easy recovery of a contact list data in case the device is lost or broken.

The new solution considers security issues and authorization of publishable personal information. The main reasons why such a service may be not acceptable from user's point of view are data privacy issues where users will not like to share their contacts. We solve this issue in terms of use and encryption system policy where no one could decrypt personal data without a password.

We announce well-known OpenID service as different type of web service [8, 9] which basically provides uniform access to multiple web sites or application which implements OpenID access as a third side authentication process. The principals are different in basic scenarios where, for example, in case of OpenID the user visits a web application and is

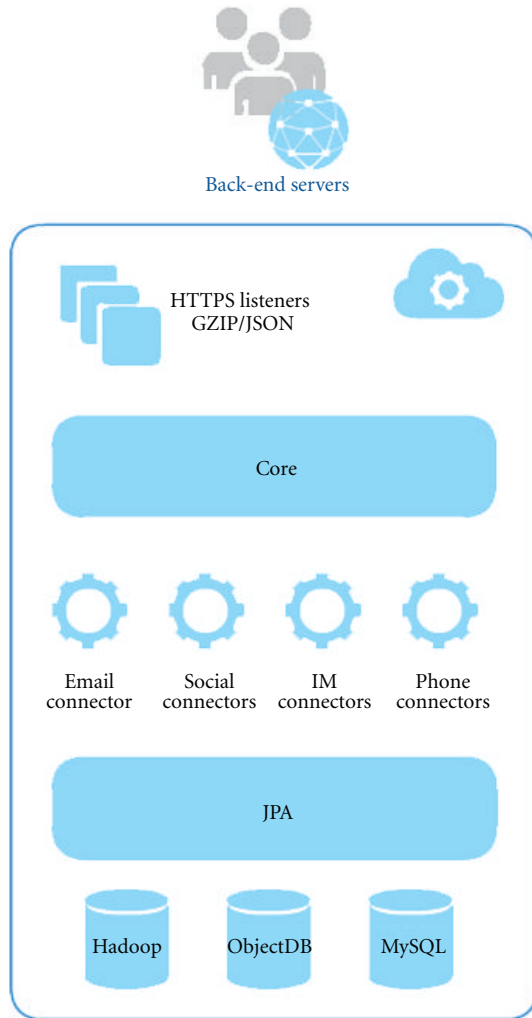


FIGURE 2: Service design: client.

able to log in without registration or native login process but instead of that the user will be only authorized by OpenID with the same credentials when service is implemented and provided. The principals about OPIS are described as following use case scenario. The user has only one place for real identity attributes and these information are in case of change automatically redistributed to connected systems or they are provided as a service like online requests by gathered data from social connectors where last update event of specific identity detail is provided.

4. Solution Design

As was mentioned in chapter above the developed solution is based on the front-end and back-end architecture where as a front-end we assume only devices which are opened to software maintenance and which are configurable such as smart phones, tablets, and computers or even, for instance, the cars with embedded customizable control unit [5, 10]. The front-end in our perspective is basically any customized client with Internet connection ability, device with contact

list accessibility, and with background processing possibility. As an extension of the front-end in term of user device application also user interface whereas the output we consider graphical (GUI) or voice interface (VUI) and as the input a touch, keyboard, or voice recognition user interface [11, 12]. Next part, the back-end could be any server technology which is able to store data of identities and their associations with clients, which has Internet connectivity and provides services on specified ports and also which is able to maintain informational flow between external resource providers such as social networks or instant messaging services and internal website accessibility for remote device administration [13, 14]. That was in short described the concept solution where we are focusing on types of user actions on the client side and then on the server side on back-end processing (Figure 2).

For more precise description of the front-end we would define common end-user's actions and divide them into two parts as an interoperability types of actions which come first and as an administrative action types which come after. The task that would not necessary start at first time after client installation is the import of personal identities processing where available resource is embedded in a device contact list, in usage of instant messaging systems or in social networks. All that kind of application would be recognized at first time or upon user's additional task completion. Therefore user's actions are about to import existing contact list, add social media connector, or add instant messaging provider. As a complementary user's actions to each of designed entities would be to create, read, update, and delete (CRUD) actions from administration point of view. During the process of an identity import is mandatory a user's support where actions as human recognition are required, because data mash or the other identity conflicts are machine irresolvable. Next actions covered administrative part of application where client behaviour settings ability options are shaped by the Internet connectivity which could become as offline or online device mode.

The offline mode recognizes active connections to Internet and automatically synchronizes changes with back-end instance. If the device does not support background listener of network status change then the responsibility of connectivity is up to user over corresponding passive sync actions. While the active online mode requires requests to be served just in time and therefore personal identities would be provided any time up to date when they are required by user or by another application. Also in this case devices without support of background processing are using contact list as a provider of identities and accessibility for other application have to use embedded contact list as an informational resource which is replicated upon user actions. Also there is a possibility to use designed communication client, where identities are automatically remotely resynchronized. Another administrative action is definition of access level permissions for each specific identity where user could globally set up public, protect, or hide permission for concrete identity or in more sophisticated customization could specify permissions based on member groups.

The back-end part actions are mainly focused on background processing of connected clients or connected external

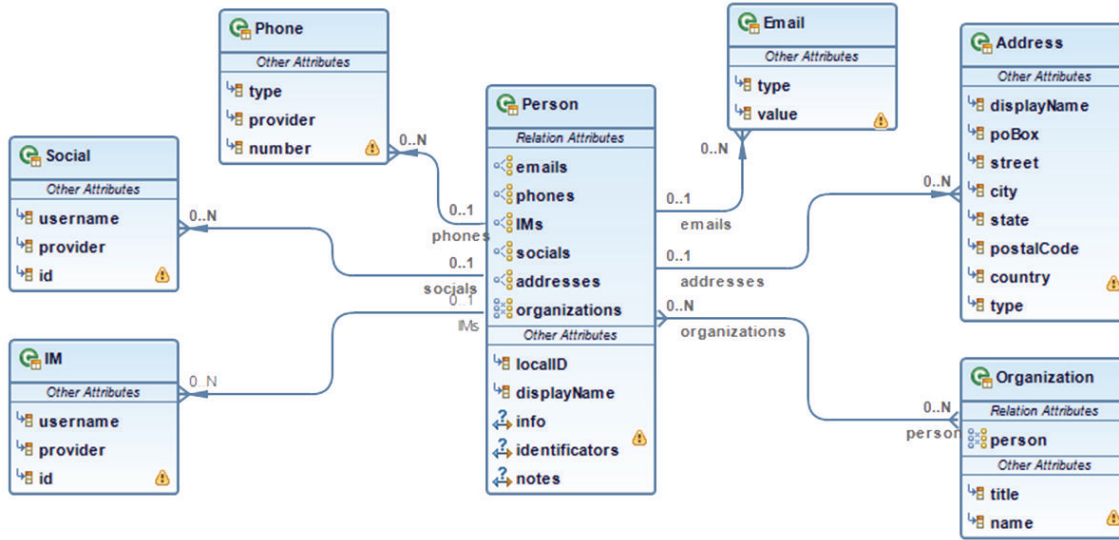


FIGURE 3: JPA Entity diagram.

identities providers. The Figure 3 above presents the entity diagram where are highlighted required information and their relations which are valued for gathering into the database. Data are consolidated within user's point of view and saved only with partial information based on social networks providers.

The social networks and instant messengers are converging subset of external identity providers. Not all are enabling open informational exchange for independent clients. One of the open exchange protocol is called the Extensible Messaging and the Presence Protocol (XMPP). Standardized on port 5222 and messages are exchanged over the Extensive Mark-up Language (XML). We considered the standard above as convenient and it will be used for interaction in further development on interface [15] with most of instant messenger providers. In case of social network providers the common authorization process with external applications is based on third sidy party access, which was mainly developed and enhanced by Facebook due to the external social content of providers who have to have only limited access to the social media private data [16]. The same principles are used in G+ for accessing personal identity details.

5. Implementation

During the project realization we were challenging the suitability of used technologies. As the most portable solution we decided to use Java object language and supportive development framework Eclipse due to Java virtual machine (JVM) technology where clients could be implemented in any kind of device which supports embedded Java even for instance in car's radios which are able to be connected instantly to the Internet [17, 18]. The prototype of testing server which provides open personal identities as a service is developed as socket Java server and running as a background process within Linux distribution (Cent OS) on virtual

private server (VPS) [19]. The testing client prototype is based on Android platform because of a rapid application development (RAD) where Java is also included as a platform development language. The communication between server and client is based on message-driven protocol. The messages are transferred by Java objects serialization. As server storage we used ObjectDB database engine caused by its performance results [20]. We consider the engine as the fastest in terms of usage Java Persistence API (JPA), where the Java objects are annotated as database entities and therefore the transformation of any type of data between persistent Java objects in memory and physical data objects in database back and forth is automated. Currently implemented part of a concept is user interface as Android native application with touch ability. We of course plan web interface for remote management with possible device management extension therefore Figures 4 and 5 present the Android client prototype application which is enabling a merge of different source of personal identities and replicates knowledge to the server. In a certain time of period the background processes are refreshing data from external resources which are announced with public accessibility. Validity for instance of email is checked with background process email checker only on untrusted inputted data.

6. Security Issues

The very important aspect of application concept, where maintained personal data are, is the security. Users are sensitive about their personal information and therefore we consider high level of security mechanism for distributing data between server and client. The secure channel is the Secure Socket Layer (SSL) based on the Rivest Shamir Adleman (RSA) asymmetric cipher algorithm. The trust store file with application certificate is included in the client application which is retrieved securely over the password

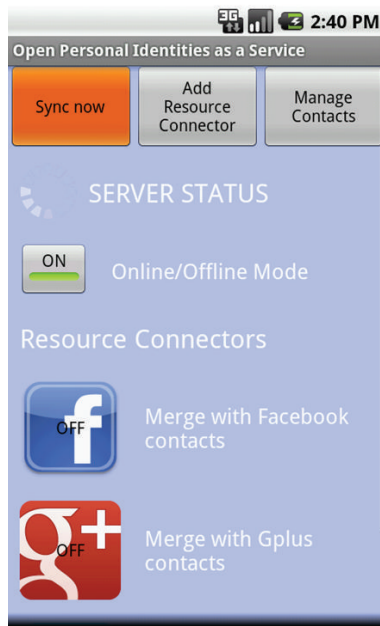


FIGURE 4: Client android application: services.



FIGURE 5: Client android application: access point.

and the secure communication would be established between client and server with trusted certificate. Therefore only clients and servers with trusted certificates which are signed by certification authority are able to start communication. In other words the channel is well secured and there is no possibility for man in the middle to decode communication secret without knowledge of 4096B long private key which is used and be covered at safe place on server under the key store password.

Another security threat for Android mobile device platform is hidden on client side in data accessibility over shared memory or over local sqlite3 database which are stored under application uid on local Linux file system. The attackers would be able to view data from memory or from database file. Such scenario is conditional to rooted devices whose users are willing to unlock mobile device for exploit more device features, but on the other hand they losing security capability of nonrooted device.

7. Conclusions

The Open Personal Identity Service solution is one part of larger scale project which covers Remote Mobile Device Management area. We consider positive influence of application usage on daily bases tasks where personal productivity increased by penetration over connected social networks. The change of any kind of personal information supposed to be automatically redistributed over the connected systems within secured channel for data exchange. We acknowledged that the users are very sensitive about their personal information and therefore we consider as a must high-security level of data processing and necessary system security capabilities. The application increase usability of maintaining social and personal identities characteristics. The open access service increase global knowledge of personal identities and positively influence human adaptability in cyber space. The real benefits of service would be recognized in further discovery with real user's behaviour. The result at first step is working prototype which provides remote service of personal contact list management for mobile device users. With an increasing amount of application users the certain of personal impacts will be more obvious.

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Research Article

Troubleshooting Assistance Services in Community Wireless Networks

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We have identified new services intended for users and administrators of community wireless networks. Troubleshooting assistance services will assist the users during solution of communication problems, gathering data for expert analysis, informing the user about the state of the network (including outages), and so forth. Network administrators will be provided with a unique tool supporting the network analysis, operation, and development. We have mainly focused on the use cases and prerequisites—the problem of topology discovery.

1. Introduction

Community Wireless Networks (CWNs), the phenomenon of the last decade, differ in many ways from the usual enterprise computer networks or access networks of Internet service providers (ISPs). We have to address common problems appearing in these networks with regard to their specifics.

Our experiments were done in local community wireless network—<http://www.hkfree.org/>—operating on the territory of Hradec Kralove town and the surrounding conurbations.

2. Community Wireless Network Characteristics

We deal with the specifics of CWNs networks in the Czech Republic in this paper, but many conclusions can be generalized. We will briefly discuss individual differences.

History of CWNs in the Czech Republic starts in 2002 when in Prague and other places the first small neighbour networks appear. Their advantages are economies of scale, removal of margin of a commercial ISP, and also the possibility to influence the functioning of the network itself and to contribute to it (e.g., to implement own services

related to the network). The development of these networks was stimulated by far too high price of fast and unlimited internet connection (broadband) and by decreasing price of electronics, especially components for building wireless radio networks (WiFi cards) [1].

Later, they evolved from unorganized neighborhood networks to large organized communities forming a civic association or other legal forms.

Other terms such as Mobile Ad Hoc Network (MANET) and Wireless Mesh Network (WMN) are related to the CWNs; Mahmud et al. [2] explains these types of network in detail. CWNs, at least in the form in which they occur in the Czech Republic, do not fully comply with the definition of either MANETs or WMNs. Its technical characteristics are closer to the ISP access networks, with the different last mile and backbone technologies. For example, unlike ADSL, they use low-cost WiFi outdoor links. Spontaneous changes in topology and outages are more frequent.

Worldwide CWNs are typically rather simple (often homogeneous) WMNs or communities sharing their own connectivity for mobile users (FON and others). Furthermore, they solve the problem of Internet infrastructure reconstruction after natural and other disasters. Many networks decline in the context of the increasing penetration of free WiFi in cities (cafes, hotels, etc.). In contrast, the

community networks in Czech Republic are expanding. They are making the technical support professional as well. Albeit from an organizational point of view, they remain primarily nonprofit organizations involving users in the network development. These are the key aspects for the proposed troubleshooting assistance services.

CWNs are a phenomenon not only in the Czech Republic [3, 4] but here it has an enormous interest of the public. For a general idea about their size we can use statistics of NFX association which covers most community networks in the Czech Republic. It registers altogether 41,000 users (households) in its member networks. For a comparison the Czech Statistical Office presents 4,150,000 households [5]. By a rough estimate, there is 1% of Czech households in the community networks.

CWNs usually provide fixed as well as mobile Internet connectivity service using WiFi access technology. Some communities support “roaming” between particular access points within their network or with other networks.

3. Troubleshooting Services

Due to an effort for effective financing of development, improvement of safety and quality of services, a natural need for central supervision, and partial planning of topology appeared. But due to the previous spontaneous development of these networks, it is difficult to satisfy this need because the whole topology, utilisation of individual links, their types, and other data are often unknown. The aim is to do the topology discovery in these spontaneously built wireless networks regarding their specific environment and to suggest a concrete applicable approach. The topology information is necessary for later troubleshooting assistance.

During the development of community networks, the need to obtain a clear and reliable picture of the entire network topology appeared. With this information it is possible to further develop the network efficiently, solve problems in network, or clarify dependencies between individual nodes according to the real topology. By analyzing the dependencies, we can properly inform users about planned network outages, since it is known on which nodes and connections are the end node (user) functionally dependent. In addition, the knowledge of the topology may be used for supporting the analysis of unplanned outages by network users, as outlined below.

From the perspective of network analysis community wireless networks have their positives and negatives. Active involvement of users in network operations is the positive aspect of community wireless networks. Users may participate in topology discovery, network monitoring, and other tasks. On the contrary, the negative is considerable heterogeneity of networks and the use of low-cost network elements, which often lack the tools for monitoring and management that are commonly available in the business sector.

Especially in case of ad-hoc networks or other spontaneously created networks, the possible supportive communication and information system could be a benefit. Its aims are

the following: assistance to a user in solving communication problems, preparation records for its possible analysis by an expert, and improvement of user's knowing about the state of the network (planned outages). It will also assist the network administrators in solving problems and as a tool for automatic documentation and for designing future changes.

3.1. Use Cases. In CWNs, there are two types of users who benefit from the supportive information system: ordinary users (community member) and network administrators.

Here are the typical use cases (scenarios) for both roles.

Ordinary user (community member) needs to be informed about planned outages. Not only in advance, but the solution should work in case he or she will connect to the network during the outage as well. The system will support the exchange of outage information between peers. For example, already (in advance) informed peer will later inform the peer that connected during the outage.

Ordinary user should be able to solve basic problems with his or her connectivity. The system assists the user. It should be able to localize the causing failure, suggest the solution, including contacting appropriate responsible person, and provide necessary observation data.

Network administrators have to efficiently develop the network and solve common operation problems. The troubleshooting services provide them with network topology information, including the historical data and continuous changes. They help with identifying and solving common topology and configuration issues and with analysis of outages. Network administrator will announce planned outages to affected users inserting this information using the troubleshooting services.

