Access network controlled fast handoff for streaming multimedia in WLAN

B. Jooris, A. Schoutteet, F. Vermeulen. and I. Moerman.

Abstract— The focus of the research presented in this paper was to develop a novel way to support voice over IP (VoIP) and streaming video applications on mobile devices over a 802.11 access network. Fast handoff in a wireless local area network (WLAN) environment has been the research topic of many previous studies, the majority of which described ways to optimize the three main 802.11 handoff phases - scanning, authentication, and reassociation. In this paper however we propose a fast handoff scheme that skips all mentioned phases. Instead, the handoff is controlled and prepared by the access network and is triggered by sending a hop request message to the mobile station (STA). At the STA the three phases are reduced to a single frequency change phase. The proposed solution extends the standard 802.11 scheme; if the extension is not available at the access network or the STA, the devices will fall back on the standard handoff procedure. Because the access network fully controls the handoff process and actively invokes the frequency change on the STA, we can guarantee a minimal duration of the time the STA stays disconnected.

Index Terms—Fast handoff, VoIP, Wireless LAN, Broadband Communications

I. INTRODUCTION

IN this work we describe the design of a fast 802.11 handoff scheme, which aims at improving the handoff process for multimedia applications. During our research we focused on the VoIP application as it imposes very strict Quality of Service (QoS) requirements.

The majority of technologies currently used to support public addressing (PA) in trains are based on analogue signals. Announcements, i.e. “The train will arrive in five minutes”, are broadcasted by the train crew using analogue equipment. Since 2000 however Televic [1] has been developing train specific voice communication systems which use a proprietary VoIP protocol. These systems are interconnected using a train backbone which is composed of a series of onboard service switches (OSS). The OSS is a QoS enabled railway switch which provides network connectivity between train vehicles and which has recently been developed and implemented in

cooperation with IBCN. Each vehicle equipped with an OSS, can communicate with its neighboring vehicles, if these have an OSS installed. Vehicles communicate with each other using the Ethernet protocol. An example logical topology, deployed on board a train, is depicted in Figure 1. The OSS provides five external interfaces: two to the neighboring OSS (called Previous Element and Next Element), one to the Public Information System (PIS) backplane (which is restricted to the crew), one to third party systems (not shown in figure), and one to interface with the Public Network, i.e. for passenger internet. An extra internal interface to create a PIS-public gateway can also be included. The OSS does not handle all Ethernet traffic equally; it will assign a priority level to all passing packet streams. Thus, the traffic generated by the PIS backplane will have a higher priority level than passenger traffic arriving from the Public Network Interface.

Today, Televic offers a complete digital wired solution for PA. By integrating the fast handoff scheme, discussed in this paper, the existing products can be extended to additionally support wireless devices. This scheme is not restricted to crew terminals only but also supports passenger devices.

The rest of this paper is organized as follows. In section II, we provide background information on existing handoff algorithms. Sections III and IV provide a description of the Moving Access Point concept and the implementation details. After discussing the results of our experiments and simulations in section V, we follow with the conclusion in section VI.

II. BACKGROUND AND RELATED WORK

The 802.11 standard defines a layer-2 handoff mechanism in an extended service set (ESS), covered by several access points (AP) with the same ESSID that allows a station to associate with a new access point. The mobile station monitors the signal to the current access point and initiates handoff only after the current link quality degrades below an unacceptable threshold. Consequently, as a mobile 802.11 client reaches the limits of its current coverage region, it must temporarily

Figure 1 Train topology

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abandon its access point, scan the network to discover alternatives, and only then reconnect to the new best access point from the ESS. The MAC layer handoff system consists of multiple stages, which include the active/passive scan, the authentication and the reassociation stage. Optionally the Inter Access Point Protocol (IAPP) [2] buffers the packets during this handoff and it can deliver these buffered packets once the terminal is connected to the new AP.

