Mobility and multihoming possibilities in Network Layer, using smartphones

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***Abstract*—It was the first time in late 2010 when the majority of newly sold mobile phones in Europe were smartphones. These devices integrate more and more useful applications, which reach their full potential while accessing Internet. In this article the top mobile activities and some important areas with special needs have been collected and analysed from the viewpoint of Quality of Service, mobility and multihoming. Network layer mobility and multihoming solutions were investigated in terms of smartphones, which usually operate as client-only type mobile nodes. Mobility support for IPv4 and IPv6, Homeless Mobile IPv6, and some other third layer mobility solutions were examined to consider the Network Layer suitability of mobility and multihoming for client-only type mobile nodes.**

I. Introduction

These days, mobile phones are much more, than simple voice communication devices. Top smartphones provide large array of functions, with wide range of usability. The most interesting and important new features are: improved e-mail and messaging services, integrated social networking functions, navigation and location-based services, mobile games, multimedia solutions (like HD quality video recording, playback and sharing), and browsing with mobile broadband communication on larger screens with better resolution. And of course these devices extend the limits of voice communication with VoIP (Voice over IP) solutions as well. The role of cellular devices is continually transforming, and the most of the new services are based on network communication. For this reason the evolution of network management functions of smartphones is expected soon, extending the network software with some new features, like mobility and multihoming.

A. Smartphones

It was the first time in late 2010 when smartphones made up the majority of newly acquired mobile phones in Europe. In December 2010, 50.8% of newly acquired devices were smartphones. The growth was 69.7%, compared to the last year [1]. Because the diversity in smartphone usage is immense [2] and varies widely from region to region, it is almost impossible to make a global rank with the leading mobile activities. We can clearly see that people are still using their mobiles mostly to communicate with each other, but the way of communication is shifting day after day. In the last quarter of 2010 only the 13.5% of the EU5[1] mobile users used the voice communication only, 49.3% of them used the possibilities of SMS and MMS services. 37.2% accessed mobile media (browsed, accessed applications, downloaded content or used e-mail services). The latter is a very large and fast growing group of mobile users [1].

[1]Germany, France, Italy, Spain, and the United Kingdom

B. Top mobile activities

Based on a comScore report [3] sending text messages was the top mobile activity among EU5 users, with 82.7% share in the last quarter of 2010. Taking photos and capturing videos were also popular, however it is more interesting from the viewpoint of data mobility, that 41.1% of the EU5 mobile users used connected media (browsed, accessed applications or downloaded content) in the last three months of 2010. Besides text messages, e-mails, instant messaging, and social networking sites are gaining bigger and bigger share in communication with friends or business partners. The number of daily users using Internet on mobile phone has grown rapidly in 2010. Number of daily e-mail users accumulated by 52%, news and other information services access by mobile users increased with 65%, and the number of social networking users has doubled (+104%) since last year survey in the EU5 countries. For that reason web browser and advanced e-mail client are the key elements of any modern smartphone now.

Among the applications, mobile games popularization is significant, which is not surprising in the light of new mobile software and hardware environments. The hardware of today's smartphones integrates 3D acceleration in high-end models, and they are more powerful than the early Intel® Pentium® III PC-s. Using mobile phones as a "Wii-like" controller [4] with built in 3D motion sensors, mobile games become more and more popular. Many on-line games were extended with mobile clients last years, using the large, high resolution touchscreen of mobile phones, but recently network based (server-client or peer-to-peer) multiplayer games are also popular.

C. Special mobile activities

Besides the most popular fields of mobile phone activities and application types, there are some special areas which have special importance for smaller groups or need specific circumstances to work efficiently.

1) Remote login: Mobile phones with QWERTY keyboard and high resolution display are very useful devices for system administrators. With remote login they have the possibility to

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manage remote devices (servers, clients) without a notebook or desktop computer through the command-line interface (CLI). Of course these effectiveness is not comparable with computers using full size keyboard, but the remote shell's availability is more important than simplicity in many delicate situations.