The services are not purely focused on the central administration, but will also allow for network analysis by the user using the software running on his or her computer. Therefore, the user will indirectly help administrators to solve network-related problems providing the information of an expert nature.

The services will also efficiently inform users of planned outages. In case a peer could not have been informed about the outage because it had been out of reach of network or switched off then the outage was planned. After its joining to the network, it is not able to communicate with the central node (server) which had originally propagated the information. Using the troubleshooting services peer will find active and available neighboring peers and ask them for information about the failure. The neighboring peer remembers (cache) this information from the time it was announced. The result is the user is correctly informed about the planned dropout, including its duration.

The service will automatically identify the situation that there was an unscheduled outage of the primary link that the user uses to access the Internet and will inform the user that the backup path is used and may have a worse connection parameters.

3.2. Architecture. According to Figure 1, new components implementing the troubleshooting services need to be

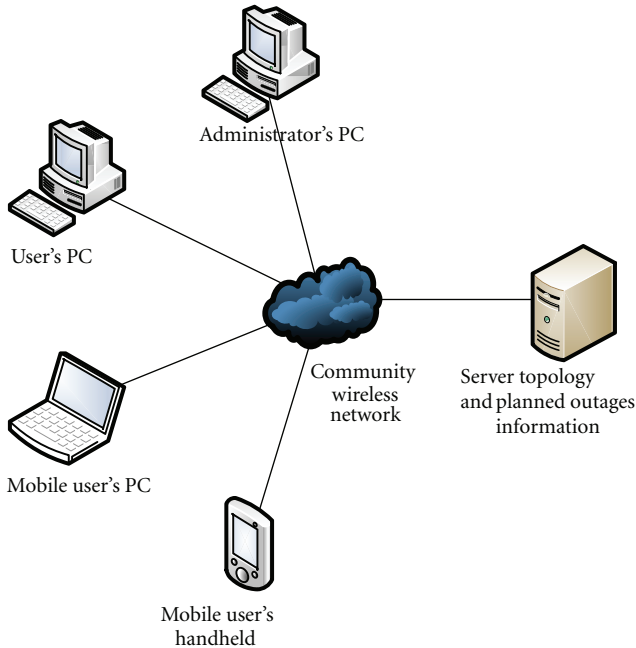


FIGURE 1: Conceptual architecture.

deployed on all types of peers—supportive server, administrator's PC, and user's devices (at least PCs). We discuss the communication architecture later.

Particular service will collect available information about the network in any node (including end user nodes) and analyze this information with the purpose of gaining information about topology of the network, its utilization, bad or improper configuration of some nodes, safety risks and attacks. Analysis results will be provided to others nodes for global analysis.

Such system can be characterized briefly as distributed database system or peer-to-peer database. This database provides information for local analysis (i.e., problems with the node and its environment and root causes of these problems). Database also enables global analysis leading to gaining information about the state of the network and solution of its main problems such as optimization of the network, routing, and so forth.

The fact that the network is communication medium and the observed subject at the same time introduces new challenges. The communication architecture described later respects this peculiarity.

4. Topology Discovery Modules

Model of the network topology is essential for later troubleshooting assistance. We will briefly describe particular modules for topology discovery on layer 3 (L3) and layer 2 (L2) of ISO/OSI model and the method of link-type classification. These methods were specially designed for community wireless networks. Common solutions of topology discovery in enterprise networks are not applicable here as they highly rely on the simple network management

protocol (SNMP). Unfortunately, CWNs are built using low-cost consumer-market network components that lack SNMP support.

4.1. L3 Topology. Community networks widely use OSPF dynamic routing protocol that is useful for our application.

Routers and links are often connected to such redundant structures to be able to use another path in case of failure. In such event it's necessary to immediately update the routing tables' entries. Exchange of information among the routers and consequent updates of tables is specified by the given routing protocol.

The fact that each dynamic router in the network contains the network graph in its data structures can be used for obtaining the current state of the network and to visualize the overall topological map.

Dijkstra's algorithm is used for construction of the shortest paths' tree, based on edged labels. These labels in a database of network topology use a special metric called the *cost*. This metric is set for each link separately and gives preference to the direction of the link. The lower the cost is, the more the link is preferred. Router administrator has an opportunity to influence preferences of individual links by setting their costs. The most important is usually the path towards an Internet gateway, so he or she chooses costs of links in the way to prefer a qualitatively better link and to use other links as a backup in case of a dropout of a primary link and as a part of path to other locations in the network (for intranetwork communication). Load-balancing using equal cost multipath via more links is not commonly used but is also possible. Every point-to-point link is from the OSPF view composed of two oppositely oriented edges and the cost of every edge can be chosen. In case of multipoint links, the cost from a given node via a given link (regardless of the target node in this link) is common.

OSPF protocol is based on so-called link-state algorithm designed to distribute changes in connections between routers. Each router in the network will form a model called OSPF network—a topological map of the whole network area—based on this information. This map can be represented by a directed graph with edge labels based on costs assigned to each link in both directions. Then (and after each topological change) router calculates the shortest paths' tree in each of the nodes using Dijkstra's algorithm applied to the graph. Entries in routing table are created, modified, or deleted according to these paths.

Using OSPF protocol has the following advantages [6].

- (i) Routers know the topology of the whole network area.
- (ii) Fast convergence—routers spread topology changes data immediately, and then use the information for the calculation. Some of the other protocols are designed to perform the calculation first, then to spread the information further. Convergence is, of course, adversely affected by frequent changes of links' states (flaps).

- (iii) Event-driven distribution of information about the states of links—no need for periodic updates at short intervals; information is spread when there is a change.

Currently, our subject network's (<http://www.hkfree.org/>) topology consists of 161 routers and approximately 3440-connected workstations (using the Internet connectivity service) [7]. OSPF routing protocol suitable for such a large network is used for internal routing. Most routers of this network are common computers running GNU/Linux operating system. Routing daemon Zebra Quagga (open-source routing software that is a fork of GNU Zebra) is deployed in order to be an implementation of the OSPF protocol.

The routing software is managed through the command line administration console. It provides the ability to retrieve data from a database of network topology of one of the routers, which are input data for the topology discovery module.

The structure of such a wide network of routers can be hardly overviewed by an administrator, that's not able to easily find the key nodes. Searching for a specific router among dozens can be quite a challenging task. It is, however, expected that the administrator knows the approximate geographic location of the router(s). That is why we require the feature to layout the network graph according to the real geographical positions, assuming that the positions of some network devices will be available.

Some known anomalies may occur in the network configuration. Typically, it is the assignment of asymmetric costs in two directions of the same link. This situation may be the intention of administrator as well as a misconfiguration. Troubleshooting service should be able to warn the administrators about these anomalies and visually highlight them in an appropriate manner in the network map.

As the service provides the view of network state at a certain moment, administrator may lack the information about some router or link that was not active at that moment. For this purpose, the archive of OSPF database snapshots taken in regular intervals is created and made available via the HTTP protocol. In a history analysis mode it is suitable to detect hot spots where frequent (i.e. unwanted) topology changes occur. This analysis also allows analyzing the historical states of the network, so ex post we are able to identify the possible causes of failure such as temporary malfunction or misconfiguration of a router.

For network analysis, the data about costs of links can be further used for visualization of a primarily used path between two nodes, for example, the Internet gateway and a chosen node.

The implementation of the troubleshooting service displays (see Figure 2) the costs as labels of the edges and enables to display a tree of the shortest paths from a given node to all other nodes in the network and the shortest path between two nodes—in case of asymmetrically labeled edges (input and output costs are different) two different paths exist, regarding the direction of a data flow. The service also enables to highlight asymmetrically labeled links. This is an

anomaly which does not have to be always deliberate and the highlighting can contribute to a revelation of a mistake that could stay unseen to the administrator and manifest itself sometime in the future due to other changes in the topology. The service should support an interactive design of the network in order to test configuration changes and troubleshoot the whole topology before real implementation.

4.2. L2 Topology. L2 topology discovery in the whole network's scale without the SNMP support is very problematic. Many standard protocols such as Cisco Discovery Protocol (CDP) or Link Layer Discovery Protocol (LLDP) are implemented in devices out of a consumer market where they support also the SNMP. All these protocols are not usable in a network based on consumer devices.

Link Layer Topology Discovery protocol (LLTD) is promising solution in CWNs. It is implemented in some consumer devices and especially in operating systems MS Windows from the Vista version and on. In the similar way, it would be possible to use the basic ARP protocol for getting an overview about the number of active devices in a given subnetwork.

The problem is the mentioned techniques work at the L2 level only—for transfer of the obtained information about a local L2 topology it is necessary to use a proxy which would transform the information from the given subnetwork into the form transportable into the central repository (topology server).

But in this consideration, the community networks offer a potential in participation of their members in the topology discovery process. In many places it can be more feasible to deploy monitoring software at the users' PCs than at the active network elements (or than replace these elements by the modern ones equipped by the SNMP). Service component deployed into the user's computer would mediate the exchange of information at least about the topology of a given L2 segment into which the computer is connected. By aggregation of this information, it is possible to discover at least a part of the network "peripheries" and to contribute more information to the overall view of the network. In this procedure, we can see certain parallels with the multiagent systems which represent a good theoretical basis for the following procedure and offer already existing frameworks for the following implementation. The communication architecture described later may be implemented using multiagent framework.

Motivating of the users for the installation of software for collecting topology information at their computer will be a specific issue.

4.3. Wireless Links Classification. For the administration of the network and planning its development, the described topological map is not sufficient. For the support of decision, it is useful to find out a technological level of every used links, in an ideal case also their concrete parameters such as bandwidth. While in fixed enterprise networks, it is not a problem (e.g., via SNMP) to find out a type (and its corresponding technology) of the individual interfaces at

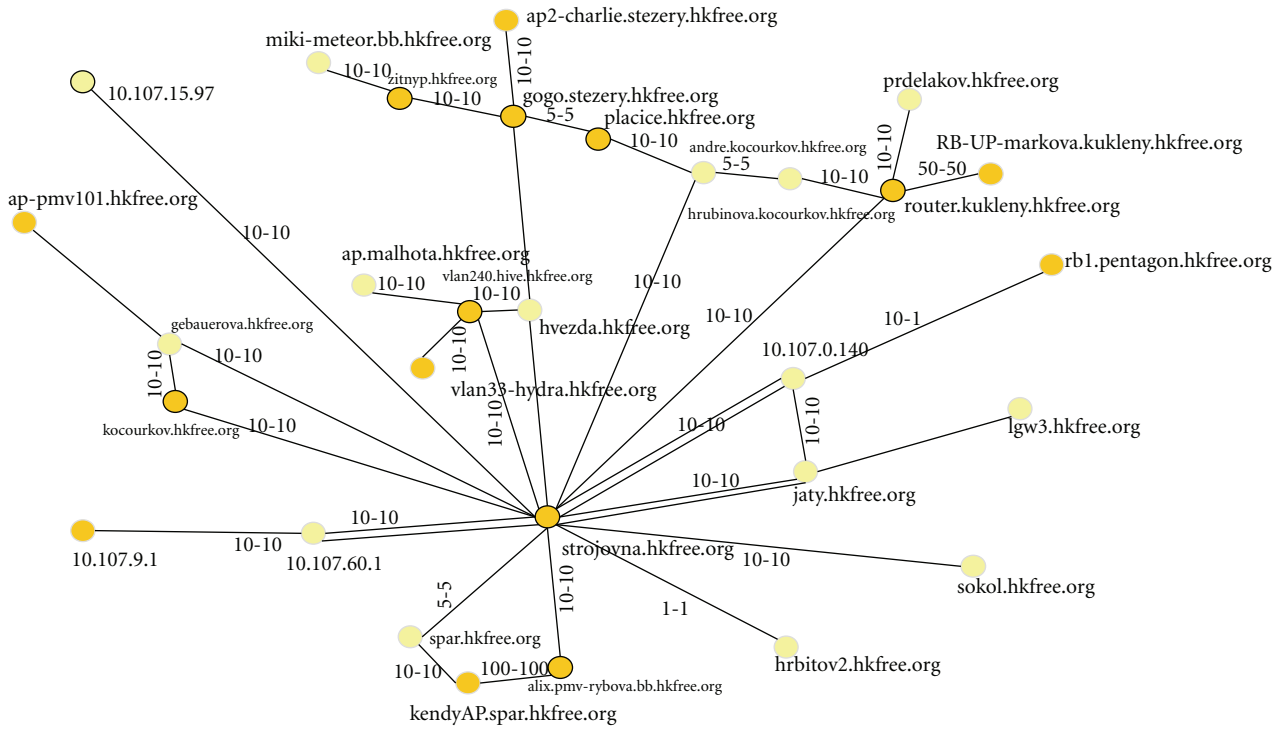


FIGURE 2: L3 network visualization (sample output of the “ospf-visualiser” interactive tool).

particular router or switch; in wireless links this procedure does not always have to be possible. The link realized by a device connected via a common-fixed technology (e.g., 100BASE-TX) can be fully transparent at the L2 level but has a smaller bandwidth and other different parameters.

There has been just a primary research into point-to-point links classification based on a statistical analysis performed in this field. As an input data, we used measured characteristics of latency of each links—minimal, maximal, and average latency in milliseconds for each link. Let us note that the results of measurement on unsaturated link did not have a sufficient information value. That's why it was necessary to systematically saturate the link during the measurement. During our experiments, we found the parameters for MTR tool that saturated measured link in appropriate manner:

```
mtr -r -report -c 10000 -i.0000001 -s1472 $ip
```

In <http://www.hkfree.org/> network, most links are based on wireless radio links in 5 GHz (half-duplex) and 10 GHz (full-duplex) bands, so the task of classification was reduced to resolution of links into these two groups. From descriptive statistics of the measured data resulted conclusions (e.g., that the measured characteristics not always have a normal distribution) determined the used methods of classification.

The methods of *binary logistic regression* and the algorithm (as a reference method) from the field of machine learning *k-nearest neighbors* were used for classification.

In both methods, minimal and average latency were identified as important explaining independent variables.

Using the binary logistic regression method, we created the following classification model.

Classification function:

$$\hat{L}(X) = -3,063 + ,027 \cdot \text{LAT}_{\text{AVG}} + ,587 \cdot \text{LAT}_{\text{MIN}},$$

$$P(A_{5g} | x) = \hat{\pi} = \frac{e^{\hat{L}(X)}}{1 + e^{\hat{L}(X)}}, \quad (1)$$

where LAT_{AVG} and LAT_{MIN} are average latency and minimal latency measured on particular link using the mtr tool with parameters specified earlier.

Threshold probability values is 0.5.

That is, if

$$P(A_{5g} | x) > 0,5, \quad (2)$$

then the link is classified as 5 GHz link according to our model. Otherwise, it's 10 GHz.

Figure 3 describes the training and validation sets of k -nearest neighbors method.

Comparison of results of both methods was performed by 10-fold cross-validation using a training set of 71 links. Total rate of true classification was 91.5% at the logistic regression and 95.8% at the k -nearest neighbors. This shows that both methods are very well usable for the classification.

During the analysis of outliers, it was found out that both methods incorrectly classified the same links in the class 10 GHz into the class 5 GHz. In a more detailed examination of particular types of these links, it was found out that these were the oldest models used in the network which with their features approximate more to the less quality 5 GHz links

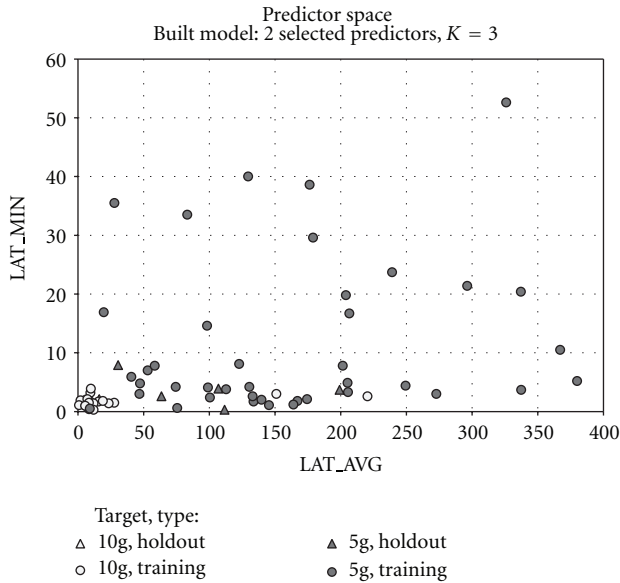


FIGURE 3: K -nearest neighbors model (IBM SPSS Statistics Viewer).

(suffering from interference issues similar to 2.4 GHz band [8]).

Wei et al. [9] used a similar method of classification for identification of access networks types (Ethernet, ADSL, etc.) but with the use of a median and latency entropy as basic characteristics. We did not use them in our initial research because they are not produced by the standard diagnostic tools such as ping, traceroute, mtr, and so forth.

5. Communication Architecture

Special communication architecture *M-client M-client server* suitable for the network troubleshooting assistance support was proposed [10].

