Wireless Internet Architectures: Selected Issues[1]

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Abstract: After discussion of both: basic issues related to wireless data transmission and internet principles we identify and discuss fundamental problems of their merge. Following this discussion a vision of a specific approach and architecture for organizing wireless internet access called AMICA is outlined.

1. INTRODUCTION

Usage of internet services not only becomes a habit, in fact both in their professional and everyday life people become increasingly dependent on the access to these services. Or might achieve significant profit – both in the business and quality of life sense – if such access would be possible frequently enough. In fact, there are good reasons to consider moving all the communication solutions to the internet platform. Wireless transmission technologies have definitely a potential to contribute to the deployment of easy accessible, flexible internet access. The merger of wireless transmission with the already established internet paradigm appears, however, to be more complex than it might have been expected at the first glance. Therefore this merger is recently one of the hottest research topics in the area of telecommunication networks. In order to focus our discussion let us start

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with an informal, intuitive definition of the notion of wireless internet access.

For the sake of simplicity let us constrain ourselves to a very classical kind of terminals: just laptops or personal digital assistants. Let us also assume, that terminals can use some kind of digital wireless transmission to/from another device, called further an access point, being in turn connected to the world-wide internet using fixed lines. We assume further that the real data exchange takes place in periods called further sessions, separated by idle periods. Initiation of each session will be mostly triggered by terminal itself, but might be also triggered by some other systems, called corresponding systems.

Our further considerations will be structured as follows: In section 2 we will discuss some basic scenarios and identify major general differences between wireless and wired access. In section 3, we will recall basic internet paradigms, consider what are the implication of introducing a wireless hop in internet, and discuss the different possible meanings of the notion of internet access. Finally in section 4 we will outline AMICA - our specific system vision, with special attention being paid to the transport layer services.

2. WIRELESS ACCCESS

Let us first introduce three different scenarios for the usage of wireless access in general:

In the first scenario, which we will refer to as **basic wireless access** the motivation for using wireless technologies is mainly avoiding installation of cable, which might be kind of cumbersome. In this scenario terminals can be moved exclusively within the range of a single, always the same access point, and the movements are slow (if any)[2]. Let us think here for example about a swimming pool area, or just university courtyard. On the other hand, even using the terminal at home (say in ones favorite armchair, or at the kitchen table) gives good reasons for wireless transmission. One could consider this variant as generalization of cordless telephony. The major challenge in this case is assuring the proper quality of service to the terminal. Numerous wireless transmission technologies are already available, or will

[2] The transmission range might be, technology depend, short or large. By the way: wireless access is attractive also in the case of no movement at all- this case is in the classical telephony referred to as the WLL- wireless local loop. Due to fixed positioning of the terminals relative to the access point several techniques for improvement of the quality of signal might be applied. We will not discuss this case in depth in this paper.

soon become available, for the support of such scenario: Wireless LANs, Bluetooth, IrDA belonging to the most frequently mentioned ones.

In the second scenario, which we will refer to as **nomadic wireless access** the terminal is expected to be moved over distances essentially exceeding the transmission range of a single access point. It is assumed, that multiple access points will be deployed over some area (which might be a building, a campus, a city or a continent) creating islands of connectivity around these access points. We assume for this scenario that terminals may switch between the access points only between the consecutive sessions. This movement takes usually times which are long as compared to the session duration (one might think here in the terms of a scientist visiting in turn several universities). In fact there are no hints in which location – close to which access point – the terminal might appear after movement[3].

Let us stress that multiple parameters like supported bit-rate, error rate, the maximum speed of mobility and the supported range around the given access point are in general not identical even among individual access points supporting the same technology (due to static or dynamic set-up differences). Assuring a simple set-up in the new environment seems to be a major challenge for this scenario (different access points in distant locations might even support heterogeneous technologies). An additional challenge is assuring reachability under the original address in the actual, temporary environment as well as security considerations. This problem is frequently referred to as roaming.

