A flexible Multiplexing Mechanism for Supporting Quality of Service in Mobile Environments

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Abstract

According to current trends in the area of mobile communication, mobile devices rapidly gain significance. These trends go hand in hand with the growing demand for a mobile and wireless access to a corporate network or to the internet with those devices, which might be a laptop running common operating systems, a PDA, or a mobile phone using the Wireless Application Protocol (WAP). Depending on the actual location, there is currently a plethora of techniques that enable wireless communication. In this paper, we propose a Management Entity that allows a seamless handover between different networking devices: The Management Entity uses multiplexing mechanisms inside the network layer and is affected by the MAC layer. In order to evaluate this management service, we are currently implemening a prototype for the Windows operating system. Therefore, we will be able to measure the impact of switching between two network devices on the behavior of higher layer protocols.

1. Introduction

The current evolution in mobile and wireless networking and the advances in hardware technology are the essential reasons that mobile devices gain more and more importance. Currently there are several wireless networking technologies that co-exist together, such as IEEE 802.11, HomeRF, Bluetooth, or GSM. But, one single communication technology will never cover all aspects of communication and cannot provide the desired quality of service all the time. While wireless local area networks offer acceptable bandwidth and delay to users, they are restricted to a small area, whereas area-wide communication systems (e.g., GSM in Europe) allow for a location independent access to Internet services with low data rates (up to 14.4 kbit/s) and high delays. Thus, we currently have an extremely heterogeneous environment of wireless networking technologies which will be more variegated in the future (e.g., UMTS), and mobile devices will be able to choose between different transmission paths for their communication. Thus, concerning the quality of the communication there is in many cases a trade-off among coverage, performance, and price.

According to the current trend towards mobility, (mobile) users also want to communicate to each other and to access Internet and WAP services, or services in the home intranet – independent of their current location and with an acceptable quality of service. Concerning mobility, Mobile IP is one technology that supports mobility in IP-based networks. But, Mobile IP does not exploit the opportunities of the heterogeneity in a wireless communication environment. Current mobile devices such as laptops, palmtops or handheld PCs already integrate several networking technologies, as can be seen in Figure 1. Those devices have an integrated IrDA port, in the near future they will contain a Bluetooth module for exchanging data with other devices in an ad-hoc fashion, they may have an integrated IEEE 802.11 adapter for communication in high-speed wireless LANs, and can be extended by GSM modules, DECT PC-Cards or use the PSTN via an integrated modem (which can be used if PSTN access is available).

Most infrastructure-based communication systems support mechanisms for handing over connections from one point of attachment to another within the same communication system, called a horizontal handover. As an example, connections in an IEEE 802.11-based network can be passed over to a new access point if the mobile node recognizes a stronger beacon signal from another access point. The same principle is also used in GSM networks, where phone calls can be handed over between different base stations. However, it is currently not possible to perform a handover between different communication systems, the so called vertical handover. In this case, all TCP connections have to be closed, the new communication link must be established and all applications need to set up new connections. Even the use of Mobile IP does not allow a seamless switching to another networking technology. The vertical handover is one of the most important preconditions for the mobility support of users: They can use the wireless LAN in their office for high speed communication; when leaving work, their device should be able to switch to another network that is currently available in a seamless way, i.e., current connections need not to be closed. Thus, the mechanisms for providing such a handover must be transparent to the applications, so they can be used in a common way.

