The Wireless Media System: A Mobile Broadband System with Invisible Infrastructure and low Radio Exposure of Humans

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Summary:

A new radio access network architecture and a new service concept for a mobile broadband system are introduced. This concept aims at a new generation of integrated mobile and wireless systems and networks characterised by an extremely high spectrum efficiency and thus enabling an outstanding low radio exposure of humans compared to 3G systems under equal conditions. Highest efficiency and lowest possible transmission power as main targets will be obtained by the use of low power (1 W) pico base stations using a wireless or mobile broadband air interface and Fixed Wireless Routers (FWR) to trade the high capacity available from a pico base station against radio coverage range. Base stations and FWRs are very small in size allowing to closely approach the aim of an "invisible infrastructure". The Wireless Media System (WMS) will provide broadband access to terminals with medium velocity of movement and is embedded into a cellular radio network to support a high terminal velocity with medium transmission rate. An Intelligent Service Control and advanced radio resource management for a power-optimised exploitation of multiple air interfaces substantially contribute to reach the aims of the WMS. Transmission with low power leads to a pico-cellular concept relying essentially on multi-hop communication across wireless bridges/routers and to some extent also on ad-hoc networking. The concept combines broadcast, multicast and single-cast services to minimize the number of transmissions required (and thereby again reduces the radio exposure of humans) to provide the contents asked for by the users. The new concepts to achieve broadband radio coverage in densely populated areas are described and first analysis results of some crucial elements of the WMS are presented.

1 Introduction

The proposed Wireless Media System (WMS) is a cellular mobile broadband system for "hot area" and indoors radio coverage integrated with cellular mobile radio systems for large area coverage. The WMS is aimed to have an especially high spectrum efficiency, very high multiplexing rate of multiples of 100Mbit/s at the air interface for medium velocity terminals in hot areas, highly compact radio access system elements through mass production, invisible infrastructure and very low radio exposure of humans. The known candidate spectrum bands for operation of the broadband component of the WMS, e.g. most probably beyond 5 GHz will allow a size of pico-cellular base stations (Access Point, AP) and Fixed Wireless Routers (FWR), including the antenna, so small that the radio network infrastructure can be termed more or less to be "invisible". FWRs are relays serving for both, to extend the radio range of an AP beyond what is possible with the available transmission power and to cover shadowed areas by relaying around the corner of an obstacle. Both, AP and FWR use 1 W EIRP transmit power outdoors and 200 mW indoors. The focus on low exposure of humans will contribute to increase the public acceptance of mobile radio communication systems in densely populated areas.

The designs of a new system including interactive and location aware services into one spectrum efficient system, needs sophisticated transmission-, protocol- and device concepts along with the appropriate technologies. The WMS will be embedded into a cellular mobile radio network supporting high terminal velocity that will evolve from current 3G technology. Both, the WMS and the Beyond 3G network will share a common IPv6 based core network. The control and provisioning of services will aim at any data communication to be realised with a minimised transmit power, e.g., by transmission during low interfered time intervals, reducing the radio exposure of humans and thus contributing to

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make the new technology accessible in the most trusted way to all societal groups. The low transmission power and thus power dissipation in the WMS will allow to use very small equipment cabinets, reduced forced and passive cooling, less mains power consumption and less cost. This will also contribute to make the equipment non conspicuous and make installations invisible.
The discontinuous radio coverage available in the service area from the WMS will be hidden to a maximum degree to the user by an intelligent service control so that the subscribers are provided the contents they need within given time limits.

2 System Concept of the Wireless Media System

The WMS is based on Wireless Broadband System (WBS) technology that stepwise will be further developed to become a Mobile Broadband System (MBS) [BW2000, BW2001.1, BW2001.2, WAS2002, WK2002]. The WMS relies on multi-hop and to some extent on ad-hoc networking concepts in a pico-cellular infrastructure to provide a well defined Quality of Service (QoS) to applications running on mobile terminals. Figure 2 shows by means of an example the discontinuous radio coverage available from the WMS in densely populated areas. The small pico cells highlighted around a pico base station called Media Point (MP) shown in the circular areas called Media Point Subnetwork represent areas where broadband radio coverage is available. The feeder systems connecting APs to the fixed network are either wire/fibre based or wireless, e.g., Point-to-Multipoint (PMP) LOS radio systems or HAPS (High Altitude Platform System) feeding MPs using directed (smart) antennas, see Figure 2. Some MPs are wirelessly connected to other MPs to reduce the number of Access Points (AP) needed to connect to the fixed core network. Wireless MPs are called Fixed Wireless Routers (FWR). In Figure 2 the radio coverage areas served by FWRs are shown in a colour different from that of the APs. Both, APs and FWRs appear to mobile terminals like base stations to connect to the WMS. High mobility supporting wide area networks shown as hexagonal cells and broadband access networks are closely cooperating based on common functions like subscriber identity module (SIM), authentication, authorization and accounting (AAA) and localisation. This is what the concept distinguishes from the Infostation concept [FBBY2000] that considers a stand-alone wireless broadband system deployment.
The WMS is characterised besides others by