Finally in the third scenario, which we will refer to as **true mobile access**, dynamic changes of the supporting access point during a session, usually referred to as handover, are expected to appear (possibly even several times during a single session). For mobile access to be attractive, the deployment of the access points should be more dense as for the nomadic wireless access, usually a significant (although not necessarily all) part of the area will be in the range of at least one of these access points. We frequently use the notion of coverage while referring to the ratio of the area being within the range at least one access point to the whole area under consideration. In this scenario.

The grade of service continuity in spite of handover is one of the essential quality features for this scenario. Continuity of service might be expressed in terms of no information loss during the handover, sometimes even so called seamless handover, i.e. handover not observable by the user at

[3] It should be pointed out that the principle of nomadic access is in general NOT necessarily to be discussed in the context of wireless communication, nomadic computing can be also considered using wired transmission. It seems, however, that wireless transmission might encourage broader deployment of nomadic computing- think for example in the terms of passengers in airports or scientific conference participants

all, is required. This requirement might result in a necessity for the terminal to remain during the handover in the range of both participating access points. In any case the requirement for frequent, possibly interruption-less handover implies usually a homogeneous system concept in which all the access points (and the end-system) are incorporated. In addition it seems almost natural (although not necessary!) to assume that also the transmission techniques will be always unified. In fact this is the case for the majority of solutions deployed or considered today, like GSM, GPRS or the emerging UMTS.

WIRELESS ACCESS DESIGN ISSUES

During the discussion of wireless access scenarios, we have referred several times to the range/coverage issues. In fact it might seem that the general design goal might be developing of technologies supporting possibly high bit/rates within a possibly large range. We will now discuss reasons why this is not the case:

Any wireless communication uses a given band of frequencies which – according to basic communication theory rules – has to be proportional to the targeted bit-rate. This band is shared with any other device (not necessarily communication device!) which can emit frequencies belonging to this band within the same area[4]. With some simplification one might think of a frequency spectrum in a circle defined by the transmission range in the terms of a single precious resource, which might be shared, but not multiplied. A notion of system capacity, expressed for a given frequency band in (Mbits/s)/(Mhz*square_mile) is frequently used. Assuming a constant range, there is an obvious trade in usage of a frequency band between the number of users and the bit-rate available for each of them.

Increasing the capacity – for example to support a higher number of users with given bit-rate and quality within a fixed range around an access point is achieved usually by acquiring additional frequency bands. This is not simple from the regulatory point of view, and in any case expensive (see the recent press news about frequency auctions for UMTS). This is an essential difference as compared to the case of fixed networks, where capacity can be increased in an (almost) unlimited way just by deployment of additional cables (mostly LWL).

Obviously one can alternatively achieve an increase of wireless system capacity by reducing the radius of connectivity. Note however, that assuring constant coverage in spite of radius reduction leads to dramatic increase of the number of required access points, in addition supporting true mobile

[4] The usage of any band of frequencies has either to be licensed for a given type of equipment or even operator, or subject to specific rules of spectrum sharing in unlicensed mode (so called ISM bands)

access unavoidably increases the handover frequency. Another option for increasing capacity is using some kind of spatial discrimination (that means communication in only some directions), with the progress in smart antennas research [21] this approach should become increasingly attractive.

Finally, the aspect of size and energy consumption is usually important in design of mobile terminals. In fact both the energy consumption during active transmission as well as energy consumption while remaining just ready for receiving have to be strongly limited. The former can be achieved by decreasing the range of communication (which is somehow in line with the phenomena discussed above) or – within acceptable limits – by decreasing QoS (mainly bit-rate and error rate as resulting from lower signal-to-noise ratio). The later one can be achieved by putting the end system temporarily in a „sleeping" mode during which the device is not available for communication.

Last, but not least, the clear trend to support communication with huge number of small devices causes strong pressure for low cost solutions.

