Towards Wireless Multimedia Communications - Current Standards and Future Directions

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Abstract

Today we face two major trends in communications technology, multimedia and mobile communications. Therefore, future wireless communication systems need to support many different services. Yet while in wired networks the migration to ATM based Broadband ISDN is visible, wireless ATM (WATM) internetworking for mobile clients is still in its infancy.

In this article first a brief overview of the current mobile communications standards GSM and DECT is presented and reasons are given, why they fail to deliver adequate performance for multimedia data transfer. Then the recently approved wireless local area network (WLAN) standards IEEE 802.11 and ETSI HIPERLAN 1 are detailed and their suitability for the transparent transfer of ATM cells is discussed. Last, the ongoing work of the ATM Forum's WATM Working Group and the efforts of the ETSI RES 10 regarding the further development of HIPERLAN 2, 3 and 4 are shown. Finally, WATM prototypes in testing are described, too.

1 Introduction

Simultaneously with the ever increasing performance of mobile terminals the size and power requirements of these systems drop. The resulting communication need of these terminals has pushed the development of data services in already existing wireless systems like GSM and DECT. Furthermore, new standards have been approved for WLANs. All of this approaches were initially developed for special application environments and therefore fail to deliver satisfactory support for multimedia communications. Table 1 shows the quality of service requirements of the most important services [1, 2].

Application	Bandwidth [kbit/s]	Transit delay [ms]	BER
Voice Telephony	13-64	< 140	$< 3*10^{-5}$
High Quality Audio	1.4 Mbit/s	< 500	$< 3*10^{-5}$
Video Telephony	32 kbit/s - 2 Mbit/s	< 100	$< 10^{-7}$
Telefax Group 4	64	< 200	$< 10^{-5}$
Television	15-44 Mbit/s		$< 10^{-10}$
File Transfer	64 kbit/s - 2 Mbit/s	> 1 s	$< 10^{-8}$

Table 1: Quality of service requirements of some basic services

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In order to support all these services the Asynchronous Transfer Mode (ATM) has been developed for the fixed Broadband Integrated Services Digital Network (B-ISDN). This technology enables the transport of all kind of traffic over a common network. Several standardisation bodies recently started to develop specifications for the use of ATM in mobile communications in order to exploit it's inherent ability to support multimedia traffic.

In the following sections an overview of the current mobile communication standards is given and the suitability of these systems to support multimedia communication is discussed. Last the ongoing efforts of the ATM forum and ETSI to standardise WATM is presented.

2 Current Standards

In this chapter a brief overview of the well-established mobile communication standards Global System for Mobile communications (GSM) and Digital Enhanced Cordless Telecommunication (DECT) and the new WLAN standards ETSI HIPERLAN and IEEE 802.11 is given.

2.1 GSM

Many countries throughout the world have offered mobile cellular services to the public for several years [3]. Although quality and area of coverage may vary widely, the growing demand has surpassed almost all estimates. Still, the variety of technical standards used has been a major obstacle for subscribers intending to roam between countries. Especially in highly-populated Europe with it's multitude of small countries, mobile telephony used to be constrained to the country for which the equipment was designed.

To overcome this obstacle, most of the european countries agreed to allocate the same spectrum for mobile communications and the GSM initiative developed a common standard, GSM, that covers almost all aspects of a cellular network. GSM has been very successful and is now being used in Europe and Asia in the 900 and 1800 MHz band, and in the USA in the 1900 MHz band. At the same time that GSM has started to boom, ISDN has made it's final breakthrough. Since GSM has been designed to be compatible with ISDN as far as appropriate, interworking between the two standards is assured and thus a rich variety of communication services is available [3].

Multimedia and GSM

GSM is like IS-54 or IS-95 in the US a standard for cellular radio communication. The major design goal of GSM was the provisioning of good quality speech service with wide area coverage of the system. This service is still the most important service of GSM networks. In addition, a wide variety of data services can be used without a separate modem. This services include

Messaging Service, Facsimile transmission and data communications at rates up to 9600 bit/s full duplex. Data transmission is provided with very low error rates if error correction is selected.
Current GSM data services are based on circuit-switched technology and each connection uses one TDMA time slot [4]. Since each of these GSM traffic channels (TCH) has a maximum capacity of 13 kbit/s for speech and 9600 bit/s for data if error correction is used (TCH/F sub-channel), the multimedia capabilities of GSM are rather constrained. In recognition of this fact, the ETSI is currently at work on GSM phase 2+. The two main data items to be standardised in this phase are High Speed Circuit Switched Data (HSCSD) and General Packet Radio Service (GPRS) [4].
HSCSD tries to enhance circuit switched GSM data services by providing higher user rates than 9600 bit/s. This is done, comparably to the primary interface of ISDN, through the bundling of multiple TCH/F sub-channels to provide N x 9600 bit/s [4]. By using a maximum of 7 TCHs, a 64 kbit/s simplex channel could be realised.
GPRS on the other hand provides actual packet radio access for mobile GSM users and reserves radio bandwidth only when there is something to send. By using up to 8 TCHs GPRS can provide up to 110 kbit/s. In contrast to HSCSD GPRS leads to a change in the network architecture. Special GPRS Support Nodes (GSN) have to be included in order to provide the GPRS service.
A major problem of both, HSCSD and GPRS, is the lack of available bandwidth. If these services are introduced using the currently available spectrum, bandwidth needed by a user of these services can not be used for the already existing services, therefore reducing the overall number of possible users [22].
Although GSM’s usage will increase further, it is rather ill-suited for the transmission of multimedia data within local area networks (LAN). It only supports small-scale data services and lacks capacity for the bandwidth requirements of today’s workstations and video equipment. Support for packet oriented data transfer has still to be implemented. GSM is currently only used for computer interconnection if the required mobility outweighs the cost disadvantage compared to a modem or ISDN line. Further modifications of the GSM standard will doubtless improve many aspects, but will not change its principal design as public wide-area network with low bitrate capabilities.

2.2 DECT

Whereas GSM describes a complete cellular network, the Digital Enhanced Cordless Telephone standard (DECT) initially defined little more than an air interface for cordless telephony. DECT was intended to be a private system connected to a private branch exchange (PBX) to give users mobility within the coverage of the PBX. Alternately, it could be used as a single cell in a home or a small company [5]. During it’s development in the 90’s, public access was included and so

DECT became part of the public network [6], although it is in no way a replacement for an existing network. Instead, it is designed to be an interface to existing and future networks like the public switched telephone network (PSTN), the integrated services digital network (ISDN), the GSM and PBX networks.

One of the most intensively discussed areas of application for DECT is the Radio in the Local Loop (RLL), where a wireless link allows new network providers to cover the last mile to their potential customers.

