On the importance of WLANs for 3G Cellular Radio to become a Success[1]

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Wireless access to fixed networks is seen to be of increasing importance, since wired communications, i.e. via cable or fibre, severely limits the usage of network dependent services, e.g., Internet services. Wireless Internet access needs high bit-rate data transmission and a much larger capacity of the radio spectrum then is available to date with cellular systems to enable multiple users at the same time and same location to communicate concurrently.

1.1 Applications and Services

Humans and machines will be transmitters and receivers to exchange real-time and non real-time application data of large volume as indicated from Figure 1. The machine to machine wireless communication is expected to raise more traffic than that resulting from or destined to humans.

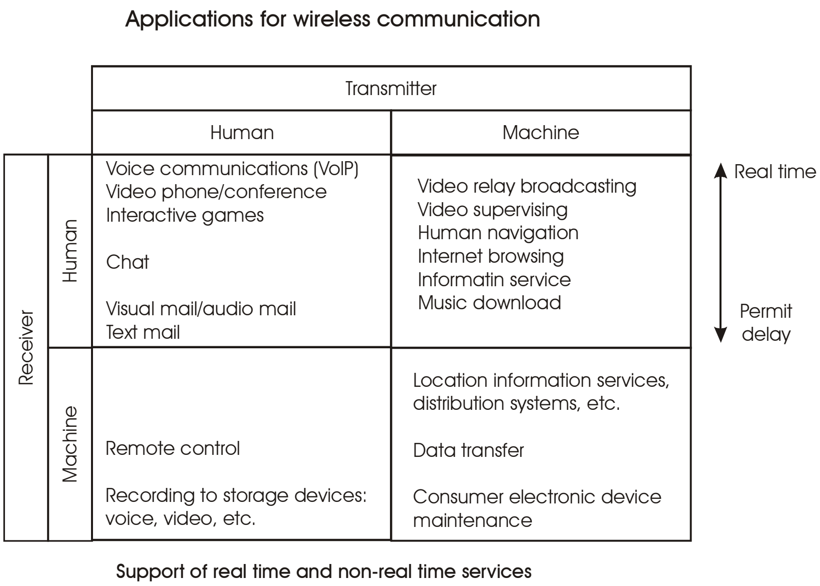

Figure 1: Applications and users of future mobile and wireless services

Today's restrictions of the quality of service such as data throughput, delay, or bit error rate, will be substantially reduced. By allowing a wideband or even broadband access to the fixed network, the user will get also access to various (high bit-rate) multimedia applications and services at the office, at home, at hot spots and even on the move. At the bottom of Figure 2 fixed and mobile radio networks, called transport platforms, are shown to access the example multi-media applications shown in the upper part of the figure that are running on workstations, called service platforms.

Our recent investigations have shown that the demand on the provision of MM services to moving and mobile users for many applications could be satisfied by a much more cost-effective system than cellular mobile radio, which would take then the function of back-up to provide the services that must be realized instantaneously to users without any cost concern, e.g., speech and urgent data. The next generation (NG) system foreseen and described later in this Section is based on a hybrid system approach comprising 3rd generation (3G) cellular and wireless broadband. Multi-mode terminals would be needed for that. This vision is going beyond the evolution scenario depicted in Figure 3 that was presented in a workshop on "Visions of the Wireless World" [HE2000].

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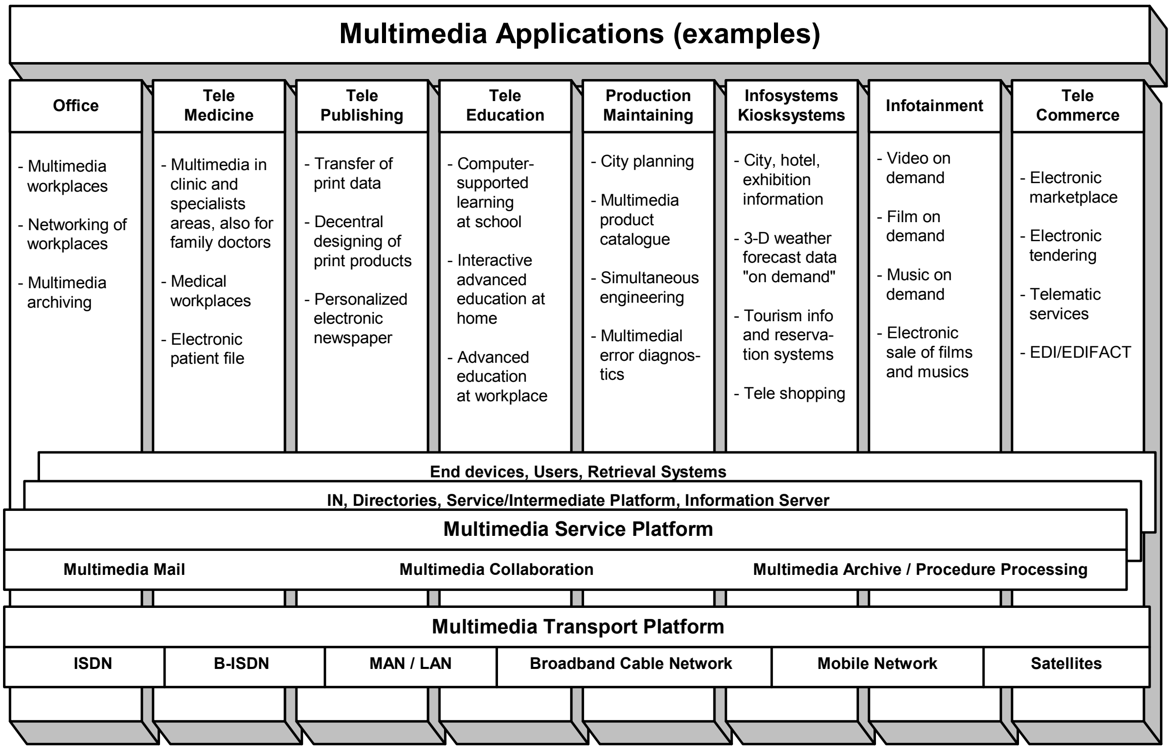

Figure 2: Multi-media (MM) applications based on MM-workstations connected via various MM-transport networks