Initial works that identified the problem of layer-2 latency during handoff in 802.11 WLANs were [3, 4, 5 and 6]. It was shown that existing layer-2 schemes lead to handoff latencies in the order of hundreds of milliseconds. While such disruptions may be acceptable for applications with limited mobility and flexible response time requirements, applications like voice-over-IP, which require a maximum end-to-end delay of 50ms [7], and real-time video streaming are far more demanding. Measurements have shown that the channel scanning phase is the most time consuming phase during the handoff as it contributes to over 90% of the latency [3]. The time spent on the authentication phase, nonetheless, can also prove to be significant, but strongly depends on the type of security used [8].

An important, but often ignored, factor is the time required to discover the necessity for a handoff. Generally a rate adaptation algorithm is implemented at the client, which will reduce the transmission rate when the signal deteriorates. It is therefore necessary to be able to timely initiate the handoff process if applications with stringent bandwidth and delay requirements are to be supported. As was mentioned before, typical commercial implementations monitor the current received signal strength indications (RSSI) value and will initiate the scanning phase when this value passes a pre-defined minimum threshold. In [5] a scheme is proposed where a simple trigger of three dropped packets is used as a signal to initiate the scanning phase and it is shown that this technique is quicker and more accurate than the commercial approach.

Previous work on layer-2 handoff has mainly focused on decreasing the probing delay. Most improvements to the active scan handoff strive to scan fewer channels.

The 802.11k standard [9] defines a beacon request where an access point asks a client to go to a specific channel and report all the access point beacons it hears. It also can provide a client with a neighbor report, an ordered list of access points, which can assist in optimizing the scanning process and gives an indication of the load on each access point.

The authors of [10] propose a MAC layer fast handoff scheme. Channels are selectively scanned and the scan results are recorded in an access point cache for future use. When a wireless station moves to a location it has visited before, it uses the access point cache to find out which channels were previously used by access points. Only those channels and channel 1, 6, and 11 will be scanned.

Other related work includes the use of context caching [11] to reduce authentication delay. Here the current security state is cached and passed between access points.

In [12][13], each access point records information on the neighboring access points in a “neighbor graph” data structure. Using this structure the access point can inform wireless stations which channels currently are used by neighboring access points.

In [14] the authors propose a fast scan handoff scheme. Instead of broadcasting a probe request frame to all access points, wireless station probe specific access points. When a probe request frame is sent to an access point it will be the sole responder. The designated access point sends a probe response frame after a SIFS delay, thus a wireless station only has to wait a few microseconds for a probe response.

In [15] a scheme called smooth handoff is proposed, in which the channel scan phase is split into multiple subphases to reduce packet delay and jitter. The wireless station uses the intervals between these subphases to send and receive data frames. A second proposed scheme, called greedy smooth handoff, extends this scheme by reducing the total number of scanned channels.

The authors of [16] propose a MAC layer handoff scheme called SyncScan. It strives to improve the performance of passive scanning where the client waits for beacons to arrive from an access point in stead of actively probing for a response. It assumes that all access points working on the same channel are synchronized and broadcast beacon frames within the same short interval. The wireless station switches to a channel at the time beacon frames are being broadcasted. The actual time used to listen on each channel can be very short, because the wireless station exactly knows when the access points will announce themselves.

The 802.11r [17] task group is studying algorithms and pre-authentication schemes to keep handoff times low. 802.11r refines the transition process of a mobile client as it moves between access points. It defines a fast BSS (Basic Service Set) transition algorithm where the client can communicate and retrieve information on candidate access points prior to transition. The protocol also allows a wireless client to establish a security and QoS state at a new access point before making a transition, which leads to minimal connectivity loss and application disruption. The communications with the target access point can take place over the air or through the client’s existing association with its current access point.