- A new air interface with a multiplexing data rate of multiples of 100 Mbit/s available at a terminal speed up to 60 km/h
- Dynamic channel selection, link adaptation, power control, smart antennas and re-configurable terminals
- Small (“Invisible”) base stations (MP), Hamburger sized (including antenna) mounted below roof top (say on signal posts or in street lamps) with low EIRP value.
- Radio coverage provided by MPs operating either as Access Points to the core network or as Fixed mounted Wireless Routers (FWR) in a pre-planned multi-hop communication based infrastructure
- Multi-mode re-configurable terminals and base stations
- Smart antennas and beam forming at terminals and base stations (MP and FWR) for higher spectrum efficiency and lower radio exposure of humans
- Ad-hoc operation of mobile broadband terminals at the periphery of the WMS.
- An Intelligent Service Control that simulates a virtual continuous radio network connectivity to applications of the wireless terminals
- New service concepts like the integration of combined push-pull services and of broadcasting.

The WMS infrastructure is aimed to be very cost efficient and flexible to use, e.g. using multi-hop radio relays (bridges or routers) to connect MPs to the network, thereby trading the too high traffic capacity available from an APs against range of radio coverage. Further, shadowed areas are covered by relays that allow to extend the radio range behind an obstacle.

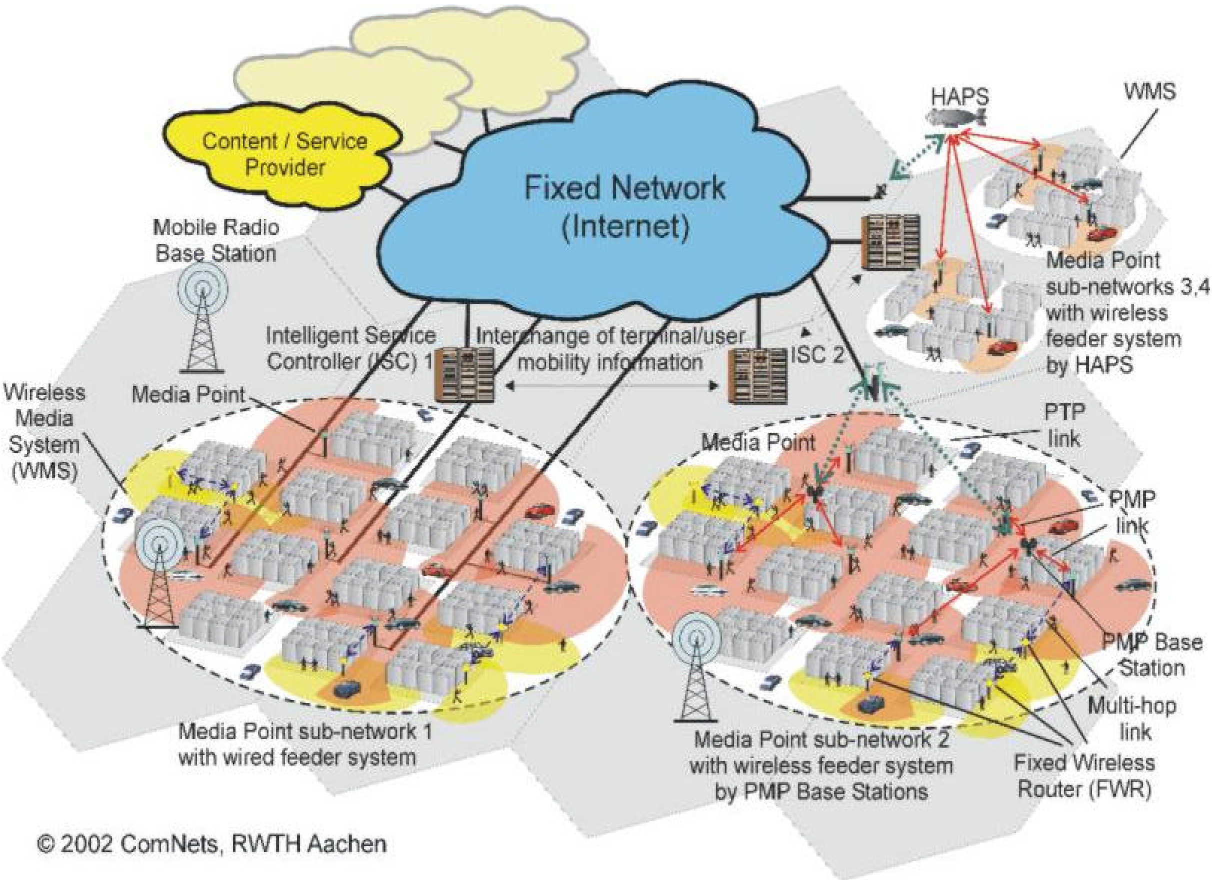

Figure 2: Wireless Media System integrated to a mobile radio network

2.1 Most Important Features of the Wireless Media System

The WMS is intended to provide broadband radio access for densely populated areas using low power wireless/mobile broadband systems (MPs) built up in a cellular radio network layout.