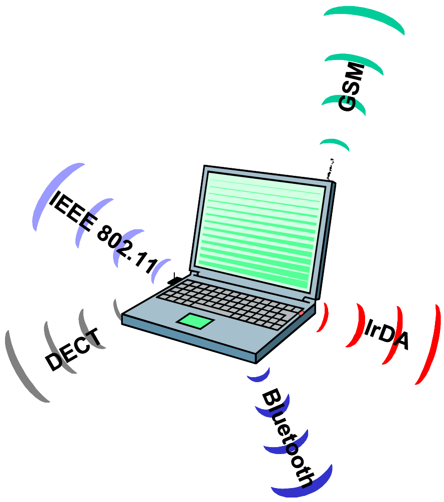

Figure 1. Different networking technologies for mobile and wireless computing

In this paper, we propose a flexible and efficient Management Entity located within the end system. The basis of this entity is a multiplexing mechanism that enables a mobile device to hand over connections between different bearers in a seamless way. This functionality, which is integrated within the operating system's network stack, works transparent to the applications so that they need not to be modified. This Management Entity is part of an overall quality of service architecture that empowers (mobile) end systems to work in an adaptive way. We show how our Management Entity improves the quality of service in environments using Mobile IP for supporting enhanced mobility of mobile end systems.

This paper will be organized as follows. In section 2, we give a brief overview of the research currently going on in this area. Section 3 describes the Management Entity in more detail and the way it is integrated in an overall architecture for supporting quality of service to adaptive applications. This paper will be focused on the multiplexing mechanisms that are used for realizing a seamless handover between different networking technologies. We also describe how this entity can be used for improving the quality of service support in Mobile IP networks. The last section summarizes the paper and gives an outlook to further work we will do in this research area.

2. Related work

The problem of a heterogeneously networked world has been seen from others also. There are several projects focusing on the provision of an improved support for mobile hosts at different layers of the network stack. In the following a few approaches are discussed in more detail.

2.1. BARWAN

With the BARWAN project (Bay Area Research Wireless Access Network, [1], see also [2]) at UC Berkeley we basically share two ideas.

1. Future networks will be built upon heterogeneous wireless networks, ranging from in-house networks to metropolitan and wide-area networks. In the BARWAN project this is called wireless overlay networking.
2. In order to compensate the network conditions in wireless environments, mobile end systems have to perform dynamic adaptations. Those adaptations base on the availability of information from other layers in the network stack to achieve a cross-layer optimization. However, this results in breaking the strict and hierarchical OSI networking model.

To overcome the problems of handover between these different network types, an extension to Mobile IP, called Overlay IP, is proposed, which enhances Mobile IP with the awareness of different subnets on the way to a mobile node. The care-of address of the foreign agent has to be a multicast address. Thus, seamless handover is based on multicast trees and a good knowledge of the geographical conditions of transmission. Decisions for handing over connections are done on the network side. This assumes that there is a hierarchy in the overlay network: If a network is currently not available, the end system switches to the next higher network in the overlay network, even if other more powerful or cheaper communication technologies might be available. A unifying management entity on the side of the mobile host is missing.

Handovers between hybrid mobile data networks is also subject of [3]. The idea of switching between different network systems is basically the same – however, the work described in this paper only allows for switching between GPRS and IEEE 802.11. Albeit this paper gives an impression of the theoretical handover performance between the two networking systems, it does not provide a generic architecture for switching between arbitrary network systems. In contrast to our work, the Overlay IP mechanism described in BARWAN project (see above) is used for switching between the two networks.

2.2. MosquitoNet

The integration of wireline and wireless access was also an idea behind the MosquitoNet project [4]. The basic approach in this project was a modification of Mobile IP in a way that the mobile node in the foreign network has a temporal and topological correct IP address, which is assigned by, e.g., DHCP [5]. Therefore, no foreign agent is needed and the mobile node is responsible for signaling its handovers.

Nevertheless, later work did not focus on the problem of managing the handover between different network technologies. On the one hand, the work currently concentrates on personal identities in mobile environments (described in [6]), and the use of flow-based mechanisms in the context of Mobile IP [7]. The basic idea of the latter topic is an improvement in the quality of communication by supporting multiple packet delivery methods as an extension to Mobile IP, e.g., HTTP streams use regular IP, whereas other streams (such as voice over IP) might use Mobile IP, triangular routing, and/or bi-directional tunneling of data. This idea is different to our approach where it is up to the end system to decide which connection is currently the "best" one for a mobile application, and mobile IP remains unchanged.