2) Voice over IP: In the last few years, several new, Internet based services and applications appeared on the market, but Voice over IP (VoIP) was the most prominent one [5]. With VoIP our phone calls are transported through Internet, rather than public switched telephone network (PSTN). Nowadays, VoIP is the most cost effective way to make long distance calls, but frequently the local calls are also very cheap, or free of charge. Smartphones and IEEE 802.11 compatible mobile phones mostly have built in SIP clients (widely used application layer protocol to support VoIP) or we can download the necessary application to support IP based voice communication. Using the smartphone's WiFi interface, the client operates independently from the mobile network, but a 3G (3.5G) or 4G mobile network is also sufficient to handle the transfer requirements of a VoIP call in expected quality. Thanks to the popularity of wireless networks, the radically growing service areas and decreasing cost of mobile broadband, the proportion of VoIP calls is increasing every day, and not only in office networks, but on mobile clients as well. In cellular networks the share of IP based voice calls is continuously increasing at the expense of GSM calls, but at the same time the popularity of voice based communication is generally reducing.

II. Quality of Service, Mobility, Multihoming

In this section the importance of Quality of Service (QoS) parameters and the relevance of mobility and multihoming possibilities have been specified in top network activity fields. We focused on mobile phones, especially on smartphones, where the QoS requirements are differ in some cases form the needs of notebooks or desktop computers. Table I represents the collected result.

	Web access	E-mail	Content up/download	Instant messaging	Network games	Remote login	VoIP
Bandwidth	◐	◑	●	○	◑	◑	◑
Delay	◑	○	○	◑	◐	◑	●
Jitter	○	○	○	◑	◑	◑	●
Reliability	●	●	●	●	●	●	◑
Mobility	○	◑	◑	◑	◐	◐	●
Multihoming	○	◑	◑	◑	◐	◐	●

○ Not Important ◐ Somewhat Important ◑ Important ● Very Important

TABLE I
IMPORTANCE OF QOS, MOBILITY AND MULTIHOMING

A. Quality of Service

Quality of Service (QoS) describes the needs of a flow, usually with four primary parameters: bandwidth, delay, jitter, and reliability. Considering the nature and the limited hardware resources of smartphones, the QoS parameters might be different from mobile or desktop computers in some cases. There is no difference in reliability, where the goal is to deliver each bit correctly to the destination, independently from the client's nature. However in some special fields like VoIP, reliability is not essential, some lost or damaged packet does not cause problems.

The classic Internet services are not delay sensitive, but network games and VoIP is. It is important to know that the latency in cellular networks is usually much bigger than in wired or 802.11 wireless networks, therefore to maintain this value under the acceptable quality level in sensitive fields, is a bigger challenge than in other popular networks standards. In a few years Long Term Evolution (LTE) with less than 5 ms small packet latency and the next generation of mobile networks will eliminate this diversity. The increasing delay is rarely a problem using smartphones when accessing a remote CLI, because the user cannot use the smartphone's keyboard fast enough to notice the delay. Typically, jitter can be problematic only with VoIP solutions, where the irregular time intervals between packets are hardly manageable with restricted potentials of buffer use in this field.

Finally, the listed network activities differ in bandwidth needs, content up- and downloading require the biggest value. Interesting tendency, that download is not dominating considerably, though most of mobile data networks offers faster download speed than upload. On one hand the limited storage capacity of these devices, on the other hand the increasingly popular social network shares (mobile picture and video uploads) make this rate different in the smartphone segment.

B. Mobility

Host mobility is a relatively new problem, which did not appear at all in the development stage of Internet. The most commonly-used IP routing mechanism is based on the IP packet's destination field, using the network part of the IP address, which means that the host cannot use the same IP address in different networks. For this reason mobility management is a very complex objective, and does not belong to only a single layer. Both in OSI and in TCP/IP model, we have the chance to find the best layer to implement mobility support to the specific task, service, or field.

Mobility is even more difficult if not only the hosts are mobile, but also the router. This type of ad-hoc networks requires more complex routing mechanism [6], but smartphones usually move in a fixed network infrastructure.

If mobility covers only a small geographic territory in the same subnet, we are talking about *micro mobility*. In this case the Link Layer support is sufficient to change for example from an Ethernet network to a wireless solution. Roaming between access points of the same subnet also easily manageable in the second layer. But in case of changing subnets, the bottom layer where the mobility handling might be possible, is the Network Layer (called Internet Layer in TCP/IP stack). Of course, the Link Layer – placed one level lower – support is also necessary (but not sufficient) to a working *macro mobility* solution, what we really need to support mobile devices like smartphones.