Application		Page of text	e-mail	Picture on laptop	WDR web home page	30-pp simple colour presentation	e-mail + excel file	Book (300 pp text)	30-pp simple colour presentation wimages	Professional quality photograph	15 minute video	CD-ROM
Size in bytes		3,125	3,125	50,000	100,000	100,000	750,000	937,500	2,000,000	2,400,000	300,000,000	650,000,000
Book equiv's (300 pp)		1 page(s)	1 page(s)	16 page(s)	32 page(s)	32 page(s)	240 page(s)	1 book(s)	2.1 book(s)	2.6 book(s)	320 book(s)	693.3 book(s)
Size in bits		25,000	25,000	400,000	800,000	800,000	6,000,000	7,500,000	16,000,000	19,200,000	2,400,000,000	5,200,000,000
Size in mega/kbits		25 kbits	25 kbits	400 kbits	800 kbits	800 kbits	6 mbits	7.5 mbits	16 mbits	19.2 mbits	24 gbits	52 gbits
Technology	kbits	Time to transmit (secs)										
GSM today	9.6	2.6 secs	2.6 secs	41.7 secs	1.4 mins	1.4 mins	10.4 mins	13 mins	27.8 mins	33.3 mins	2.9 days	6.3 days
HSCSD	28.8	0.87 secs	0.87 secs	13.9 secs	27.8 secs	27.8 secs	3.5 mins	4.3 mins	9.3 mins	11.1 mins	23.1 hours	2.1 days
GPRS	115	0.22 secs	0.22 secs	3.5 secs	7 secs	7 secs	52.2 secs	1.1 mins	2.3 mins	2.8 mins	5.8 hours	12.6 hours
EDGE	384	0.07 secs	0.07 secs	1 secs	2.1 secs	2.1 secs	15.6 secs	19.5 secs	41.7 secs	50 secs	1.7 hours	3.8 hours
UMTS on the move	384	0.07 secs	0.07 secs	1 secs	2.1 secs	2.1 secs	15.6 secs	19.5 secs	41.7 secs	50 secs	1.7 hours	3.8 hours
Stationary UMTS	2,000	0.01 secs	0.01 secs	0.2 secs	0.4 secs	0.4 secs	3 secs	3.8 secs	8 secs	9.6 secs	20 mins	43.3 mins

Telecoms speeds are measured in bits per second but most items that are transmitted are measured in bytes (there being 8 bits to a byte)
Bytes are measured in powers of 2 - 2^{10} is 1,024, a kilobyte, where as a kilobyte is 1,000
The indicative speeds are theoretical measures of raw bandwidth; effective bandwidth is inevitably slower given the performance of modems, switches and other network elements

Source: UBS Warburg

Table 1: Required transfer times for example objects over various mobile radio systems

Table 1 shows the times needed to transfer some exemplary media objects of different sizes, such as web pages, book content or video, over various mobile telecommunication systems. Accordingly, it is obvious that systems like (E)*GPRS* or *UMTS on the move* cannot support continuous media even with the unrealistic high data rate assumed there. One example of this is the *15-minute video (300,000,000 bytes)*.

The expected evolution of terminals, radio interface standards, core networks and applications for mobile usage are shown schematically over time in Figure 2. Terminals have evolved from single to multi-band and must further evolve to become multi-mode terminals to adapt to the various air interfaces expected for 3G and NG systems. The radio interfaces soon will see 3G+ systems, e.g., integrating cellular and digital broadcasting or modified 3G systems to be able to provide asymmetric data transport. The core networks will evolve to provide packet based high data-rate transmission via advanced Internet technology or ATM based networks.

High speed multimedia applications will be served by combining the most effective radio access technologies. The services available from any type of mobile or wireless system will be portable across the various air interfaces to provide the feeling of an unified unrestricted connectivity across the radio space.

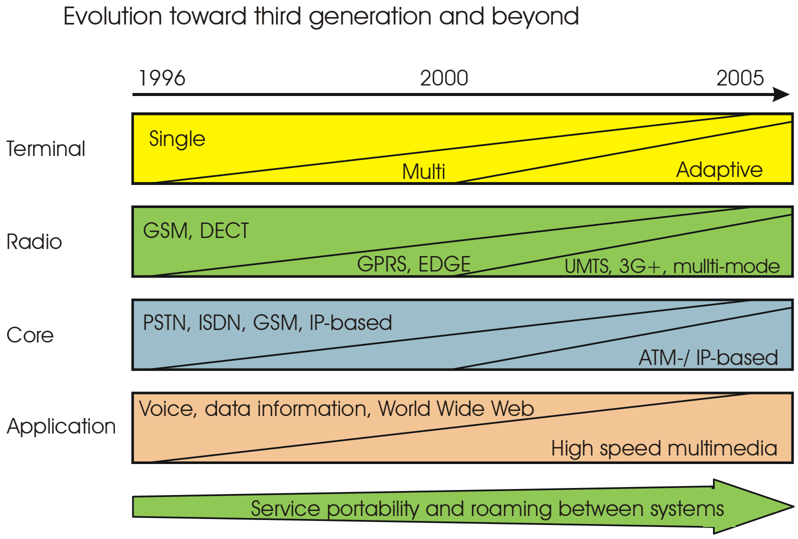

Figure 2: Evolution of terminals, network elements and applications towards NG systems

Broadband wireless access for mobile (moving) terminals, e.g., for terminals installed in vehicles, poses higher system requirements than for stationary terminals. High bit rate wireless access will be provided by the 3G mobile telecommunication systems, e.g., UMTS. Since UMTS will provide a gross transmission rate of about 256 kbit/s to mobile users in vehicles that will result in somewhat like 64 kbit/s net bit rate, only small displays for multimedia communication may be realizable with an accepted picture quality.
Table 2 shows the sequence of generations of radio systems extrapolated to 4G systems expected to be launched in the year 2011.
Figure 3 shows the evolution from 2G to 4G cellular systems and underlines that multiple radio interfaces competing worldwide to serve the same applications will continue to exist in the future, although based on new technology compared to 3G systems. It becomes very clear also that

- the intention of the IMT-2000 initiative to end-up with one universal 3G air interface standard has not been met and will not be met in the future
- new applications and related frequency bands require air interfaces optimised for the specific task and will contribute to extent the multitude of radio interface standards
- the spectrum range to be covered by 4G systems will make difficult to implement the respective radio interfaces as part of one single terminal, since the size and energy consumption will then not well fit to the specific requirements
- the 3G radio interface will be a temporal solution that will be replaced soon by much more advanced systems, probably based on OFDM modulation instead of spread spectrum
- higher transmission speed per user is one of the most demanding parameters and that spectrum availability is a prerequisite to make this vision a reality.