2.3. Dynamic network reconfiguration

A similar approach to the MosquitoNet project is described in [8]. In this work, the mobility support for computers is achieved by dynamic network reconfiguration. The authors define an abstract set of device characteristics, which could also be useful for our Management Entity. In order to achieve mobility, guards within the operating system detect the validation and invalidation of the device characteristics. Depending on those parameters, the system enables an "intelligent adaptation" on network layer, transport layer, and application layer. At the network layer, the adaptation process reacts to invalidations of routes by modifying the routing tables within the kernel of the operating systems. This is different to our approach, as we provide a more flexible approach by directly choosing the networking interface without changing the bindings from IP addresses and routes to the NICs.

2.4. IETF

In the area of the IETF many drafts deal with Mobile IP and extensions. Many slightly different mechanisms for improving and managing handovers between Foreign Agents are presented, claiming for usability in an environment with different access network technologies ([9], [10] and others). These approaches argue from the point of view of Mobile IP, and do not focus on the way how the need for switching to another NIC is detected and realized inside the mobile host.

3. Multiplexer for supporting QoS

Devices communicating in mobile and wireless environments have to cope with several challenges. As an example, two typical scenarios are described in more detail.

- The quality of a wireless communication link may vary over time, covering scenarios from short term disruptions to the complete loss of a link. The availability of different communication systems changes dynamically while a mobile device moves around. Thus, in Mobile IP environments it becomes necessary to perform a handover to another point of attachment, resulting in the loss of packets.
- Ad hoc networks are characterized by a highly dynamic topology without using infrastructure-based communication technologies. Communication should be possible even if the networking topology changes rapidly, as mobile devices sending data might move as well as mobile routers and the mobile devices receiving the data. Mobile devices should also be able to communicate with each other using different networking technologies, resulting in a highly heterogeneous networking environment.

In both scenarios, an improvement of the quality of service could be achieved if it would be possible to utilize the availability of several networking technologies coexisting together. As an example, communication between two mobile devices could be performed via Bluetooth as well as using a GSM PC-Card. If both sender and receiver are close together, they will use Bluetooth for communication as it is cheaper and offers higher data rates. When the devices move out of communication range, nowadays all connections will break, and the user has to set up a GSM connection to continue communication.

The Management Entity described in this section avoids such a breakdown of current connections described in the example above by handing over the established communication links to a new transmission path.

Before the Management Entity is described in more detail, we first identify the requirements that are necessary for its implementation.

3.1. Requirements and goals

Future mobile multimedia networks will be also integrated in the overlay networks and, thus, have to cope with the challenges of seamless handovers. [11] gives an extensive and general description of those challenges, whereas more specific requirements have to be considered for the implementation of our Management Entity.

In order to improve the quality of networking services in mobile and wireless scenarios as described above,