	GSM	**DECT**
Band	900/1800/1900 MHz	1900 MHz
Bit Rate	270.8 kbit/s	1152 kbit/s
Power (max.)	0.8 - 6 W	250 mW
Number of carriers	125	10
Channels per carrier	8	24 (=12 duplex)
Data rate for speech	13 kbit/s	32 kbit/s
Cell Size	< 35 km	< 400 m
User velocity	< 250 km/h	< 50 km/h

Table 1 Key GSM and DECT specifications [4, 7]

Table 1 shows the key features of GSM and DECT. It can easily be seen, that GSM was designed for large numbers of highly mobile users using low data rate services, whereas DECT serves slow moving terminals with high data rates up to N-ISDN in geographically small areas. Due to the limited range of a DECT system, it is well suited to cover areas with high user population (e.g. stations, airports, companies).

Figure 1 shows how DECT works. DECT uses frequency division multiple access (FDMA) in combination with time division multiple access (TDMA) and time division duplex (TDD) for transmission [5]. There are 10 carrier frequencies in conjunction with 24 time slots per TDMA frame. Of these 24 slots, the first 12 are dedicated for downlink transmission and the latter for uplink, although there are operation modes where this distribution is changed. A bi-directional channel is formed by the combination of a carrier frequency and one or multiple pairs of time slots, e.g. Carrier 1 and slots 2+14.

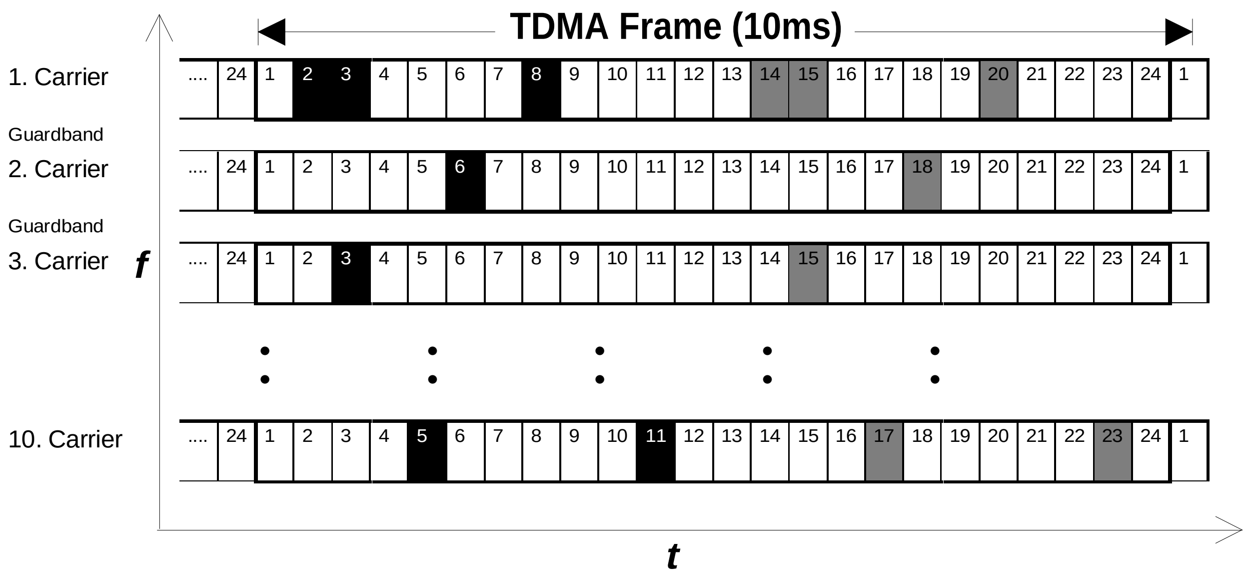

Figure 1 DECT Transmission

Multimedia and DECT

DECT allows a high amount of functional choices to be made regarding the air interface. To facilitate the deployment, the usage of DECT in conjunction with data networks is laid down in DECT Data Service Profiles (DSP), which can be looked upon as a selection of CI standards setting the exact requirements of the air interface and the interworking functionality towards the external network [4].

The DSPs for non-voice networks range from low rate messaging service at approximately 1.3 kbit/s to a frame relay service with throughput up to 552 kbit/s unidirectional (23 slots at 24 kbit/s) or 288 kbit/s bi-directional (12 slots at 24 kbit/s) [4]. Apart from this, there are profiles for interworking between DECT and ISDN as well as GSM.

The DECT/ISDN interworking profile (IAP) allows transmission of ISDN speech and the ISDN 64 kbit/s Unrestricted Digital Information (UDI) service. With the combination of forward error correction (FEC) and limited automatic repeat request (ARQ) [8], the error rates at the radio interface are improved and the DECT terminal formed by the Fixed System and the Portable System can figure as ISDN terminal.

To access GSM services without GSM radio support, the DECT/GSM Interworking Profile (GIP) can be used, which covers GSM speech, supplementary and facsimile services.

Video Conferencing over a DECT radio link can either be performed by highly compressing the video and audio signals and transmitting them within a single standard DECT link with 32 kbit/s [9], or a common ISDN video conferencing tool could be used in combination with the IAP.

DECT's capability to transport multimedia traffic is comparable to present-day Narrowband ISDN, which can be used for low-quality video conferencing. Yet a maximum bi-directional transfer rate of 288 kbit/s [4] rules out all current MPEG standards for compressed video, not to mention HDTV. Compared with today's proprietary wireless LANs like ARLAN, it offers roughly the same bandwidth plus an isochronous data service.

2.3 IEEE 802.11

The stifling effects of the lack of accepted standards for wireless LANs have been visible during the last five years. Although mobile computing devices have boomed for some time, network interconnection still has to be done through connecting by cable, unless the user commits himself to a wireless LAN with unsatisfactory throughput and usually, incompatibility with other vendor's products. In recent years, this restraint was recognised and addressed by two major standardisation bodies, namely the Institute of Electrical and Electronic Engineers (IEEE) and the European Telecommunications Standards Institute (ETSI). In 1990 the IEEE formed the 802.11 committee with the aim to establish a standard for wireless LANs [10, 11]. The work has been completed in 1996 and mainly covers the Media Access layer (MAC). In the following paragraph the main features of the proposed architecture are described.

Architecture

As shown in Figure 2, the 802.11 standard supports two primary topologies: one in which the mobile stations connect to the backbone network via access points (AP, representing base stations), and one in which the stations form an ad-hoc network and communicate directly with each other [11]. The base station oriented topology is intended to provide complete wireless coverage within buildings through preinstalled multiple access points. The stations communicating with such an access point are called *members* of the AP's cell.

The ad-hoc topology is intended for situations like meetings, to facilitate file sharing between two portable computers without requiring a preinstalled infrastructure.