1.2 Spectrum Issues for Next Generation Systems

In the year 2000 in the U.K. and Germany license fees of about 5 and 8 Bio. Euro per operator have been paid for 10 MHz of paired UMTS spectrum. The cost for infrastructure, even when limited to highly populated areas including subsistence costs for the new terminals will amount to another 5-10 Bio. Euro per operator. As a consequence of high license, infrastructure and subsistence costs in Europe, it is expected that high bit-rate services will be too expensive to afford and the focus of UMTS operators will be on narrow-band data services, where not much has to be transmitted per event, but a charge comparably to that of a one-minute speech conversation can be charged. The short message service of GSM and I-mode of NTT DoCoMo are examples of this.
Current 3G systems with the spectrum available, in principle, can support high bit-rate Internet access for a very small number of concurrent users per cell only, but it has even been shown that with the

standardized UMTS protocols in combination with TCP/IP only medium bit-rates will be reached for WWW Internet access when using HTTP 1.0 version, see Figure 4.

Generations

Perspective	1G (1981)	2G (1991)	3G (2001)	4G (2011?)
Business Model	Monopoly Network Centric			Deregulated Client/Server
Application	Voice	Voice SMS	Voice Multi Media	Voice Virtual Reality (3D)
Terminal	Phone	Phone w. Message	Multi Media Terminal	Virtual Reality (3D) Device
Bearer	Symmetric Circuit		Symmetric Packet (GPRS)	Asymmetric Packet
Network	"Old" Circuit	ISDN based	All IP	
Access	Analog FDMA	Digital TDMA cdmaOne	Digital WCDMA EDGE cdma20001Xev	Multi Access WCDMA/EDGE Bluetooth WLAN MBS New air i/f ?

Table 2: Generations of radio based systems and services provided

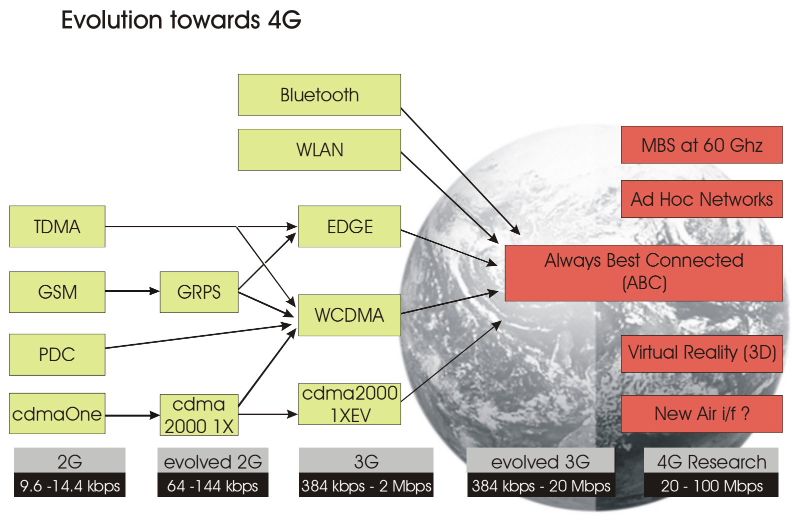

Figure 3: Evolution from 2G to 4G wireless systems [HE2000]

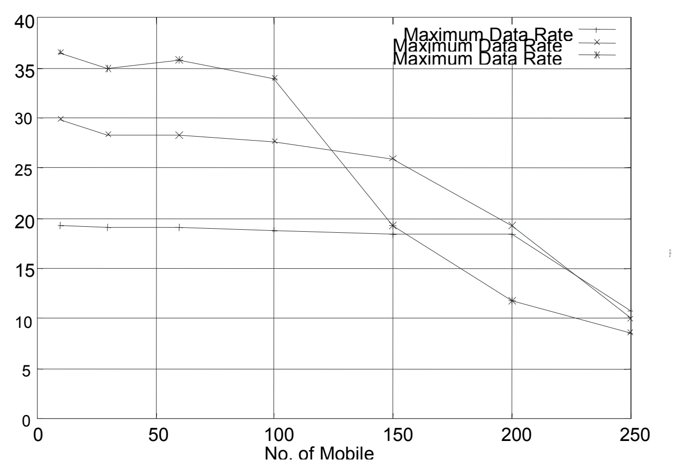

Figure 4: Mean bit rate with WWW service over UMTS

The current spectrum allocations of WARC-92 for 3G are not sufficient to provide the spectrum capacity needed for wideband or even broadband data transmission [BW2000].
To reach this capacity would require about 300 to 500 MHz of additional spectrum exploited in a pico-cellular network layout. Such an amount of new spectrum is available only beyond 2.69 GHz, i.e., beyond the IMT-2000 extension bands as defined by WRC-2000. Figure 5 shows a comprehensive overview on the frequency bands identified by WARC-92 and by WRC-2000 for IMT 200 systems. ITU-R WP8F - Spectrums Group currently is discussing the usage of these bands. The bands shown are not available in all the member regions internationally.
These bands consist of 169 MHz at 2.5 to 2.69 GHz of new spectrum plus the re-farming of 319 MHz of spectrum currently being used for cellular, e.g., GSM in Europe. Since the applications served in these 319 MHz are existent already, the re-farming will not contribute to increase the capacity to serve more mobile services at all but only shift services from 2G to 3G systems.
Frequency bands in use today for second generation mobile radio services, e.g., 806 to 960 MHz dependent on region and country (GSM900) and 1710 to 1885 MHz (GSM1800) will be available for IMT 2000 after the respective licenses will have expired or after the regulation conditions will have been changed accordingly. New assignments of these bands will be possible, e.g., in Germany for the GSM bands from the year 2015 on.
The IMT 2000 extension band 2500 to 2690 MHz – devoted for terrestrial radio services in the range from 2520 to 2670 MHz – is not available in some countries of Asia and in North America. This band will become available in other countries between the years 2005 and 2010, e.g., in Germany the band will be available from January 2008 on.
Facing this facts, WRC´92 has also allocated spectrum between 5 and 6 GHz for wireless broadband systems that are also called Wireless LANs (WLAN), see Figure 6. The spectrum is proposed to be license-exempt and amounts to 455 MHz in Europe, 300 MHz in the USA and 100 MHz in Japan and will speed up the breakthrough of wireless systems, that recently have been standardized an IEEE 802.11a and HiperLAN/2 systems. The WLAN spectrum partly has been allocated for indoors with 200 mW EIRP transmit power and partly outdoors with 1W EIRP.