Mobility includes the process by which an active Mobile Node changes its point of attachment to the network, which is called *handover* or *handoff*. There are different types of handovers, but to minimize the interruption to sessions in progress is a priority. With seamless handover there is no significant degradation in service capability or quality, and the handover latency is minimized. The main goal is to make the network changing process transparent from the application side. [7][8] In some special fields, like VoIP, to hide the process from the users is even more complicated.

C. Multihoming

To have a reliable VoIP availability on our cellular phone, a continuous, stable data link is essential. This is very hard to provide, because the client device is moving together with the subscriber, through many heterogeneous networks each day. To stay continuously connected the capability for mobility is not enough in itself, we need to build up a new connection earlier, than we disconnect from the last used service area. To reach this, we have to handle more than one globally routable address at the same time, which is called multihoming.

However, mobile broadband is not the optimal solution in many situations, but in most of the areas where the continuous connection is usually necessary, mobile broadband is accessible as the primary or secondary link of mobile devices. If we are indoor and the mobile broadband coverage is poor or useless, we usually have the possibility to switch to a local WiFi network. This step is recommended in addition, to get higher bandwidth, better Quality of Service (QoS) parameters, and reduced energy consumption even if the mobile services are still appropriate. Another important aspect, that using local wireless networks is generally more cost effective than mobile broadband.

Obvious, no-one needs this type of continuity for every application. If the phone downloads e-mails or refreshes the weather forecast in the background, the fail of the connection does not cause a problem. If the system software detects the next usable network, it will connect to it, and the download process will start again, and maybe the user will take no notice of the restarted operation. But if we have an ongoing business call via VoIP, or we get a big raise in the on-line poker room, a lost connection is very annoying. When moving across networks, the only way to keep connected in these delicate situations is to belong more than one communication network at the same time with multihoming. If any of the links fail, we still have the second or backup line. This is only one of the possible advantages of multihoming, which does not only belong to server environment anymore. Connect to more than one home network at the same time would be very useful at the client side in many other situations as well.

III. Mobility and multihoming in network layer

The Internet Protocol (IP) nowadays unquestionably the most important protocol of the Network Layer. The original Internet Protocol (RFC 760 [9], obsoleted by RFC 791 [10] in 1981) has been designed over 30 years, but the issue of mobility was not taken into consideration at that time. In 2002 RFC 3344 [11] extended the original IP (version 4) with mobility support, and the revised version of IP mobility support for IPv4 (RFC 5944 [12]) was just released in the end of 2010. This revision clearly shows the importance of IPv4 mobility, despite the fact that IPv4 reached its limits when IANA distributed the last five "A class" address blocks to the Regional Internet Registries at early 2011.

A. IPv4 mobility

The main problem with network layer mobility is the dual function of the IP address, which has two separate parts. The host part identifies the individual host, and the network part identifies the network the host is member of. When the mobile client does a vertical handover and connects to an other provider, it has to use different IP address, as a part of the new network. Consequently a Mobile Node (MN) can have a permanent and portable IP address, which is usable globally, in every segment of Internet neither. Without this unique and permanent identifier it is impossible to initiate a new connection to the MN. To handle this, we can follow the addressing structure of *IP Mobility Support for IPv4* (RFC5944) recommendations.

1) Home and Care-of IPs: This type of network layer mobility uses two different IP addresses to each MN. The Care-of Address (CoA) belongs to the Mobile Node's actual network, and the Home Address is always in the home network's IP range. The connection between the two addresses has been made by the Home Agent (HA), which handle the binding between the actual value of Care-of Address, and the permanent Home Address of the Mobile Node. To keep this binding up-to-date, the MN has to inform the HA every time with a Binding Update packet, when the CoA of the mobile client changes. The Corresponding Node (CN) can send packets to the MN through the HA, using the Home Address of the Mobile Node. In this case the Home Agent is intercepting the incoming traffic arrived to the Home Address, and tunneling it, using the actual CoA value (which could be the *co-located care-of address* of the MN or the *foreign agent care-of address*) of the binding as endpoint [12]. In the reverse direction, the packets from Mobile Node to the Corresponding Node are usually routed by the Foreign Agent (FA), using standard IP routing mechanism, without passing through the home network or the HA (Fig. 1).