In [18] three mechanisms are introduced. The first method periodically performs an active scan in the background to gather neighborhood information, even if there is no direct need for a handoff. In the second algorithm a second radio card is exclusively used to probe for neighboring access points. Information obtained from this control card is then used by the other card during handoff. In the last method the control and data communication functionality alternates between the two cards and a single IP address is shared between them. This allows the mobile client to establish a new connection before breaking the old one.

Most of the discussed schemes try to accelerate the handoff process by optimizing one of the handoff phases. The sole

scheme that tries to improve the complete handoff process is the last described mechanism. This however requires the availability of two wireless adapters at the mobile client, which may not be feasible in real-life situations.

III. MOVING ACCESS POINT (MAP)

In this paper we present an alternative handoff mechanism which is controlled by the access network and which requires no alterations to the 802.11a/g client adapters as they can be purchased today. As the mobile station moves from base station (BS) to base station in our access network, it is assigned a private virtual AP that follows the terminal. We implement this virtual AP as a software object that moves from one BS to the next. For each mobile client the required logic is installed on its nearest base station. Every BS works on a fixed frequency. Only the installation of a small vendor-independent software package is required on each mobile terminal which allows us to locate the mobile terminal in the network and lets us adjust the working frequency of the mobile terminal. To aid us with the localization of the terminal we let it send beacons to the access network. Two interfaces are installed in each BS to aid with the handoff process. The active (A) interface runs the virtual AP of all nearby terminals. The passive (P) interface will tune to the frequencies of the neighboring base stations and measures the signal strength of the beacons sent by the previous mentioned software package that is installed on the nearby mobile clients as shown in Figure 2. If the passive interface of a BS, BS Y, detects that the signal it measures from a mobile terminal is stronger than a threshold plus the signal measured on the active interface by the BS, BS X, to which the terminal is actually connected, the virtual AP object for this mobile terminal is copied from BS X to BS Y. To inform the mobile client that his virtual AP is now also located on BS Y, BS X requests the terminal to change its frequency to that of BS Y. The installed software package interprets this frequency hop request and immediately sends a beacon on the new configured frequency. When the first beacon from the mobile client arrives at the active interface of BS Y it requests BS X to destroy its copy of the virtual AP object. When we take the train environment into account, which can be viewed as one-dimensional, we can limit ourselves to the use of only three frequencies.

Figure 2 Topology of the proof of concept demo.

Consequently, the passive interface of a BS should divide its time between listening on each of the two frequencies of neighbors. When a mobile terminal is located outside the range of the train access network, our software will not affect the standard way a handoff is handled.

IV. IMPLEMENTATION DETAILS

A first implementation issue on which we had to decide is the type of system we would implement: a centralized or a decentralized system. In a centralized solution a single location is chosen on the train and all management packets, required to move an AP, travel to this location over the one-dimensional train backbone. On long trains this results in large round-trip times which result in slow handoffs. Therefore we decided to implement a decentralized system for our proof of concept demonstrator.

A. All the interfaces of the base stations in our access network must have the same MAC address

In the previous section we mentioned moving a virtual AP between the base stations of the access network. An AP or more general a service set is identified by a basic service set identifier (BSSID which is a MAC address), a service set identifier (SSID which is a string) and a channel. We also mentioned that every nearby mobile terminal has its own virtual AP which implies that it must be possible to run multiple service sets on one base station. The wireless Madwifi driver [19] we used for our experiments allows us to run multiple virtual APs on one single adapter. There are however some restrictions. The number of virtual APs is restricted to four and the MAC addresses of the virtual APs are directly derived from the MAC address of the adapter. This implies that a virtual AP can not be moved from one adapter to another as a MAC address is unique. This restricts our possible options to the use of only one MAC address for all the BSs in our access network. We further won't use the virtual AP functionality provided by the Madwifi driver as we don't want to be restricted to four virtual APs in the access network. We therefore use code-division multiplexing based on the MAC address of the mobile terminal to distinguish between the different terminal parameter sets. To do this we implemented a tool which can change the MAC address of a wireless adapter (Atheros chipset). These decisions will result in a simplified MAP implementation, but the fast handoff principle remains.