The proposed architecture includes and provides advantages of two architecture concepts: Classical client server architecture and Peer-to-Peer architecture. Client server architecture with central (sometimes replicated) server is used in ordinary operation when clients are directly accessible from the server. In case the server is not available, the clients may switch to Peer-to-Peer communication model and obtain server information by cooperation with surrounding accessible nodes.

This architecture allows network users to cooperate on peer-to-peer basis in case of network failure. They are able to exchange important information regarding the failure, for example, information about planned outages or topology information specifying the point of failure.

6. Conclusion

We have described the main use cases for network troubleshooting assistance services and focused on their requirements—topology discovery. Community wireless networks require a new approach for this complex task

because common solutions using SNMP are not applicable here.

The core module for L3 topology discovery has been successfully implemented and tested as a part of the application for visualisation of the OSPF network. This application fulfills all described use cases for network administrators (except announcing planned outages). This application is available at <http://code.google.com/p/ospf-visualiser/>.

Solution of the cooperated L2 topology discovery based on LLTD protocol was proposed and is currently tested.

Wireless link classification based on statistical analysis of average and minimal latency was successfully evaluated and is a subject for integration into the implemented application. The network model will be enriched with obtained link types.

These new services bring the better user experience in community wireless networks, help network administrators with their common tasks, and allow the rational further network development. Although the initial demand for these services came from the field of community wireless networks, their use is not restricted to this area.

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Research Article

The Concept of the Remote Devices Content Management

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Modern mobile communication devices which are often used as remote access to information systems bring up many advantages for user. Unfortunately in some cases when user has several different mobile devices for the same remote access, a problem of multiplatform and multivendor environment fragments productivity by user knowledge in principals of approach to possible services, controlling or management of devices as well as features is available. The customizable interface of remote device management benefits by the control of all owned, authorized, or publically accessible devices from single point of user perspective. We propose a concept of such information system which takes into account mobile devices and their content. Concept is suitable not only for Apple iOS or Google Android, but also it covers all mobile platforms as well as the sensors capabilities of mobile devices which can turn such mobile Smart Device to Smart and mobile sensor concentrator.

1. Introduction

Future resource-based economy will dramatically shape current daily processes in many parts of human activities. The consumer society will face the effective artificial self-responsible subsystems with behaviour where cost-effectiveness and nature-related responsibility would be on first place. Global acquirements of devices power used for developing smart environments, that could dramatically increase human productivity as a side effect, would be recognized as a middle step of oncoming technology evolution. We acknowledged that nowadays the current market with mobile devices is more and more fragmented cross-vendors or platforms where different users approach could be confusing. As an alternative we would present future vision of Remote Device Management (RDM) which could positively shape human productivity and could be simply used for actual and future user centric multidevice environment as a convenient interface. Our Remote Device Management is designed as a productivity concept for users who prefer centralized management point and confident approach to multiplatform types of devices in comprehensive way. The future user content management challenges will have to take into account multidevice environment where

different User Interfaces (UI) and platform are and device-specific features [1].

1.1. Multidevice Environment. As a device, we define all the devices which are able to connect to network, that is, to the internet resources using an online or offline mode. The multidevice environment from single person point of view naturally underlines future realistic scenario where user would own or have to manage more than one device. We acknowledge multivendor environment and multiplatform environment as Android [2], iOS, Mango, and so forth. Every common user has currently at least more than one device which would be as an interface to cyberspace or which would be an extension to visualization of electronic world. The scenario would be about connectivity to cyberspace where user prefers conventional way more and more. The basic idea of the multiple-device management is based on simplify user friendly environment, where the same User Interface (UI) is presented for different devices or types of devices from multiple vendors or manufactures. What could happen when user reclaims the same type of device interface; for instance, mobile phones, where the same functionality and content exist? The user has to know as many device

interfaces as possible many types of platforms exist. What if there exists one customizable device interface which accesses the most common features of different devices. Is that a good experience in evaluation of human productivity? What if user could be independent on platforms and type of devices and in case of device crash or device lost, it could be easily recovered by one button click? Even more when user realizes that there is a possibility to manipulate content of different devices which is accessible from single interface. Of course it is all about capability of devices which could in the future lead more and more to massive usage of smart solutions and could make mobile device as natural connection between human and groups of devices (e.g., car, fridge, or boat).

1.2. Mobile Device Apple Platform. The Apple platform provides for developers fundamental and well-prepared design support with framework named COCOA, which is basically using Object-C as programming language. There are other extensions from point of developer view where Java or other scripting languages could be used. The mobile devices are used as operation systems the iOS and the most convenient way for developing an application is at using common system calls as application interfaces, application services, and core services [3]. The advantages of the Apple platform are basically comprehensive, publishable, and distributive application channels over Internet.

Another plus of this platform architecture [4] is one-vendor device based on a solution where the certainty of proper system calls and their behaviour is well defined and supported. As well as device hardware access in terms of mobile device development the screen resolution where as ratio between height and width constantly 5:3 could be announced another beneficial aspect in Rapid Application Development (RAD). Apple platform establish fundamentals of mobile application ecosystem environment. The increase of usability of mobile device is enormous. Identity of application is consisting of small image and short-term expression with remote update framework possibility known as an application market.

1.3. Mobile Device Android Platform. The mobile platform as Android is due to self-interopen ability suitable for the 3rd party solutions where partial problems are solved [5]. The security and stability of the system which is based on an Open Source concept is outstanding [6]. A device types which are currently running under Android platform are well-known for smartphones and tablets but also for other device types [7] due to suitability of platform design for, instance laptop, netbooks, smart books, e-book readers, smart TVs, wristwatches, headphones, car players, smart glasses, vehicle navigating systems, refrigerators, home automation systems, games consoles, mirrors, cameras, or portable media players. The architecture of Java-based platform fully provides multi-threading environment where gathering of precise data form sensors are required. The architecture [8] allows services which are running on background as a provider or as a consumer of external services [9].

2. Problem Definition of Remote Device Management

In this chapter we summarized problematic areas in device management in consideration of possible remote use. We focused on cross-device features which are mainly based upon the management that provides measurement, controlling, and maintenance over sensors or content of device. Other point of view would consider the platform aspects which are supportive to some key benefits in the Remote Device Management (RDM). At last the focus would consider the network access and its capabilities in terms of usability and sustainable processing. For better overview we outline ideas expressed in the mind map on the following figure (Figure 1) which are described in more details below in this chapter.

The aim of Remote Device Management is about to provide consistent cloud service where key benefits are open framework accessibility with simple to use Application Program Interface (API), social connectivity, content consistency, and security policies. Let starts with identity connector (Figure 1) problematic which is bound by correct user identification over native account provided and where all user data are mounted on.

2.1. Identity Problematic. The identity is nowadays spread over web application mostly and therefore we include into account the main of them which are divided into Social Networks, Emails, Mobile, and Desktop devices identity providers. The Social Networks are considered only the main ones such as Facebook, G+, Twitter, and LinkedIn. The identity from most of them is provided over inner-defined application which after user authorization by Open Access (OAuth 2.0) process acquired user permission on specific tasks and is able to process user's information and establish secure 3rd side authentication for login session. The other way of user identification used world widely is email authorization where over the provided user email in registration process is authorization link sent and after user activation we assume the email is correct as communication channel or current browser is authorized for login session temporary or permanently. Another case is about mobile devices where the authorization channels are SMS, Voice Call, or Native Application. The identity acquired is Mobile Number or Device Identity where each provides authorized secure channel. The last one case is desktop which uses for access browser or native client in terms of specific platform (iOS, Windows, Linux), and where user identity is acquired over registration process with or without any parts mentioned before.

2.2. Content Problematic. The core feature of Remote Device Management is multiply, sync, or backup content over different types of devices. Content is any kind of information related to user and in terms of device management, we consider content as an end-user data which are important to keep safe on devices due to daily usage even in offline mode of the device connectivity and also accessible from

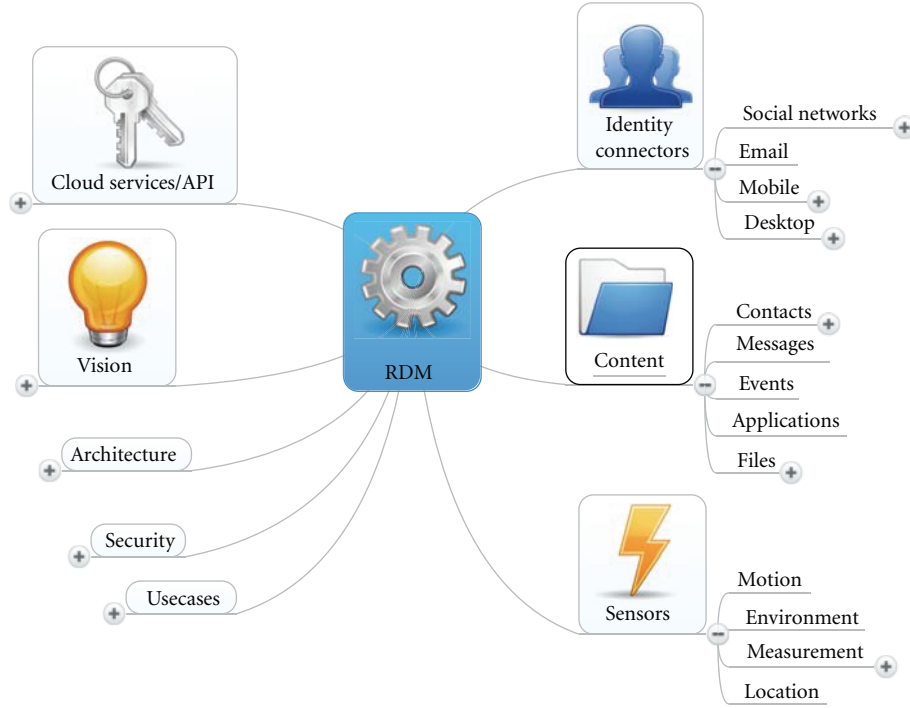


FIGURE 1: Mind map-Remote Device Management.

different mobile or desktop devices. As representative types of user content we recognized Contacts, Messages, Events, Applications, and Files. These kinds of content would be smart distributed and synchronized over user owned devices or be backed up automatically in terms of lost or broke accident. Management of content would be more convenient on desktop device rather than small screen mobile device. On the other hand in time or in location tasks are required event from nonconforming user interfaces for specific tasks of content management. Contacts are very specific content which requires correct personal identification and actual communication channels availability resolving therefore supportive part is Social Networks, Email Contacts and Phone Contact list in terms of distributive social knowledge. Messages are consists of SMS, Voice mail or IMs which provides open access to 3rd sides. Also the problematic is mounted by personal identification based on contacts. Events represents all activity provided by device or user action. Applications are content which in mobile point of view is mostly provided over platforms dedicated applications web or desktop (iTunes-iOS, Play-Android, MarketPlace-Windows Phone) therefore at least the list of application resources with time spent monitoring is considerable for sync. The last one kind of content we assume as files where the requirements are limited to amount of date and share purposes. The file content is achieved by implemented Camcorder, Camera, Microphone, or Universal Serial Bus (USB) for other types file content. The main reason for defined file content is to share further postprocessing on desktop.

2.3. Sensor Problematic. As the sensors we define all measurable informational providers of devices which are accessible and are enabled for gathering motion or environment data such as wireless signals, sensorial data, or long-term indicators. There are more types of sensors and therefore we divide them into Motional, Environmental, and Locational-based sensors [1, 10–12]. The motional types are connected to movements of device or its position in space for instance Accelerometer, Magnetic field, or Gyroscope sensor (Table 1).

The environmental types are associated with conditions of current location such as pressure or temperature and also knowledge-based measurable information which are gathered over long-term time period where for instance the home environment is recognizable as the most occupied place of device where the sleeping time of user is recognized by motion or microphone sensor inactivity [13, 14].

And the location-based sensors we consider as Global Positioning System (GPS) sensor, Global System for Mobile communication (GSM) signal sensor, or Wireless Local Area Networks (WLAN) signal receiver which in cooperation establish precise measurement of device location accordingly to energy efficiency. The way of gathering sensor data is over allowed platform system calls where access is authorized by an end-user or by device management provided for platform or by overriding manufactured firmware within dedicated customized distribution of opened platforms which would be available as an Open Source. We are focusing on allowed 3rd party sensor access which is available through framework API, for example, in Android (Table 1).

TABLE 1: Android sensors [18] for smart and ambient environments—overview.

Type	Functionality
Accelerometer	Sensor calculate acceleration without gravity acceleration $g = 9.81 \text{ m/s}^2$ as following equation: $Ad = -g - \sum F/\text{mass}$ The reason is user centric-suspected behaviour for an end-user where device in a stable position placed on the table should have acceleration 0 instead of +9.81
Ambient temperature	Ambient (room) temperature in degree Celsius
Gravity	A three-dimensional vector indicating the direction and magnitude of gravity. Units are m/s^2 . The coordinate system is the same as is used by the acceleration sensor
Gyroscope	Values are in radians/second and measure the rate of rotation around the device's local X-, Y-, and Z-axis
Light	Ambient light level in SI lux units
Linear acceleration	A three-dimensional vector indicating acceleration along each device axis, not including gravity. All values have units of m/s^2 . The coordinate system is the same as is used by the acceleration sensor The output of the accelerometer, gravity and linear-acceleration sensors must obey the following relation: $\text{acceleration} = \text{gravity} + \text{linear-acceleration}$
Magnetic field	Values are in micro-Tesla (uT) and measure the ambient magnetic field in the X-, Y-, and Z-axis
Orientation	All values are angles in degrees
Pressure	Atmospheric pressure in hPa (millibar)
Proximity	Proximity sensor distance measured in centimeters
Relative humidity	Relative ambient air humidity in percent
Rotation vector	The rotation vector represents the orientation of the device as a combination of an angle and an axis, in which the device has rotated through an angle θ around an axis $\langle x, y, z \rangle$

The measurement requires at least separate thread to perform precise measured result therefore architecture suites to producer and consumer concept. In case of remote consumer the results would not be influenced by dilation of time of transport or transaction. With consideration of network latency the result would be notified or expected in correct time form. We recognized two groups of sensors where one of them is real-time changed and the other one consists of state long-time sensor changes.

The following article [15], where the domain of sensors data gathering is well defined, was considered as contributory for our solution design. The informational system as extension would provide user status resolution over sets of gathered sensor data, where sleeping, sitting, running, walking, or driving have informational value in current context point of view. Also the environment context is valuable in terms of user productivity for instance vacation, work, or distance movement.

2.4. Universal Platform Approach. The most significant aspect which influences usability of mobile devices is platform based solution. All positive and negative user experience leads to platform evolution where useless platforms are terminated. Therefore platform survival depends on scalability and open mind accessibility where openness to new solutions and approach both technical and future ideas predetermine the platform success. The accesses to device features as well as technical capabilities which are not user invasive are essential to be included in our universal solution where native client on device is realized as connector between user and platform.

3. Solution Design Concept

This paper describes solution concept of remote device management focused mainly on server side architecture. Designed concept is variable in terms of technology use case. We suppose to use as development framework all Java based technology because of effectiveness in productivity, scalability and reuse of available Open Source components. The following figure (Figure 2) highlights important parts of architecture which are required for specific needs especially from network connectivity characteristics [16]. The informational system consists of three main parts which are remote client part, core system part and end-user interface part. We start to describe remote part where all possible devices potentially could be connected to the system. The devices are highly fragmented hardware area due to competition of manufactures and vendors about end-user's goodwill. We recognize basically two sets of devices from system point of view.

The first contains all mobile devices which have to care about power supply management and without power-saving management the unnecessarily draining battery would lead to uselessness of developed application. The second group of devices is an independent of power supply where for instance we classify cars because of their external power supply. For these reasons each group would behave differently in terms of kind of connectivity mode. The devices which could be connected to the system over any kind of network and could provide peer-peer internet connectivity instantly or for exact amount of time we called as active devices. The others we called as passive where which would not be all time online or connected to a dedicated server. The passive mode would respect user's defined network connectivity due to cost effectiveness or power management. Next figure

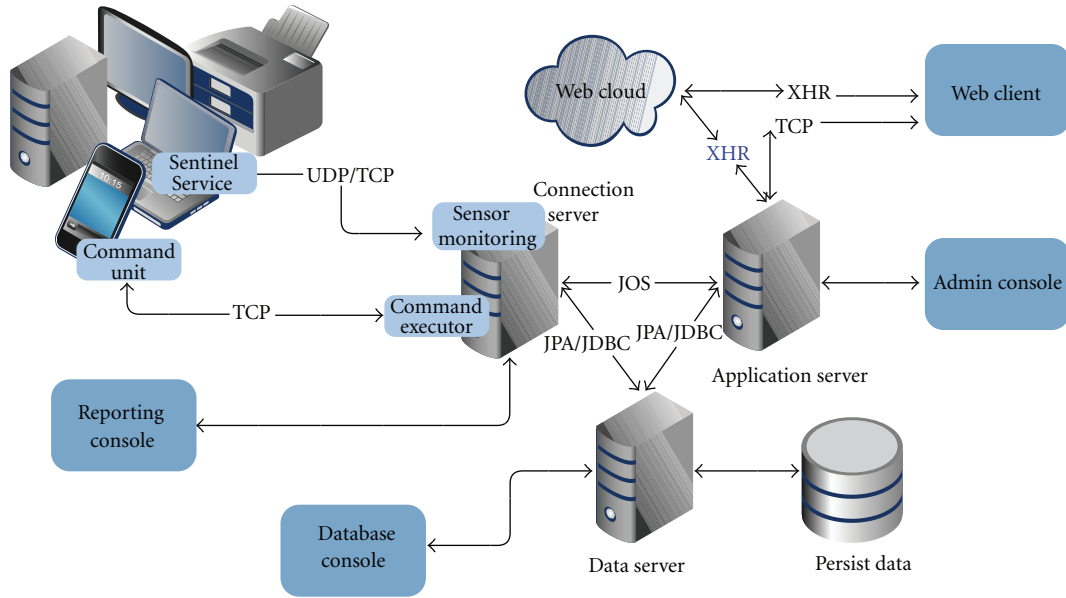


FIGURE 2: System architecture-Remote Device Management (using gliffy UML).