As you see from this packet flow, the routing is asymmetrical and the outgoing traffic of the CN's is not optimal either, because all datagrams destined to the mobile node are

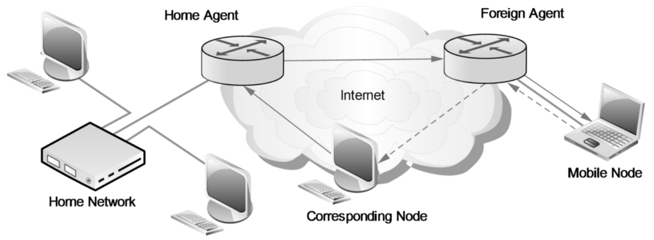

Fig. 1. IPv4 mobility packet routing

forced to be routed through the Home Agent. The packets sent by the MN are routed on the basis of the destination address of the CN, which will result normal path selection and best route between the MN and the CN. The different paths result triangle routes between the CN, the HA, and the FA, as you see in Fig. 1. Because the incoming and outgoing routes are not the same, triangle routes usually lead to different throughput and dissimilar response times between the incoming and outgoing traffic, especially when the CN and the MN are close together but many hops from the MN's home network (e.g. the CN and the MN are VoIP capable smartphones in the same subnet in Budapest, and the HA is in Tokyo). In general with this topology the latency of one direction is increasing, and the bandwidths are usually different as well. On account of the asymmetric directions and non optimal route caused unwarranted delay, this mobility technique does not fit to all examined smartphone activities.

Another problem may occur when the MN sends a packet to the CN, using the Home IP Address in the source field of the IP header. This is topologically incorrect, and if the datagram sent by the MN indicates the home IP address as source in a foreign network, the firewalls of the routers might drop the packets, based on ingress filtering rules. In this case, when the standard IP routing mechanism fails, the FA tunnels back the packets received from the MN to the Home Agent, which forwards the packet to the CN with the Home Address of the MN, in accordance with the network topology (Fig. 2). This feature is called *reverse tunneling* [13].

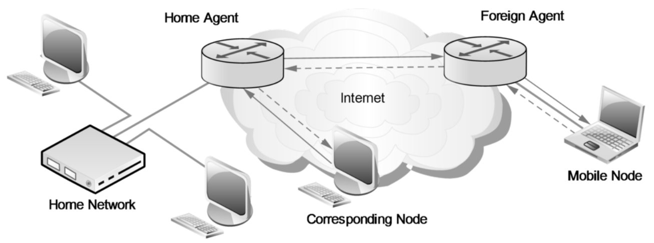

Fig. 2. IPv4 mobility reverse tunneling

Reverse tunneling solves the ingress filtering issue and eliminates the asymmetric routes, but the route is still not optimal, and the round-trip delay time continues to increase in both directions. With the nonstandard *Route Optimization in Mobile IP* extension [14] the potential of the base protocol was extended to allow more efficient routing operations, such the possibility of sending the IP packets to a Mobile Node directly from the Corresponding Node, without passing trough the Home Agent first. Using this Internet-Draft, the triangular routing is mostly eliminated, however the initiation process continue to use the Home Agent. From that point when the HA sends a Binding Update (BU) message to the CN, with the Care-of Address of the MN, the CN can send the IP packets directly to the MN, addressing datagrams with the CoA. However this solution is only an extension, and not a standard, many hosts are not prepared to handle BU messages. These Corresponding Nodes have to use the HA to forward messages to the Care-of Address.

But all this is not enough to a well working global mobility solution for mobile phones. With IP mobility support for IPv4 the client has to belong to a dedicated Home Network, which is not ordinary in case of smartphones. Since mobile Internet providers does not support this type of mobility, the Home Agent of the client can operate only in a private network, like company networks, which is not accessible for personal use. The other problem is that we have to deploy Foreign Agents to each foreign networks as well. This supposes that we have influence on all foreign network's behavior, which is impossible with today's internetworking. To find the optimal solution, we cannot dedicate a primary or only one home network, which is always reachable. With the required implementation, application data must reach endpoints without crossing any dedicated node or network, and the MN has to be capable of operating without any other special entity.

B. IPv6 mobility

Mobile IP support in IPv6 (Mobile IPv6) is based on the opportunities provided by IPv6, and also uses the experiences achieved with the development of Mobile IP support in IPv4. The main difference lies on the base protocols, because IPv6 is designed for today's challenges with mandatory support for network layer security and mobility. The proper base and the integrated features of MIPv4 offer many improvements on the mobility support. Mobile IPv6 operates in any location without any special support (Foreign Agent) from the router of the foreign network. The route optimization is a fundamental part of the protocol, which avoids triangular routing, making Mobile IPv6 as efficient as the original IPv6. Route optimization can operate securely with strong authentication and encryption features, and efficiently, even with routers that use ingress filtering [15]. However the HA is still necessary to realise a working mobility solution, which does not meet the nature of everyday smartphone use, where these devices are almost always client-only type hosts, without any home agent support. The other insufficiency of IPv6 is the lack of any standardized multihoming support, without which no vertical handover can pass undetectedly in some fields, like VoIP.