Another issue discussed in the previous section is the message that has to be sent to the terminal to invoke a channel switch. We have implemented this as a layer 4 message (UDP) and process it in the vendor-independent software package.

B. Inter base station protocol (IBSP)

Every base station has two wireless interfaces; an active interface which runs the AP and a passive interface which listens on the neighbors' channels. For all the incoming packets on both interfaces we maintain a record per mobile terminal. In this record we keep track of the MAC address of the terminal, a flag which indicates if the beacons from the

mobile terminal are received on the passive or the active interface, the last five measured RSSIs, a timestamp of the last received packet, the IP address of the terminal (we sample the IP address from the IP header), if beacons from the mobile terminal are received on the passive interface we also need to know the IP address of the BS the terminal is currently associated to and the average RSSI values measured by the neighbors. The IBSP runs on the wired interface of the BS.

Several times per second an algorithm is scheduled which sequentially loops through all the records. If a record indicates that beacons from the considered mobile terminal arrive on the passive interface, we send a message report to the BS the mobile terminal is currently associated to. If the IP address of this BS is not known the access network is probed by sending a broadcast *"whereIsTheTerminalConnectedTo"* message. The BS which is serving the terminal will respond with a *"terminalIsConnectedHere"* message. If a frequency change is observed on the passive interface then the first message is resent. For each record which indicates that beacons from the considered mobile terminal arrive on the active interface, we check whether the terminal has a stronger average RSSI value at a neighboring BS. If this last statement is true, a *"terminalHop"* message (which will be discussed in the next section) is sent to the terminal and a route update message is sent towards the switch. All records have an expiration time based on the time of arrival of the last received packet from the mobile terminal. Consequently, when a record expires it is deleted. When new packets from a mobile terminal arrive at the active interface of a BS where before, they used to arrive at the passive interface (or vice versa) all the stored RSSI values and the recorded IP address of the serving BS will be cleared.

C. Terminal information protocol (TIP)

To have an indication, in the proof of concept demonstrator, on the strength of the signal received from a mobile terminal at the nearby BSs, a message report is sent from the serving BS to the connected terminal. This message contains the channel used by the serving BS and a list of the average RSSI values measured at the serving BS and all neighboring BSs. Of all messages the *"terminalHop"* message is the most critical as it contains the new channel the terminal must switch to. The beacons sent by the terminal towards the access network can also be seen as a part of the terminal information protocol. These beacons are broadcast messages and are terminated at

Figure 3 Setup in the Qosmotec system.

the BSs. The beacons contain the current working frequency of the terminal; this is needed to inform the passive interfaces of frequency changes.

V. RESULTS

After acquiring very promising results in an ns2-click [20] environment we decided to test the protocol on real devices.

A. Hardware & Software

For our BSs, we selected the PC Engines Wireless Router Application Platform WRAP.1E-1 (233 MHz AMD Geode SC1100 CPU - 2 LAN - 2 miniPCI - 128 MB DRAM - 128MB compact flash (CF)). Two Wistron CM9 cards were inserted into the miniPCI connectors. For the operating system we chose Debian Linux (the voyage distribution) with a click patched 2.6.16.13 kernel optimized for i586. The wired interface driver is the National Semiconductor driver included in the kernel. The MAP principle is implemented as a part of the click kernel module. For the crew terminal we opted for the HP Compac tc1100. For the operating system we decided in favour of Debian Sarge Linux with a click patched 2.6.16.13 kernel optimized for i686. The driver used for the wired interfaces is the bcm4400_1.00g driver. We implemented the one time vendor-independent software package using the java programming language. It ran as a server application in the jre-1.6.0. On both systems we ran the Madwifi 0.9.2 driver.

