Proxies, Active Networks, Re-configurable Terminals: The Cornerstones of Future Wireless Internet[1]

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Abstract: *After discussing basic issues related to both 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 improving wireless internet access called AMICA is outlined. Furthermore, we analyse the need for re-configurable terminals and active networks to enable advanced wireless Internet services and the support of hierarchical, heterogeneous wireless access, which are indeed the fundamentals of AMICA.*

1. Introduction

Using internet services not only becomes a habit, in fact both in their professional and everyday life people become increasingly dependent on access to these services. Or they 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 first glance. Therefore, this merger is recently one of the hottest research topics in the area of telecommunication networks.

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 reflecting our approach on wireless internet access.

2. Mobility and Wireless Access

In general, the usage of wireless access can be described by mobility scenarios [25]. We concentrate our discussion with a scenario called **true mobile access**. Terminals can be moved within and between the range of multiple access points. Dynamic changes of the supporting access point during a session are expected to appear. Such changes are usually called handover. For mobile access to be attractive, deployment of access points should be dense; usually a significant (although not necessarily all) part of the area will be in the range of at least one of these access points.

The degree of service continuity in spite of handover is one of the essential quality features. Continuity of service might be expressed in terms of the amount of information during handover. The case of frequent, possibly interruption-less handover usually implies 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 identical. In fact, this

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is the case for the majority of solutions deployed or considered today, like GSM, GPRS or the emerging UMTS.

2.1 Wireless Access Design Issues

Using the same technology, homogenous systems consist of access points with similar range/coverage and bit-rates. Such technology might be developed with the general design goal to support bit/rates as high as possible within a range as large as possible. We will now discuss reasons why this does not make sense

Any wireless communication uses a given band of frequencies, which – according to basic communication theory rules – is to be proportional to the targeted bit-rate. This band is shared with any other device which can emit frequencies belonging to this band[2] and act within a given coverage of a access point. If the coverage is increased, the number of devices in the range of the access point is also increased and the bit-rate for each device or the overall capacity is decreased (not taking into account lower signal quality on longer transmission paths)

Increasing the capacity by acquiring additional frequency bands is in any case expensive (see the recent press news about frequency auctions for UMTS). Alternatively, one can achieve an increase in wireless system capacity by reducing the radius of connectivity. Note, however, that assuring constant coverage in spite of radius reduction leads to a quadratic increasing the number of required access points. However, supporting true mobile access unavoidably increases the handover frequency. Another option for increasing capacity is using some kind of spatial discrimination (meaning communication in only some directions), with the progress in smart antennas research [16]. This approach should become increasingly attractive.

Because of the essential differences in the bit-rate/range combinations supported by different technologies on one hand, and the strong push for high economy of spectrum usage 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.

3. Fundamental Issues of Wireless Internet Access

First of all we have to decide what we really understand by 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 [9]. "Internet" refers to a global information system that:

1. is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
2. 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
3. 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 (1) IP addresses have a hierarchical structure. This enabling 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 is a local issue. This does, however, imply that a host can (without additional measures) only be reached by IP packets if it remains within its proper network.

[2] 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)

Ad (2) The Internet concept supports a model of uncontrolled resource sharing. At the IP level, being the common denominator, there is only one, very limited approach to congestion avoidance: dropping packets. It 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 behaviour from UDP based applications (see [12]).

Ad (3) The fundamental Internet Protocol (IP) addresses only the whole end system, where we would mostly like to address individual processes. This granularity, jointly with additional error recognition, is given by UDP (for delay-sensitive, error-insensitive applications), while granularity jointly with reliable delivery is provided by TCP (for error-sensitive, delay-insensitive traffic). The two transport-layer protocols operate on top of IP. In effect, essentially all the applications operate on top of TCP/UDP rather than IP and know nothing about the TCP/UDP/IP protocol operation.

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

3.1 Wireless vs. Wired Internet Access

As the internet model intentionally avoids any assumptions about how IP packets will be transported by the lower protocols and IP packets are – by definition – forwarded on a best-effort principle, 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 about usage of wireless communication technologies for accessing the internet? What makes wireless so different?
Due to the nature of the wireless channels, they 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 remedy of introducing a reliable link-layer protocol with ARQ error recovery can only shift the problem, as ARQ translates bursty packet losses [19] into significant additional variable delay.
In wired links, packet losses caused by transmission errors are very rare. Therefore, in the course of the internet development end-to-end packet losses (as well as delay variations!) became a synonym for congestion in the nodes (routers). The TCP congestion control, crucial for healthy operation of the internet, uses late/missing acknowledgement as an indication of congestion.
Compared to all wired links, 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 [3]. This behavior is very bad as the bit-rates are anyway lower in comparison to the wired case.
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 [4].
Due to these facts TCP has performance degradation when using it for wireless Internet access.