Because of the essential differences in the bit-rate/range/power/QoS combinations supported by different technologies on one hand, and the strong push for high economy of spectrum usage (see the recent frequency spectrum auctions!) on the other hand, the diversity of deployed technologies will remain quite impressive. Thus we assume, that a single terminal will have to be able to use alternatively one out of multiple different technologies. In fact as one of the first steps in this directions mobile phones, able to switch between DECT cordless and GSM cellular have already being constructed. Technically this might be achieved by using multiple radio interfaces, however the more attractive option is offered by following the soft-radio concept [22].

3. FUNDAMENTAL ISSUES OF WIRELESS INTERNET ACCESS

First of all we have to decide what we really understand under the term internet access, a concept being recently used in several different ways, and discuss what makes the wireless access/mobile access so different.

Let us first recall the real fundamental concept of internet, following US Federal Networking Resolution from October 24 1995 [13].

"Internet" refers to the global information system that:

(i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;

(ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP-compatible protocols

(iii) provides, uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein

Let us stress in context of this definition a couple of issues important for our further discussion.

ad(i) IP Addresses have a hierarchical structure: their bind the end-systems (hosts) to a cluster called class A, B, C network. This feature is very useful for hierarchical routing: the global routing is concerned only with identifying the route to the proper network, establishing the route to the individually addressed hosts within the proper network (or- more frequently to some smaller clusters – sub-networks, like a classical ethernet) is a local issue. This does, however, imply that the hosts can (without additional measures) be only reached by IP packets if it remains within the proper network.

ad(ii) The Internet concept supports a model of non-controlled resource sharing. At the IP level, being the common denominator, there is only one, very limited approach to overload avoidance: just dropping packets. Which might cause their retransmission, or loss of larger application units. It is frequently overlooked, that the basis for stable operation of the internet is the TCP congestion control. This works fine, as long as TCP traffic remains the prevailing part of the total internet traffic. Recently a lot of research efforts aim at developing solutions for enforcing a similar behavior from UDP based applications (see [16]). In fact even an idea of introducing for each end-system a kind of universal „congestion manager" controlling the total amount of data transmitted by this end-system into the internet has recently been presented [2].

ad(iii) The fundamental Internet Protocol- IP addresses only the whole end-system, in fact we would mostly like to address individual processes. This granularity, jointly with additional error recognition is given by UDP (for the delay sensitive error non-sensitive applications), while granularity jointly with reliable delivery is supported by TCP (for error sensitive, delay non-sensitive traffic): the two transport layer protocols operating on top of IP. In effect essentially all the applications operate on top of TCP/UDP rather than IP and know nothing about the protocol operation.

Applications do not see protocols, they see a service interface. In the case of internet, these are predominantly sockets; applications use just UDP and TCP sockets. It is commonly accepted fact, that establishing and widely deploying the socket interface contributed essentially to the growth of amount and diversity of internet applications.

CONNECTING THE END SYSTEM VIA A WIRELESS HOP

As the internet model intentionally avoids any assumptions about how the IP packets will be transported and IP packets are – by definition – forwarded on a best-effort principles, there are no design rules which possible level of link quality might be acceptable or non-acceptable. Thus it is assumed that IP packets should be transportable over any kind of medium. So why should we care especially about usage of wireless communication technologies for accessing the internet? What makes wireless so different?

Due to the nature of the wireless channels, their are essentially more error prone than their classical wired counterparts. Not only is the mean bit error rate generally higher, but the error rate is fluctuating. The most straightforward looking remedy of just introducing a reliable link layer protocol with ARQ error recovery can only shift the problem, as ARQ translates bursty packet losses [24] into significant additional variable delay.

In the wired links packet losses caused by transmission errors are very rare. Therefore it was only reasonable that in course of the internet development end-to-end packet losses (as well as delay variations!) became a synonym to congestion in the nodes (routers). In fact the already mentioned TCP congestion control, crucial for healthy operation of the internet, uses late /missing acknowledgement discovered by time-outs as the congestion indication.

So we can conclude that the adverse influence of a wireless link in terms of packet losses and/or delay variability dominates the characteristic of the end-to-end packet transfer. As the result TCP will keep executing its congestion avoidance functionality in a „pessimistic" way: the stability will be assured but with a (possibly strong) decrease of the transmission speed as seen by the application (see [4] for extensive discussion of this effect). Which is very bad in case where the bit-rates are anyway lower in comparison to the wired counterparts. In the context of the earlier comments on required TCP –friendliness of UDP traffic, this pertains also to all "well behaving" UDP traffic.