B. Benchmarks

To test if the chosen hardware would suffice for our experiments we ran a loopback click configuration (*FromDevice (eth0) -> Queue -> ToDevice (eth0)*) in the click kernel module on both the WRAP and the tablet. We used the Smartbits SMB-2000 [21] test system to send 1500 byte frames at 95Mbps/s through both devices. This resulted in a maximum delay of 250µs for the WRAP and 100µs for the tablet. A standard switch has a delay of 30µs, needed to store and forward the unicast frames in hardware.

C. Configuration

The passive interface in a BS changes its frequency every 200 ms. The terminals broadcast a 300 byte beacon every 100 ms. The inter base station protocol algorithm is scheduled 3 times a second, we use a parameter value of 0.12 for the calculation of the floating average of the RSSI value and the handoff threshold of the RSSI is set to two. We did not research solutions to recover the lost packets as this can be handled by the IAPP protocol. The topology of the proof of concept demonstrator looks like Figure 2.

D. Movement simulation in the Qosmotec

We used three BSs and one terminal as shown in Figure 2. We further used four shielded boxes (SB), six attenuators (ATT), two 4:1 splitters (4:1) and one 2:1 splitter (2:1) as shown in Figure 3, which also depicts the Qosmotec [22] system available at the IBCN lab. Attenuators that are connected to the same BS use the same attenuation value. We simulated motion as shown Figure 4. We used the iPerf [23] application to generate a downlink UDP traffic stream towards the terminal with a data rate of 20Mb/s. In our first experiment

we did not simulate any motion. We observe that no packets loss occurred and the click process on the active BS uses 26% of the CPU time (this could not be measured at the terminal). During the next experiments we did simulate motion. We triggered a handoff every 15 seconds and measured an average of 15 lost packets during every handoff. The number of lost packets ranged from 10 to 50 packets and 30 of the 37 handoffs resulted in less than 14 lost packets which implies less than 10ms disconnection time. When we checked the system log of the terminal we saw multiple occurrences of the Madwifi generated "*kernel: tx tasklet restart the queue*" warning, which most likely correspond to the moments of higher packet loss. We were unable to repeat this warning outside the Qosmotec. Even if we include the packet loss peak of 50 packets, we have a maximum disconnection time of 29ms. As mentioned before this time should stay under 50ms for VoIP applications. We're confident that if our solution is implemented in hardware this time can be reduced to 10ms.

VI. CONCLUSION

The IEEE 802.11 standard does not define a handoff mechanism that guarantees a smooth and seamless handoff between access points. Furthermore, in literature 50ms is described as the maximum delay that can be tolerated by VoIP applications. In this paper we presented a fast handoff scheme which guarantees that the disconnection time during a handoff of a wireless station in our access network remains under 50ms. The proposed horizontal handoff mechanism takes advantage of the linear train topology. The solution can easily be adjusted to cover other topologies.

The main constraint with our scheme is the fact that a terminal has to be able to interpret a frequency hop request from its access network. Once the terminal is able to handle such a request it is of little matter which scheme actually is implemented in the access network (MAP or our simplified MAP implementation). With the current technology it is impossible to implement MAP. Implementing MAP will become feasible however if it becomes possible to acknowledge (ACK) on a dynamic set of terminal MAC addresses. MAP has the advantage of also being able to move the security state of the terminal.

The installation of our current Layer2 implementation on a train and plugging it into an existing single Ethernet backbone is straightforward. Outside our train environment however scalability can become a problem. In our future research, when it becomes possible to implement MAP, we will further investigate the scalability aspect of the handoff scheme. At this moment we possess a proof of concept demonstrator on which a MPEG4 video (peaks to 8Mbit/s) is streamed.

Figure 4 Attenuations in function of time

When moving at pedestrian speed handoffs can rarely be noticed, even without recovering the lost packets.