(see Table 2) overviewed connectivity of devices and their statuses according to an active or passive device policy.

Explicitly defined states of connectivity would not get rid of some cases where the uncertain behaviour of network connectivity could appear. The problem would be eliminated by control queuing management based on messages. The messages of events and data would be handled on a client side as well as on a server side in correct time frame. In case of network unavailability the queue substitute consumer and when network status changed and reconnects the message queue processed all First In First Out (FIFO) messages in time order. The sentinel measurement data which are with low level importance and are not supposed for real-time processing are lastly consumed. From technical point of view the messages are sent from client to server by User Datagram Protocol (UDP) in such low level importance cases and where high measurement precision is not required but is preferred speed of delivery or amount of transmitted data. Otherwise the Transport Control Protocol (TCP) is used for confident types of measurement or data delivery of content [17]. The connection server consists of datagram resolver and socket transport object resolver where socket resolver due to usage with sensor monitoring and also with command executor is practically core functionality of connection server. The socket resolver either being client or server is providing communication between device and system. The main responsibilities are maintenance of connection and transportation of data objects between both sides. Objects are transported over serialization Java technology where content is fast serialized or de-serialize on binary code and sent over network.

The second part called as system part basically handles core features of informational system from device monitoring, device command execution and device management with predefined device or user policies up to the system

external data storing, system content providing, and system authorized access ability for all kinds of requests from front or background processing. Also as a connection server we would use Java programming language for implementation due to object interserver exchange. The application server and client application service decides what and when would be transported. Device execution commands are initiated also by application server where are authorizations of requests dispatched from an end-user actions or device routines with associated permissions. Application server is responsible for all other types of requests from the device or the end-user. The calls consist of group with data visualization calls, group of background routine calls based on the time triggering settings and maintenance group or administration group of calls. All calls are related to specific tasks or concrete device or group of devices therefore also security and authorizations are part of responsibility of application server. Last component is data management of informational system based on Java Persistence Application Programming Interface (JPA) technology which is being used due to extraordinary developing capability and time development saving. The data objects are defined in Java classes and relations between entities are expressed as a member of concrete class with specific annotation which specific cardinality and type of relation. The objects are transformed to database though persistent commands and after the commitment are saved to hard file on disk.

The last part of the system is focused on web content delivery and interactions with an end-user. The web content is hosted on external web server as a cloud solution where the user identity and cloud services could be used. The web client is connected to the web cloud services either to the application server over secure channel. Web cloud is used due to implicit network traffic monitoring tool and cost-effective load balancing for web clients with minimal

TABLE 2: Table of connection modes.

Device mode	Connectivity/status	Initiator	Purpose
Active	Persistent/live	Server	After client registration server establishes peer-peer connection for live command requests channel triggered by web user interface Client sentinels could send event change statuses
Active	Interval/command routine	Server/client	In defined interval on server side based on configuration or policy system connects and performs commands on background Client sends interval defined sentinel updates
Active	Zero-base/online	Server	Heart beat protocol for devices in active mode to maintain stable persistent connection
Active/Passive	Session/online	Server/client	Requested commands related to established session by web user interface where in passive mode explicit authorization is required Registration request of client with meta data for system connection Batch updates of sentinels in passive mode
Active/Passive	Not available/offline	Server/client	Connection with client or server is lost or could not be established. Data or tasks are queuing and waiting for the connection to be established

impact on the maintenance. Web cloud is basically used as secured fast traffic response container for web client which mainly communicates with application server in global world scale where continental redistribution is a case. Web client itself implements data visualization and requests posting and corresponding response handling. The client is based on HyperText Markup Language (HTML) version 5 and JavaScript (JS) concept. Communication with an application server is performed over Transmission Control Protocol (TCP) by Web Socket technology due to convenient and fast responsive way in comparisons to classical Asynchronous JavaScript and Xml (AJAX) technology. The Web Socket technology provides persist communication channel over a well-known port 80 with advantages of socket connectivity. Therefore the reaction time of committed commands in live online mode increases usability of the entire system where round trip time (RTT) to server is multiple times faster than common Xml Http Request (XHR) for short messages.

4. Conclusions

Over the current multiple device environmental interfaces and subsidized functionality we would decrease human time spent with maintenance of an authorized, owned or public group of devices in terms of content, settings, policy or gathering sensor information and to increase human productivity accordingly to comprehensive user's interface for multiple devices and within comfortable working space. The fragmentation of devices is more increasing in time due to the technological innovations and therefore Remote Content Device Management would be convenient also for nongEEK personalities. The advantages of proposed system concept are single user interface customizable by user-centric behaviour undependable on platforms or vendors settings and recovery optionality over uniform or nonuniform devices with a user synchronized content delivery.

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Research Article

Real-Time Communications in Autonomic Networks: System Implementation and Performance Evaluation

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This paper describes the design and prototype implementation of a communication platform aiming to provide voice and video communication in a distributed networking environment. Performance considerations and network characteristics have also been taken into account in order to provide the set of properties dictated by the sensitive nature and the real-time characteristics of the targeted application scenarios. The proposed system has been evaluated both by experimental means as well as subjective tests taken by an extensive number of users. The results show that the proposed platform operates seamlessly in two hops, while in the four hops scenario, audio and video are delivered with marginal distortion. The conducted survey indicates that the user experience in terms of Quality of Service has obtained higher scores in the scenario with the two hops.

1. Introduction

Mobile ad hoc networks have received particular attention the last years due to the wide range of applications such as real-time communications including video apart from voice where existing telecommunication infrastructure may fail. The introduction of low-cost wireless technologies and the standardization efforts of the IETF MANET Working Group have been generating renewed interest in research and development of MANETs outside the military field. The advent of new products in both hardware and software has eliminated many of the barriers of the past, enabling the development of integrated platforms providing a wide spectrum of services.

In this dynamic and distributed environment it is important to deploy multimedia application and services. This necessitates the deployment of P2P Voice and Video in a large scale, since many users become aware of the abilities of these newly developed architectures and migrate to them. Wireless multihop networks often show great potential, due to some characteristics such as node mobility and extended packet-forwarding ability [1]. Simply applying current peer-to-peer overlay techniques to MANETs is rather undesirable due to node mobility, energy consumption, and lack of

infrastructure. Always keeping in mind that the overlay technology needs for power consumption and response time reasons to reflect the underlined physical network topology, wired network control schemes are unable to accommodate a constantly changing peer group where nodes constantly join and quit. An additional issue in the overall idea of this network architecture is peer cooperation. As shown in [2], most topology control algorithms assume that peers are cooperative, which is simply not the case. Peers are always trying to minimize their own costs such as the number of necessary communication links or the distance to other peers. Several studies [3] investigate the selfish peer impact on topology unfortunately in a rather theoretical approach where peers have global knowledge that is considered fundamental for overlay construction. Due to lack of a practical overlay topology control algorithm other means need to be established. Since traditional approaches tend to show decreased performance, peer-to-peer services in MANETs might need a fresh new design which would enable better results. It is certainly not a coincidence that even network operators are searching methods of using these novel applications in terms of profit [4]. Alas, the main issue in those topologies is no other than network capacity. A performance evaluation presented in [5] shows the influence of intra and

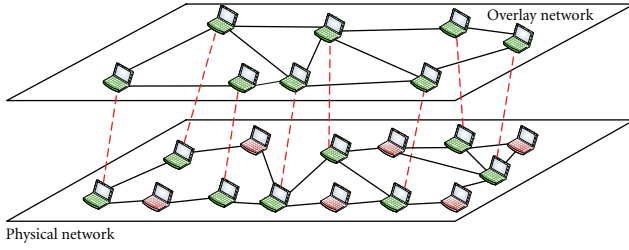


FIGURE 1: Diagram of an unstructured peer-to-peer overlay, green nodes participating in the overlay network.

interflow interference in channel utilization, which directly impacts the VoIP capacity. In more controlled environments such problems are not that obvious or additional components such as wireless mesh routers [6] could be an effective solution. Nevertheless, current P2P searching and routing arithmetic do not meet the requirement for extremely low time delay real-time multimedia application demand [7] so other network and parameters are to be examined. Figure 1 presents an example of an unstructured peer-to-peer overlay in comparison with the overall nodes participating in the physical network.

In this paper we describe the design and prototype implementation of a communication platform aiming to provide voice and video communication in a distributed networking environment. Performance considerations and network characteristics have been taken into account in order to provide the set of properties dictated by the emergency and sensitive nature of the targeted application scenarios. The proposed system has been evaluated both by experimental means as well as subjective tests means. The results show that the proposed platform operates seamlessly in two hops, while in the four hops scenario, audio and video are delivered with marginal distortion. The conducted survey indicates that the user experience in terms of Quality of Service obtained higher scores in the scenario with the two hops.

The rest of the paper is organized as follows. In Section 2 we present the basic system architecture, while in Section 3 we present the results regarding the objective performance evaluation and the subjective survey-based user rating of the platform. Finally, Section 4 concludes our paper.

2. System Architecture

2.1. Network Organisation. A primary decision that needs to be made in defining the proposed communication platform is the type of underlying network organization. The autonomous nature of the network, where each node operates in a standalone fashion, is matched by several network organization paradigms, namely, peer-to-peer networks, mobile ad hoc networks, and so forth.

Given that the application focus of the proposed communication platform is on real-time multimedia provisioning, a set of basic properties of the underlying network organization needs to be met. To begin with, ease of deployment is necessary so that the network is quickly set up in a straightforward manner. Depending on the conditions on

the deployment area, the network topology should be formed using simple procedures without requiring much computational or communicational effort. Furthermore, the decisions made about the construction and the operation of the network should be distributed across the network nodes, thus avoiding single (or a limited set of) point of failure. Resiliency in order to overcome potential failures of nodes is another requisite of the underlying network.

By definition, mobile ad hoc networks (MANETs) satisfy all the aforementioned properties. MANETs consist of wireless network devices that operate without any kind of centralized control or fixed communication infrastructure. Each network node operates not only as a host but also as a router forwarding packets to other nodes, which may not be within direct transmission range to each other. Therefore, each packet is transmitted to its destination in a multihop manner. The autonomous nature of MANETs fits the required properties of the real-time multimedia provisioning, while in the same time posing interesting challenges in defining efficient protocols in this direction.

2.2. Peer-to-Peer MANETs. In order to efficiently provide real-time multimedia transmission over MANETs, some notions of the formation and operation of peer-to-peer (p2p) networks are employed. Such networks are constructed based on an overlay network topology that is formed on top of the actual (physical) network topology and dictates the way the network peers are logically connected between each other.

Generally, three classes of peer-to-peer overlay networks related to the structure of the topology create structured, unstructured, and hybrid peer-to-peer architectures. In structured overlays, the architecture is controlled in an organized manner with content distributed at specific locations across the network to increase the efficiency of lookup queries. In unstructured overlays, the network is organized randomly in either a flat or hierarchical manner and execute queries using flooding, random walks, or expanding-ring Time To Live (TTL) techniques. Each peer receiving the query will initiate the search on its own local content which allows the execution of more complex queries. Finally, in hybrid peer-to-peer architectures, queries are handled by a central server which contains a database of content and its location within the overlay network, peers lookup the content on the main server then connect to the peer containing the specific content using the overlay. Peers are responsible for contacting the main server with the information on which resources and content they wish to share, making them an unfavorable solution on MANETs due to the single point of failure.

In order to setup, maintain and tear down multimedia sessions between network nodes, clearly define procedures for establishing, using, and terminating a logical connection between the terminal nodes. These procedures are part of a signaling protocol that in the proposed communication platform is based on the P2PSIP protocol [8]. P2PSIP is a peer-to-peer approach of the Session Initiation Protocol (SIP) [9] communication protocol that enables solutions for distributed storage of user information such as registration

info along with logical position within the overlay and then handles all possible user queries leading to real-time communication session establishment. The most essential component of P2PSIP architecture is no other than the Distributed Hash Table (DHT). Its distributed nature originates on the fact that it is divided into several parts each located inside an overlay peer and stores the physical addresses of all participating nodes in order to use them for resource availability lookup. Each node that receives a query for the address of a certain node searches its DHT fraction and if it contains the requested info, it returns it to the node that posted the query, otherwise it forwards the request to its logical neighbors [10].

2.3. Routing Protocols. Due to the multihop nature of the packet forwarding in MANETs, routing is a primordial task directly affecting their performance. Therefore, efficient routing mechanisms are integral to a communication platform providing real-time multimedia in this context.

Designing a routing protocol for MANETs has been a very active research field in the recent years. The challenges that must be met are both numerous and diverse. The frequently changing topology is among the basic factors that must be taken into account, since the routes calculated at every time instance are subject to repeated change. Another priority is energy conservation, since, in the general case, the lack of fixed infrastructure means that energy recharging in network nodes is very difficult or costly, if not impossible. Furthermore, attention should be paid so as to evenly distribute the traffic across the network.

Traditionally, the basic categorization of routing protocols in MANETs is made based on whether their operation is proactive or reactive (on-demand). A protocol is defined as proactive when the routes from every node to everyone else are calculated and updated in a periodic fashion, while in the on-demand case a route is obtained only upon request from a packet. Both categories have advantages and disadvantages. Depending on the special characteristics of the network deployment setting, each of the aforementioned types of routing protocols may be suitable. Typical representatives of the proactive protocols are DSDV [11] and OLSR [12], while DSR [13] and AODV [14] are classic examples of on-demand protocols.

In the proposed communication platform a hybrid routing protocol is employed, ChaMeLeon (CML) [15]. The main concept of CML is the adaptability of its routing mechanisms according to the changes in the network topology. More specifically, it consists of 3 phases of operation, namely proactive, oscillation, and reactive. The basic criterion for the operation type selection is the network size. In relatively small networks, routing is implemented in a proactive fashion using the OLSR protocol, whereas when the number of nodes grows larger, CML utilizes the reactive Ad hoc On-Demand Distance Vector (AODV) [14].

2.4. Architecture Design. While attempting to implement a certain prototype that takes under consideration the latest trends in all aforementioned signaling, architecture, and routing protocols there were certain issues to be addressed

mostly regarding the actual communication scheme amongst all participating entities. For being totally clear prior to the implementation the signaling diagram presented in Figure 2 was introduced.

There are five individual entities in this signaling diagram, the Joining Node (JN) which tries to access the overlay for the first time, the Initial Overlay Node (ION) which acts as the point of entry of the JN, the Bootstrap Node (BN) which operates as the key entity when it comes to DHT and overlay access and update, the Intermediate Node (IN) which plays the role of the packet carrier in the communication process and last but not least the Destination Node (DN) with whom the JN tries to establish communication in the first place. Normally, between the JN and DN there are several peers acting as IN thus facilitating communication. In all the tested scenarios described in the following paragraphs, more than one intermediate node is present. Nevertheless, for simplicity reasons for this particular diagram only one hop in the overall communication process between JN and DN is illustrated.

The joining peer first initiates a neighbor discovery mechanism in order to detect if there is someone within its communication range. JP broadcasts a HELLO message that is identified by every peer already connected to the overlay and receives an ACK HELLO message as response. Then JP transmits a JOIN Request to the ACK HELLO message sender, which in this particular case is the ION. After receiving the JOIN Request, ION forwards it towards the Bootstrap Node. BN then issues a JOIN Response towards the JN along with a STORE Request containing the public keys of JNs' logical neighbors, while JN confirms the successful reception of the later with a STORE Response message. Bootstrap then issues UPDATE Requests towards both JN and its logical neighbors (in the particular case the IN) informing them that they are connected to each other, in a message that contains the local view of the JP for the overlay. Finally, BN asks for overlay join confirmation by the JN receiving a 200 OK message in response.

Communication between JN and DN will include video and sound over IP network. Therefore after the software described in Section 2.5 becomes operational, JN sends a request regarding Videoconference (VC) initiation. The particular request is being forwarded through IN to the DN in a single-hop path which will be used for all signal and packet transfer for the whole session. DN responses also travel through the particular single-hop path. After JN receives the 200 OK message to its VC request the actual call begins. Through the monitoring software, the whole call was identified as UDP packet traffic, a common method used in all VoIP and real-time communication schemes. After the conclusion of the call JN sends a Termination request and the overall process finishes through a 200 OK message from the DN.