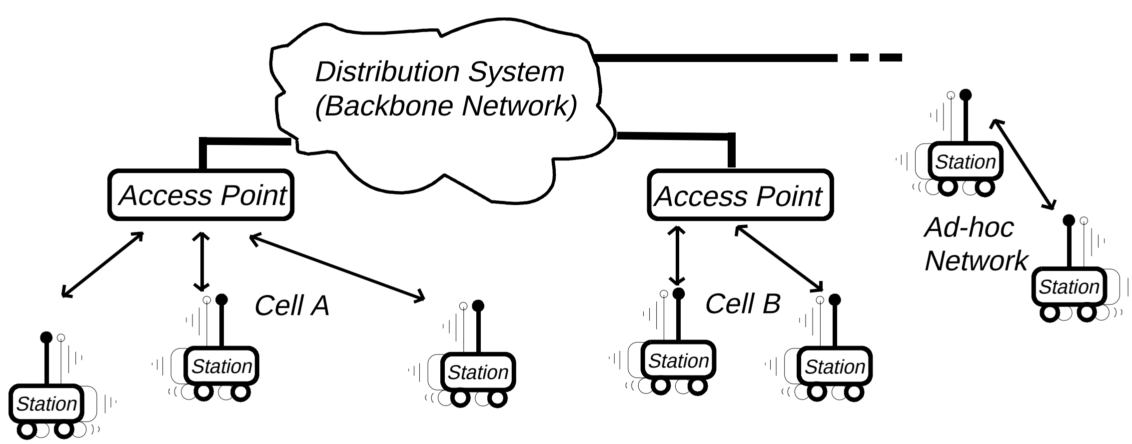

Figure 2 Topologies of the 802.11 network standard

The 802.11 MAC protocol allows both topologies to coexist, that is to transmit within the same coverage range. Basic ad-hoc networking is possible, yet the necessary mechanisms for multihop routing were omitted. That means that a station can only communicate with stations within reach, but not with remote stations through an intermediate working as relay.

At the physical layer, three different types are provided: 2.4 GHz ISM band frequency hopping (FH) or direct sequence (DS) spread-spectrum (SS) and Infrared (IR) light. In addition to these three possible physical layers, two different data rates of 1 Mbit/s and 2 Mbit/s were specified [11, 10, 12]. While this bounty of options allows plenty of different 802.11 compliant networks to be designed, it also complicates interoperability and thus increases equipment costs.

	802.11
Band	2.4 GHz with FHSS or DSSS
Bit Rate	1 Mbit/s / 2 Mbit/s
Power	< 100 mW
Number of carriers	FHSS: 79, DSSS: 11 (US and Europe)
Channels per carrier	variable
Data rate for speech	unspecified
Cell Size	< 150 m

Table 2 802.11 specifications (without IR)

Multimedia and 802.11

Whereas DECT and GSM were designed with isochronous data in mind and thus support such traffic without further actions, 802.11 is mainly designed for asynchronous data like such originating from 802.x wired networks. Still, it supports time-critical traffic (time-bounded in 802.11 terminology) like voice or video by switching from Distributed Co-ordination Function (DCF) to Point Co-ordination Function (PCF). While in DCF all stations negotiate media access among themselves [13, 14, 15], in PCF the Access Point/Base station controls media access by polling the mobile station allowed to transmit [16, 10]. The station transmits its information, receives an acknowledge and the AP polls the next station in it’s list. Because the PCF requires an AP, transmission of time-critical data is limited to base station oriented networks.

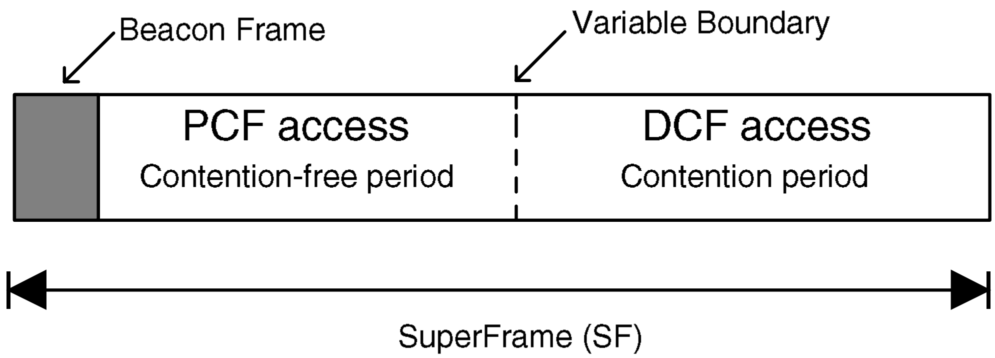

Figure 3 Alternation of contention-free and contention periods

As shown in Figure 3, the AP periodically starts every SuperFrame period the PCF phase. Every station within reach of the AP is informed of the maximum duration of the PCF phase. At the end of the PCF, the AP notifies the stations of the beginning of the DCF. This divides the SuperFrame into a contention-free and a contention period [11, 19].

While this provides a mechanism for time-bounded services lacking in other IEEE 802.x network standards, 802.11 wireless networks suffer from a number of problems when multimedia traffic is to be transmitted:

- *Transmission errors* through fading, hidden stations and interference. Although some of these effects only affect the DCF, they still lower the total throughput within a cell.
- *Overhead*: A MAC frame has an overhead of 32 bytes just for header and CRC information. This leads to extreme inefficiency when small packets like audio samples are transmitted. If, on the other hand, this is countered by transmitting multiple samples in one frame, the necessary time to fill the frame introduces a packetization delay which is, especially for highly compressed audio or video, worse than those of satellite links.

[11] discusses the transmission of ATM cells over a 802.11 wireless network, an expectable challenge for a multimedia network. The authors propose to transmit multiple ATM cells within one frame. Although transmission errors were assumed to be zero, the mean MAC frame delay experienced by 5 stations transmitting 8 cells per payload at 256 kbit/s lies beyond 1000 ms.

Although 802.11 specifies support for time-critical data, the standard has obviously been optimised for wireless extension of 802.x packet data networks. Even with 2 Mbit/s total bandwidth only video sources with 64 kbit/s can be supported with reasonable delays. The present maximum bitrate of 2 Mbit/s as well as the design for the overcrowded and small ISM band at 2.4 GHz limit further improvement of the standard. Still, the performance of 802.11 for transmission of packet data is better than GSM or DECT as long as time-critical data accounts only for a low percentage of traffic.

2.4 HIPERLAN 1

Since 1992 the ETSI works on the specification of standards for wireless LANs under the title 'HIgh PErformance Radio Local Area Network' (HIPERLAN) [17]. The intention behind this move was to design a wireless LAN that would be indistinguishable in performance from wired LANs such as Ethernet, plus some support for isochronous services [11].