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FOREWORD

Foreword to the Proceedings of the 16th IST Mobile and Wireless Summit (by Dr. Joao Schwarz da Silva)

Mayor's Welcome (by Dr. Gábor Demszky)

Chairman Welcome (by Prof. István Frigyes)

Foreword to the Proceedings of the 16th IST Mobile and Wireless Summit

This year, we meet for the 16th edition of the IST Mobile and Wireless Communication Summit. All those of us who have been committed to the development of the mobile industry over these last 16 years can be proud of what has been achieved. You probably remember that in the early 90's the most optimistic forecast would predict around 40 millions GSM users in Europe by the turn of the millennium. Today, we have almost 3 billions mobile terminals in commercial operation world-wide, with GSM representing more than 2.5 billion users. Prospects for mass market deployment of 3G technology are becoming real with the introduction of broadband technologies like HSPA.

More than 5 million jobs have been created in the world by the mobile industry, which is also permeating low income economies, hence bridging the digital divide and opening opportunities for novel forms of economic activities. Research and development, and notably European R&D have been at the heart of this success.

For the younger researchers that have joined the mobile community more recently, it is important to keep in mind that in spite of all what has been achieved, much remains to be done. More than ever, Europe needs their enthusiasm, innovation skills and unconstrained imagination capability to help this vibrant economic sector to keep abreast with the numerous challenges it is facing.

As digital convergence opens new horizons, future mobile systems will have to face at least three main challenges: the successful evolution towards effective broadband on the move, the adaptation to the new content and media usages, and the integration of the Internet technological and business landscape. The plenary sessions of this year will allow you to get the views of top players on these issues. Our colleagues from Asia will tell us how this dynamic region of the world is moving towards 4G broadband mobile systems. A second panel will discuss how Internet is likely to transform the mobile technological and business landscape whilst a third panel will address the impact of new media and content. Throughout the Summit, packed with interesting sessions and excellent papers, we will again have the opportunity to assess the latest results of FP6 projects.

Beyond these core themes, other innovative technologies such as RFID, NFC, MEMs or sensors associated to mobile technologies will pave the way to evolved machine to machine or device to device communications, beyond the classical person to person usages of today. New business perspectives will be unleashed and much greater levels of social networking will be achieved.

In the longer term, the ever growing demand for scalability, broadband, mobility, security, rich media content, flexible and personalised services and cost efficiency will impose a significant evolution of the underlying Internet architecture as we know it today. Other regions of the world have started to work on this issue. I am convinced that the European mobile industry and research community can continue to excel in this domain. These issues will naturally be at the heart of the ICT theme of the 7th Framework Programme for research and development with major financial support being provided by the European Union. As we are now completing the evaluation of the proposals submitted under the first call of this programme, I am confident that the resulting portfolio of selected projects will allow us to put in place a critical mass of world class research teams and consortia, eager to contribute to the emergence of a European approach on the "Network of the Future" with unconstrained mobility.

This edition can also be considered as a "premiere", as it is the first time that the Summit is organised in one of the 12 Member States that recently joined the European Union. Opening the mobile research community to our colleagues from the new Member States more than being a political requirement, is a unique chance to tap onto the imagination, ambition, skills and excellence of new fellow European citizens.

I am particularly grateful to the hosts and organisers of this year's Summit, and notably to Prof. István Frigyes, Prof. János Bitó and Peter Nagy who spared no effort to organise the 16th IST Mobile and Wireless Communication Summit in the beautiful city of Budapest. Let me also warmly thank all our plenary speakers, who managed to find a slot in their busy agenda to share with us their views on the issues at stake.

I expect that further to this conference we will collectively gain greater insight into the ways which our mobile and wireless future will be shaped. I wish you a very pleasant stay in Budapest and fruitful discussions during the Summit.

Dr. Joao Schwarz da Silva,
Director, Converged Networks and Services
DG-Information Society and Media
European Commission

Mayor's Welcome

Dear Madam and Sir, dear Participants!