2.5. Extended WengoPhone Prototype Implementation. A prototype implementation was a matter of utmost importance for the necessary proof of concept of the solution we propose in this paper regarding real-time multimedia communication over ad hoc networks. With voice and

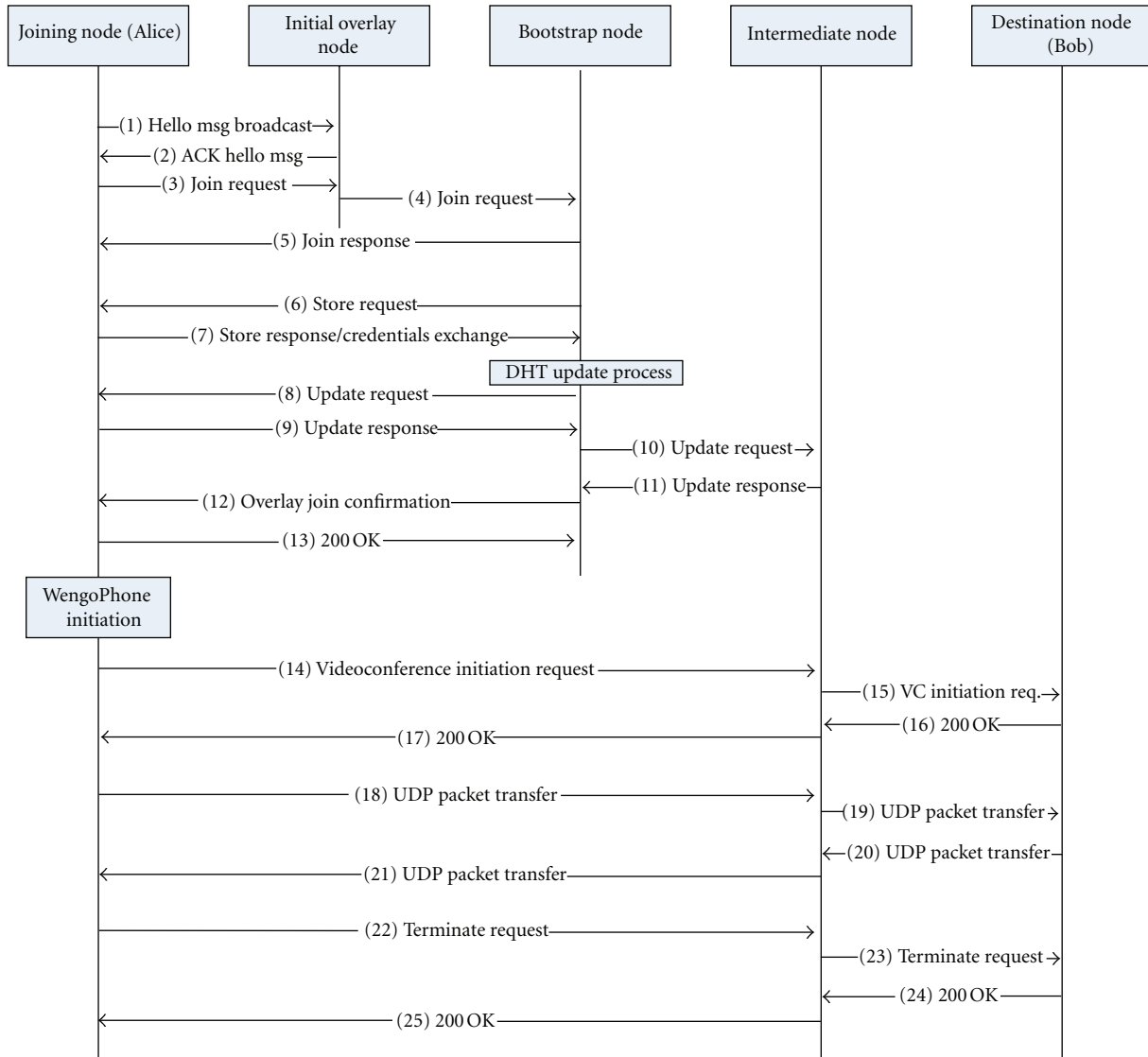


FIGURE 2: Join and single-hop communication signaling diagram.

video being the two most fundamental elements of human interaction, the prototype was designed in such a way that endorses both attributes in a seamless binding. Voice is integrated by the VoIP capability, the platform included and the additional feature of videoconference support were added to further improve Quality of Service and user experience. The implemented software utilized libraries and repositories of a certain project called WengoPhone [16], a SIP compliant VoIP client developed under the GNU General Public Licence (GPL). In addition, we extended the provided features of the software by developing tools that initiate a mobile device's web camera, capture video, and encode it using the H.263 video compression algorithm [17]. This algorithm is considered to be optimized for video transmission over wireless networks and also published under open source licence, unlike its successors that have many patent limitations blocking us from exploiting all their attributes. The latest version of WengoPhone with the new

enabled features has a redesigned Graphical User Interface (GUI) that is shown in Figure 3.

Providing that video quality is a key feature, we decided to include several quality levels that can be accessed instantly by a menu located in the bottom of the graphical interface presented in the previous figure. The new window for video settings is shown in the previous picture. After setting all attributes in order according user's preferences along with wireless network's capabilities, a video call is performed as shown in Figure 4.

The application was developed using Microsoft Visual Studio 2005 and was tested on three different Asus EEEPCs having the following specifications: Atom CPU running at 1.6 Ghz, 1 Gb RAM, 160 Gb HDD, and Windows 7 Professional Edition, each representing a mobile device of an extreme emergency communication scenario. For the GUI, Qt, a cross-platform application framework was used by installing a certain widget toolkit, since several alterations

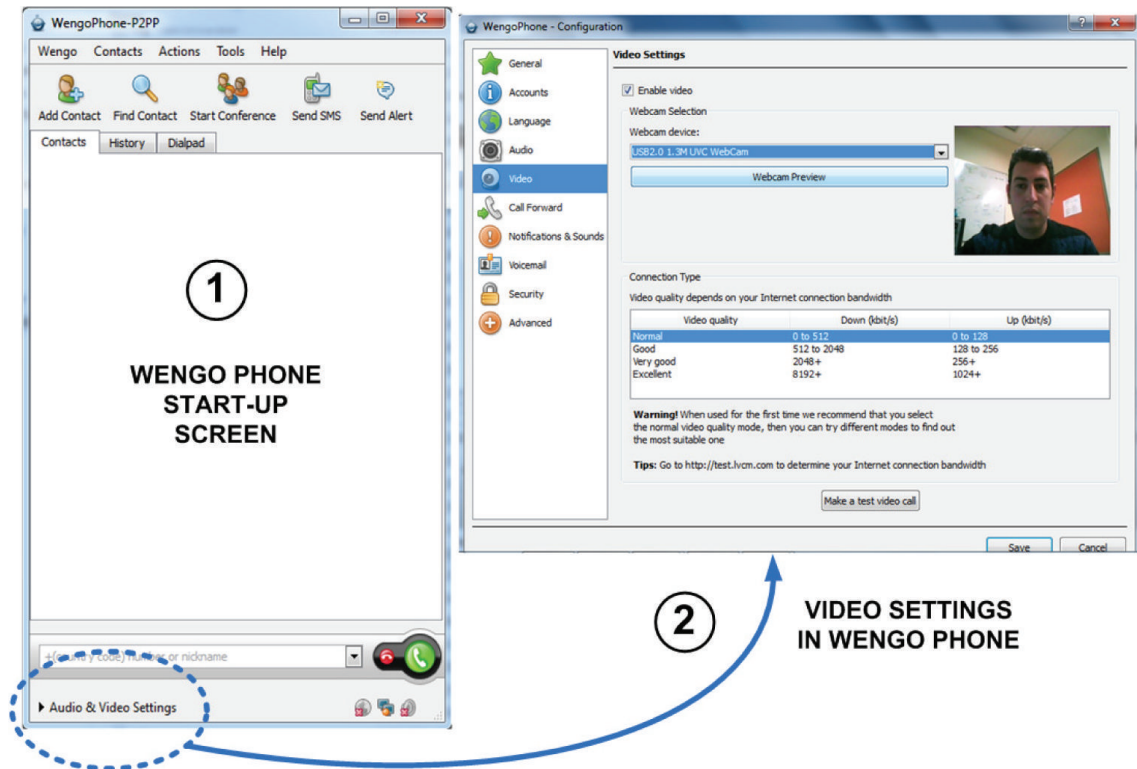


FIGURE 3: WengoPhone startup screen and video settings.



FIGURE 4: Video call on WengoPhone software.

were considered necessary in terms of user friendliness, for providing direct access to the new features. No external video camera or wireless card was used apart those provided by the EEEPCs, a 1.3 Megapixel Logitech Camera and an Atheros 802.11 g/n compatible interface. A major concern during Wengo Phone extensions development was how to abandon the monolithic architecture the previous version had and move towards a more flexible platform that would make future changes and code upgrades easier. We manage to achieve this goal by keeping the H.263 algorithm

implementation relatively modular, avoid to temper with preexisting pieces of code when possible, apart in case that this was absolutely necessary.

3. Results

The software prototype described in a previous paragraph requires a whole testbed for extended evaluation of the new abilities it supports. In particular six wireless nodes forming an ad hoc network were used in order to check

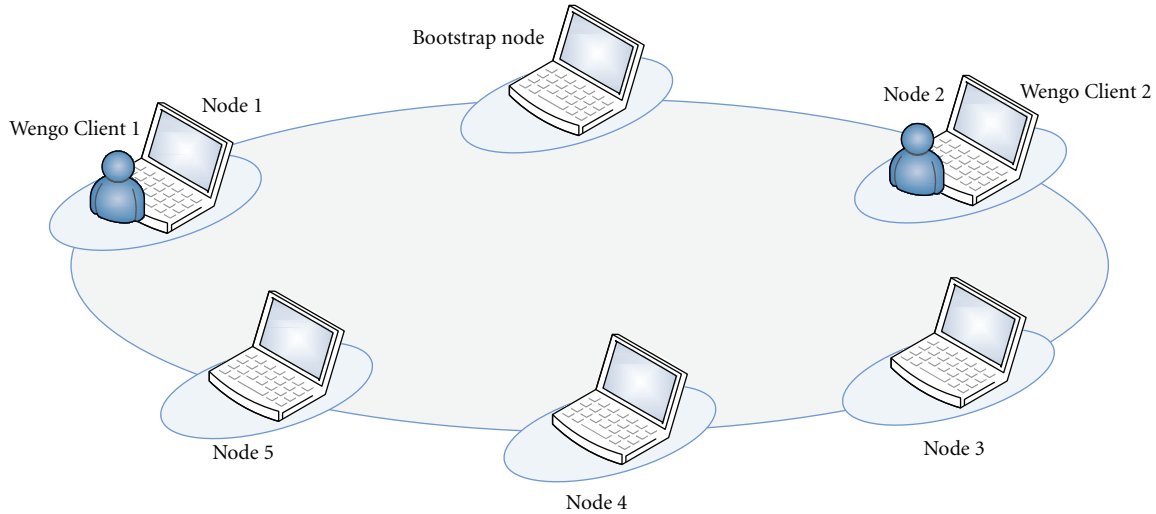


FIGURE 5: Testbed topology.

voice and video quality. In all our tests, although we expected that this relatively demanding platform would consume all available CPU and memory capacity of a low-range piece of equipment such as an EEEPC, CPU utilization never exceeded 40% and memory was constantly under 15% of its total capacity. The topology used for our tests is illustrated in Figure 5.

Only two out of six nodes had Wengo Phone software installed and they are depicted clearly in all pictures as WengoClient 1 and 2. Most nodes forming the necessary ad Hoc network use Windows 7 as their operating system, together with a compatible OLSR implementation for routing purposes. There is one exception the node that plays the role of the Bootstrap Node which is running Ubuntu Linux. Static IP addresses were given to all nodes in order to ensure that no interference from any foreign network will compromise the evaluation. OLSR and CML protocols were configured in such a way that a certain amount of hops between nodes to be established, according the two evaluation scenarios presented in the following section.

3.1. Evaluation Scenarios. For evaluating the performance of the implemented software, two scenarios were designed. Nodes 1 and 2 having Wengo Phone installed are trying to establish a call to each other. In order to achieve that call, they first have to join the overlay which is maintained by the Bootstrap Node. The main difference in these two scenarios is the actual routing configuration in OLSR and CML protocols. In the first scenario all IP packets involved in the call between Node 1 and Node 2 are being diverted through Node 3, achieving a total amount of two hops within the network overlay until they reach the destination node, Node 2 and 1, respectively. This is expected to keep the packet loss and the jitter relatively low thus providing a service as close to direct connection calls as possible. In the second scenario the OLSR and CML configuration has changed dramatically. Instead of a total of two hops, IP packets from Node 1 to Node 2 are being routed through all overlay nodes

which means a four-hop route. This extensive rerouting is likely to increase packet loss and jitter causing issues in video quality due to image distortion. In order to have a more complete estimation regarding the performance of our software implementation in terms of video delivery under all conditions, two sets of measurements per scenario were taken. During the first one, video quality was set to “Normal” requiring available bandwidth of 0–512 Kbit/sec for upload and 0–128 Kbit/s for download, while for the second the video quality was increased to “Very Good” requiring available bandwidth of 512–2048 Kbit/sec for upload and 128–256 Kbit/s for download, quite an increase compared to the previous scenario. For monitoring all traffic between nodes we used the Wireshark network analyser [18]. In both scenarios the actual length of each call was set to 120 sec, enough time frame for measuring all network characteristics.

3.2. Experimental Results. Real-time applications such as VoIP and Video conferencing platforms are extremely sensitive in terms of jitter and packet loss. Packet loss compromises voice and video quality since data flow from the source to the destination is interrupted instead of being a continuous event, time slot is expired and the communication becomes unbearable. System cannot have the luxury to wait for a retry as in other applications and users do not experience best possible Quality of Service. Jitter refers to undesired variation in packet receiving. If there is a traffic delay, data might be buffered accordingly but when this delay keeps accumulated, buffer can no longer sustain packet delivery and this could result in video distortion or jerkiness. When it comes to voice jitter it causes gaps in communication and problematic system behaviour in general.

We used Wireshark [18] network analyser in order to monitor and record traffic and packet exchange between nodes as shown in Figure 6. In both scenarios, Wireshark daemon was strategically placed so that traversal packet flow can be logged, thus creating a file for further analysis.

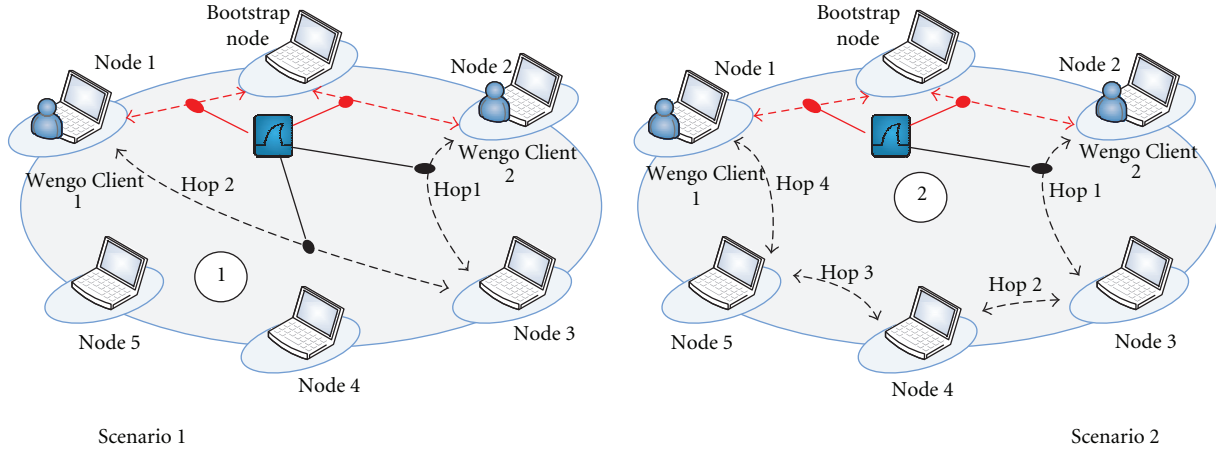


FIGURE 6: Evaluation scenarios.

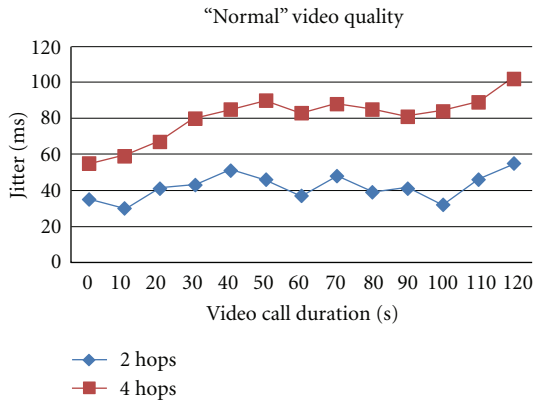


FIGURE 7: Jitter when video quality is set to “Normal”.