During a first phase of the system introduction, the speed of movement of terminals when communicating over the WMS might be limited. In a second phase, after introduction of a new broadband radio interface the speed of movement will be up to about 60 km/h or even more. The system will support any kind of communication service, e.g., voice, video, data etc. with the appropriate service specific QoS parameters. The system will cover the needs of services of future mobile broadband systems that have been predicted to need highly asymmetric data traffic support with an especially high load on the downlink, see Figure 3.

The high asymmetry shown comes from the transport of high bit rate multi-media services and - to a small extent - from medium bit rate multi-media services. The goal is to carry in densely populated areas most of the high and medium bit rate multi-media traffic by the MPs of the WMS. In addition, some amount of the other traffic classes (like voice) also can be carried by the WMS. The WMS that will offer a cell radius of a MP in shadowed environments quite below 100 m but much larger range under line-of-sight (LOS) conditions, is able to generate at least an ten to hundred-fold area capacity compared to current 3G systems assuming the same width of the frequency band used. According to the spectrum assignment in Europe, US and Japan, the WMS will use a much wider spectrum range than cellular radio will ever get for its operation. The capacity of the WMS therefore will be multiple orders of magnitude larger.

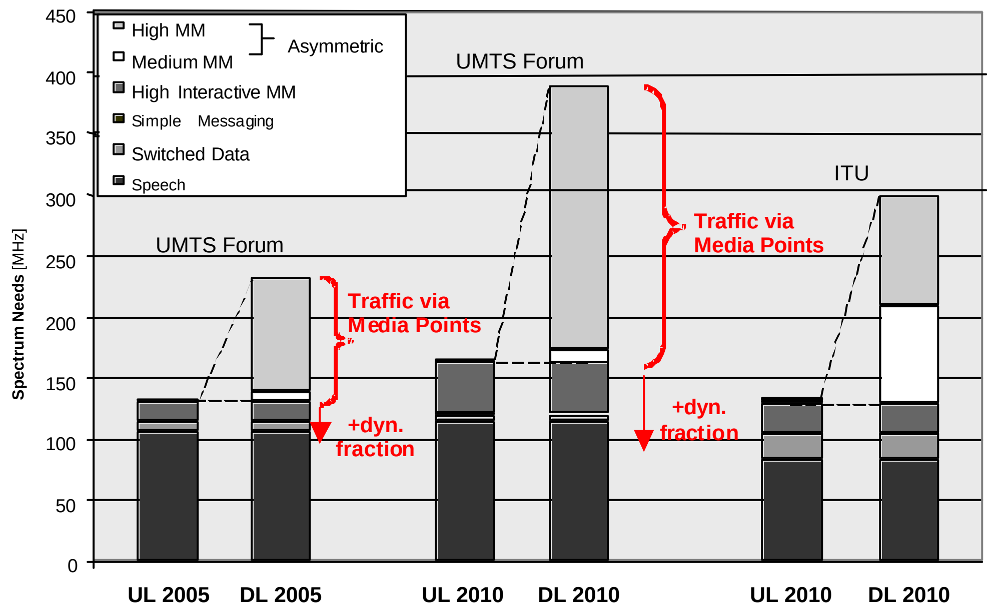

Figure 3: Predicted spectrum needs for UMTS per traffic class from UMTS-Forum and ITU-R for the years 2005 and 2010

The mobile terminal that must be able to support both, mobile cellular radio and the WMS air interfaces, but not at the same time, is shown in Figure 4. Instead of the two buttons (red and black) shown in the figure, a terminal internal agent will decide what air-interface to use at what location and for what type of service. The agent might decide to load high volume data preferably via the broadband air interface and wait for a radio connectivity for some time duration, since the broadband over WMS service is deemed to be much cheaper than over the B3G network. The agent also might decide that voice and other real-time oriented services are to be provided via the WMS air interface if the mobile terminal has radio connectivity to it and is not moving very fast.
An operator of a WMS that is integrated to a cellular mobile radio system might apply a mixed cost calculation to be able to trade the low cost for transporting mass data via the WMS against the high cost of data transport across the cellular system. And he might end up with a very attractive tariff for all of its services compared to an operator purely relying on B3G technology.