The standard as described in [20] is restricted to the MAC layer. In the course of work on HIPERLAN, the difficulty of realising a truly universal low-cost wireless LAN was recognised. As a consequence, in 1996 after completition of HIPERLAN 1, different application scenarios were defined and assigned to the HIPERLAN specifications 1, 2, 3 and 4. Because of the fundamental design difference, the latter are described further in section 3.1. All these wireless systems will utilise the HIPERLAN radio spectrum allocated in Europe.

HIPERLAN type 1 (ETS 300 652) is a privately operated wireless LAN, which can be used independently from any fixed infrastructure as an ad-hoc network. On the other side, HIPERLAN 1 allows the access to conventional wired LANs like Ethernet. Multiple networks can be operated in parallel, automatically sharing the available bandwidth without requiring interaction of the user. The channel access protocol is decentral, supports priority flags within the packets and can handle hidden stations. In contrast to 802.11, forwarding is supported and thus allows transmission within partly meshed networks. Table 3 gives an overview over the technical specifications of HIPERLAN Type 1. Figure 4 illustrates the channel access (MAC) scheme of HIPERLAN 1, called EY-NPMA for Elimination Yield Non-Pre-emptive Priority Multiple Access, which allows collision-based access after sensing the carrier.

In this example, 5 stations use the channel. After station 1 has completed transmission, the recipient station 2 acknowledges the received data. Now station 3, 4 and 5 contend for the channel.

First, the three stations signal the priority of the packet they intend to transmit, which in this case happens to be the same for all. If one station would have had higher priority, it would have sent in an earlier priority slot, and the other stations would have, after sensing this, refrained from further competing for transmission.

In the following elimination phase, each station randomly prolongs sending the priority pulse and then immediately listens for other stations sending even longer. The winners are those who send longest.

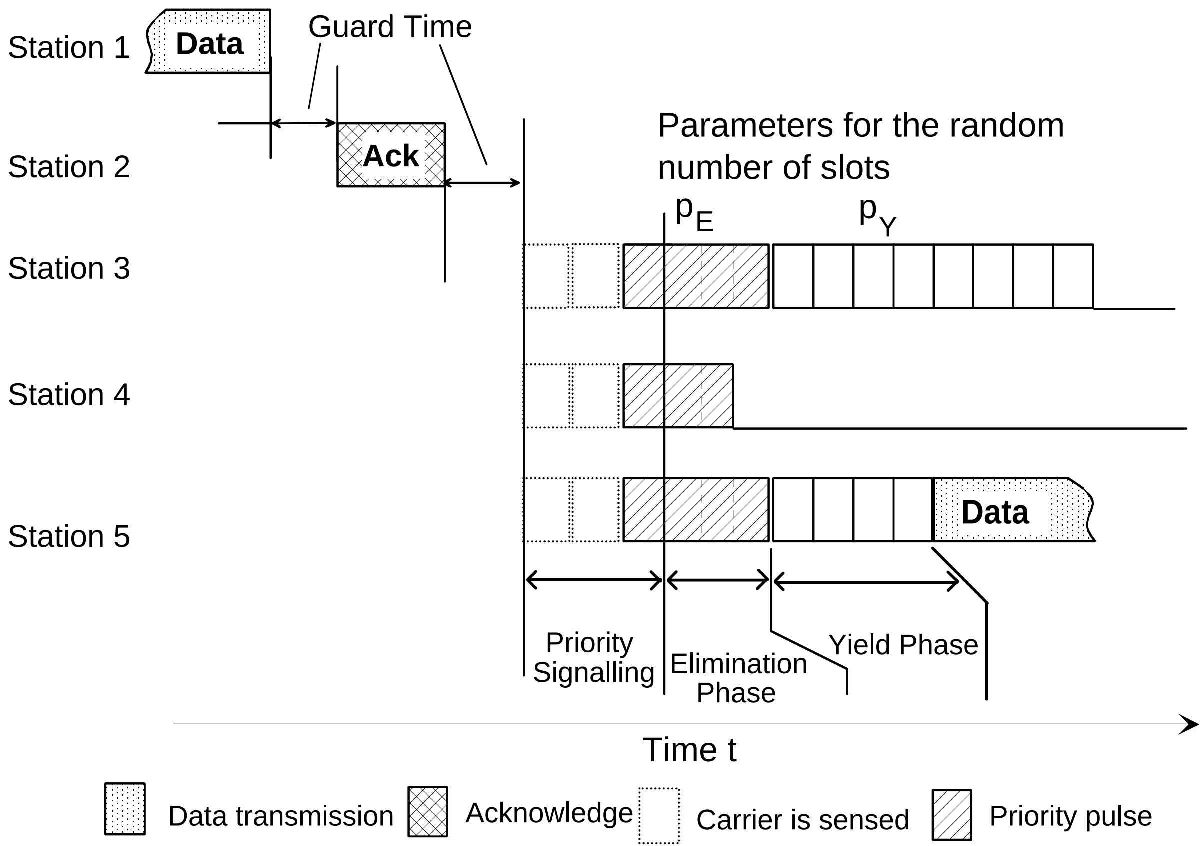

Figure 4 Channel Access in HIPERLAN 1 [17]

The ensuing yield phase reduces the competing stations further by making all remaining listen for a random number of slots whether the channel remains free. If, after this time, the channel is still free, one or multiple stations transmit, if not, the station refrains from transmission.

This complicated scheme ensures a low constant collision rate of about 3.5 %, which is almost independent from the number of competing stations and other external parameters. This is a major advantage over channel access schemes with non-constant collision probabilities, like CSMA/CA used in IEEE 802.11, as [15] shows.

Simulation studies at the Daimler-Benz Research Centre have dealed with the suitability of HIPERLAN 1 networks as potential carriers for connection-oriented multimedia traffic [17].

In the simulation whose results are shown in Figure 5, a HIPERLAN 1 network with 16 fully meshed stations was assumed. While for big service unit sizes net data rates of up to 14 Mbit/s were attained, throughput dropped dramatically for small sizes such as 64 Byte to values of 1.9 Mbit/s. The reasons for this behaviour are rooted in the decentral basic design, the ad-hoc topology, the resulting consequences of connection-less oriented transport and the collision-based channel access scheme of HIPERLAN 1.