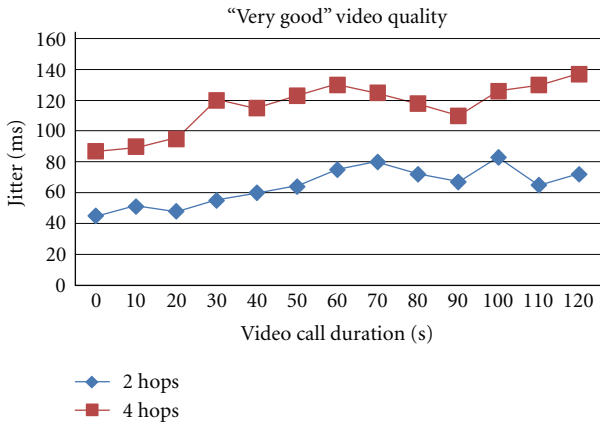


FIGURE 8: Jitter when video quality is set to “Very Good”.

Focusing on Jitter and Packet Loss we were able to compare the overall testbed behaviour, not only the improved version of WengoPhone we developed. Our analysis brought to light several interesting results regarding multihop topologies and how the hop number increase inevitably leads to voice and video quality deterioration.

Figure 7 presents jitter measured when a video-call session was established between Nodes 1 and 2 in each of the scenarios presented earlier. Video quality is set to “Normal” in both sessions making number of hops their only difference. In Scenario 1, when only two hops are needed for a UDP packet to cross the gap between source and destination, jitter never exceeded 60 ms in absolute numbers. On the other hand, in Scenario 2, with four hops between source and destination, jitter had an average value of 81 ms, significantly increased compared to the previous topology, yet acceptable.

We measured jitter again, this time after terminating all previous calls and restarting WengoPhone setting video quality of the established video-call session between Nodes 1 and 2 to “Very Good”. This time jitter values were generally increased due to higher traffic caused by packet increase in each topology. The results are shown in Figure 8, with jitter in Scenario 1 having a mean value of 64.3 ms while that of Scenario 2, with four hops end-to-end, rises well above 110 ms. A jitter value greater than 100 ms urges for buffer implementation, a temporary fix sometimes of no use in real-time applications.

In addition to jitter, Packet Loss was measured for all previously mentioned scenarios and video quality settings. The results are shown in Figures 9 and 10.

Typical numbers for acceptable packet loss during a videoconference system range from 0.1% to 1%. Video is less sensitive than voice. According to VoIP standards packet loss greater than 1% is likely to compromise the whole session, leading to several audio drop-outs [2]. This inevitably draws the conclusion that in the four-hop routing of Scenario 2 users might experience problems, since packet loss percentage rises to 1.03% after less than 120 sec of established audiovisual communication.

3.3. Subjective Evaluation. The International Telecommunication Union (ITU) has published several recommendations that intend to define standards for subjective assessment methods to be used in the one-way overall audiovisual quality evaluation. These methods can be used for several

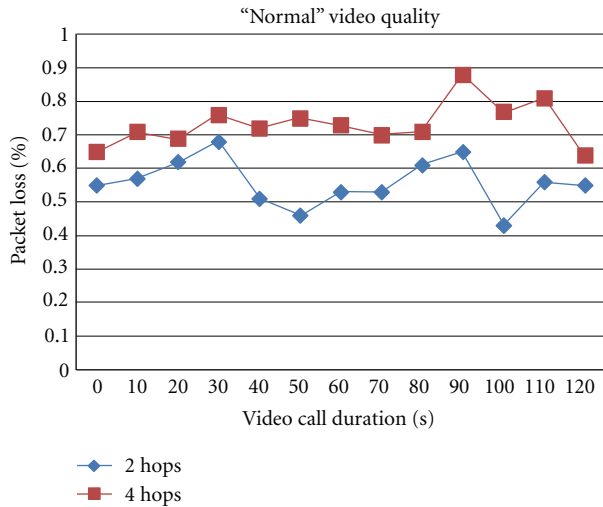


FIGURE 9: Packet loss when video quality is set to "Normal".

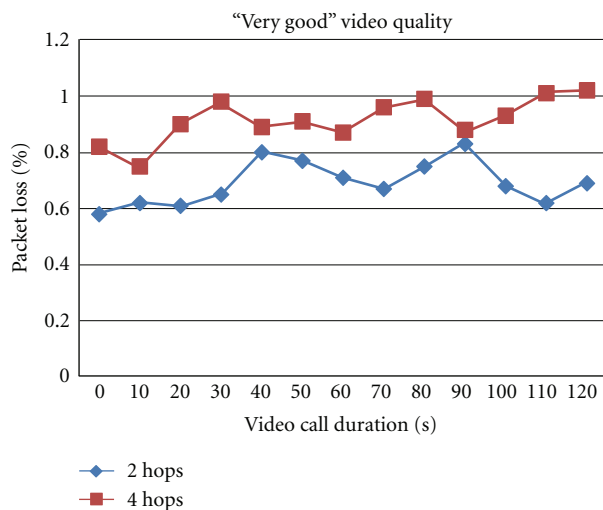


FIGURE 10: Packet loss when video quality is set to "Very Good".

different purposes, including but not limited to ranking of audiovisual system performance and evaluation of the quality level during an audiovisual connection. The most commonly used ITU Recommendation is P.911 [19], where several test methods and experimental design techniques are presented. Although a number of such methods have been validated for different purposes, the final choice of one of these methods for a particular application depends on various factors such as the context, the purpose, and where in the development process the test is to be performed. Out of all proposed methods described in [19] the most suitable for our evaluation seems to be the Absolute Category Rating (ACR). More information regarding this method as well as the numerical evaluating scale we used can be found in Appendix.

3.3.1. Subjects. The possible number of subjects in a viewing and listening test along with usability tests on terminals or

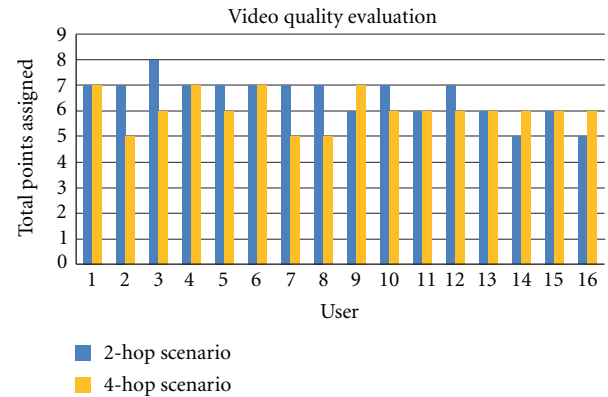


FIGURE 11: Video quality evaluation.

services varies from 6 to 40. Four is the absolute minimum for statistical reasons, while there is rarely any point in going beyond 40 [19]. The actual number in a specific test should really depend on the required validity and the need to generalize from a sample to a larger population. In general, at least 15 subjects should participate in the experiment. They should not be directly involved either in picture or audio quality evaluation as part of their work and should not be experienced assessors. Prior to the session the observers should usually be screened for normal color vision as well as normal or corrected-to-normal acuity. During our evaluation 32 individuals were divided in two groups. Each group participated in videoconference sessions in random pairs without knowing the total amount of intermediate hops packets were routed into, for not making them provide relatively biased overall experience evaluation.

After a videoconference session of 120 sec was concluded, subjects were given a form containing a set of four standardized questions for the aforementioned rating. These questions were as follows.

- (1) How would you rate the video quality of the connection?
- (2) How would you rate the audio quality of the connection?
- (3) How would you judge the effort needed to interrupt the other party?
- (4) How would you rate the overall audiovisual quality?

Answers for questions one, two, and four were given on the nine-level scale with greater numbers indicating more assigned points ergo proportional to user satisfaction. The third question was evaluated in a different way; since in a perfect video-call little effort would be sufficient for one participant to interrupting the other, points were assigned disproportional. More points indicate less effort therefore better user experience.

3.3.2. Subjective Evaluation Results. In Figure 11 the results of video quality evaluation are shown. A significant fact is that although video quality was set to "Normal" in both

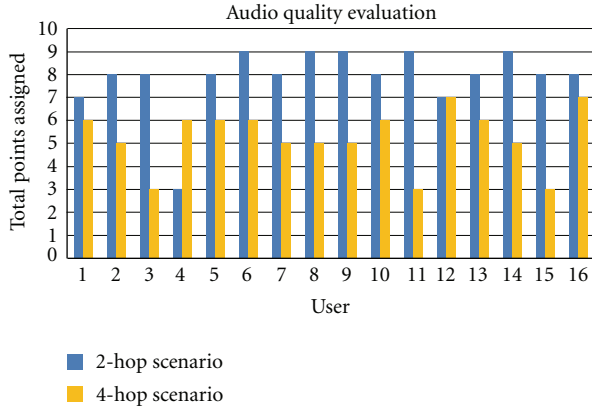


FIGURE 12: Audio quality evaluation.

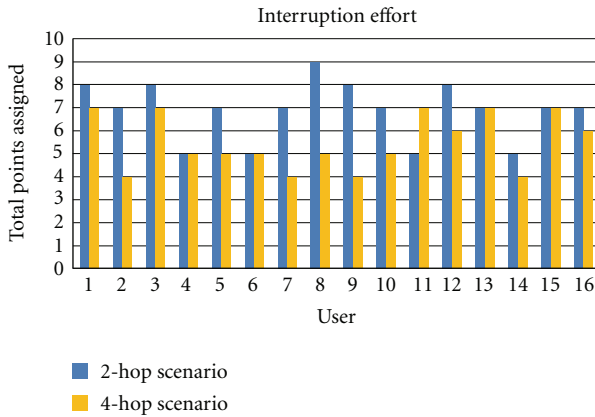


FIGURE 13: Interruption effort needed during video conference.

cases, there is little yet existing variation in user scores. This has a very profound explanation. Video quality in our testbed depends not only on the software prototype configuration but to the architecture and topology parameters as well. This means that video sessions of better quality that might reach to their destination distorted, delayed, or jerked due to jitter or latency is likely to satisfy users less than lower quality ones, scoring lower than expected. In our evaluation this seemed to be the case.

Audio quality evaluation results are shown in Figure 12. Once again network parameters seem to play a vital role to user satisfaction, since in almost all cases scenario with two hops leading to lower jitter and packet loss prevailed in user preferences.

In Figure 13 interruption effort results are depicted. Once again there is a slight user preference for the two-hop topology. This might be explained if we consider the fact that although video is involved in the conference, the most natural way of human communication is verbal and when this is compromised for instance due to jitter, subjects feel uncomfortable and assign points accordingly.

In Figure 14 overall audiovisual quality evaluation can be found. Scenario 1 once again overcame Scenario 2 in terms of user satisfaction proving that in video-conference

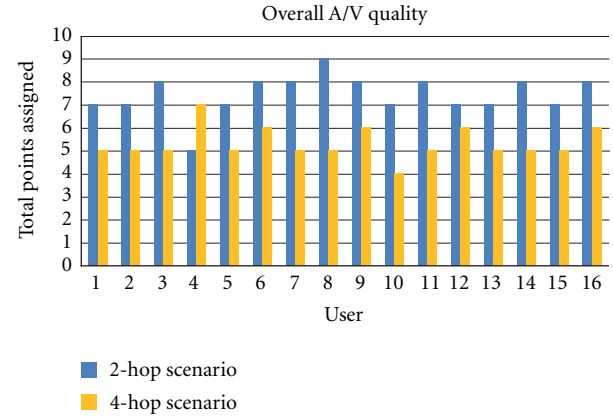


FIGURE 14: Overall audio/video quality evaluation.

applications as well as in all real-time communication platforms, network topologies having better jitter and packet loss ratings shall gain momentum over more complex but less effective ones.

4. Conclusions

The task of evaluating such a complex ad hoc network platform including a real-time communication prototype proved to be extremely challenging. Using all necessary software tools as well as modern industry standards we were able to perform both subjective and objective evaluation of our proposed solution. Two different scenarios were designed, based on network characteristics as well as prototype restrictions. In the first one packet routing was delivered in a total of two hops end-to-end, while in the second one a total of four hops was introduced. The results show that the proposed platform operates seamlessly in two hops, while in the four hops scenario, audio and video are delivered with marginal distortion. The conducted survey indicates that the user experience in terms of Quality of Service obtained higher scores in the scenario with the two hops. On the other hand, the objective test bears many consistencies to the subjective one. Network characteristics measurements acquired during the test indicate that the key elements of jitter and packet loss were slightly compromised in the four-hop scenario, a fact that shows clearly the limitations this topology has until today. Future research is definitely going to improve all characteristics of the mobile ad hoc networking and we hope this paper, based on an implementation rather than simulation results, paved a path towards that direction.

Appendix

A. Absolute Category Rating

The Absolute Category Rating method is a category judgment where the test sequences are presented on at the time and are rated independently on a category scale. In our case, instead of a video/audio sequence, the evaluation refers to the videoconference and its parameters. The method specifies

TABLE 1

9-8	Excellent
7-6	Good
5-4	Fair
3-2	Poor
1	Bad

that after each videoconference session, the subjects are asked to evaluate the session's quality. No explicit reference is provided by the method, although subjects will always use an implicit one. Videoconference session can be no longer than 2 minutes yet no shorter than one minute, thus providing enough time for user to consider and assign points according their overall experience. This is persistent with our measurement scenarios that limit the total call duration to 120 sec. ITU recommends a five-level scale for rating overall quality [19]. In our evaluation since higher discriminative power is required because of the low bit rate of the video conference encoding algorithm, the nine-level scale presented in Table 1 is going to be used.

Additional examples of suitable numerical or continuous scales are given in [19], which also provides examples of rating dimensions other than overall quality. Such dimension may be useful for obtaining more information on different perceptual quality factors when the overall quality rating is nearly equal for certain systems under test, although the systems are clearly perceived as different. In our case the simple nine-level scale is considered rather accurate. For the ACR method, the necessary number of replications is obtained by repeating the same test conditions at different points of time in the test. ACR is easy and fast to implement and the presentation of the stimuli is similar to that of the common use of the systems. This attribute renders ACR an optimal choice for qualification tests.

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Research Article

Impact of Used Communication Technology on the Navigation System for Hybrid Environment

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This paper deals with navigation of mobile device in outdoor and indoor environment by only navigation system or application. In the paper, the navigation system is proposed in the light of seamless navigation service. Main parts of the system from positioning point of view are based on GPS and WifiLOC system. WifiLOC is an indoor positioning system based on Wi-Fi technology. The proposal of the system will be described in detail. The system is implemented at the University of Zilina as a pilot, noncommercial project; therefore it is called University Mobile Navigation System (UMNS). The navigation system can be characterized as real-time system, that is, the system operations cannot be significantly delayed. Since delay of the system depends significantly on communication platform used for map information downloading or communication with the localization server. We decided to investigate an impact of the used communication platform on the time needs for some of the functions implemented in navigation system. Measurements were performed in the real-world application. Next experiment is focused on testing of the accuracy of used indoor positioning system. Outdoor positioning accuracy is not tested because GPS is utilized in outdoor, and this system was already exhaustively investigated.

1. Introduction

In past few years, high number of navigation systems for mobile devices was successfully developed. Most of these systems can be used in outdoor environment, where position of the mobile device is estimated using satellite systems like GPS (Global Positioning System) or GLONASS (Global Navigation Satellite System). Generally, these systems are mainly used in transport applications, to find shortest path to the given destination point in the field of navigation, but can also be used for pedestrian navigation or navigation of the blind people [1–4].

Similar situation is in the indoor environment. Many navigation systems were developed also for this environment and they are mostly used for navigation in large buildings [5–7]. Most of these systems using radio signal positioning to achieve position estimate, which is important for the navigation applications [7]. It is also possible to use a high-sensitivity GPS receivers or GPS pseudolites in the indoor environment, but this solution is still quite expensive [8, 9]. The largest number of indoor navigation systems is based on

the Wi-Fi technology and use fingerprinting positioning to estimate position of mobile device [10].

In this paper, we will propose navigation system for mobile device, which can be used in both indoor and outdoor environment. In the outdoor environment proposed system utilizes the GPS receiver, which is nowadays built in large number of smart phones. On the other hand, in the indoor environment positioning based on Wi-Fi fingerprinting localization is used to estimate position of the mobile device. In the navigation, position of the mobile device is estimated using WifiLOC positioning system [11]. This system has mobile-assisted centralised architecture, which means that measurements required for position estimation are performed by the mobile device. Measured data are then sent to the localization server, which estimates the position of mobile device.

Different communication technologies can be used by mobile device to connect with the servers, which are used to calculate optimal route to destination point, estimate position in the indoor environment or serve as storage of the maps. Since different technologies allow transmission

with different data rates, impact of the used communication technology on the performance of proposed navigation system will be investigated.

Impact of the used communication technology on the communication time, together with localization accuracy in the indoor environment was investigated in real-world experiments. For this purpose, proposed navigation system was implemented at the campus of the University of Zilina.