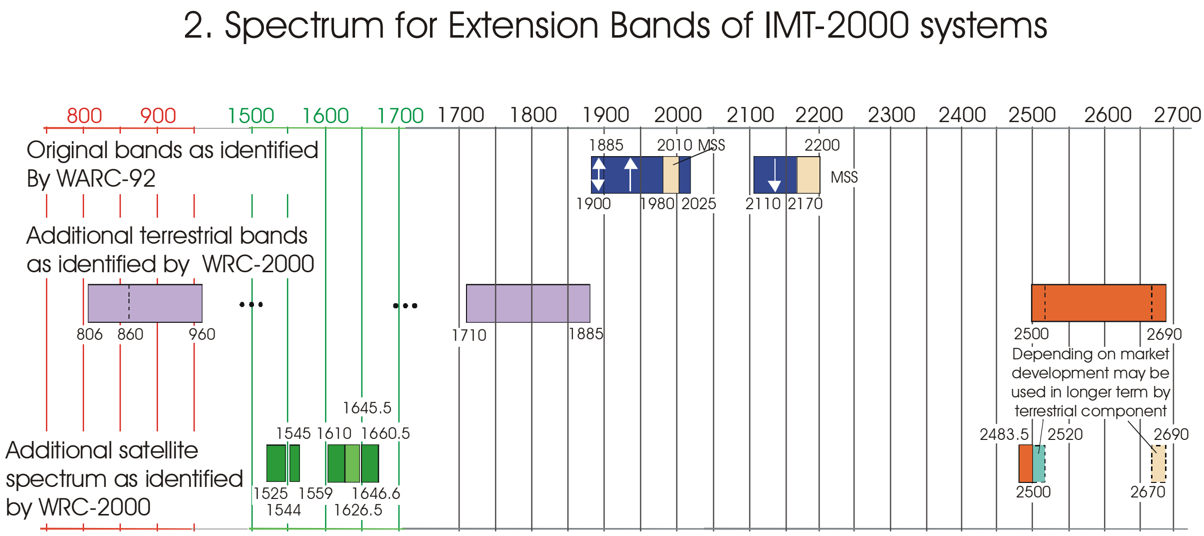

Figure 5: IMT-2000 extension bands

1.2.1 Asymmetric traffic characteristics of uplink and downlink usage

The higher the transmit rate of a service the higher is the expected asymmetry of usage of the uplink and downlink channels, making the downlink a bottleneck in IMT 2000 systems. Both, UMTS Forum and ITU-R have published a projection of the future usage of IMT 2000 systems and have identified the spectrum needed for the specific services, see Figure 7. A substantial asymmetry of the expected average traffic has been predicted there especially for medium and high rate multimedia traffic. The grade of asymmetry dependent on the services used might change from cell to cell over time and should be taken into account when considering spectrum allocation for the extension of the currently available bands for IMT 2000 systems. It would be optimum to be able to adapt the asymmetry of the

spectrum load to the occupancy of the spectrum dynamically, dependent on the current load situation in a cell and on the development of the usage of services in a mobile radio system.
This would require the further development of 3G systems to be able to support higher bit rate services on the downlink than on the uplink that could be realized by allowing a variable duplex spacing and multiple FDM channels for parallel usage on the downlink. The respective standardization is under way for UMTS.

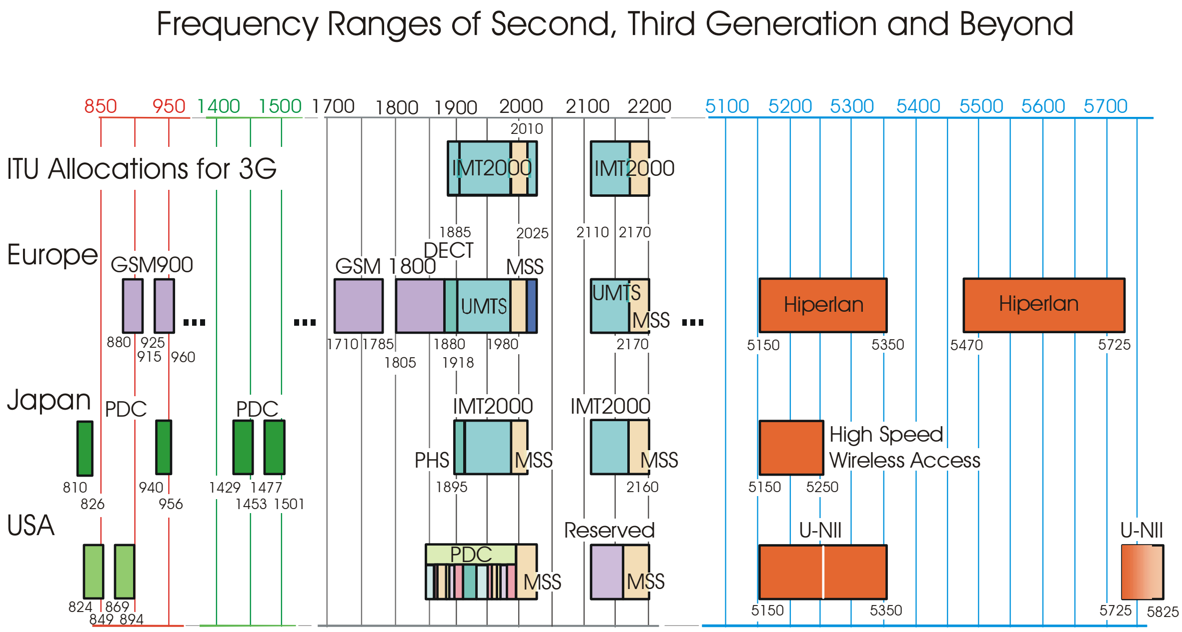

Figure 6: Spectrum allocations for some world regions for 3G and for WLANs

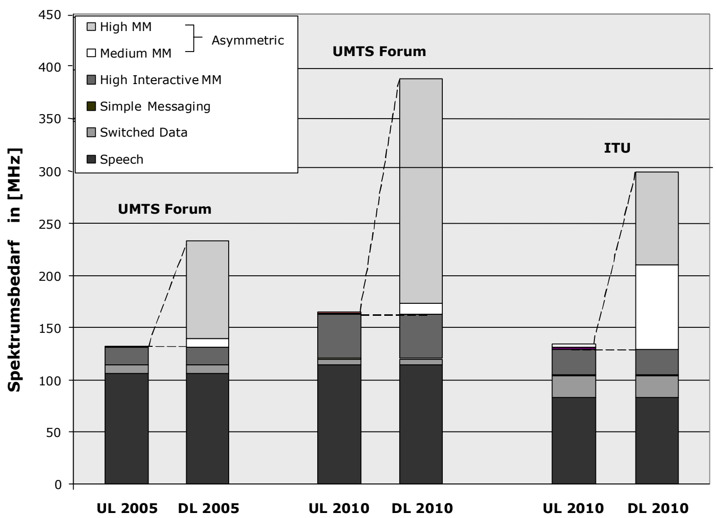

Figure 7: Projection of the future usage of IMT 2000 systems (Source: UMTS-Forum, Report No.6 and ITU-R Report M.[IMT.SPEC])

One interesting approach under study is the combination of cellular and digital broadcast services in a way to integrate the high downlink capacity of broadcast systems into a communications session supported via cellular radio. Different ways can be imagined to implement that

1. Usage of digital video broadcast-terrestrial (DVB-T) on the downlink to complement, say UMTS, as being studied in the IST/DRIVE project, with a common control of the distribution of service data to the radio links of the two systems.