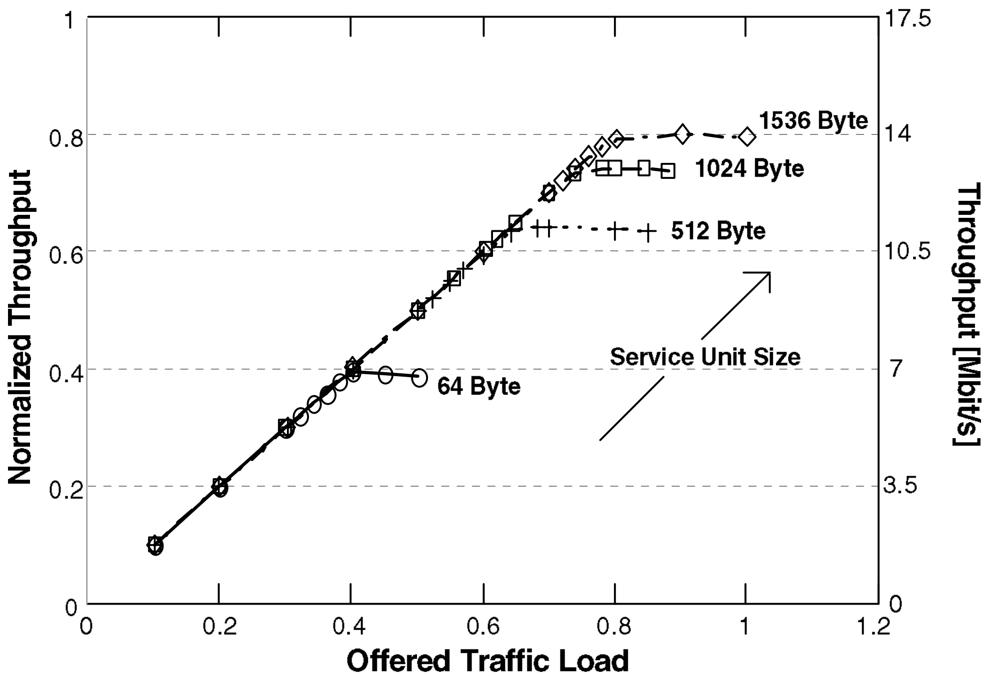

Figure 5 Throughput of HIPERLAN 1 in dependency of Service Unit Size [17]

This was the key motivation for the ETSI RES 10 committee to demand further HIPERLAN standards [18] for handling central controlled access with connection-oriented transport capabilities.

Multimedia and HIPERLAN 1

HIPERLAN 1 is not connection-oriented, all data is transmitted on a packet by packet base. Time-critical services are supported only insofar as the initial value of the packet lifetime and priority can be assigned by the application. The connection-less structure doesn't support the mapping of Quality-of-Service (QoS) requirements of applications or single connections onto the priority assignment. Therefore the achieved QoS is only best-effort and of a statistical behaviour depending on the application scenarios.

HIPERLAN 1 was designed and optimised for connection-less transport and has a performance close to wired 802.x networks. While the relatively high attainable data rates may allow some multimedia applications to run as good, or better, as bad as on legacy wired LANs, it is rather unsuited as a multimedia network.

3 Future direction

The wide-scaled access to Broadband ISDN will take place in the next few years, possibly even still this century. Public carriers like the Deutsche TELEKOM already have interconnected all major German cities with fibre optic links running ATM over Synchronous Digital Hierarchy (SDH, the European counterpart to SONET) over ATM. Prohibitively high telecommunication prizes will drop as monopolies fall and competition ensues. Because of the wide distribution of Personal Computers (PCs), even today many home consumers already apply for ISDN links. While this mainly concerns wired network infrastructure, it also shows that a necessary prerequisite for wireless multimedia networks, the high-speed backbone, will soon be easily accessible. On the other hand, the agreed-upon base technology for B-ISDN, ATM, has no standardised extension into the wireless field [23].

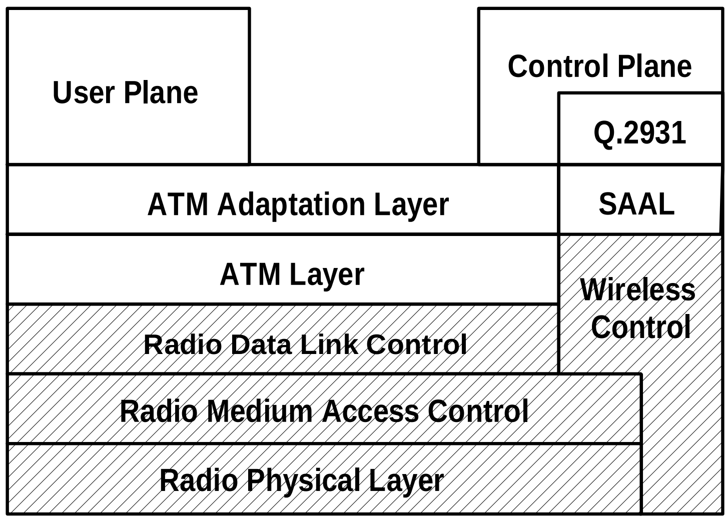

Figure 6 Layers of a Wireless ATM system

One of the main applications for a Wireless ATM network (WATM) is as an access extension to a wired ATM network, which means that they will use standardised ATM-Interfaces like UNI/NNI and will support Quality of Service (QoS) requirements of the ATM service classes Constant Bit Rate (CBR), Variable Bitrate (VBR), Available bitrate (ABR) and Unspecified Bitrate (UBR). But whereas conventional wired ATM systems handle QoS requirements in the ATM Adaptation Layer (AAL)and in the ATM layer, in WATM systems QoS parameters have to be accessible and handled at the radio channel access layer (Figure 6) [24,25].

While wired ATM systems don’t perform switching or multiple access below the ATM layer because of the dedicated point-to-point links between the systems, but WATM systems have to since the media is now shared [21]. This is illustrated in Figure 7: Without further functionality within a WATM system the emitted ATM cells from WS1 and WS4 are not distinguishable at the air interface.

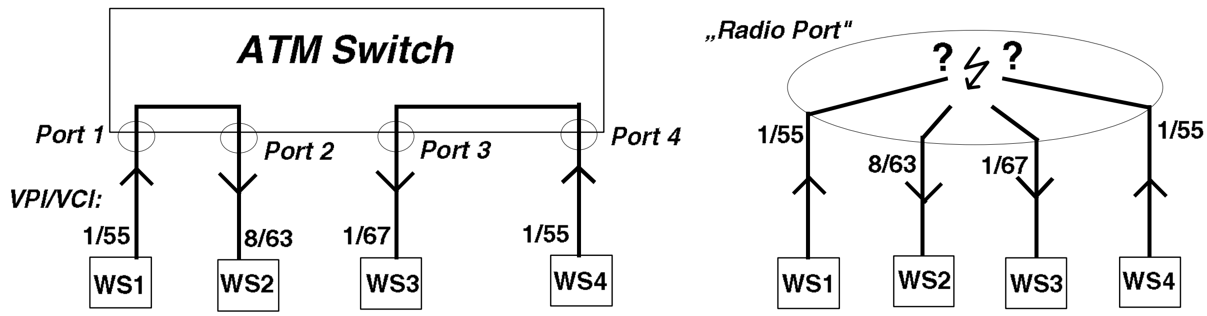

Figure 7 Wired exclusive and wireless shared channel access

Furthermore, the QoS of a connection has to be upheld for mobile stations and the associated time-variant network topologies. This requires an elaborate mobility management with handover and roaming mechanisms. Further difficulties are caused by the high bit error rates (BER) and the resulting need to retransmit erratic cells under tight timing constraints. Additional overhead through preambles and transceiver turnaround delay between send and receive make the transmission of small packets inefficient.