3.2 Connecting the End System via a Wireless Hop

Traditionally, providing internet access could be interpreted as requirement for the configuration of the terminal as the internet host with complete TCP/IP protocol stack and hence 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 [10]. 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 accordance with the internet philosophy. Alternatively, solutions with cross-layer information exchange (loss indication [18] or booster type support) are considered.
To give an example, Snoop [3] is described here in more details. Snoop is a protocol booster, which improves the TCP transmission performance without changing TCP. It works between a fixed host and a mobile host and is placed in the forwarding code of a base station to add new functionality. First, it forwards and caches every TCP packet which comes from the fixed host. Second, it keeps track of the acknowledgments sent from the mobile host. When a packet loss is noticed, it retransmits the lost packet to the mobile host as long as the packet has been cached. Snoop improved the TCP performance under high bit-error rates.
But Snoop and the other approaches mentioned above 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 statement "makes accessible higher level services" is of key importance. 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 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 [11]. The application software installed in the end-system is not able to directly contact WWW servers with the classical http protocol, but has to use a special translation server, instead. This allows to use a set of "lean" protocols between the end-system and the translation server, in case of WAP optimised for usage on links with low bit rates, and thus well suited for today's GSM wireless access. Major disadvantage of such an architecture is a break of the end-to-end concept: 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 GSM (say WLAN connectivity), it still would not be able to communicate directly with WWW servers.
Immense research effort to improve wireless internet access has lead to a broad variety of approaches. One approach, which we consider most promising, the Remote Sockets Architecture (ReSoA), will be discussed within the AMICA case study.

3.3 Proxies are essential to improve Internet access

Using only Internet Service Access opens the possibility to distribute internet protocol operation between both the end system and the network. Proxies generally do such a distribution; WAP, Snoop, and ReSoA are examples [20]. The distribution allows to take "special" care of the wireless link.
Due to the strong heterogeneity of wireless access technologies we expect that a large amount of proxy architectures will be established. They will optimised for different requirements and contexts, to name a few: the wireless technology, application service requirements, energy consumption, mobility support, state of the art, or even market needs. Therefore, it is questionable, if a single common and universal proxy architecture can be found.
Commercial wireless internet providers can use proxies to offer diversify and improved transportation services. They should be able to deploy new proxy architectures in a flexible manner with a short time to market. The deployment should be independent of the infrastructure manufacturer (to save costs). We believe that there should be flexibility way of providing Internet services. Two trends tailor the deployment of improved wireless Internet service provision: Re-configurable terminals and the active network approach.

3.4 Re-configurable Terminals

The application layer on most of the terminals is already re-configurable. Widely used Internet browsers support seamless download of new application, e.g. Java Applets, and even cellular phones and PDA are going to have similar features [21]. All these applications have the ability to use Internet services, namely TCP and UDP sockets. The Internet Protocol Stack is also configurable, but limited to changing e.g. the IP address. IP address assignment is even done automatically by the DHCP service.

Wireless terminals have to work in different environments, which include both different wireless networks and providers. This might include different wireless bearers, bit rates, frequencies, modulation or medium access protocols. To be able to operate in heterogeneous environments, end systems are equipped with multiple radio modems (e.g. GSM and DECT). If there is the need to connect to a larger number of technologies (e.g. also Bluetooth) this approach seems not feasible. More powerful is the soft radio concept [17], which combines different technologies in a single radio modem. It is an interesting question how the configuration of the soft radio will be managed and how the soft radio is controlled. However, it is not the scope of this paper. We assume that terminals are re-configurable at the physical and the MAC layer without knowing exactly how this is being done.
Terminals are re-configurable in the application and the physical (including MAC) layer. But it seems to be natural that the straightforward way will be exchangeability and re-configurablity in each layer. If we have re-configurability in the soft radio and in the application layer, why should the communication service provided by the traditional TCP/UDP/IP stack? In fact, as we mentioned there are good reasons to use other approaches. We believe that only exchangeable and downloadable communication protocols allow to adapt to even a priory unknown wireless accesses and applications' service requirements and to deploy new proxy architecture easier.

3.5 Active Networks

In the last couple of years, there have been a shift in what networks nodes do. Traditional network nodes just perform routing and forwarding of data. The research community had concentrated on improving performance and functionality. Active networks permit to dynamically inject programs into the networks nodes [9]. Networks nodes become programmable and configurable. This allows creating, deploying, and managing novel services fast. In traditional networks it was required that any service is standardised to allow proper interoperation. To develop standards is lengthy and does not keep track with market demand.
It has been proposed [26] that mobile systems have to be programmable to adapt to applications and mobile environments. We think that the access networks should be programmable.