Rest of the paper will be organized as follows; in the next section fingerprinting algorithm used for the indoor environment will be described. Proposed navigation system, described in detail in the Section 3. Section 4, introduces measurement scenarios. Achieved results are shown in Section 5. Section 6, concluding the paper and introducing plan for the future work.

2. Fingerprinting Localization

Fingerprinting algorithms can be divided into groups based on mathematical procedures used to estimate position of mobile device [12]. Basically, they can be divided into deterministic and probabilistic algorithms. In deterministic algorithms, the radio fingerprint is assumed to be nonrandom variable, which depends on the position of the device. On the other hand in probabilistic algorithms, the radio fingerprint is assumed as random variable. In our work we deal with deterministic fingerprinting algorithms based on nearest neighbor (NN) method, which can achieve sufficient accuracy as well as more complicated method, when density of radio map is high enough [13].

Accuracy of this method in radio networks is determined by two factors [14]. Firstly, signal properties vary much at relatively small area. For instance, in few meters range, signal from an AP can get attenuated, or even get lost. Secondly, these signals are relatively constant in time, what allows their use as indicators of a position.

Main disadvantage of this method is sensitivity to environment changes such as object movement in the building (e.g., people and furniture), which altogether affect signal properties. In case that environment has changed, it is necessary to update the map, but the signal is most affected by walls and furniture; therefore, update is not required so often.

2.1. Radio Map. Fingerprinting method consists of two phases. At first, it is creation of the radio map for an area where planned localization service is desired (see Figure 1). Radio map is basically a database of spots with known position (coordinates) coupled with various radio signal properties, for example, RSS, signal angles, or propagation time. The phase, when radio map is created, is called the off-line phase. Generally, the offline phase can be performed by either measurements in a real environment or by prediction as described in [15]. In the first case, it is very time-consuming, but there are precise real RSS information used in calculations. On the other hand, prediction of RSS is more comfortable, but the data are highly dependent on a quality of map model of given environment and also on used radio signal propagation model. High demands on

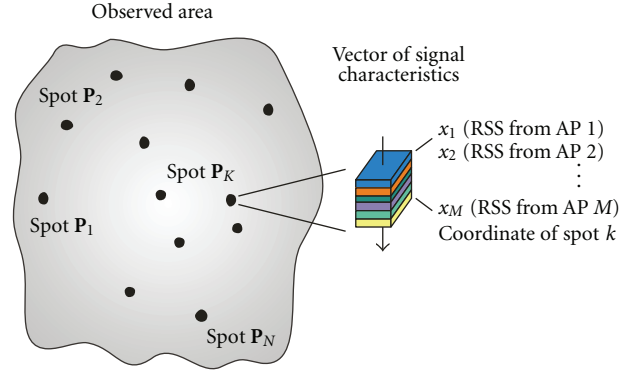


FIGURE 1: Radio map for fingerprinting algorithms using RSS.

the quality of map model and propagation model makes prediction of RSS quite hard to implement. Compromise between the demanding effort to create the radio map and achieved localization accuracy can be found in [16].

2.2. Localization Algorithm. After the radio map is created, second phase can take place. This phase is commonly called online or localization phase. During this phase MS measures signal properties at unknown spot. Then the radio map is searched to find a best match from existing spots. The match is actually the nearest point from database and is considered as MS position (for NN method).

The most common method how to find the best match and actually perform localization is use of the Euclidean distance with the Nearest Neighbor algorithm [12]. Let us assume a fingerprint in radio map, which is characterized by vector \mathbf{P} :

$$\mathbf{P} = [x_j] = [x_1, \dots, x_M], \quad (1)$$

where x_j characterizes the spot, that is, values of the signal properties (e.g., RSS), M represents the number of access points (APs) used for radio map creation. In general, let us consider the radio map contains fingerprints of N spots:

$$\mathbf{P}_i = [x_{ij}] = [x_{i1}, \dots, x_{iM}], \quad i = 1, \dots, N. \quad (2)$$

Unique identifiers of neighbor APs as well as spot coordinates are stored in radio map and they are coupled with x_i , but are not shown here for model simplicity. The whole radio map contains all fingerprints \mathbf{P}_i and creates the set \mathbf{S} written as

$$\mathbf{S} = \{\mathbf{P}_i : i = 1, \dots, N\}. \quad (3)$$

In case of mobile device localization, the signal properties are measured at unknown spot, a new fingerprint \mathbf{Q} is obtained as follows:

$$\mathbf{Q} = [y_j], \quad j = 1, \dots, M. \quad (4)$$

The Euclidean distance d_k between vectors \mathbf{P}_k and \mathbf{Q} is defined as

$$d_k = |\mathbf{P}_k - \mathbf{Q}| = \sqrt{\sum_{j=1}^M (x_{kj} - y_j)^2}. \quad (5)$$

When Euclidan distance formula is applied on the entire radio map, the vector of distances \mathbf{D} is obtained between all of the radio map vectors \mathbf{P}_i and the vector \mathbf{Q} can be calculated as

$$\mathbf{D} = [d_i] = [|\mathbf{P}_i - \mathbf{Q}|] = \left[\sqrt{\sum_{j=1}^M (x_{ij} - y_j)^2} \right], \quad i = 1, \dots, N. \quad (6)$$

Position of mobile device than can be estimated using

$$\hat{x} = \frac{\sum_{i=1}^N (1/D_i) L_i}{\sum_{j=1}^N (1/D_j)}, \quad (7)$$

where \hat{x} is estimated position, D_i (D_j) represents i th (j th) element of vector \mathbf{D} , L_i stands for the position of i th reference spot in the radio map database, and N is the number of reference spots.

The estimator (7), which keeps K positions with smallest distances is called the WKNNs (weighted K -nearest neighbors) method. WKNN with all distances $D_i = 1$ is called the KNNs (K -nearest neighbors) method [17]. The simplest method, where $K = 1$, is called the NN (nearest neighbor) method.

3. Proposal of Navigation System for Hybrid Environment

We have developed navigation system feasible for navigation in both outdoor and indoor environments. The system is able to continuously navigate from outdoor to indoor environment or vice versa. Position used by the proposed navigation system can be estimated using GPS signals in outdoor environment, or using Wi-Fi localization system based on fingerprinting in the indoor environment and in areas, where the GPS signals cannot be used, due to NLOS (non-line of sight) conditions or high GPS signal attenuations.

The proposed navigation system was implemented at the University of Zilina as a pilot, noncommercial project; therefore, it is called University Mobile Navigation System (UMNS). This navigation system is developed as user-oriented application for navigation in the hybrid environment using mobile device. Device should be equipped with Wi-Fi receiver, GPS receiver, internet connection and should be based on Android operation system. Basic concept of the proposed system is shown in Figure 2.

In the above figure is shown all equipments, which are used by the proposed navigation system to estimate position and estimate route to the given destination point. Communication between mobile device and servers is realized using different wireless technologies for the internet collection. Localization server is part of WifiLOC system and it is used to estimate position of mobile device in the indoor environment or in case that GPS signals are weak or not present. Indoor map server stores maps of the buildings, where navigation system can be used and it is represented by Ericsson Labs server. Outdoor map server is represented by Open MapQuest server, which stores outdoor maps of the world.

Geocode server is used to convert information provided by the user to geographic data. The server with OSM (Open Street Map) database stores information needed by both Open MapQuest and geocode servers.

Generally, if device is equipped with GPS receiver, and there is a visibility on the GPS satellites, the mobile device can estimate its position using directly GPS signals. On the other hand, when the mobile device is out of GPS signal range, for example, in indoor environment, position is estimated using the WifiLOC positioning system.

In case of the outdoor environment, map is downloaded from the Open MapQuest server. This open-source application is described in [18]. It is also possible to get information about actual geographic position, of the given address or add a name to the given position. In outdoor environment the route to the destination point is calculated on remote server, because of the large number of data. On the other hand, indoor maps are downloaded from the Ericsson labs servers [19]. At the beginning, the indoor maps have to be created on the server. We implemented this system as a case study of navigation service in the campus of University of Zilina; therefore, maps of the particular buildings of University of Zilina campus were created.

We decided to use Ericsson Labs servers because this server provides application to easily create maps of the indoor environment called Map Studio. Map Studio is accessible via internet connection as a web application. Advantage of this application is a possibility to create maps of any building, together with logic structure needed for the navigation. This tool also allows adding different points of interest and transfer points into the map. These points can be used to compute optimal route for the navigation.

3.1. Principle of Communication in the System. In this part, the fundamental communication between parts of the system is explained in the following example. After the startup of the application in mobile device, the mobile device is localized on the map. The localization is automatically performed by GPS or WifiLOC. There is possibility to define destination point of the route if the user wants to be navigated. If user choose this option the map is shown together with menu as can be seen in Figure 3. From this menu the destination point for navigation can be chosen in three ways. First way is to choose the destination point directly from the map.

Second way is to search for the desired destination point. In that case user write desired destination as text request. Request should be written in format: street, city, and country. Request is then sent to geocode server. This server use text from the given request to find the position of the destination point using a data stored in the database. In case that request is not given in the specified format, geocode server can send back wrong coordinates of the destination point.

When the mobile device receives information from geocode server, position of destination is shown on the map using blue circle centred on the given position. In the case that geocode server does not find requested position, or there was an error in communication between device and geocode server, application shows message "Geocode server did not find requested position."

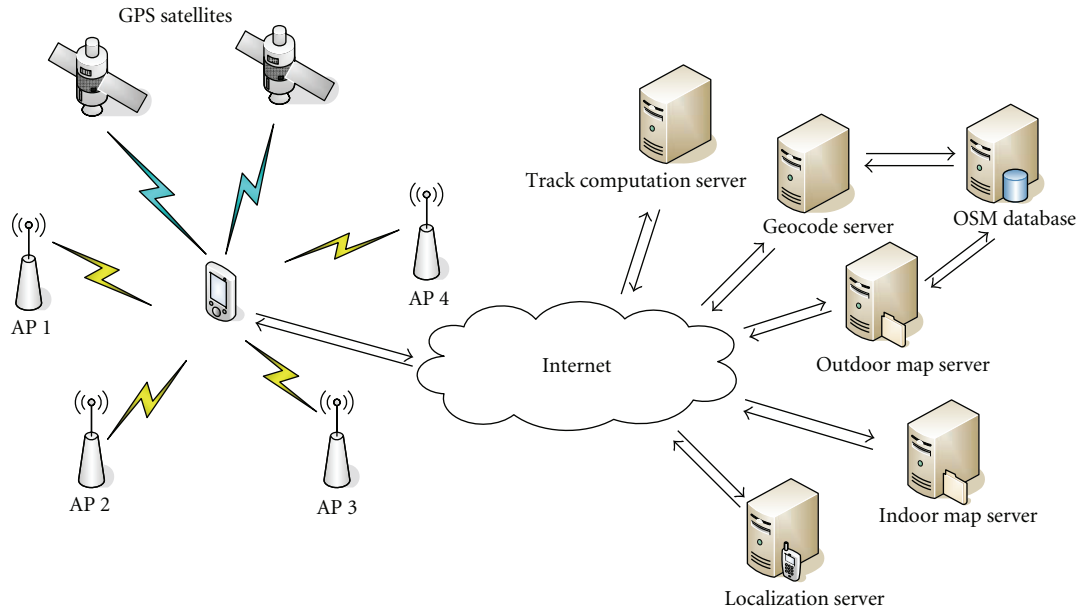


FIGURE 2: Concept of proposed navigation system.

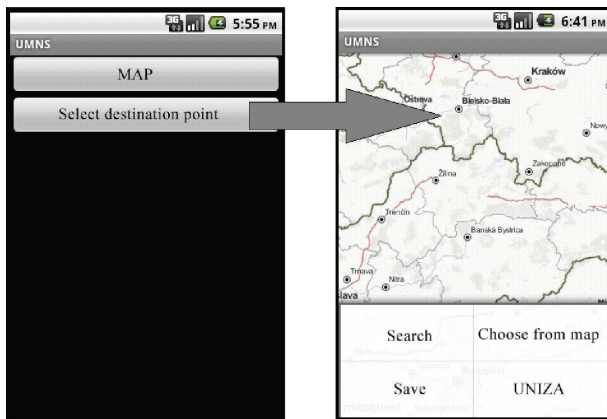


FIGURE 3: Menu to choose destination point of navigation.

Since UMNS allows also navigation inside the buildings, we implemented this system at the University of Zilina campus. There is button called UNIZA in the application menu. If the user chooses this option, it is possible to set the destination point inside the building of the university. It is possible to choose concrete building, floor, and so forth. According this information, the floor plan should be downloaded into the mobile device. This step is important because map data includes information about the whole building and also about every room. This information is needed to create a list of the rooms and a list of the persons, who have offices in the building. If data in the map was changed on the server, it is important to download the data again into the mobile device. When the maps are loaded, it is possible to choose destination point inside the building. Destination point can be chosen using room ID, or the name of a person which has office in the building from the list

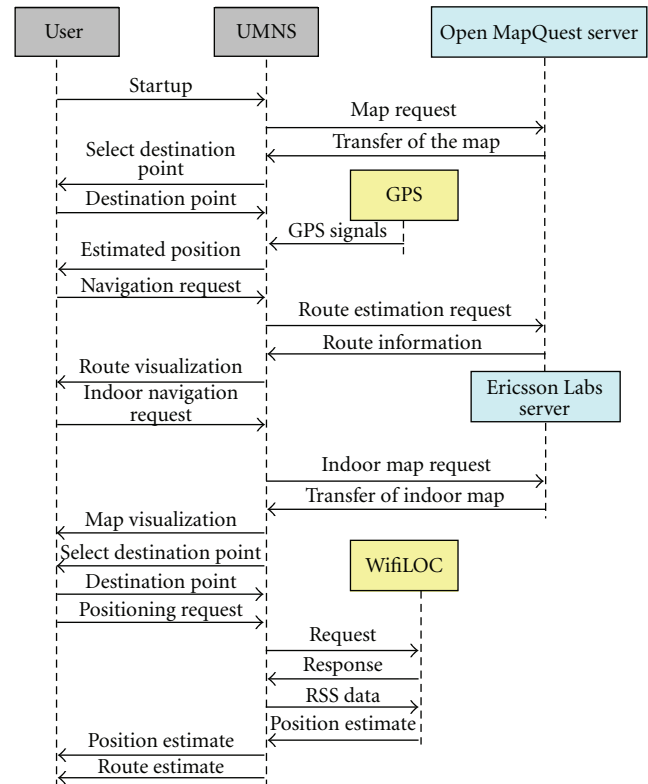


FIGURE 4: Sequence diagram of the communication in the proposed system.

generated by the application based on a data stored in the map. Sequence diagram of the communication between user, proposed UMNS application and servers is shown in the Figure 4.

3.2. Navigation inside the Building. Maps downloaded from Ericsson Labs server are used during the navigation inside the building. In case that the user is navigated from the outdoor environment, his position is assumed to be at the building entrance. Application allows viewing the maps of the building. Each floor of the building has its own map and it is possible to switch between them by pressing point of interest (PoI) showing a stairs. In case of long press of the point in the map, information about room, like room ID and names of persons who have office in the given room, is shown.

Using settings menu it is possible to turn on localization of the mobile device or switch on or off the route to the destination point. Accuracy of the route is given by map properties and number of points in the map, since the route to destination point is calculated using points in the map and Dijkstra's algorithm. Localization in the indoor environment is implemented using the WifiLOC system or SelfLoc application. SelfLoc application is based on information given by the user of the mobile device. In SelfLoc, the user needs to define the point from which he wants to be navigated to the destination point. WifiLOC system was developed at the Department of Telecommunications and Multimedia at University of Zilina [11, 20]. This localization system utilizes positioning based on Wi-Fi fingerprinting method.

3.3. WifiLOC Positioning System. The basic properties of the WifiLOC positioning system are described in this part. The system utilizes signal information from surrounding Wi-Fi networks for the position estimation. The system is based on the fingerprinting positioning method and received signal strength measurements.

WifiLOC system architecture, shown in the Figure 5, is designed as the mobile-assisted positioning concept. The mobile-assisted positioning means that the necessary measurements are done in the localized mobile device and measured results are forwarded to the localization server (LCS) in the network part. The position is estimated (calculated) at server side using basic NN algorithm (see Section 2).

The system is based on client-server architecture. From different point of view the entire architecture could be divided into three almost independent parts:

- (i) localization server;
- (ii) network of access points;
- (iii) mobile device-user, client.

The division was purposely performed because of function of particular parts. The core component of the system is the localization server. It consists of more functional entities: database server, web server, and communication platform. LCS is built on Ubuntu operating system [21]. Radio map is saved on database server based on MySQL platform, which is free to use [22].

Communication between client and LCS could be implemented by various standard communication links depending on availability. Obviously, Wi-Fi is used as default, but bluetooth, UMTS (Universal Mobile Telecommunications System) or GSM (Global System for Mobile Communications) were successfully tested.

Network of access points can consist of various network provider APs. The signals from all fixed AP are passively scanned and utilized for the positioning. The system relies on the fact that transmission power is not changed when device is not connected to the AP.