2. Usage of some 8 MHz wide channels from the broadcast spectrum to realize UMTS downlink channels with a dynamic channel selection to be able to react to the actual availability of channels in time at the respective location, see Figure 8 (Scenario 2).
3. Usage of some 8 MHz wide channels from the broadcast spectrum to realize UMTS fixed downlink channels plus dynamic channel allocation, see Figure 8 (Scenario 3).
4. Time shared usage of spectrum with defense organisations against leasing fees combined with well established rules under what conditions to clear the band from public usage when needed for military purposes, see Figure 8 (Scenario 1).

The hybrid system resulting from the integration of UMTS and DVB-T systems described under item 1) of cause would require multi-mode terminals able to support both air interfaces and a common coordination channel in the core network to dynamically decide what system's downlink should be used actually during a communications session. Experiments have proven the design to be feasible but having a limited flexibility owing to the MPEG-2 container used for data transmission in the DVB-T standard. Per DVB-T (8MHz) channel even at very high speed a total data rate of 12 Mbit/s would be possible. A capacity improvement of the combined system could be realized, especially, for broadcast applications in UMTS but not for point-to-point communications owing to the large TV broadcast cells and the resulting small capacity.
The homogeneous system resulting from scenarios 1. to 3. (when transmitting UMTS on the 8 MHz channels) appears to be much more attractive, since the downlink in the broadcast band could be provided from all the base stations of a cellular operator in the coverage area, instead from only the TV-towers, allowing a much higher capacity gain. Dynamic channel allocation to provide UMTS downlinks on TV-channels needs a concept called co-farming of spectrum [BW2000] to guarantee both, the broadcast operator and the cellular operator a mutual benefit from this. Further, the UMTS standard would need to be extended to allow various duplex spacing and multiple downlink channels.

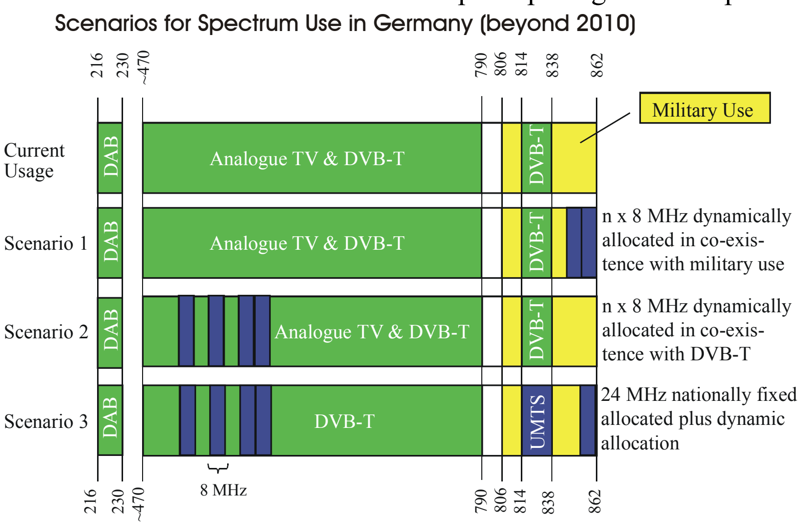

Figure 8: Various scenarios to exploit TV-spectrum for cellular downlink usage

1.3 Wireless LANs to Supplement Cellular Radio Networks

The services that especially demand an asymmetric air interface and substantial spectrum allocation in addition are termed high bit rate multimedia in Figure 7. The contents of these services are besides others text, music and image data that are stored as conserves somewhere in the network, e.g., contents of a mailbox or a server data base, typically addressed via the Internet. The related mass data typically do not have the same value per bit transmitted as speech data and in many cases of access do not require immediate service as is typically with a cellular radio network. It appears convincing to consider alternate air interfaces to provide these services in a cost efficient way, thereby unloading the cellular spectrum.
Wireless LANs have been proposed to complement the service capacity of 3G systems and have been studied, e.g., in the IST/BRAIN project [WK2000, UWB2001]. The co-operation of cellular and WLAN is by means of access to a common core network using a multi-mode terminal controlled by a mobility management function comprising both access systems to provide the user the best service

possible at a given location, see Figure 9. The idea behind BRAIN is to provide broadband services in so-called hot spots where a WLAN based pico-cellular coverage is provided, including horizontal handover across access points providing broadband access and vertical handover between the two different access networks.
The WLAN technology is expected to be based on ETSI/BRAN HiperLAN/2 (H/2) and systems combining UMTS and H/2 are expected to come into operation in Europe in the year 2003, according to announcements in 2001 of some network manufacturers.
A further step ahead would be the integration of systems like digital audio broadcast (DAB) and DVB-T, besides personal area networks (PAN) like Bluetooth into a common network architecture as shown in Figure 10 [WK2000]. Again, an architecture like this is close to implementation since the elements are available already and a combination of them into a heterogeneous system appears feasible. Then, radio interfaces developed specifically for the various speeds of mobility and classes of service will be combined as access networks to become a common core network to provide universal mobile access for all services known from fixed networks.