These aspects all have to be taken into account when wireless ATM systems such as HIPERLAN 2, 3 and 4 are designed.

The ETSI as well as the ATM Forum are busy filling this void with joint effort. While the ETSI tries to cover the lower layers like physical and media access layer, the ATM Forum intends to work the necessary extensions into the ATM and AAL layers (Figure 6).

3.1 HIPERLAN 2, 3, 4

HIPERLAN type 2, 3 and 4 are supposed to supplement ATM networks. Each type addresses a different application scenario, in which the network allows the connection-oriented transmission of ATM cells and the access of mobile stations to wired ATM networks. Several Advanced Communications Technologies and Services (ACTS) projects, supported by the European community, aim to provide wireless access to B-ISDN networks using the ATM technology, e.g. the Wireless ATM Network Demonstrator (WAND) or System for Advanced Mobile Broadband Application (SAMBA), projects targeted at fundamental research on WATM. The results of these projects will influence the further standardisation of HIPERLAN. Up to now, the ETSI has worked upon the definition of application scenarios and system architectures resulting from the technological constraints these systems face. Table 3 shows the characteristics of the different HIPERLAN types.

	HIPERLAN 1	HIPERLAN 2	HIPERLAN 3	HIPERLAN 4
Application	Wireless LAN 8802 compatible	WATM short range access	WATM remote access	WATM interconnect
Carrier Frequency	5.15-5.25 (5,3) GHz expansion intended			17.2-17.3 GHz
Network Topology	decentral, ad-hoc	cellular, central	Point to multipoint	Point to point
Antenna	omnidirectional	omnidirectional	directional	directional
Coverage	< 50 m	50 - 100 m	5000 m	150 m
QoS guarantees	none, statistical behaviour	ATM Service Classes RT-VBR, NRT-VBR, CBR, ABR, UBR		
Operator	private	private/public	private/public	private
Mobility	< 10 m/s	< 10 m/s	stationary	
Interfaces	conventional LANs	ATM-Networks		
Bandwidth	< 19 Mbit/s	>20 Mbit/s	> 20 Mbit/s	155 Mbit/s
Power Conservation	yes	yes	optional	optional
Cell Delay	-	< 5 ms	< 5 ms	< 5 ms
Cell Rate with non-detectable errors		$< 5x\,10^{-14}$	$< 5x\,10^{-14}$	$< 5x\,10^{-14}$
Product Start	1998	2000 (estimated)	after 2000	after 2000

Table 3 Characteristics of the different HIPERLAN types

In contrast to type 1, **HIPERLAN type 2** will describe a **short range wireless access network** for mobile and stationary terminals to wired ATM infrastructures over base stations (Access Points), who in turn are connected by wire to an ATM switch or multiplexer. Because of the low radio transmitting power, multiple access points are necessary for all but the smallest networks. This in turn requires handling of handover of connections between access points. The aim is to realise the transmission of ATM cells over HIPERLAN 2 user-transparently. This means that the services and QoS guarantees of wired ATM networks have to be provided by HIPERLAN 2, too. The Channel access will be controlled by base stations. Figure 8 shows the reference model which was proposed by the HIPERLAN 2 working group. Besides the well known ATM control and transport architecture, HIPERLAN 2 will include elements for handling user mobility to support handover between different base stations and roaming in the whole network. The necessary supplements to ATM signalling will be specified by the newly founded WATM group of the ATM forum.

HIPERLAN Type 3, titled **Remote Wireless Access to ATM networks**, specifies ATM based point to multipoint communication between stationary equipment. A typical application scenario is as wireless based access network also known as Radio Local Loop. Since mobility is not supported, directional antennas can be used, extending radio coverage up to 5 km and allowing better frequency re-use efficiency.

Because of the introduction of wired ATM technology in combination with rising demand for high bitrate services, a large market volume is seen for these systems.

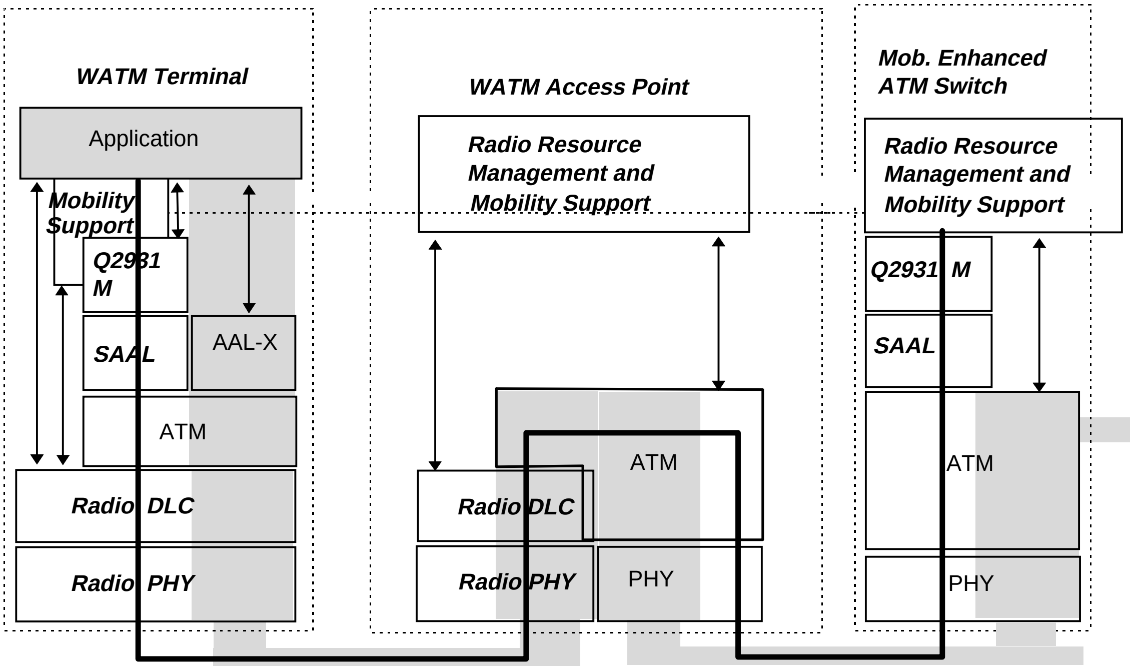

Figure 8 WATM Reference Model for HIPERLAN 2

HIPERLAN Type 4 Wireless Interconnection for ATM networks is used in applications calling for communication between wirebound infrastructure or stationary equipment through dedicated point-to-point connections, comparable with today's microwave links. High channel capacities combined with high bitrates are necessary for this scenario. HIPERLAN 4 supports datarates of up to 155 Mbit/s over distances up to 150 m. The antennas used have directional characteristics and operate at 17 GHz.