I warmly welcome you on the 16th IST Mobile and Wireless and Communications Summit in Budapest. It gives me much pleasure that thanks to the request of the European Commission Hungary can be the first state among the East-European EU countries which can host this summit. This confirms that Budapest became one of the influential capitals of the EU.

Our everyday life is now unimaginable without the Internet. Be it work, studying, collecting information or entertainment, young and elder also use the web. However, we cannot be always in our office or at home, near a computer. With its own tools the Municipality of Budapest aims to help the gaining of the Internet out of the office or home. There are several wi-fi points in the city, and thanks to these - and with the help of a notebook - the web can be reached in restaurants, venues or sitting out in the green. The Municipality of Budapest aims at providing the e-customer service to the public as soon as possible, so the administration can become much easier and quicker in the city. Although these possibilities are obviously important and can be seen as an improvement, the leadership of the city is aware of the fact that development does not and could not stop at this stage, as together with the development of technology the need of the people also changes. Obviously, in the future information on the web can be gained with more up-to-date technologies and people will not necessarily need to be near a computer to use the Internet. In order to be active participants in the improvements it is important for us to have such summits in Budapest, where the experts discuss their ideas and mark off the road to the future.

I wish all the participants a successful summit and a pleasant time in Budapest!

Yours sincerely,

Demszky Gábor
Lord Mayor

Chairman Welcome

Welcome to Budapest!

It's a greatest pleasure for me, a great honour and proud for all of us: the Hungarian telecommunications providers, the manufacturing, research and development community to welcome the 2007 IST Mobile and Wireless Summit in our capital, Budapest.

About 300 papers were accepted in this year Summit. Authors come from 39 countries, from all continents; most of them, of course, from Europe. Their papers cover virtually all topics of mobile communications. The number of papers is to some degree indicative of the most important problems; networks, applications, business models seem to be these this time. General aspects of mobile, wireless and more general communications, their perspective their future are covered by panellists of three panels. And the very important enabling technologies of broadband wireless and integrated optical/wireless is covered by the keynote talk of Dr. Steve Weinstein. Two special sessions are organized to present North-American results and medical ICT. On the preconference day, Sunday, 8 tutorials can be followed, given by leading experts of their subjects. And on the post-conference

day, Thursday, workshops are organized; these are related to and organized by various projects of the FP programs or being close to these.

We are grateful to all institutions and persons having participated in the organization. The first among these is the European Commission; not only for its financial support but also for its help in organization. Our particular gratitude is to Dr. Joao da Silva. He was initiator of this series of conferences, 16 years ago; this time he personally organized the panel sessions. Due to his efforts leading persons of the European, Asian and also American telecommunications sector will express their views in three sessions. We are also grateful to our patrons for their financial support and to professional institutions for their - I would say - moral support as technical co-sponsors. And we are grateful to all of the authors having prepared good presentations, to TPC members and reviewers making possible to choose the bests among the very good contributions.

While the technical program of this Summit is really rather diversified we tried to keep in mind: what is sometimes called "scientific tourism" is mainly for science but, to a lesser extent, for tourism. So we organized a Danube cruise to show our city and its neighbourhood as seen from the "blue Danube". (I have to add: unfortunately it is not as blue now as it was in the days of Johann Strauss.) To have a short glance about Hungarian culture gala dinner is organized in the National Gallery; before the dinner you will have the occasion to a short visit of a part of the gallery, this time at its medieval section. By the way: the National Gallery being located in the old King's Castle is one of the points of the most beautiful view over Budapest. And we hope: you will have the occasion to see further natural and artistic beauties of our country.

Dear colleagues: participants, keynote speaker, panellists, committee members and accompanying persons: enjoy your stay in Budapest, enjoy the 16th Mobile Summit.

Prof. István Frigyes

Budapest University of Technology and Economics
general chair, 16th IST Mobile and Wireless Communications Summit

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