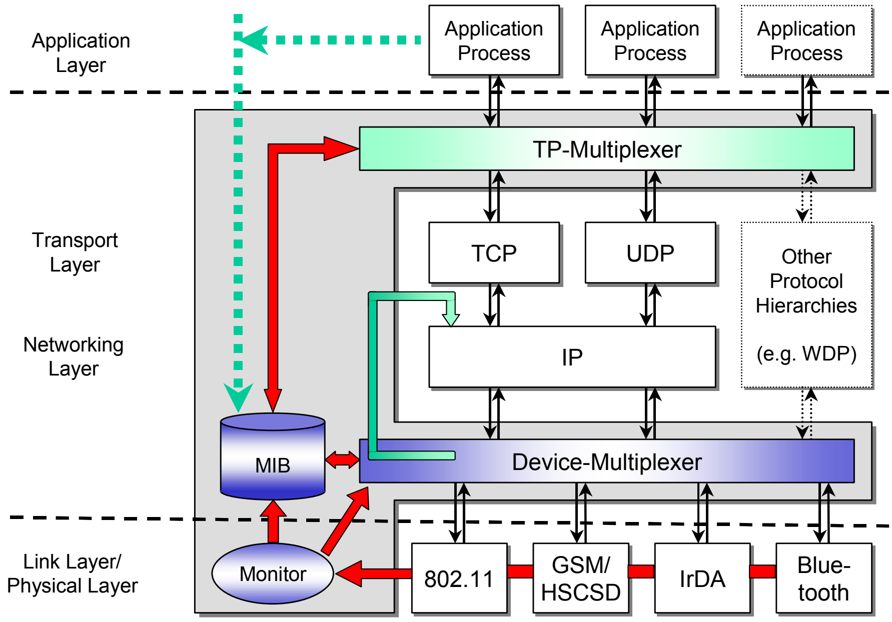

Figure 2. Management Entity

several requirements have to be considered. Networking aspects are usually time critical as packet scheduling has to be performed within milliseconds (or even microseconds) for each packet that has to be transmitted over a network device. Thus, the efficiency of the implementation is the most important feature. Another important requirement is that current protocols on network layer and transport layer must be usable without any modifications, and the co-operation with other networking protocols (e.g., TCP/IP) must not be affected by the mechanisms our Management Entity uses. The mechanisms have to be transparent to the applications so that they are not aware of their existence. But, applications will benefit from the improvement in quality of service offered by those mechanisms.

3.2. Requirements and goals

Beyond networking aspects, other resources have to be considered to provide an overall quality of service support for realizing an adaptive end system. In [12] we already proposed an architecture for adaptive end systems, which can deal with rapid changes of the Quality of Service provided by the network.

By means of a simple button, the Q-Button, the user or a proactive application itself is able to improve the quality of an application. In this architecture, a signal will be sent to the first subsystem of the hierarchy, where a flexible CPU scheduler adapts the computation time to the application's current needs. If the CPU is not responsible for the bottleneck in supporting quality of service, the signal will be passed to the next subsystem within this hierarchy, which takes care about the communication aspects. Therefore, the communication subsystem will be notified by the user and/or an application, that this application should be preferred. On packet scheduling level, [13] describes how applications running on an adaptive end system can benefit from Differentiated Services-based networks by integrating packet marking and packet shaping mechanisms. This paper focuses on the quality of service support within this architecture for improving mobility, which can be achieved by a Management Entity controlling the communication protocols.

Figure 2 shows the integration and the components of the Management Entity in more detail. On top of the communication layers are the applications currently running on the system while using the network stack for communication. To each application belongs at least one process or thread, depending on the operating system design. The dotted arrows in Figure 2 show the interaction between the operating system and the user or the application, as described above. The lowest layers, physical layer and link layer, realize the different transmission technologies, such as IEEE 802.11 or GSM-CSD (Circuit Switched Data). Within common operating systems, such as Windows 2000 or Linux, TCP and/or UDP is used at transport layer level, and IP is the protocol of choice for the networking layer, located above the link layer. As can be seen in Figure 2, the Management Entity currently covers the link layer, the networking layer, and the transport layer. Covering these three layers results in advantageous behavior of the communication protocols, as various kinds of information from other layers could be used for the protocol mechanisms of each layer. As an example, UDP on the transport layer will choose another communication path if the signal to noise ratio of the current communication path is too low, resulting in a high bit error rate. Therefore, a Transport-Protocol-Multiplexer (TP-Multiplexer) between the transport layer protocol and the programming interface of the operating system is needed. This mechanism also allows to spread the data stream and to use several communication paths for transmission. This option is especially useful in WAP (Wireless Application Protocol) communication scenarios based on UDP, where the higher layers such as WTP (Wireless Transaction Protocol) and WSP (Wireless Session Protocol) take care about the reliability of the data transport. The TP-Multiplexer is subject of our ongoing research and will not be described in depth within this paper.

In this paper, we are focusing on the link layer and the networking layer. On the link layer, a Monitor collects relevant data from the different networking technologies. In the case of IEEE 802.11, the monitoring comprises parameters such as the availability, the current signal strength from the nearest access point, or the current packet loss rate. For GSM, parameters such as the current signal strength from the base station the mobile device is currently attached to, or the existence of an established data connection are conceivable. Those parameters are stored in a Management Information Base (MIB), which is updated by the Monitor. There are three options for updating the database.