But not only the loss of packets during transmission creates a potential problem for the internet operation. Handover causes in general delays/interruptions of the packet flow, which might again influence TCP operation [6].

Talking about handover we have to stress also another fundamental issue. As mentioned in comments to (iii) earlier in this section, the hierarchical routing based on hierarchical nature of IP addresses implies that with change of a location and joining another network (in the internet addressing sense!) a new, topologically correct IP address has to be additionally assigned to the mobile host. And – in order to support the availability of this host under the old address, special measures have to be activated, for example following the mobile IP pattern (See [25] for discussion of these issues).

WHAT DOES INTERNET ACCESS REALLY MEAN?

Traditionally, providing internet access could be interpreted as requirement for the configuration of the terminal as the internet host with whole TCP/IP protocol stack and thus with ability to exchange IP packets with the access point. We have already pointed out essential performance problems appearing in this variant, which we will call the **Internet Endsystem Access**. Extensive research activities are focused on development of TCP modifications [14], however convincing proof of their efficiency is still to be provided. In addition the idea of modifying TCP according to features of the physical link is not really in line with the internet philosophy. Alternatively solutions with cross-layer information exchange (loss indication [23] or booster type support [3] are considered.

But these traditional approaches are not the only ones! The internet definition recalled at the beginning of this section opens a wide spectrum of possible interpretation of the notion of internet access. In fact the key statement “makes accessible higher level services” is of key importance.

In fact end-users are usually interested only in high level services: either the standard ones– mostly WWW access and e-mail – or even some services developed especially for a dedicated class of users (like for example specific e-commerce systems) rather than direct utilization of the communication services. This variant will be referred to as **Internet Service Access**.

A good example of a solution following this way of reasoning is the recently deployed WAP protocol stack [15]. The application software installed in the end-system is not able to contact directly WWW-servers with the classical http protocol, but has to use a special translation server, instead. This allows to use between the end-system and the translation server a set of „lean“ protocols, in case of WAP optimized for usage on links with low bit-rates, and thus well suited for today GSM wireless access. Major disadvantage of such architecture is a break of the „uniformity“: not only different protocols have to be used, but also applications have to be developed separately. Assuming that a WAP terminal could have a higher speed wireless connectivity besides of the GSM (say WLAN connectivity), it still would not be able to communicate directly with www-servers.

It is out of the scope of this paper to discuss extensively other possible variants of interpreting the notion of wireless internet access in the scope of the basic internet definition. One peculiar approach which we consider the most advantageous: the Remote Sockets approach will be shortly discussed within the AMICA concept.

4. AMICA SYSTEM VISION

After this initial discussion, it seems to be obvious, that there is a huge multidimensional space of choices in organizing wireless internet access, and behind any reasonable set of solutions there must be a consistent vision of the requirements and system concept. Several interesting approaches can be found in the literature, see for example [12][20][1][19]. We will now introduce our vision- AMICA: Adaptive Mobile Integrated Communication Architecture.

BASIC ACCESS ISSUES

We believe that it is important to organize the basic access which satisfies the following requirements:

- Only the communication layers should be involved in adjustment to the wireless technology. In line with the comment to (iii) in section 3 this means that we insist on keeping the TCP/UDP socket interface, with unchanged service semantic, available for applications running in the terminal.
- As there are essential differences between the features of the wireless hop and the fixed backbone, there should be the possibility to design and implement totally independent mechanisms for error control, flow control and congestion control for both these parts.

In line with this requirements we have developed the Remote Socket Architecture (ReSoA), presented in the case of TCP in *Figure 1* in comparison with the "classical" approach discussed in the previous section.