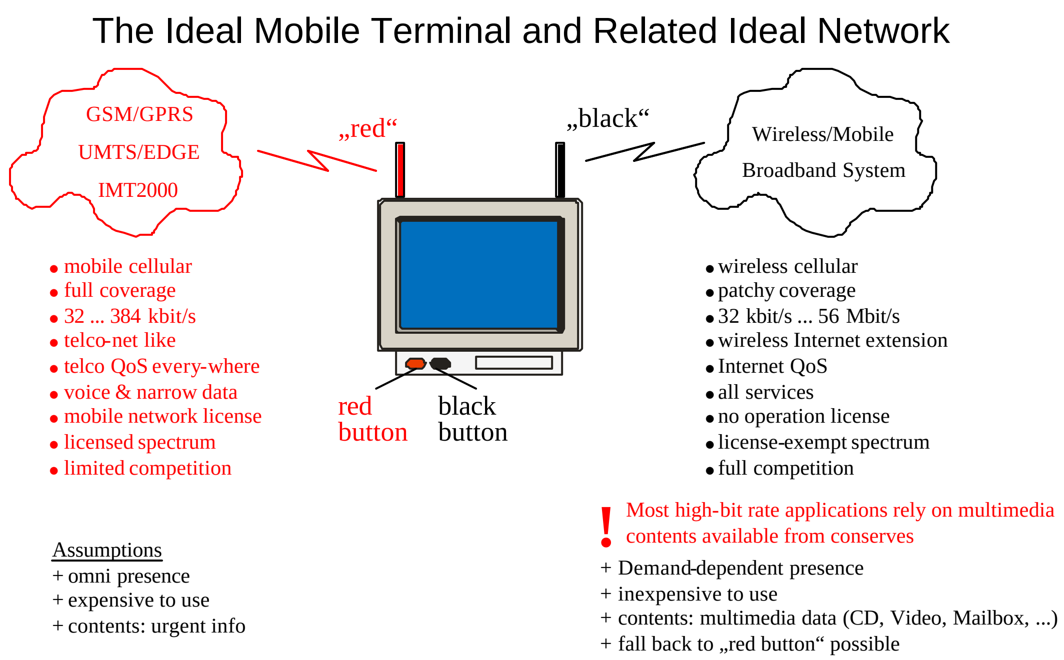

Figure 4: Multi-mode mobile terminal to support both, cellular mobile radio and the WMS

2.2 Multi-hop Operation of the Wireless Media System

Multi-hop ad-hoc networking is under discussion to improve the range and radio coverage of mobile and wireless systems. Self-organization of mobile nodes is one big issue in current research, see [BoV2001, chapter on ad-hoc networking]. Figure 5 (left) shows a city scenario with

- one AP (providing radio coverage to the areas marked white) and
- four FWRs to provide radio coverage to areas "around the corners" shadowed from the AP, shown in grey.

According to the radio propagation conditions known for the 5-6 GHz frequency band [L1998], there is nearly no diffraction and waves reflected from obstacles have a much higher attenuation than with lower frequencies. Therefore, the intersection shown can be covered well by the AP but the close by streets can only be served if a line-of-sight connectivity is available between mobile terminal and serving MP. The FWRs allow to extend the radio coverage to the streets shadowed from the AP.

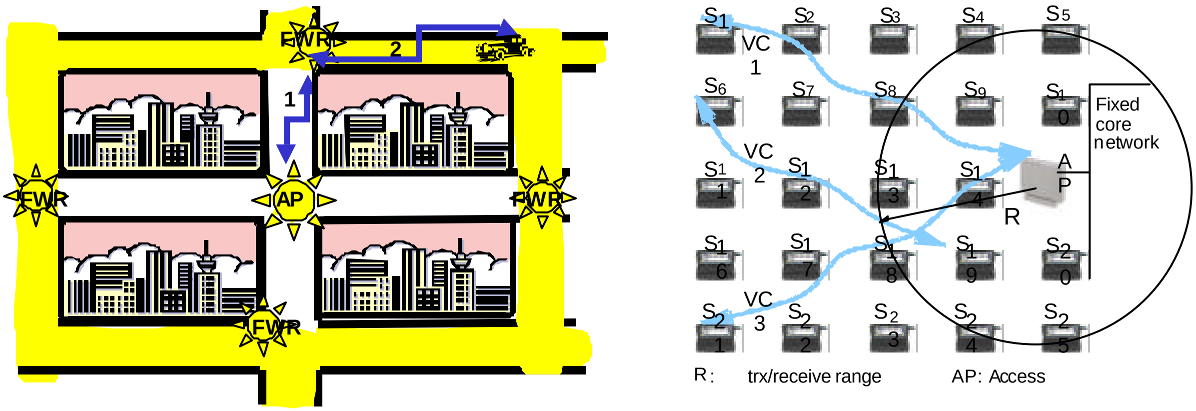

Figure 5: City scenario (left) with one AP (radio coverage in white area) and four Fixed Wireless Routers covering the shadowed areas "around the corners" shown in grey and schematic (right).