- The Monitor periodically polls the different bearer for their current status
- The different networking interfaces notify the Monitor if their parameters changed
- The networking interfaces notify the Monitor only if they are currently used for communication

If the Monitor notices a change in the connectivity, e.g., the signal strength from an access point in an IEEE 802.11 network becomes too low for communication, it triggers a Device-Multiplexer located within the networking layer between IP and the data link layer. This Multiplexer is responsible for switching to a suitable networking device for further communication. Therefore, it contacts the MIB for the current status of other communication devices currently attached to the mobile station, and chooses the one which is "best" fitted for the communication. Note that it is – according to the definition of quality of service from the ITU [14] – up to the user to define what "best" really means. This could be either the cheapest alternative, the alternative with the highest data rate, a combination of both, etc.

In order to achieve transparency for the applications, the TCP/UDP port and the IP address must not change if the Multiplexer switches to another device. However, it is harmful to change the binding of the IP address to a networking device, as the process of binding, unbinding, and the update of the internal routing table is not very efficient. Also, the address resolution protocol (ARP) might fail because of invalid entries in the ARP caches of other nodes within the local area network, and the mobile node becomes unreachable as the new address bound to the network interface might be topological incorrect. Thus, the Device-Multiplexer encapsulates the IP datagram in a new IP packet with the IP address of the chosen networking device as the source address. This tunneling mechanism, which is the main principle of Mobile IP [15], is performed by using a redirector within the multiplexing entity, that calls the IP stack a second time and, thus, redirects every packet to another networking device which sends them out (shown by the green arrow in Figure 2). Note that the outer IP packet contains modified source and destination addresses. The new source address is the one of the chosen network device, the destination address represents the tunneling endpoint. Beyond the addressing aspects, the Multiplexer also has to "mark" each tunneled packet by setting the "protocol" field in the outer IP header to 0x4, according to RFC 2003 [16]. Thus, it is ensured that the receiver is able to differentiate between original and encapsulated IP packets. On the receiver side, the connection endpoint has to perform two tasks. First, it has to unpack the encapsulated data and send them to the receiver R specified in the inner IP packet. Second, this host has to encapsulate the packets coming from R in order to tunnel those data to the mobile node. Thus, it has to be ensured that every packet from the receiver also passes the host specified as the tunneling endpoint.

The Management Entity for improving the quality of networking services can be deployed in various communication scenarios, such as mobile ad hoc networks or simple point-to-point communications for synchronizing a PDA with the desktop computer (using either the cradle, IrDA, Bluetooth or GSM). The Management Entity is also very useful in Mobile IP environments, which is described as a good example in the next section.

3.2. Management Entity

As said before, the proposed Management Entity within the end system is able to improve the quality of service in communication systems using Mobile IP. If a mobile node (MN) moves in the foreign network, it may leave the area of the current foreign agent (FA) resulting in handovers to other foreign agents. Those handovers entail two main problems:

- Typically, data loss occurs while handing over a connection to another FA. The mobile node has to find and register itself at the new FA while unregistering from the current FA. In this time period, data has to be forwarded from the old FA to the new FA, resulting in many cases in a packet loss, while the FAs propagate the handover to the new point of attachment to the home agent (HA). After this procedure, the data will be tunneled to the correct foreign agent.
- If the mobile node leaves the area of a FA and cannot find a new one via the same network device, the user has to close all current TCP connections in order to set up a new link using another network device for further communication. Even if the FA also supports various communication technologies (e.g., IEEE 802.11, Ethernet, or modems for dial in), all connections have to be closed, and a new connection has to be established with the same foreign agent.

Our Management Entity is able to improve the mobility support of Mobile IP as well as the micro mobility, as less handovers between FAs occur, and the connections need not to be closed while handing over to another networking technology. Therefore, the Management Entity has to be installed on two components in this environment: Within the mobile node and within a proxy elsewhere on the communication path between the senders and the mobile node. The only assumption here is that every packet passes the proxy. Thus, in a Mobile IP environment, two locations for this proxy are conceivable: home agent or foreign agent. Locating the proxy in the home agent is only advantageous for wide area networking support, as this host might be (physically) far away from the MN. Thus, we suggest to locate the proxy within the foreign agent which is usually in the same local area network, where several wireless LAN technologies can be used as well as short-range communication, e.g., via IrDA or Bluetooth. Additionally, a seamless integration in the Mobile IP environment is achieved as this approach only affects the link between the FA and the MN.