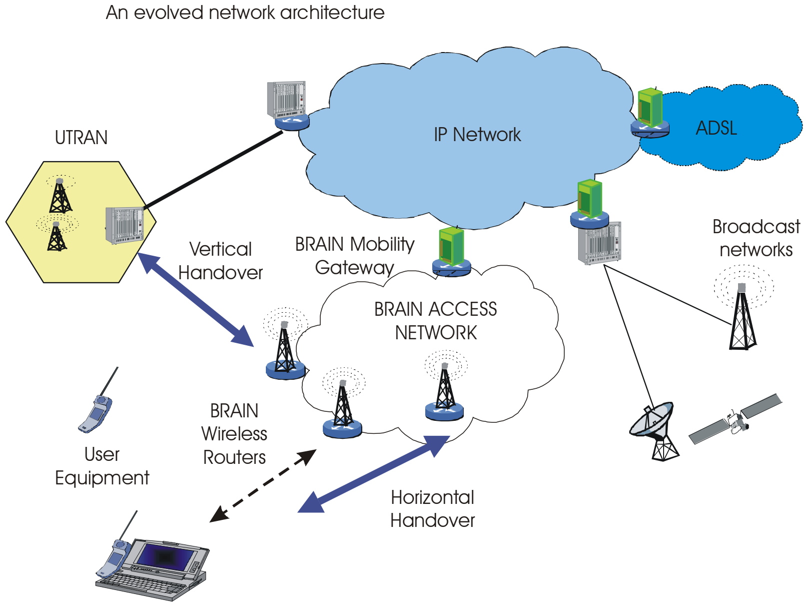

Figure 9: Hybrid network architecture studied in the BRAIN project

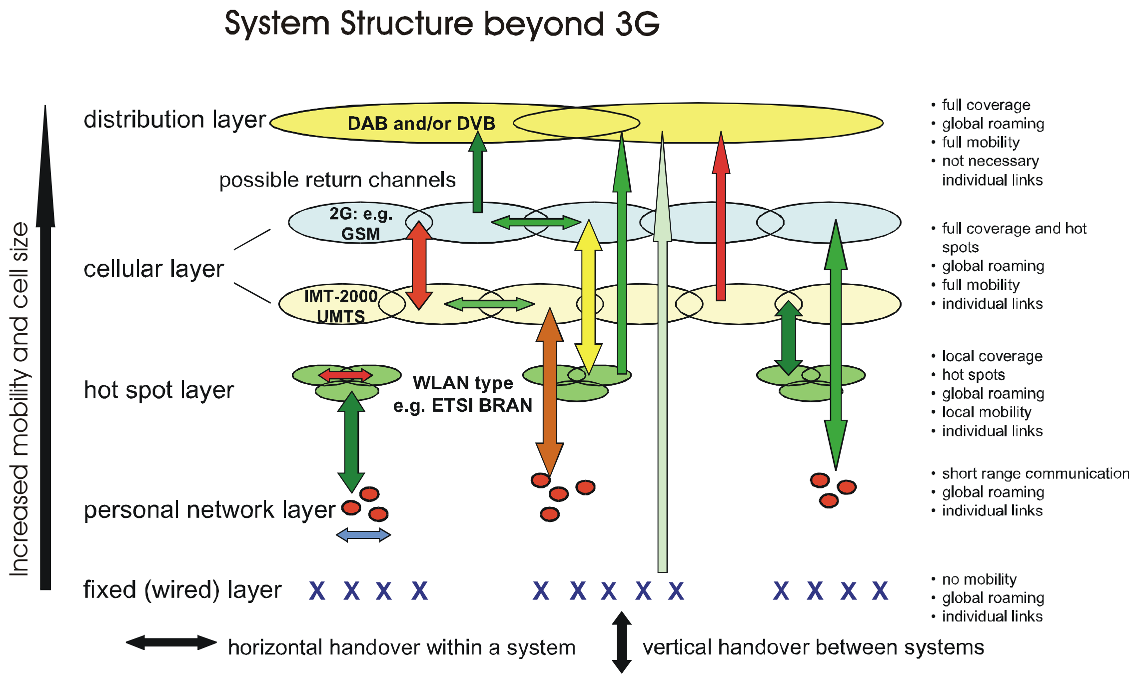

Figure 10: Layered architecture of a heterogeneous radio network comprising digital broadcasting, 2G and 3G cellular, WLANs in hot spots and personal area networks [WK2000]

1.4 The Wireless Media System – a Candidate Next Generation Systems

It is not a big step to imagine, that WLAN access will not be limited to hot spots but provided by a sufficiently dense network of scattered cells providing a non-contiguous radio coverage in the are that are controlled in a way to provide virtually a continuous connectivity of mobile terminals to a wireless broadband network for access to multimedia contents. This concept of a Wireless Media System (WMS) [BW2000.1] is similar to the Infostation system [FBBY2000] and would have a number of advantages over current designs as is explained by means of Figure 11. The figure relates two buttons of a terminal "red" and "black" to the service characteristics and costs of services available from the two radio interfaces: cellular radio and wireless Internet access via WLAN. Accordingly, cellular is characterised as a narrowband service with high quality of service (QoS) and high cost of usage whilst WLANs provide broadband access to the Internet with an Internet typical QoS and low cost of usage. Taking the current license fees and the costs to deploy the systems in the field into account it appears attractive for a subscriber to both types of systems, separately, to use as much as possible the WLAN-based system that would appear like a broadband wireless "telephone booth" but without the need to approach the AP more than, say a hundred meters outdoors.
The modems now under development for IEEE 802.11a and HiperLAN/2 allow at 1 W EIRP outdoors to bridge a maximum distance of 2.2 km at 6 Mbit/s with line-of-sight connectivity and of 92 m with obstructions. This figures are reduced at 54 Mbit/s to 322 m and 32 m, respectively. It has also been estimated that a terminal speed of about 100 km/h would be possible under reduced transmit rates.
Transmission in the proposed WMS is bi-directional between a Media Access Point (MAP) connected to the fixed core network and moving or mobile Media Terminals (MT) that are equipped with a large storage capacity. Of cause, real-time oriented media data can also be supported if a MT does not move outside the radio coverage range when communicating. Although the WMS is able to operate on its own and does not require a close interworking with a cellular radio system, it would benefit from such an integration for some applications to a great extent, for others not.

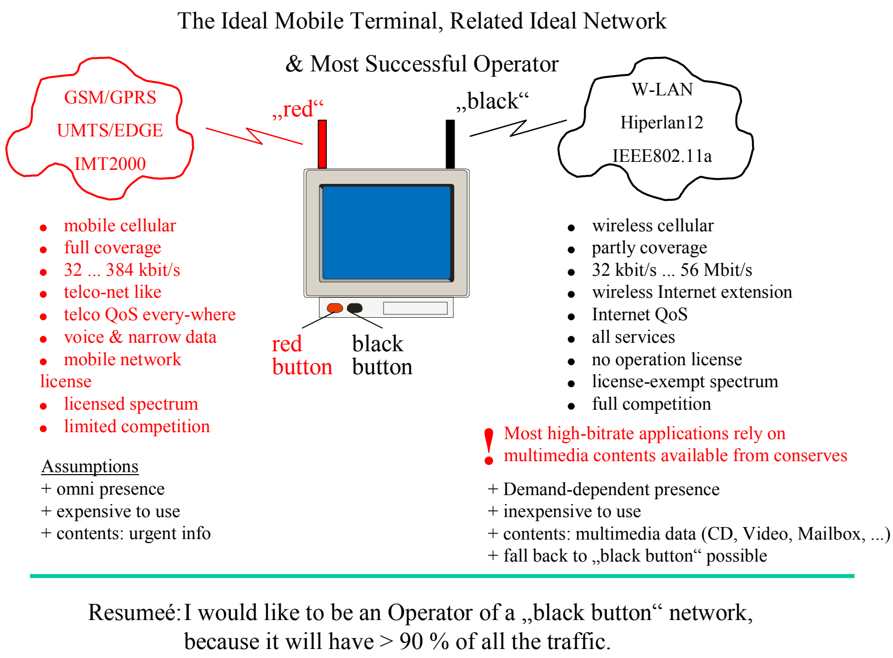

Figure 11: Terminal of the Wireless Media System

Figure 12 shows the integration of 2G and 3G cellular radio systems via their Internet Protocol (IP) based core network with the Wireless Media System (WMS) that is based on its own Intranet [BW2001.1, BW2001.2]. It is assumed that the mobile terminals at least are supporting one mobile radio and one WLAN air interface.