A schematic of this scenario - a multi-hop network with Access Point (AP) - is shown at the right hand side of Figure 5 where the transmit/receive radius *R* is shown to be the parameter determining the connectivity *c* of the nodes shown, where *N* is the total number of nodes and n_i is the number of neighbour nodes to a node. A FWR (S_1) would have to route the traffic of the wireless terminals it is serving (not shown) via the intermediate FWR (S_8) using a low valued PHY-mode, or via S_2 and S_8 using a high valued PHY-mode, and so forth from S_8 either via S_9 or directly to the AP. The interpretation of the Figure 5 right hand multi-hop network is that all but one nodes shown are FWRs and one is an AP and the invisible mobile user terminals are roaming in the area served by the nodes shown.

The concept of the Fixed Wireless Router that also could be a Fixed Wireless Bridge (a Layer 2 relay) can be realized for example as described in [WEH2001], [ES2001] for the HiperLAN2 standard. The Figures 8-12 show analytical and simulation results for the respective air interface. There are other possibilities to realize the FWR concept as shown in Figure 6.

A WMS architecture with one AP and four FWRs, as shown in Figure 5 (left), might be a basic architecture element used to cover a densely populated area. In that case, assuming a homogeneous distribution of user terminals in the service area, the capacity available from the AP would have to be shared with the FWRs: all of the mobiles roaming in the combined service areas of the AP and the four FWRs will have to share the capacity of the AP. This would mean that the terminals served directly by the AP would have available only a reduced amount of capacity, exactly what is aimed at by introducing the FWRs. While the basic element shown in Figure 5 applies a maximum of 2 hops per connection, larger elements with one AP and 12 FWRs can be thought of, as illustrated in Figure 7.