Figure 3 shows the integration of our approach in a typical Mobile IP environment (according to RFC 2002 [15]), where the proxy is located in the foreign agent. The mechanisms used for communication outside the domain of the foreign agents are unaffected by our approach and work in the same manner as described in RFC 2002. If a sender S wants to communicate with the mobile node, the data is sent to the well-known IP address of that MN, and all data will attain the HA. The HA itself knows about the current location of the MN, especially the care-of-address of the FA the MN is currently attached to. Thus, the data is tunneled via IP-in-IP encapsulation to the foreign agent, which unpacks the data and sends it to the MN having a topological incorrect IP address by directly addressing the MN with its MAC address on link layer (which is shown in (1) in Figure 3).

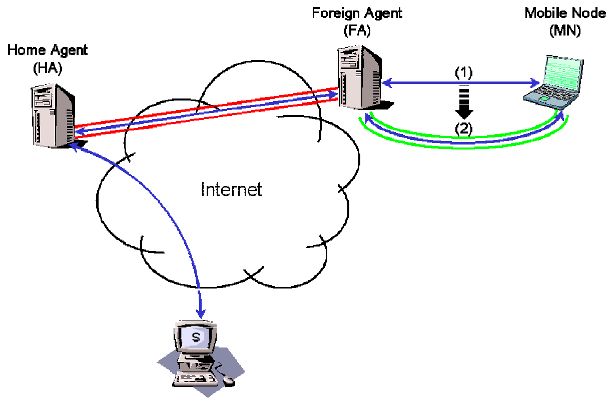

Figure 3. Integration of ME in Mobile IP environments

If the FA realizes that the communication characteristics of the current link to the MN become worse, it initiates a handover to an other communication device (which is on the same FA), and the Management Entity encapsulates the unpacked data in new IP packets and tunnels them via the new networking interface (chosen on the decision of the MIB) to the MN. In Figure 3 this process is shown by switching communication from arrow (1) to arrow (2) between FA and MN. Note that the initialization of handing over a connection could come from the MN as well as from the FA. The tunneling will always be done in both directions, i.e., if the Management Entity notices encapsulated incoming packets (as described above), the communication path back to sender will also be tunneled in the same way. The MN is now able to move within the different domains covered by one FA with its different networking devices while performing seamless handovers between those different communication technologies. The result is an improvement of the micro mobility. If the FA also supports networks with a larger coverage (e.g., GSM), the mobility in general will be improved as handovers in overlaid networks could be performed using this mechanism.

If the MN moves within his home area network, this situation can be seen as a specialization of the process described above. In this case, the HA and the FA are logically closed together in one host, while the MN has a topological correct IP address. Thus, the same operations for switching could be performed between the MN and the FA, also resulting in an improved mobility support.

4. Implementation issues

In order to evaluate our Management Entity, we implemented the Device Multiplexer for the Microsoft Windows operating system. Currently, the Multiplexer runs under Windows NT 4.0; we are currently porting the driver to WDM (Windows Driver Model) for the Microsoft Windows 2000 operating system.

In order to achieve transparency to the applications, the Device Multiplexer has to reside below the transport protocol. As Figure 4 shows, the networking applications access the transport protocol via their common interface, e.g., a socket. The socket interface itself accesses the transport driver using the Transport Driver Interface TDI. Both the interface to the applications as well as the TDI are unmodified. On the bottom of this hierarchy, a miniport driver interacts immediately with the NIC (networking interface card), and offers an NDIS miniport interface to the upper layers. This abstract interface offers the basic functionality for performing networking operations, e.g., function calls for sending and receiving data. As it is not practicable to modify the miniport drivers for each networking device and the transport driver, we implemented an intermediate (IM) driver that resides between the miniport driver and the transport driver. For the transport driver, the IM driver looks like a miniport driver and vice versa – therefore, it seems to be the most obvious way to implement the Device Multiplexer as an IM driver.