C. Homeless Mobile IPv6

Homeless Mobile IPv6 (HMIPv6) is a backward compatible variant of Mobile IP Support in IPv6 protocol, which provides mobility and handover support for hosts without any permanent home address. HMIPv6 allows the applications to maintain transport and higher-layer connections when a host changes its IP address as a result of a handover or simple network change. The difference is that the connections are not maintained by hiding the actual IP address (CoA) of the host with a permanent Home Address, HMIPv6 uses a local host cache, which contains a set of local IP addresses, and any of these IPs can be the source address of outgoing IP packets. [16]

The last version of Homeless Mobile IPv6 draft expired in September 2001, and left several issues open. First of all, HMIPv6 is not backward compatible with some applications, where the IP address is stored for a longer time or also used in higher layers. The cache entry creation policy is not clarified, because only the upper-layer protocols can decide that a cache entry should be trusted or not. And finally there are some special cases, where address confusion could occur [16]. The lack of full backward compatibility is not the most serious problem, because these types of applications are usually old-fashioned – working with lower layers identiers, assuming that identiers will be unchanged during the whole connection – and should be updated soon. However the lack of a proper cache entry creation policy and the possibility of address confusion are potential sources of a number of security vulnerabilities.

D. Alternative host identification techniques

It is clearly seen, that most of the third layer mobility problems lie on the dual function of the IP address. IP Mobility Support for IPv4 and IPv6 try to overcome the relating routing restrictions, but some other research use fundamentally different approach, overshadowing the IP address with new unique host identifiers.

The end-to-end approach of Snoeren and Balakrishnan [17] is based on dynamic updates to the Domain Name System (DNS) to follow host location, and uses the Fully Qualified Domain Name (FQDN) as the changeless name of the mobile host [18]. This solution uses Dynamic Updates in the Domain Name System [19], when the A and the PTR records are updated each time in the DNS server of the mobile host's home domain when the MN moves. With this approach we have to prevent DNS caching with zero TTL values, which means the Corresponding Node has to do a DNS lookup every time when initiating a new session. If we use client-only type smartphones, no DNS record is necessary, but the migration from an old IP address to a new one, which is the key element of this solution, is difficult to attain nowadays. This migration is realizable in upper layers only, but today's popular transport protocols, like TCP, are not supporting this kind of mobility.

The Host Identity Protocol (HIP) uses a new namespace, the Host Identity namespace. The Host Identity has two main representations, the full Host Identifier (HI) and the Host Identity Tag (HIT), where the HI is a public key and represents a globally unique identity for any IP host, and the HIT is a 128-bit representation for a variable length Host Identity [20][21]. Using a public key, instead of IP address (which is used for routing only) as the host identity, the HIP architecture decouples the transport layer from the network layer, which opens the door to hide the IP address changes during mobility from above layers, creating a new possible solution to network layer mobility and host multihoming [22]. To reach frequently moving mobile hosts, HIP uses the rendezvous mechanism, where the rendezvous server (RVS) plays similar role like the Home Agent in IP mobility, and handles the current HIT and IP address mappings [23].

IV. Conclusion

After analysing the most popular Network Layer mobility techniques, we have clearly seen that these solutions are designed for different type of mobile nodes. Client-only type smartphones do not need globally usable addresses, because these devices are mostly not open for incoming connections. If the communication between the Mobile Node and the Corresponding Node is initiated by the MN, we only need to handle mobility after the establishment of the connection to keep the link alive when the MN is moving. Because of the dual role of the IP address, the fact can be laid down that network layer mobility using IPs always needs a special entity (like Home Agent) which can guarantee the possibility for a CN to reach the MN independently from the MN's current address and network. On other hand, a new, globally unique identifier (like HIP's Host Identity Tag) can solve this problem, but these solutions need the cooperation of the upper layers. Because the Transport and/or Session Layer's support looks essential to manage multihoming and Network Layer changes during mobility, a survey for Transport and Session layer mobility for client-only mobile nodes would be reasonable.

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