The basic idea (see [18] for details) is to move the TCP protocol engine from the terminal to the access point, and use on the wireless part a two-layer protocol structure consisting of **the export protocol** (EXP) and the **last hop protocol** (LHP) to make the socket calls available in the terminal. The design of EXP is wireless technology independent, the goal of this protocol is twofold. On one hand the remote execution of socket calls has to be assured. On the other hand this protocol has to be coupled with the TCP protocol engine in a proper way, assuring that the socket call semantic will remain unmodified. We can achieve that by careful distinguishing between the TCP protocol semantics and the socket service semantic, being the refinement of the earlier. Let us explain the difference using the example of the "send" call issued by the corresponding host in the "classical" architecture. In fact, the issuing application will return from this blocking call as soon as data associated with this call will be copied in the buffer of the TCP engine at the corresponding host. This is totally de-coupled from the reliable operation of TCP- at this point in time a proper TCP segment has not even been send! So how can the sending application profit from the luck of TCP acknowledgement (i.e. TCP reliability) in case of difficulties in passing data over the wireless hop? Well a “send” call pertains in TCP always to some already opened, existing connection. If there will be problems in sending some data, either the connection would be aborted, or a requested later graceful connection close will be denied. Both these events would mean that data send over this connection can not be assumed as reliably delivered.

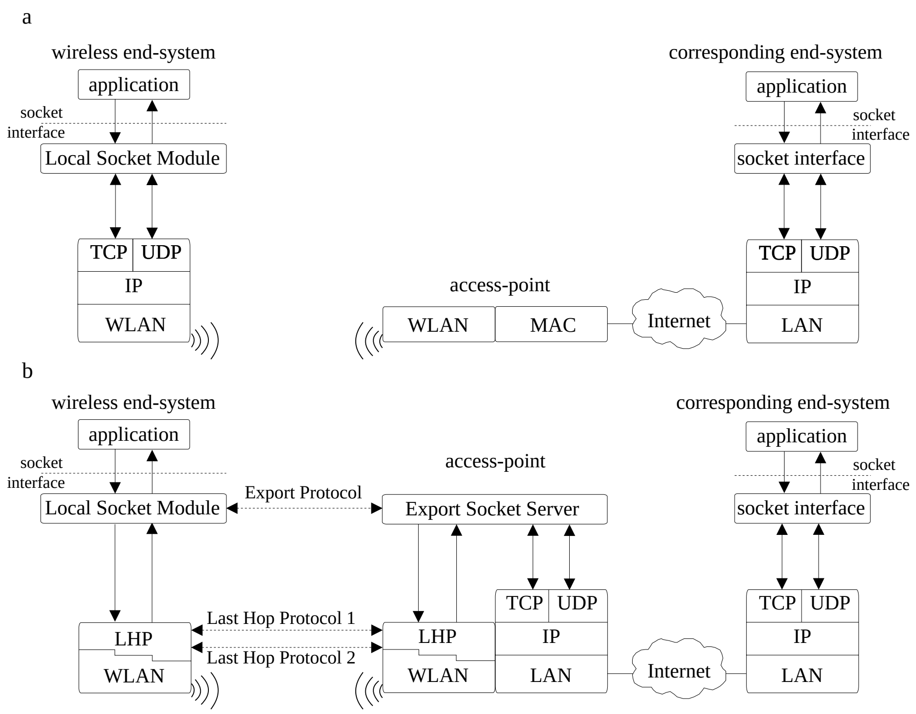


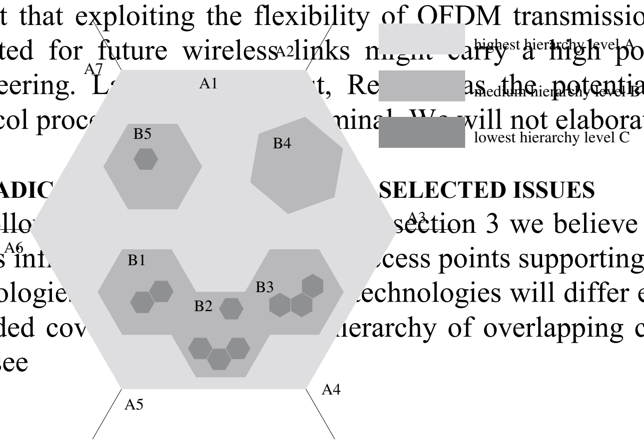
Figure 1. Wireless Internet access using ReSoA