NDIS (version 4.0 and higher) also supports functions for retrieving the current status of a connection for a NIC. This status is stored in the parameter `OID_GEN_MEDIA_CONNECT_STATUS`, and could be used as a source for the MIB. When we implemented the Device Multiplexer, the drivers of our NICs did not support NDIS 4.0 – therefore, we derive the information for the current connection status from the routing for sending data via NDIS. After a predetermined number of unsuccessful trials for sending data, we assume that the connection is currently broken and the multiplexing mechanism is triggered.

Beyond TCP and UDP, the TDI interface also supports a raw IP interface. Thus, the IM driver intercepts every packet from the transport driver and encapsulates it in a new IP packet using the TDI raw IP interface, which is shown in figure 4 by the fat arrow from the IM driver to the transport driver. Due to the encapsulation of an IP packet, the new IP packet might be larger than the specified maximum transfer unit. In this case, the IM driver also has to care about segmenting and reassembling of packets, as the Windows NT 4.0 transport driver is not able to treat IP packets with a 0x4 in the protocol field within the IP header. On the receiver side, the IM driver recognizes IP packets with a protocol field of 0x4, extracts the inner packet, and forwards it to the transport driver.

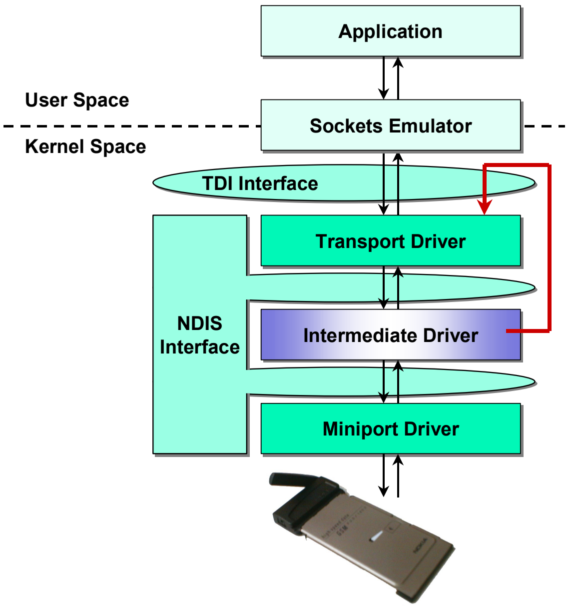

Figure 4. Implementation design

The next version of our IM driver will use the WDM functionality from Microsoft Windows 2000 for getting information on the current status of a connection. There is also an implementation for the Windows CE operating system in preparation.

5. Conclusion and outlook

In this paper, we describe a way that enables a mobile device to perform a seamless handover between different network technologies it is currently attached to. This is a basic requirement for a minimum of quality of service in a world of heterogeneous networks. Using the same network technology in all places – in the office as well as outside in urban or rural areas – is in many cases not possible and in most cases not useful. Instead, a mobile node has to adapt to the available technology and is expected to switch over to the one currently offering the optimal service for communication. Therefore we presented a Management Entity located within the mobile host. The lower part of the layered Management Entity realizes the switching between different network devices, e.g., a Wireless LAN and a mobile phone NIC. The cooperation with Mobile IP is described in more detail, as our Multiplexing Entity can be seen as an extension to Mobile IP for supporting micro mobility.

Future work will comprise two main areas: In the area of the Device-Multiplexer a detailed analysis of the network technologies is needed in order to define parameters and hints for the switching decisions. A MIB has to be defined accordingly. In the area of the TP-Multiplexer, the ongoing research currently focuses on multiplexing the UDP stream of an application over different network devices simultaneously.

Depending on results of the ongoing modifications and optimizations of Mobile IP, the proposed Management Entity can be the basis for a better support of both macro- and micro-mobility in a mobile node.

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