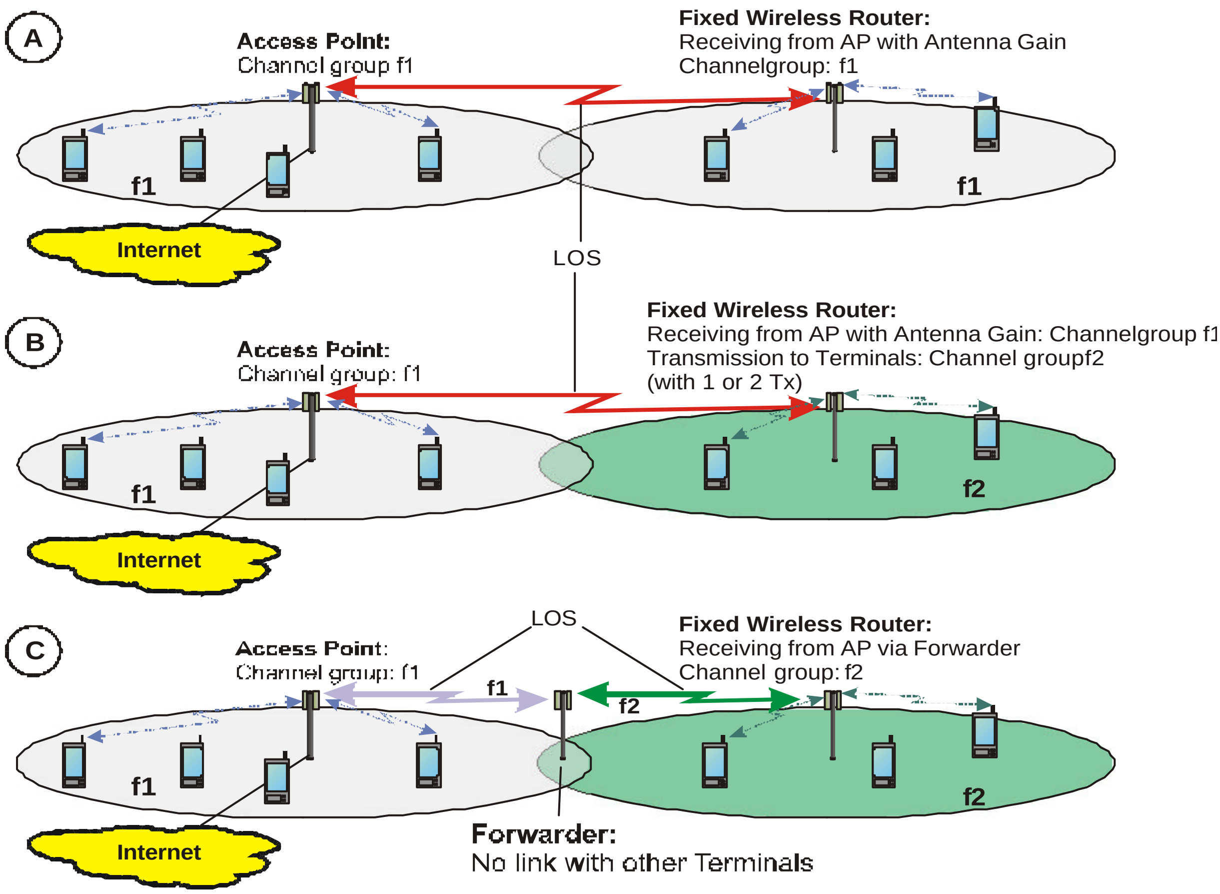

Figure 6: Various relay concepts based on Fixed Wireless Routers:
a) Relaying in the time domain with both, AP and FWR, operating at the same carrier frequency f1 [WEH2001]
b) Relaying in the frequency domain where AP and FWR operate on different frequency carriers. The radio link between AP and FWR is based on LOS radio with transmit and receive gain antennas at AP and FWR. AP and FWR have to be in synchronous operation to be able to switch the frequency accurately.
c) Relaying in the frequency domain where a fixed mounted forwarding terminal that is in the range of both, AP and FWR, connects AP and FWR by store and forward operation and dynamically switches its membership to frequency carrier f1 or f2. AP, FWR and forwarding terminal might use both, transmit and receive antenna gain [HW2001, HW2002].

Figure 7 shows how the basic elements shown in –Figure 6 can be used to provide a city wide radio coverage. Of cause, the same schemas also could be used to provide a planned indoors radio coverage, e.g., for exhibitions, conference halls, hotels, homes, etc. An AP is shown in the left hand side of the figure that serves four (twelve, in the second case) Fixed Wireless Routers. The resulting element using one frequency (or frequency group) to cover a number of adjacent streets is applied in the right hand side scenario to provide a full radio coverage using this basic element and two (groups of) frequencies. It can be shown that this is already a workable wireless broadband system for outdoors, providing more or less the same throughput at any location in the basic i-hop cell element (i = 1, 2, 3,..) [EWKZ2002].

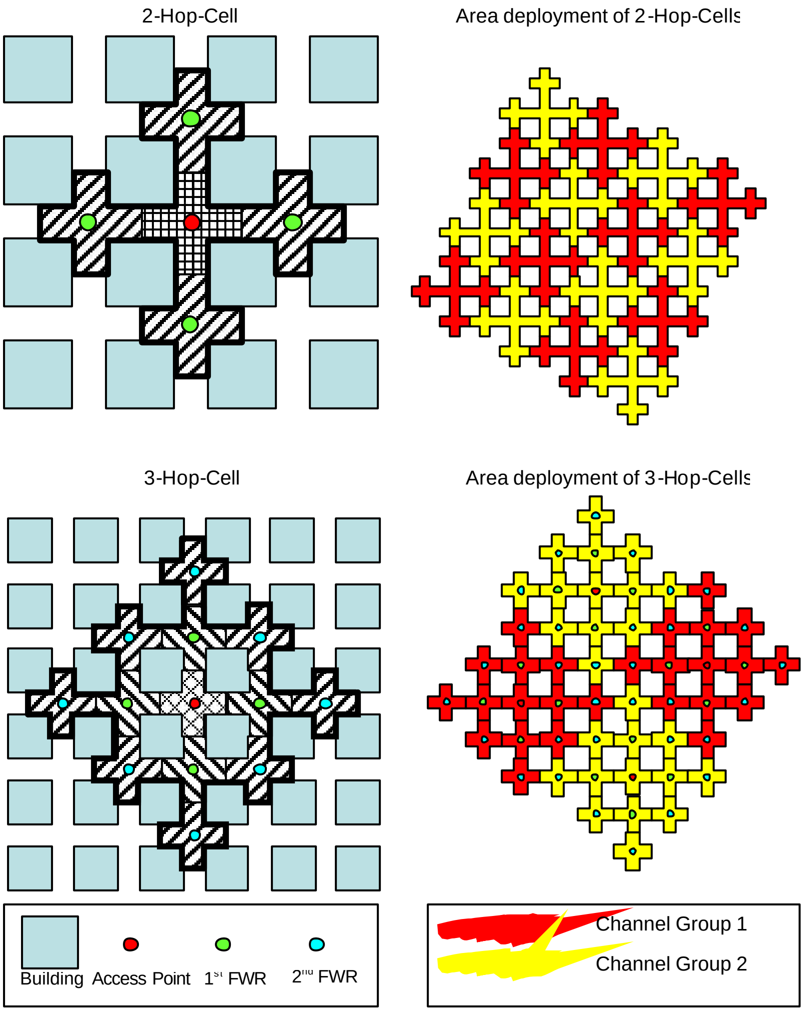

Figure 7: Full Manhattan city radio coverage based on the left hand basic element with one AP and multiple FWRs and two frequencies used [EWKZ2002]

The bit rate over distance from an AP that is supported by FWRs to extend the radio coverage range for the approach according to Figure 6a) is shown in Figure 8, schematically. If the FWR1 would not have a receive antenna gain, it would have available only a bit rate equivalent to the value *b* [Mbps] instead *a* [Mbps] that would be available with receive antenna gain. A similar consideration applies to

FWR2 and FWR 3.