Now, in the case of ReSoA the TCP engine in the corresponding host might get an acknowledgement for the data segment which has been received by the access point, but could not be transferred to the terminal. But the proper coupling of the Export Socket Module of EXP with the TCP engine in the access point will make a graceful close of the TCP connection impossible. Permanent troubles in connectivity between the access point and the terminal might also cause aborting the TCP connection. We believe to have demonstrated with this example the possibility of providing socket service semantic equivalence.

LHP has a different role. This protocol covers the functionality of link layer (including MAC) and is in any case wireless technology dependent. But in addition to that, we believe that spectrum utilization can be maximized, if QoS requested from the wireless link will be adjusted most closely to the real QoS requirements of individual flows. This is difficult in the "classical" architecture, as all IP packets are equal, the situation might improve if QoS supporting architectures, like DiffServ will be agreed upon and supported in wireless links. But in ReSoA we have the possibility to use at least port numbers, and probably additional information available at the transport service interface, in order to differentiate the QoS requirements of individual flows. Different LHP support of TCP flows (reliable LHP) and UDP flows (limited reliability, limited delay) might be a simple example.

There is a huge potential of LHP optimization from different points of view namely QoS support, spectrum efficiency and power saving for the mobile which we follow in a set of research activities. Among others we are investigating optimal use of CDMA type channels (see for example [10][9] for the idea of reducing jitter by using multiple parallel codes for transmission of a single flow), IEEE 802.11 channels (see for example [7] for energy optimization).

Internet end-systems generate usually a strongly asymmetric traffic: majority of the end-systems using high level services get much more data than send, quite a few acting as servers (or sources of data streams – like remote cameras) generate much more data than receive. Knowledge of such traffic patterns can also be mapped on the link layer design. Particularly we expect that exploiting the flexibility of OFDM transmission, being widely accepted for future wireless links might carry a high potential for LHP engineering. L... t, Re... as the potential to reduce the protocol proc... minal. We will not elaborate this idea.



NOMADIC ... SELECTED ISSUES

Follo... section 3 we believe that the internet access in... cess points supporting very diversified technologie... echnologies will differ essentially in the provided cov... ierarchy of overlapping cells of different size, see

Figure 2. Note, the smaller cells will usually not provide complete, 100% coverage of the surface of the overlapping larger cells.

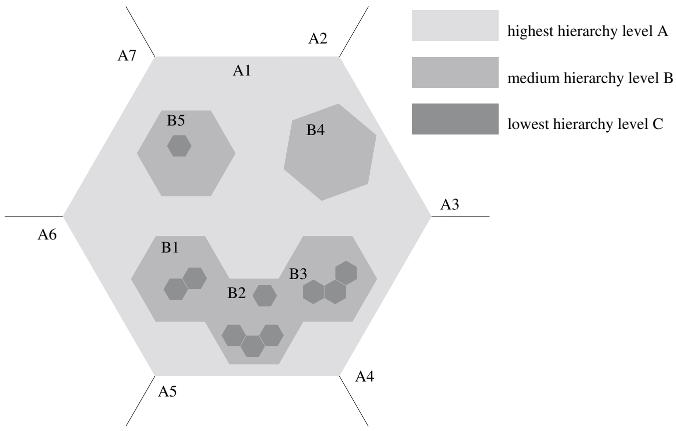


Figure 2. Hierarchical Wireless Network

We assume that access points of all hierarchy levels are connected using high speed fixed links, using Internet protocols (possibly in their emerging QoS enhanced version). However we do NOT assume the existence of a single backbone, like today's public Internet. Contrary, we believe there will be multiple internet backbones with different observed QoS. Access points (or border routers of subnetworks connecting a group of access points) will be able to make decisions as to which backbone to use. This decision will be made on per flow basis, e.g. IP telephony flows might be routed differently from WWW flows.