4. The AMICA System Vision

After this initial discussion, it is 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 [8][15][1][14]. We will now introduce our case study – AMICA: Adaptive Mobile Integrated Communication Architecture.

4.1 Mobility: Selected Issues

Following the considerations in section 3 we believe that the Internet access infrastructure will consist of access points supporting very diversified technologies. Most probably, these technologies will differ essentially in the provided coverage, leading to a hierarchy of overlapping cells of different size (see *Figure 1*). Note, the smaller cells will usually not provide complete, 100% coverage of the area of the overlapping larger cells.

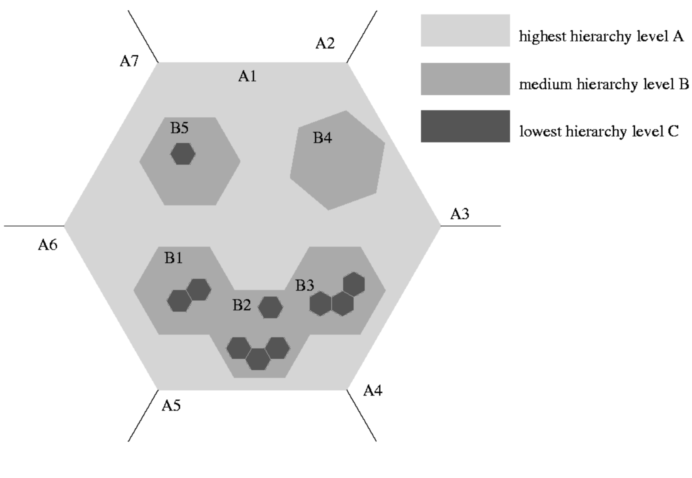

Figure 1. Hierarchical Wireless Network

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 terms of GSM-like connectivity). Switching to a lower hierarchy level (like wireless LAN) will be done if it is reasonable.
The 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. On the contrary, we believe that 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 a per-flow basis, e.g. IP telephony flows might be routed differently from WWW flows.
In order to support multiple communication technologies we assume that terminals will be soft-radio equipped. In addition, we assume that within each 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. Furthermore, a new technological approach – smart antennas – seems to give additional boost to such considerations. We will refer to such changes in parameters of communication between a single pair terminal node and 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 case of internal handover, the access point does not change. In 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 case of the vertical handover, we will usually have to consider a change of the network (in the internet sense).
To complete the discussion of our philosophy in supporting handover, we would like to mention that we intend to extensively use asymmetry of flows as seen by end systems. As the majority of mobile systems will rather download data, we believe that multicasting the data to the addressed target end system and to several access points which "potentially" might "take over" this target system can substantially reduce the QoS disturbances caused by the handover. Our intention is here to use not only the "classical internet style" multicast but also consider some possible modifications (see e.g.[6] for one of our investigations).
Unlike the majority of wireless internet access systems, which follow the "classical" internet philosophy of keeping all state in the end system, we believe that it might be advantageous to keep some state information about the mobile systems within the network. We assume [7] that there will exist a special (logically centralized/physically distributed) repository keeping - on a soft-state basis - temporary information about all terminals. This information should be used (among others) for supporting handover itself, but also supporting "lightweight" re-authentication after handover.

4.2 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 adjustments to the wireless technology. In accordance with the comment (3) in section 3 this means that we insist on keeping the TCP/UDP socket interface, with unchanged service semantics, 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 accordance with these requirements we have developed our proxy architecture, called Remote Socket Architecture (ReSoA), presented for the TCP case in *Figure 2* in comparison with the "classical" approach discussed in the previous section.
The basic idea (see [13] for details) is to move the TCP protocol engine from the terminal to the access point. Over the wireless link 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 is used. 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 semantics will remain unmodified.