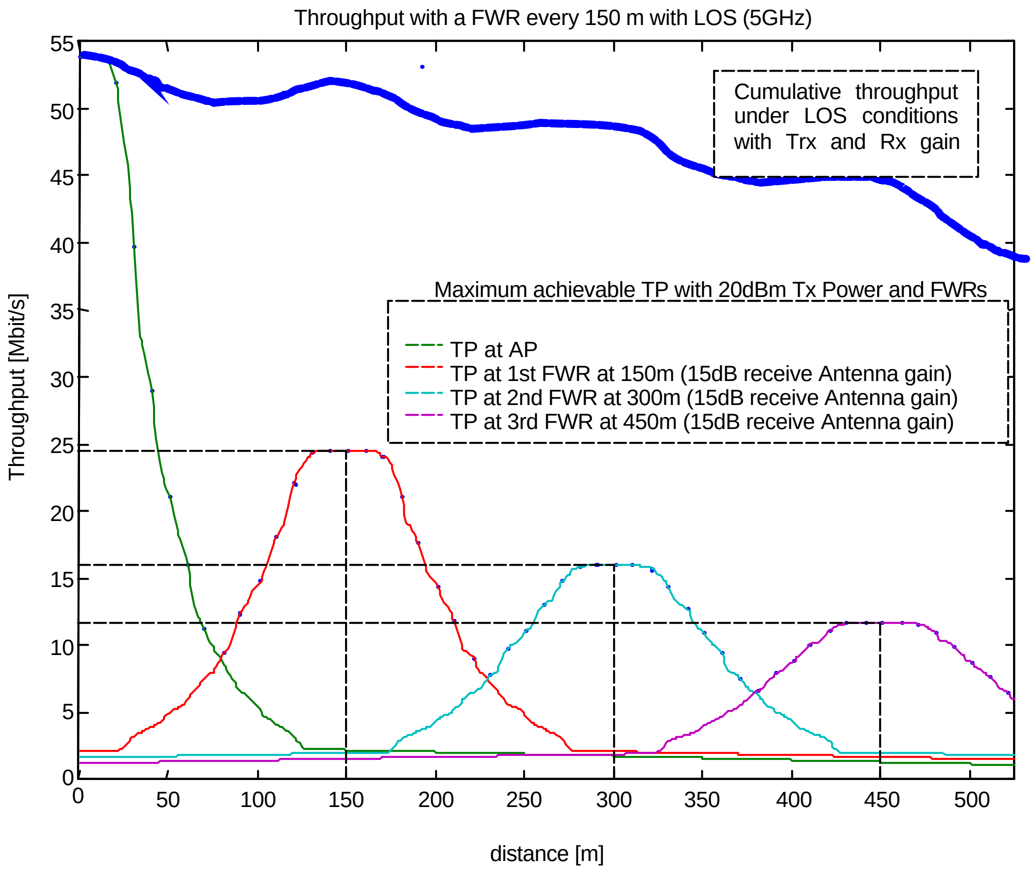

Figure 8: Extension of the radio range of an AP by Fixed Wireless Routers with receive antenna gain

The downlink interference calculated for a Manhattan grid placement of Media Points using the HiperLAN2 modem (that is the same as IEEE 802.11a modem) with cell radius of 100 m and Walfish-Ikegami propagation model (below roof-top) at a TX-power of 30dBm (1W) is shown under high cell load for the WMS in Figure 9 (a) from MATLAB® calculations.

Apparently, the system is interference limited and the overall interference power level at locations with high interference level is everywhere below -50 dBm but at most locations more than 20 dB less. The peaks shown can be found close to the antennas of the MPs that out of reach of humans. If it would be possible to mount the MPs such that some protection distance for humans can be guaranteed, the downlink interference level would be much lower, e.g., below –60 dBm or less, a value that is much lower that with current systems. As a comparison, the right graph in Figure 9 (b) shows the Downlink Interference calculated for a hexagonal cell layout (500m radius) of 3G Macro-cells, each transmitting at 40dBm (10W) based on the Hata-Okumura propagation model. It is obvious that the interference floor and the peak received power is approximately 20dB higher (factor 100). Figure 10 proves this: The cumulative distribution functions (CDF) of downlink interference for the WMS and a 3G cellular radio are compared. It becomes very clear how superior a WMS using a very limited transmit power would be compared to cellular radio systems using micro or macro cells. Both Figures 9 and 10 show the high potential of Media Points to reduce the radio exposure of humans and motivate to think about measures to improve it even more.