1. The integration might be tight if the Intranet of the WMS is part of the core network of the mobile radio network.
2. The integration might be loose if both fixed IP networks are connected to exchange control and signaling information.

3. It might also be that both systems are operated completely separated from each other. For example a mobile terminal might contain two subscriber identification modules (SIM) according to the two different contracts signed with the operators of the mobile radio network and WMS, respectively.

The system proposed in Figure 9 incorporates a vertical handover between the mobile radio network and WLAN-based WMS. One possibility is to rely instead on a fast re-establishment of a connection when switching between systems if both systems don't have a mobility management function in common, see variant 3 above.

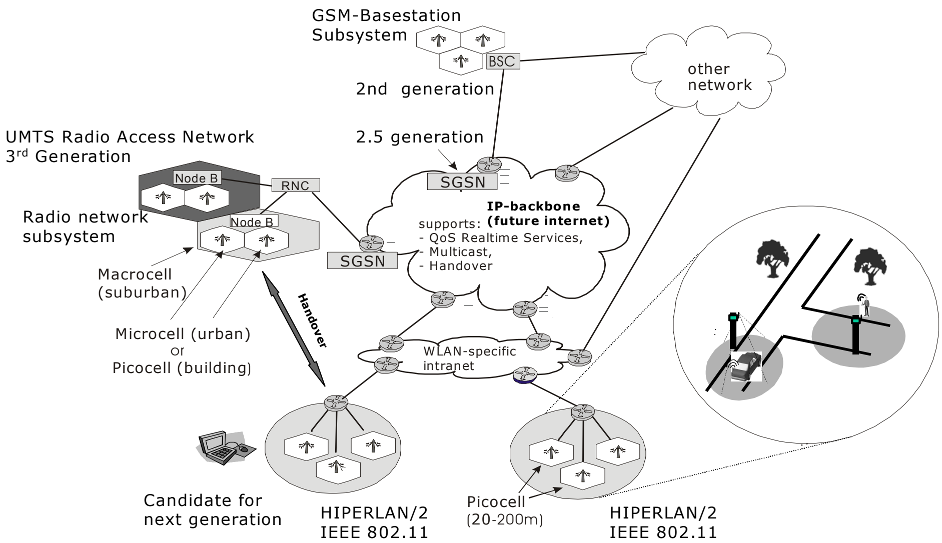

Figure 12: A Next Generation System by example of the Wireless Media System (WMS)

A handover from WMS to mobile radio network anyway would result in a substantial degradation of quality of service for multimedia services and the subscriber would not be happy with a handover at all. A handover in the other direction should happen under the control of the current communications application and could then avoid an interrupt to the ongoing session completely since the mobile radio networks can be assumed to cover the area where the WMS is available in addition.

The following characteristics of the WMS are worth mentioning:

- Operation in a license-exempt (license-free) or in a low-cost licensed band using a broadband standardized radio interface, e.g., HiperLAN/2, IEEE 802.11(b/a), etc.
- High bit-rate wireless transmission of media data between a MT and the MAP that is connected via LOS radio, cable or fibre to an Intranet containing WMS-specific multimedia servers.
- An MAP provides a certain radio coverage and is located in the service area in a number according to the expected MT density and service usage. An MAP is equipped with a large capacity storage (cache) to be able to download media contents with the full speed available at the air-interface.
- The MAPs alltogether are not able to serve a contiguous area but only a scattered radio coverage of the service area. The service area might be quite large comprising motor ways, a city ore highly populated area. Smaller service areas are sports arena, air port, railway station, city centre, etc.
- Continuous availability of media contents is provided to the user of an MT, in spite of a discontinuous radio coverage, through a specific service control software running on the MT and on top of the Intranet that simulates a continuous connectivity to the WMS by buffering of content data in MAPs and MTs. A spontaneous access request to new content data, typically, is executed with some delay only, since the respective MT must wait until it has radio connectivity to the WMS.

- At each MAP the MS receives media data to be stored in its local cache from the network in an amount that is required for the expected processing and consuming within a planned future time period, e.g., within an hour. On the uplink the MT transmits its cached data in the radio coverage range of an MAP.
- A MT when reaching an MAP relates to the association that it had established earlier with the WMS-service and then receives the data it had requested earlier with the high bitrate of the WLAN air interface to be stored in the MT's local cache to be consumed or processed later. The amount of data transmitted is large enough to cover the expected time of processing (e.g. contents of mailbox) or to cover the duration of local consumption for a well defined time horizon, e.g. half an hour. Further, when reaching a MAP, the MT transmits all data waiting locally via the WMS to the final destination.
- The MT may use all the services known from mobile radio networks and the Internet, e.g., speech, data, broadcast contents reception and also may operate interactive multimedia connections.
- Commands issued by the MT to the WMS will determine, which media data should be transmitted next and the appropriate MAP to download the respective data will be determined either by the MT or the network itself, e.g., based on geographical information or routes of terminal movement known or estimated by the network. Before reaching the next MAP the data stored locally in the MT is consumed or processed without a link to the network, and the results may be transferred to the network at the next MAP.
- A cellular radio system might be used at any time as back-up and to order data to be cached at some MAPs in the vicinity of the MT for download, when it has arrived there.
- An AP may use a highly directive antenna to only cover areas where MTs may roam, e.g., streets where MTs are operated in vehicles or urban areas for portable MTs.

An example scenario is shown in Figure 13 (left), with two MAPs and their transmitting and receiving devices (transceivers) that are mounted on two gantries of a highway. An AP is equipped with a control unit that is connected to the Internet or local multimedia servers via a service control in the network.