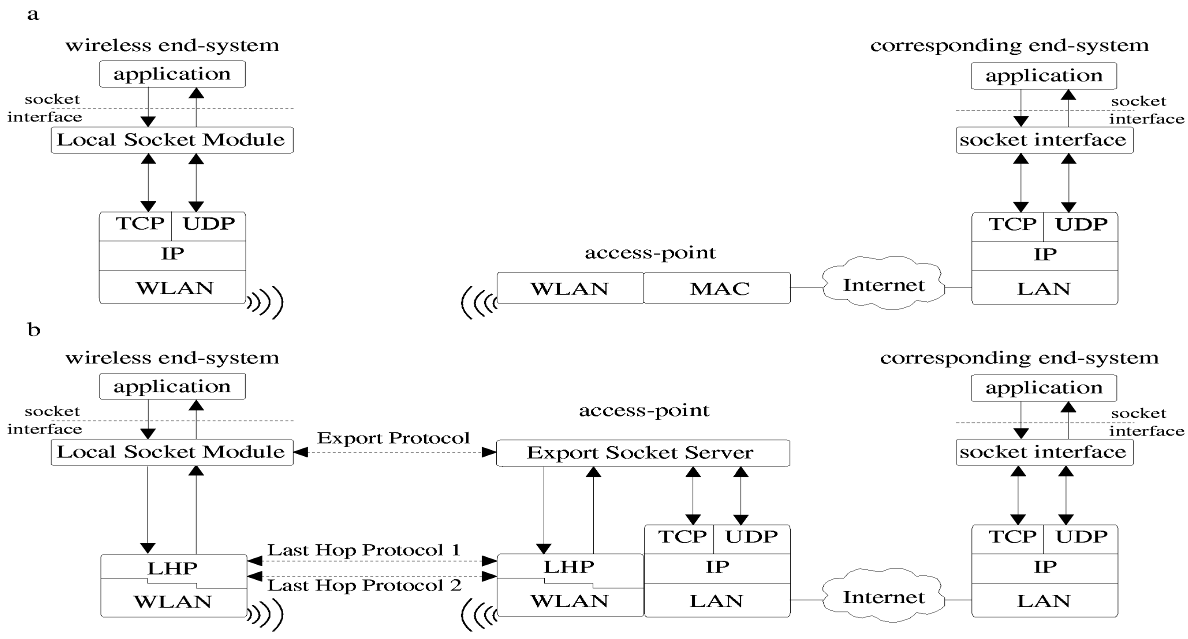

Figure 2. Wireless Internet access using ReSoA

LHP has a different role. This protocol covers the functionality of the 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 investigate 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) and IEEE 802.11 channels (see for example [7] for energy optimization).

4.3 Downloading of protocols

To facilitate the use of different last hop protocols, we propose that the LHP can be downloaded to the mobile end system. Furthermore, when new proxy architecture will be deployed it should be possible to download it to both the access network and the mobiles.

Two projects in our institute are dealing with the downloading and deployment issue. The first project, FLEXINET, is dealing with the access network and is funded by the BmBF[3]. The other one, MOBIVAS, is financed by the EU and concentrates on the mobile wireless end system.

We concentrate on making communication protocols in re-configurable terminals exchangeable and downloadable. In general, the protocol stack existing in operating systems is rather static and integrated in the kernel. There are no ways to exchange the communication protocols dynamically at

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runtime. This liaison has to be broken and an execution environment is needed which has clear interfaces between the operating system and the protocols.
The communications protocols reside below the socket interface and above the soft radio (recall that ReSoA does not require a full IP stack at the end system). The socket interface is well defined but might be developed further, e.g. QoS support is added. But not only the operating system interfaces but also the interface for accessing soft radios has to be standardised [23].
Communication protocols, which operate in the kernel space, underlie no restrictions and are free to crack the system. The protocols must therefore run in execution environments, which include at least some security features to inhibit misbehaviour of malicious or buggy protocols. It has to be evaluated whether and how downloadable protocols are signed and authenticated to avoid obtaining them from untrusted sources.
Due to the heterogeneity of microprocessors, hardware platforms, and operating systems we might have to find a nearly platform independent way to insure protocol code deployment. The concept of virtual machines, e.g. Java, could be an appropriate execution environment. The Java Virtual Machine needs quite lot processing and memory resources, which are limited on a portable device. Another alternative is to develop a kind of runtime environment (e.g. C or C++ based) composed of runtime compiler, dynamic loader, and linker. Hence, exchanging protocols is done by transferring source code (maybe pre-processed), compiling the source code and loading and binding it. The solution, which offers highest performance, will be to transfer precompiled binaries for each hardware platform.
All these requirements sound very familiar in the context of active technology [22]. Indeed, active network technologies are the basis for reprogramming communication protocols

We expect that dynamic installation and configuration of proxy architectures in the access network is needed. Several platforms will be evaluated for their suitability for the provision of new communication services.

5. Conclusion

Let us just conclude, starting with the mobile terminal. It should be able to support adjustment of the communication layers, but keeping TCP/UDP sockets. The mobile terminals will have a soft radio, which is configurable by the communication layers. On the wireless hop (and also on the fixed backbone) mechanisms for error control, flow control and congestion control should be changeable. Namely ReSoA (but not as the only approach) should deployed with the LHP being exchangeable. The access points are connected using Internet backbones. Either the access points or border routers should make decisions which Internet backbone is being used. Further more the access network should support vertical handovers by positioning the mobile terminal. Multicast support is used for addressing the mobile terminal. A virtual repository keeps temporarily information about all terminals.

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