In order to support multiple communication technologies a mobile terminal has to be equipped – at least conceptually – with a set of different wireless interfaces. In fact as for recent experiments, this is really done using several different physical interfaces (and several device drivers), which definitely is inefficient in terms of size, cost as well as flexibility.

In AMICA we assume that terminals will be soft radio-equipped, and that it will be possible to configure the radio interface according to the actual needs. In addition we assume that within each of the cell type there will be a possibility to select on the fly one out of a set of supported QoS profiles, including bit rate, error rate, spatial coverage and mobility. Examples are easy to point out: in IEEE 802.11 LANs both modulation (equivalent to bit-rate) and power level are adjustable. Furthermore a new technological approach – the smart antennas – seem to give additional boost to such considerations. We will refer to such changes in parameters of communication between a single pair: “terminal- access point” as to **internal handover**. In addition we will talk about **horizontal handover** among access points of the same hierarchy level, and **vertical handover** between access points of different hierarchy levels.

These types of handover differ essentially. In the case of internal handover the access point does not change. In the case of horizontal handover, both the previous and the new access point will (mostly) belong to the same service provider, in the Internet sense they will belong (mostly) to the same network and domain. In the case of the vertical handover, we will usually have to consider a change of the network (in the Internet sense), and even domain: Think in terms of changing from the local network of one of the university institutes, to the GPRS network of some telco. As for the quality of handover mechanisms, we believe that avoiding loss of data and extensive delay should be required. We are, however not necessarily convinced that the existing TCP connections should always be supported, contrary establishing of new connections after handover might frequently be the better choice, especially if full slow start might be avoided. This is subject to vivid investigations.

In AMICA we assume, that for the true mobile access, a terminal is always **at least** in the range of an access point of the highest hierarchical level, the one with the largest coverage, probably most expensive, possibly having lowest QoS (think simply in the terms of GSM-like connectivity). A possibility[5] of vertical handover to a lower hierarchy level (like wireless LAN) will be considered “network initiated” or at least “network supported” as soon as it becomes feasible. We intend to investigate different policies for such handover.

On the other hand, vertical handover from the lower to higher hierarchy level is simple in the sense, that location of a higher level access point “covering” the lower level cell is usually known. But also here a spectrum of different policies as for the decision about handover is to be considered.

To complete the discussion of our philosophy in supporting handover, we would like to stress, that we intend to use extensively the mentioned earlier asymmetry of flows as seen by end systems. As the majority of mobile systems will rather download data, we believe that multicasting data

[5] One, very attractive way to asses the possibility of handover is the usage of terminal location information (being available from several technologies – see the 911 support as well as newest results in wireless LAN supported location like [5]), in connection with the information on location of lower-level base stations. This seems to be possible not only from GPRS to WLAN but even for handover from, say WLAN to Bluetooth interface...

addressed to a target end system several access points which "potentially" might "take over" this target system might essentially reduce the QoS disturbances caused by the handover. Our intention is here to use not only the "classical internet style" multicast of today internet, but also consider some possible modifications (see e.g.[8] for one of our investigations).

Contrary to the majority of wireless internet access systems, which follow the "classical" internet philosophy of keeping all the state in the end-system, we believe that it might be advantageous to keep some state information about the mobile systems within the network. In fact, we assume [11] that there will exist a special (logically centralized/physically distributed) repository keeping temporarily, on a soft-state basis, information about all terminals. This information should be used (among others) for supporting handover itself, but also supporting "lightweight" re-authentication after handover.

In fact we believe, that there is a need for a special "logical signaling channel" for supporting the information exchange between the end-system and this repository. This "logical signaling channel" might be mapped at the same hierarchy level access as the data transmission. On the other hand, there are good reasons to consider mapping this logical channel on a connectivity with a higher hierarchical level: the bit rates on this channel will be relatively low, and continuity of it's use in case of either horizontal or vertical handover would be assured. Strategies for assigning this channel to different hierarchy levels will also be considered.

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