Spectrum Constraints

At present, 100 MHz of spectrum at 5 GHz have been designated by the European CEPT for the license exempt use of HIPERLAN systems, while in the US the FCC has announced to free 300 MHz of spectrum for so-called U-NII (Unlicensed National Information Infrastructure) devices. 200 MHz of spectrum are available at 17 GHz, but only 100 mW RF power is allowed.

Multimedia and HIPERLAN 2/3/4

While HIPERLAN 2, 3 and 4 surely will have the capacity and functionality to carry high-volume multimedia traffic, their implementation, even their standardisation will take several years to come. It is very probable that before this time has elapsed, several vendors will offer Wireless ATM network systems with moderate to good performance characteristics, thus either making part of the standards to become obsolete or outdated, or forcing the standards to be modified. Since this phenomenon has taken place several times before in history, it is bound to repeat itself again. The ETSI has recognised this danger and tries to co-operate closely with the ATM Forum, representing vendors and customers of ATM equipment.

3.2 ATM Forum

Since the ATM Forum's main intention is to remove obstacles in the way of rapid market growth for ATM equipment, it is only reasonable that a WATM Working Group was established in 1996. Figure 9 illustrates the application scenarios of a WATM system as defined by the ATM Forum. In the centre lies the fixed public switching infrastructure. Surrounding the public infrastructure are the applicable communication scenarios that are envisioned at present.

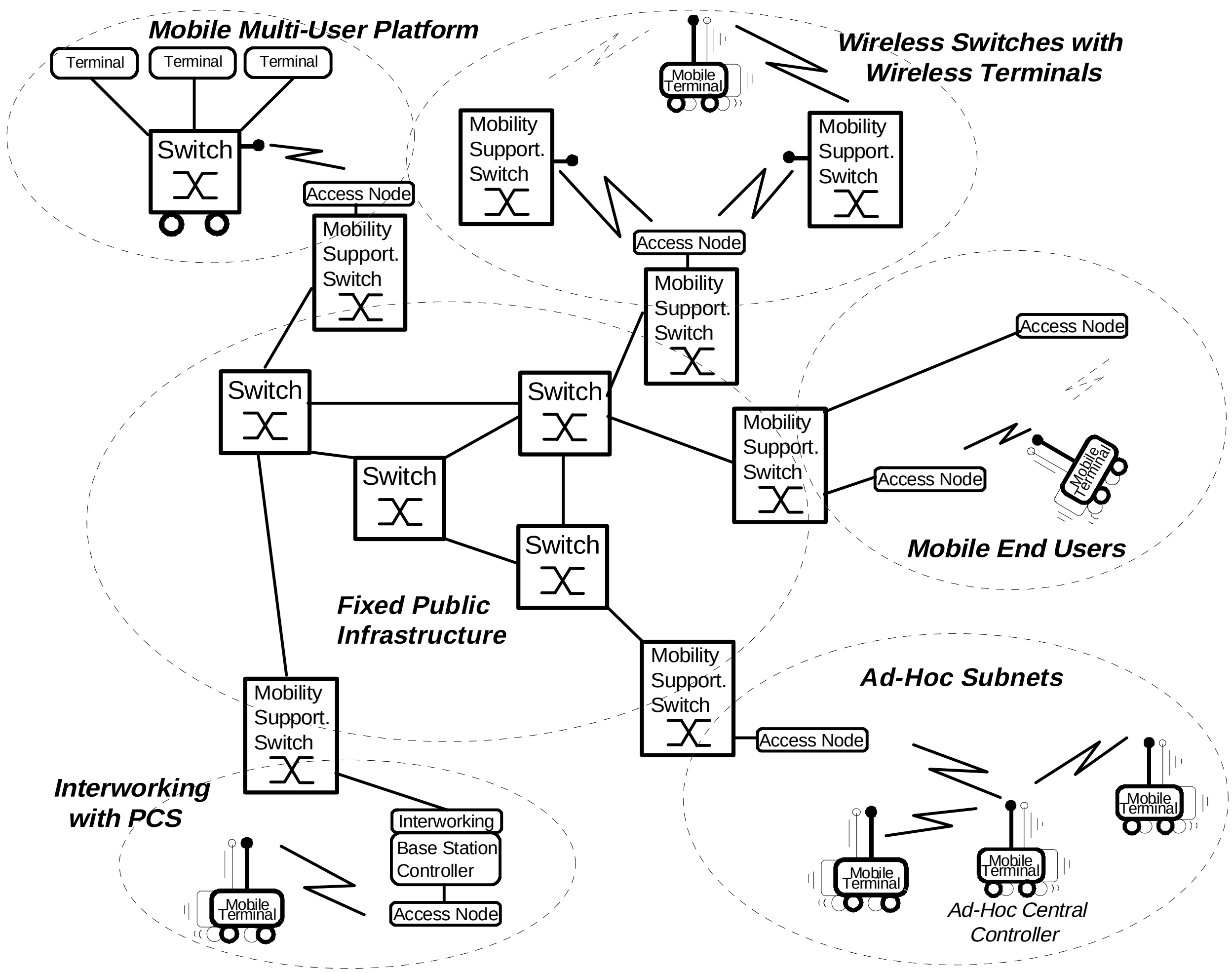

Figure 9 WATM Reference Configuration

- **Mobile End Users** are communicating directly with the fixed network through a wireless access node. This is the case for Wireless LANs and digital cellular systems.

- **Wireless Switches with Wireless Terminals**. The terminals establish connections with the fixed network through wireless and mobility supporting switches. One example is satellite-based switching.
- **Mobile Multi-User Platform**. The end users have a wired connection to a switch, but the whole system is mobile and the switch has a wireless connection to the fixed network through a wireless access node. This could be the case for naval or military vessels carrying a fixed network.
- **Interworking with PCS**. In this case the users are PCS terminals. The mobility and rerouting capabilities of the mobility supporting ATM switches is used to route traffic to the appropriate PCS base station, similar to today's GSM basestations using N-ISDN as backbone.
- **Wireless Ad-hoc networks** are useful for a multitude of situations, such as portable PC's in a business meeting. In many cases no access point is available or the coverage of a basestation doesn't suffice and forwarding through one of the wireless terminals has to be performed.

The Wireless ATM specification to be developed by this group will cover both requirements for mobility control in ATM infrastructure networks, as well as requirements for seamless radio extension of ATM to mobile devices [26]. The following work items can be divided in two distinct parts: **Mobile ATM**, covering higher-layer control or signalling functions for generic mobility support; and **Radio Access Layer**, covering radio link protocols for WATM access.