As long as a vehicle resides in an MAP´s coverage area, a MT in the vehicle can set up a connection to request and download its application data wirelessly, or to send data that has been prepared meanwhile, e.g., emails or video recordings. When the vehicle leaves the coverage area, no radio link exists anymore. In another scenario depicted in Figure 13 (right) the transceivers of the MAPs are mounted on the masts of street lighting within a residential area. There, a user using a portable MT may set up a radio link to an MAP and transmit as long as he/she stays within the corresponding coverage area.

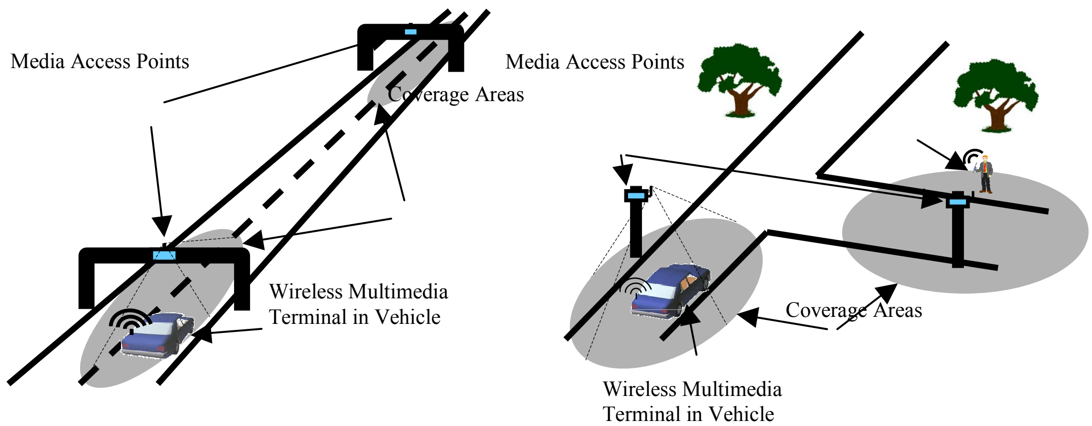

Figure 13: Wireless Media System scenarios with MTs on highway and in residential area

One example of a content to be moved in a short while across the air interface of the WMS is the *15-minute video (300,000,000 bytes)* of Table 1. The 20 min needed with UMTS for a radio terminal will be reduced to 1.6 min with 25 Mbit/s available from the MAP, e.g., at a crossing equipped with traffic lights. The video may be a part of a film that could be consumed (re-played) offline. The next part of the film (the next 15-minute video-scene) can then be downloaded at the next access point. If the

download processes at several access points can be controlled (synchronized) perfectly, the user may enjoy seeing the film without any interruption (on the backseat of a car in the city).
In order to minimize the number of MAPs a trading of spectrum load against infrastructure costs is possible, e.g., with HiperLAN/2 systems by extending the coverage area of an MAP through multi-hop communication using a wireless MAP working as a relay, see Figure 14.

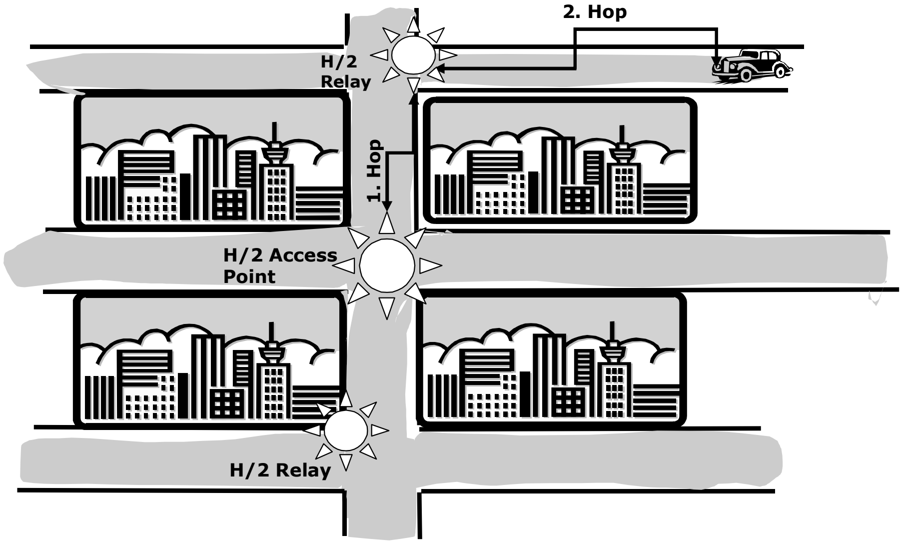

Figure 14: Multi-hop communication with H/2 Access Points and H/2 Relays to extend the coverage zone
The MAP is realized there by an H/2 Access Point that is able to illuminate the whole crossing and in addition with line-of-sight coverage provides radio coverage in all the streets that go straight ahead form the MAP. Another WLAN system that is affixed at the next crossing and is operating as a relais (without a connection to the fixed communication network) enables to provide radio coverage into those streets in a city that are shaded with respect to the MAP. Communication between the vehicle shown and the MAP would the be via two hops, one from the vehicle to the relais (2. hop) and another from the relais to the MAP (1. hop) and vice versa.

Literature

[BW2000] Bernhard Walke, Spectrum Issues for Next Generation Cellular, Proc. Visions of the Wireless World, Workshop of the Wireless Strategic Initiative, December 12, 2000, Brussels, Belgium

[BW2000.1] Bernhard Walke: HiperLAN/2 – Ein weitgehend in Deutschland entwickelter Standard, BMBF Symposium „Zukunftsperspektiven Mobilkommunikation", Juni 2000, Neu Ulm, Germany

[BW2001.1] Bernhard Walke: Mobile Radio Networks – Networking, Protocols and Traffic Performance, John Wiley & Sons, 2nd Edition, Chichester, Weinheim, New York 2001.

[BW2001.2] Bernhard Walke: Mobilfunknetze und ihre Protokolle, B.B. Teubner Verlag Stuttgart, 3. Edition 2001[FBBY2000] The Infostation Challenge: Balancing Cost and Ubiquity in Delivering Wireless Data, IEEE Personal Communications, April 2000, pp. 66-71

[UWB2001] Josef Urban, Dave Wisely, Edgar Bolinth, Georg Neureiter, Mika Liljeberg, Tomas Robles Valladares: BRAIN – an architecture for a broadband radio access network of the next generation, Wireless Communications and Mobile Computing 2001; 1: 55-75

[WK2000] Walter Konhäuser, Innovating the Mobile World beyond the Third Generation, Proc. Visions of the Wireless World, Workshop of the Wireless Strategic Initiative, December 12, 2000, Brussels, Belgium