Mobile device can be any mobile phone, personal device, tag or laptop equipped with IEEE 802.11 chipset. Localization application is developed in Java language SDK (Standard Development Kit) due to its easy implementation and cross-platform compatibility.

4. Measurement Scenarios

Navigation system described in previous chapter will be extensively tested for its parameters evaluation. Measurement scenarios were proposed to estimate the most important system parameters from navigation function point of view:

- (a) time needed for the function of the proposed navigation system;
- (b) indoor localization accuracy.

Time needed for the function of the navigation system is estimated as time from sending of the request till the end of the data processing on a mobile device. Each measurement was performed in the 50 independent trials. Sequence diagram for the measurements is shown in Figure 6. Concretely, there will be investigation into:

- (a) time needed to download the map and route for indoor and outdoor navigation;
- (b) time needed to download the map and navigation route (itinerary) for different route lengths in outdoor;
- (c) time needed for position estimation by WifiLOC (indoor).

In the first scenario, measurements were performed to estimate time needed for maps downloading into the mobile device in outdoor environment. It is clear that downloading time is given by size of the given part of the map and also by used internet connection. The second part of this scenario was performed in the same way, but measurements were performed for downloading of indoor map instead of outdoor map. The impact of three different communication platforms was investigated: EDGE, UMTS/HSPA, and Wi-Fi. We agreed on the platforms because they are the most widespread and implemented in almost all current mobile devices.

In the second scenario, time complexity of indoor localization part was estimated using time measurements similarly to the first scenario. In this case, estimated time was given by time needed to send the request for position estimation, time needed for position estimation by localization server, and time needed to send localization information from the localization server to the mobile device. Same communication technologies as in previous scenario were tested and compared.

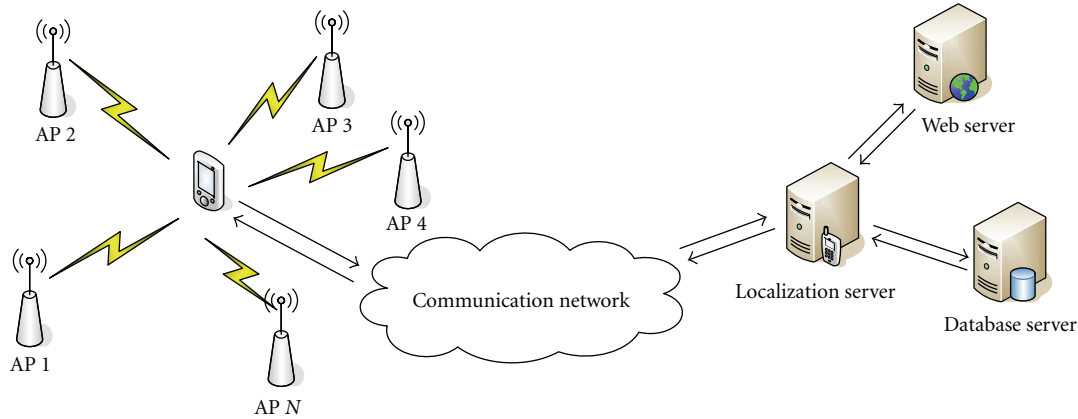


FIGURE 5: Architecture of the WifiLOC positioning system.

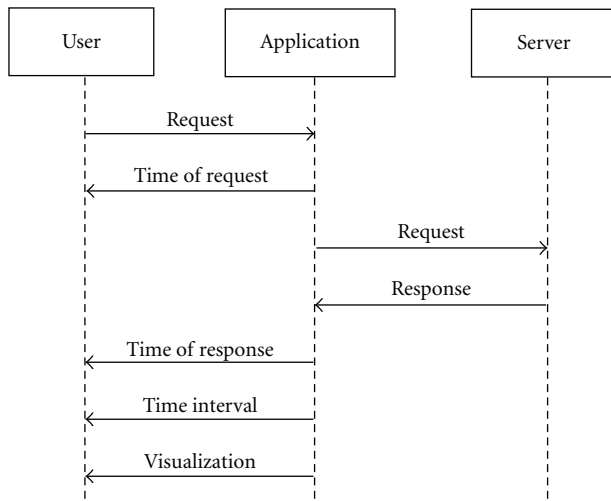


FIGURE 6: Sequence diagram for the time measurements.

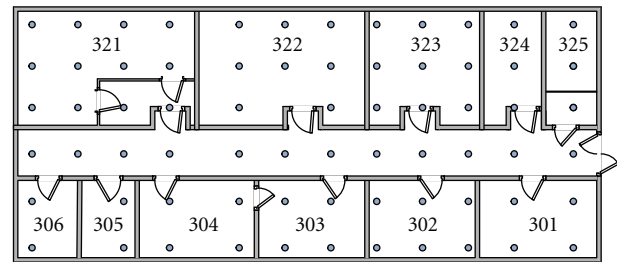


FIGURE 7: Environment where measurements were performed.

In the third scenario, the accuracy of the WifiLOC positioning system was investigated. In this scenario, influence of the environment on the achieved localization accuracy was examined. Measurements were performed in different room types and during different times of the day. These measurements show how the small changes in environment caused by moving peoples affect achieved positioning error. In this scenario, position of mobile device was estimated in 50 independent trials for each of the four cases (200 position estimations in total). The area where localization accuracy of the WifiLOC system was tested is shown in the Figure 7. Localization area was situated on the one floor with size of approximately 333 meters squared. There were 67 spots in the radio map distributed in grid with regular distance of 2 meters.

Measurements performed in the last scenario were also aimed to evaluate positioning accuracy. In this scenario, measurements were performed during two days. This helps us to estimate impact of environment changes on the accuracy of proposed navigation system. Measurements can

be divided into measurements performed in rooms and measurements performed in corridors. This helps us to investigate room accuracy of the localization algorithm. In this case, the measurements were performed for 80 positions in the rooms and 90 positions in the corridor during both days.

5. Achieved Results

In this section, results achieved during the measurements will be shown. All measurements were performed in the campus of the University of Zilina using HTC Legend mobile device. Results achieved in the first scenario are shown in Table 1.

According to the results shown in Table 1, there can be seen that the shortest time needed to map downloading was achieved by UMTS/HSPA communication platform. It can also be seen that mean time needed for the download of the map using Wi-Fi technology as communication platform, was almost the same compared to UMTS/HSPA. Disadvantage of Wi-Fi technology is high deviation of the time needed to download the map. This is probably given by background traffic in the Wi-Fi network generated by other users in the area. On the other hand, the advantage of communication over Wi-Fi platform lies in the economical point of view, since in most cases user is not charged any fees to use Wi-Fi network.

From the results it can also be seen that the longest time to download the map from the server was necessary for the EDGE communication platform. This result is not

TABLE 1: Time needed to download the map and route for navigation.

	EDGE	UMTS/HSPA	Wi-Fi	
Δt (ms)	7891.03	1240.59	1383.22	Outdoor
σ (ms)	2578.53	395.56	1495.28	
Δt (ms)	4456.52	1891.62	2135.72	Indoor
σ (ms)	2628.99	437.74	651.62	

TABLE 2: Time needed to download the map and navigation route for different route lengths in outdoor environment.

	Used communication technology			Length of the route
	EDGE	UMTS/HSPA	Wi-Fi	
Δt (ms)	7891.09	1240.59	1383.22	$d < 10$ km
σ (ms)	2578.53	395.56	1495.28	
Δt (ms)	12316.96	1551.57	1657.16	$d < 100$ km
σ (ms)	6607.07	6607.07	423.39	
Δt (ms)	13722.92	2043.61	1871.86	$d < 500$ km
σ (ms)	3886.06	353.09	738.38	
Δt (ms)	27242.92	2550.19	2992.82	$d > 500$ km
σ (ms)	8668.71	829.79	445.13	

surprising, due to much lower transfer speeds in the EDGE technology. It is commonly known that theoretical maximum transfer rate for EDGE technology is 384 kbps, UMTS/HSPA technology can achieve maximum transfer rate of 14 Mbps for downlink and 5.74 Mbps for uplink and Wi-Fi technology can work with data transfer rates up to 54 Mbps.

When achieved results for the indoor and outdoor maps are compared, it can be seen that time needed to download maps has changed. Transfer time has decreased in the EDGE communication technology. On the other hand, particular times achieved for UMTS/HSPA and Wi-Fi communication technologies increased. It was caused the fact that indoor maps are much smaller compared to outdoor maps. These results seem to be affected by speed of the login process needed for the connection to the server of Ericsson Laboratories, where the maps are stored.

In next step, time needed to download map and route for different lengths of the navigation route was measured. In this case, measurements were divided into four groups based on the length of the navigation route. First group was created for the route with distance smaller than 10 km. Second group was created using distances in the range from 10 km to 100 km. Third group consisted of distances in the range between 100 km and 500 km. The last and fourth group was created from routes with long distance navigations over 500 km. Achieved results are shown in Table 2.

From the obtained results it can be seen that times achieved using UMTS/HSPA and Wi-Fi technologies were almost the same. It is also clear that difference between times needed to download the map and routes information when distance is lower than 10 km and 100 km are almost the same. Difference in the needed time is only 0.3 s, it is very low. It can also be seen that time achieved using EDGE communication platform was much higher. In case

TABLE 3: Time needed for position estimation.

	EDGE	UMTS/HSPA	Wi-Fi
Δt (ms)	1593.22	630.65	443.26
σ (ms)	572.01	128.8	162.36

that distance of the route is lower than 10 km, time needed to download map and route information using EDGE is more than 5 times higher compared to Wi-Fi and UMTS/HSPA platforms. When distance to the destination is higher, results achieved using EDGE technology gets even worse and in case that map needed for long distance navigation needs to be downloaded the needed time is more than 9 times higher compared to Wi-Fi and UMTS/HSPA technologies.

Results achieved in the second scenario for delay of the position estimation, using WifLOC localization system, are shown in Table 3. On the basis of the results it can be seen that communication technology seems to have significant impact on delay of estimated position.

It can be seen, that UMTS/HSPA and Wi-Fi communication technologies achieved almost the same delay of estimated position report. When communication between mobile device and localization server was based on connection via EDGE technology, delay of the estimated position was about 150% higher compared to Wi-Fi communication technology. From the results, it can be seen that time achieved using EDGE technology is too high for the navigation system application, since the time is higher than 1 second. Time of 1 second is assumed to be the highest position estimation delay time which is feasible for the navigation applications.

Results achieved in the third scenario can be seen in Figure 8. Measurements were performed in four cases, representing different conditions in the environment. In the first case both phases of the fingerprinting localization were performed during the same day, in the same conditions in the environment. In the case number 2, the localization phase was performed during the other day, there was different number of moving people in the area and few pieces of furniture were moved. In the third case, the online phase was performed in the empty building, so there were no moving people that can affect the signal propagation. All the measurements performed in the fourth case were done when there were no moving people in the building during the both phases.

From the results it can be seen that changes in the environment have impact on localization accuracy. It can be seen that, when there was no moving people during the localization phase, accuracy achieved was much lower even if the radio map was created in different environment conditions (case 3). It is clear that best results were achieved in case 4 representing ideal conditions, because disturbances caused by the dynamic changes of the environment were minimized. On the other hand, the worst results were achieved in case 2 which can be identified as real conditions since it represents most common environment in real-world applications.

TABLE 4: Localization precision of WifiLOC positioning system.

		Number of estimations	Number of accurate estimations	Number of false estimations	Success rate (%)
Rooms	Day 1	80	74	6	92.50
	Day 2	80	71	9	88.75
Corridor	Day 1	90	76	14	84.44
	Day 2	90	77	13	85.56

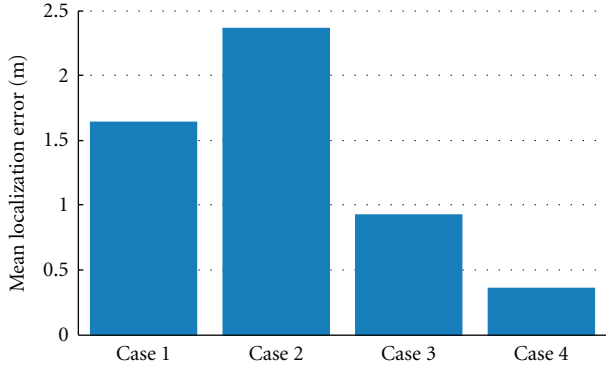


FIGURE 8: Localization error achieved in the different conditions in the indoor environment.

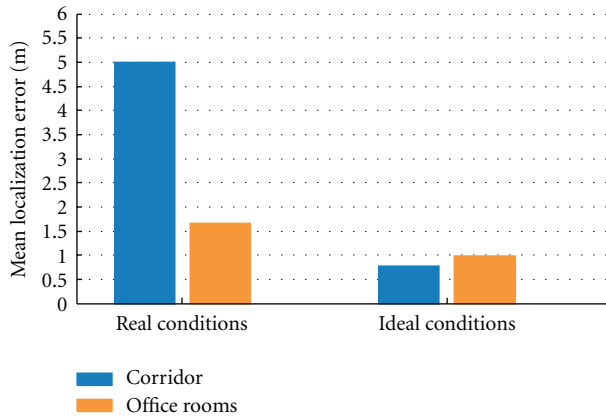


FIGURE 9: Localization error achieved in the different conditions and different types of the indoor environment.

In the next step, localization accuracy achieved for both ideal and real conditions, for two different types of rooms was compared. Rooms were divided into office rooms and corridors, achieved results can be seen in Figure 9.

According to achieved results it can be seen that localization error depends on the type of room in the environment. In the real conditions, localization accuracy in the office rooms was much higher compared to corridor. This is caused by differences in propagation and by different impact of the moving people on the localization accuracy. For the office rooms, the difference in achieved localization error is much lower compared to change in corridor.

In the last scenario, measurements were performed to evaluate positioning precision of the proposed navigation system. In this case, measurements were done in the real

conditions, in different days and in all kinds of above investigated environment. Localization precision is evaluated by comparison of estimated and real positions. When estimated position is in the same area (same office room or same part of the corridor), then estimated position is marked as accurate, and in case that estimated position is not in the same area position is marked as false estimation. Achieved results are shown in Table 4.

From the table, it can be seen that higher precision was achieved in rooms compared to corridors. It can be seen that in case that mobile device was in the room, positioning precision was about 90 %. It is also evident that number of false estimated positions was almost the same during both days, so precision of the positioning system seems to be stable even in case that there are some minor changes in the localization area.

In the corridor, number of false estimated positions was slightly higher; accurate estimations achieved 5% worse value compared to results achieved in rooms. This can be caused by the fact that Wi-Fi signals in corridors have a bit different characteristics due to differences in propagation of radio waves. The differences in the accuracy in the corridors, when there are minor changes in the environment, are even smaller compared to results achieved in the rooms.

Results achieved in the measurements show that localization accuracy of the used localization system for indoor positioning should be improved. Results also show that there is impact of the used communication platform on the delay of the estimated position report. The worst results were achieved by EDGE communication technology, but even delay achieved by EDGE technology is suitable for the proposed application.

6. Conclusion and Future Works

In this paper, a novel navigation system applicable to the hybrid environment was described. The system can provide a navigation service in the hybrid environment where mobile device has to be localised in outdoor in indoor. The system was implemented as University Mobile Navigation System (UMNS) at the campus of the University of Zilina. The real-world testing of the system was performed in this environment.

Real-world measurements were performed to evaluate time complexity of localization and map and route downloading using different communication platforms. According to the achieved, results we can conclude that communication platform has significant impact on the time necessary for a relevant data downloading. As we expected, the most reliable platform was UMTS/HSPA from a time relations point of

view. The best results were achieved by the UMTS/HSPA platform for both outdoor and indoor environments. Communication based on the Wi-Fi technology achieved similar results compared to UMTS/HSPA from the time delay point of view. Advantage of Wi-Fi technology lies in the fact, that communication via this technology is mostly free of charge. Communication based on EDGE technology had the highest delay. These results are caused by the transport speeds of particular communication technologies.

Delay of the position estimation was only investigated in the indoor environment, because GPS was used in outdoor environment and it is a well-known tested system. Indoor positioning was performed by part of the system based on WifiLOC positioning system. Achieved results have almost the same characteristic as previous results for all used communication platforms. Delay of the position estimation achieved using Wi-Fi and UMTS/HSPA was almost the same. When EDGE platform was used for communication with localization server, achieved delay was much higher. From the achieved results, it is clear that EDGE communication platform is not feasible for the navigation purposes due to high delay of the position estimation.

In the last experiment, the positioning accuracy in indoor was extensively investigated. The changes of the localization area during both offline and online phases have significant impact on positioning accuracy. Therefore, the radio map should be periodically optimized. Finally, the successful position estimation rate was tested. The position estimation was successful if the estimated position is in the true area (same office room or same part of the corridor). The successful position estimation rate was more than 85% of all position estimations. These results confirm that idea about positioning seems to be optimal for positioning and navigation in hybrid environment. The accuracy of the used indoor positioning system should be increased. The success rate can be improved by implementation of optimization algorithm which takes into account previous position of the mobile device. The implementation of the optimization algorithm to the navigation system belongs to our future research goals.

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