Mobile ATM protocol extensions:

- *Handoff control*. Handoff is a mobile network functionality supporting in call terminal migration in PCS, cellular or WAN backbone and end-to-end WATM. This requires signalling extensions at the UNI and NNI interfaces for dynamic re-routing of a set of virtual connections from one radio port to another. This process is in general initiated by the mobile terminal or radio port and may involve VCs connected to different fixed or mobile end points.
- *Location management* for mobile terminals. This refers to mapping of a mobile device 'name' to a 'routing ID' used to locate the ATM endpoint [26]. Although this functionality may be provided by existing networks like GSM, a high performance location service integrated into mobile ATM is also in consideration. The widespread use of IP-based terminal equipment requires mobility support for IP-over-ATM applications, too.
- *Routing* consideration for mobile connections. Routing considerations are required for the mapping of mobile terminal 'routing-IDs' to paths within the network, as well as route identification and optimisation for handoff. The present routing algorithms of ATM have to be upgraded to support these mobility functions.

- *Traffic and QoS control* for mobile connections. Terminal mobility has a impact on Call Admission Control (CAC), traffic control and QoS management, possibly forcing dynamic QoS renegotiation.
- *Network management*. Wireless mobile networks require dynamic network reconfiguration capability. Performance management and fault identification are more difficult than in fixed networks.

Radio Access Layer protocols:

- *Radio Physical Layer*. The requirements currently discussed are: Range of 100-500 m, minimum bit rates of 25 Mbit/s, short burst preambles (< 16 Bytes), efficient frequency usage (> 2 Bit/s/Hz) and power levels of 100 mW combined with low bit error rates [27].
- *Medium access control* for wireless channel with QoS support. This layer is necessary to support shared use of the radio channel by multiple terminals and must support standard ATM services such as ABR, VBR, CBR and UBR with QoS controls. At the same time a high radio channel efficiency must be maintained.
- *Data link control* for wireless channel error handling. Because performance drops significantly in presence of high cell loss rates, powerful error control procedures are required. Possible solutions may include error detection and retransmission in combination with forward error correction dependent on the used ATM service class.
- *Wireless control* protocol for radio resource management. This protocol supports control plane functions related to the radio access layer and additionally, wireless control metasignaling to support mobile ATM functions like registration, authentication and handoff.

These tasks and the involved amount of work in co-operation with the ETSI RES 10 committee have caused the following time schedule (Table 5) to be established. It can be expected that the first draft-compliant WATM systems will be generally available in the midst of 1998, especially since many manufacturers of wireless equipment are involved in the working group.

Work area	4Q96	1Q97	2Q97	3Q97	4Q97	1Q98	2Q98	3Q98	4Q98	1Q99
Reference model (Liaison with RES 10)	start		end							
Requirements	start		end							
Radio sub-system			start				end			
Mobile ATM			start				end			
Specification							Refined Spec.	Straw ballot	Resolve comments	Final ballot

Table 4 WATM working group time schedule

3.3 WATM prototypes

In this section we briefly discuss some of the numerous wireless ATM prototypes.

Symbionics

Symbionics has built a laboratory prototype with a data rate of 8 Mbit/s operating in the ISM band at 2.4 GHz [27]. The system has a low packet error rate of 0.1 % for 2 kB data packets, optionally uses antenna diversity and forward error correction (FEC). The authors point out, that a WATM system needs an equaliser due to delay dispersion and path loss.

SWAN and BAHAMA by AT&T Bell Laboratories

The Seamless Wireless ATM Network (SWAN) described in [28] uses off-the-shelf 2.4 GHz ISM band radios. The network is intended for indoor pico-cells covered by mobility-aware basestations, who in turn are interconnected via an ATM wired backbone. A raw bi-directional channel bandwidth of 312 kbit/s, round-trip delays of up to 25 ms and cell loss rates of less than 0.25 % characterise this prototype. SWAN distinguishes itself through it’s low-latency VC routing algorithms based on performance triggered rebuilds and end-to-end ATM over both wired network and wireless last hops.

The Broadband Ad-Hoc ATM Anywhere (BAHAMA) project described in [29] is an earlier attempt at designing a wireless ATM LAN capable of supporting mobile users with multi-Mbit/s access rates. The term Ad-Hoc only refers to the interconnection of the so-called Portable Base Stations (PBS) providing microcell coverage, the mobile users operate in a basestation oriented network featuring peer-to-peer communication. The paper does not report specifics on an technical implementation. BAHAMA uses a new VPI/VCI concept for routing within the mobile network similar to [21].

WATMnet by NEC C&C Research Laboratories

The WATMnet system described in [30],[31] and [32] is a prototype wireless ATM network for multimedia personal communication. The experimental system’s hardware consists of laptops with special wireless interface cards, multiple base stations and a mobility-enhanced ATM switch. The wireless network interface cards (NIC) operate at data rates up to 8 Mbit/s in the 2.4 GHz ISM-band. The wireless network protocols support ABR, CBR and VBR transport services and use a TDMA/TDD based MAC protocol for channel access. It is intended to replace the current modem with a new 5 GHz-radio supporting up to 25 Mbit/s till the end of 1997. Due to part of the network protocol being run by the mobile hosts processor, applications can only achieve throughputs of about 1 Mbit/s.

Magic WAND

Magic Wireless ATM Network Demonstrator (WAND) is an European Council Advanced Communications Technologies and Services (ACTS) project. The main effort within the project is directed towards WATM network with mobile terminals for multimedia access. The system will operate at 5 GHz with 20 Mbit/s bandwidth and is supposed to influence the ongoing standardisation of HIPERLAN type 2.

Philips

In the ATMmobil program Philips is implementing prototype WATM systems as part of the Wireless LAN project. These systems are aimed at the low-cost home consumer market and will interconnect laptop PCs, printers, fax machines and audio and video equipment. Philips will build an Ad-Hoc as well as a basestation demonstrator, but the focus is on the Ad-Hoc topology [33, 34]. It is intended to run a distributed algorithm over the supported peer-to-peer links to select one among the mobile nodes to act as logical centralised wireless controller who is responsible for resource and QoS management. Because Philips promotes the ad-hoc topology within the ETSI RES10 WATM group as well as in the ATM Forum, a controversial discussion has been started.

4 Conclusion

Today there are many standards for wireless communication systems available like cellular systems for speech service (e.g. GSM, DECT, IS-54), cellular systems for data service (e.g. ARDIS, TETRA, Mobitex) and wireless LANs (e.g. 802.11, HIPERLAN 1). All of these systems were originally designed to mainly support one service and therefore lack sufficient support for multimedia wireless communications. Hence, experts all over the world agree in the need for WATM networks to support multimedia wireless communications. Therefore the WATM working group of the ATM Forum and the ETSI RES 10 standardisation group spend great effort to standardise WATM networks. They try to bundle their capacities and try to avoid double work by harmonising their research areas in order to speed up the standardisation process. Moreover several public funded research projects are already established in this area in order to support the standardization work.

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