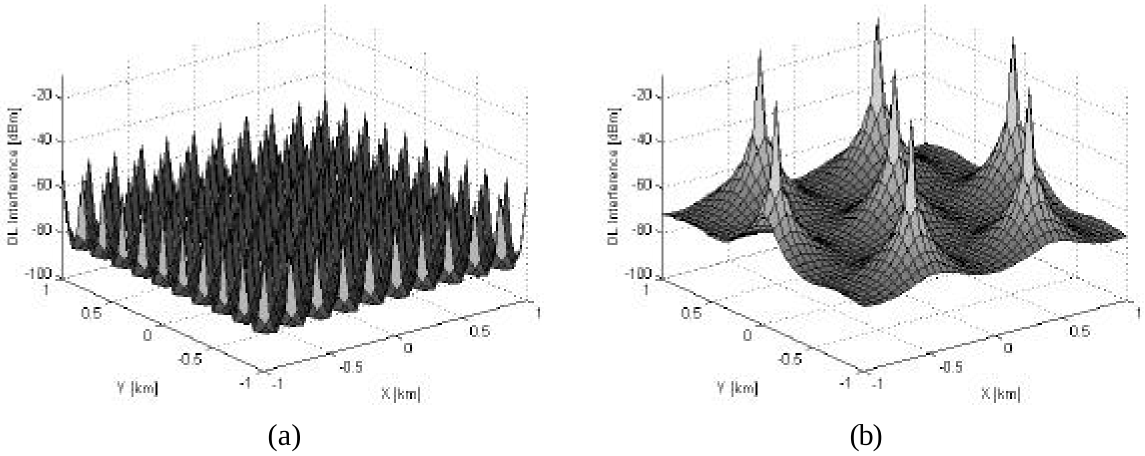

Figure 9: Downlink Interference for typical deployments and settings.
(a) Manhattan grid placement of WBS-APs with cell radii of 100 m and Walfish-Ikegami propagation model; TX-power: 30dBm (1W)
(b) 3G cellular, hexagonal cell layout (radius 500m), 40dBm Tx-power (10 W), Hata-Okumura Propagation

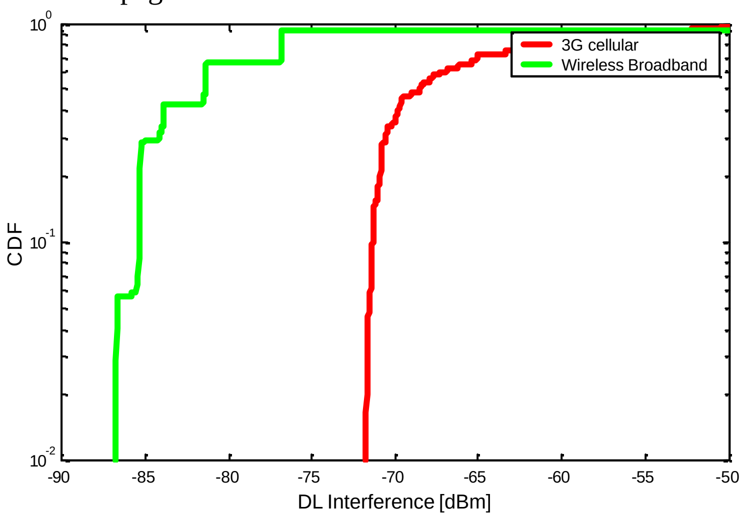

Figure 10: Cumulative distribution functions of DL interference for WMS and 3G cellular radio

Figure 11 shows for the approach shown in Figure 6a) the end-to-end throughput between an AP and a Remote Mobile Terminal (RMT) that is located in a distance *d* for different modulation and coding schemes of the HiperLAN2 or IEEE 802.11a modems [EWKZ2002]. The RMT is shadowed by a building at the street corner and is therefore connected “around the corner” with the help of a FWR. The shaded area under the curves in Figure 11 shows the gain in throughput possible from the use of the FWR without which the RMT could not be connected to the AP. It can be seen that the range extension resulting from using the FWR is substantially large.

Recent work has proven that the capacity of an AP when using a modem as standardized for HiperLAN2 and IEEE 802.11a is much too large, compared to the communications traffic needs of mobile terminals expected in its pico cell area resulting from omni-directional or sector antennas and a power of 1 Watt EIRP allowed for these systems [MLM2002].

It is worth noting that smart antenna technology at the AP or mobile terminal cannot contribute to provide a radio coverage to shadowed streets: the FWR is the only technology able to do that.

The FWR concept can also be used to extend the range of an AP to non-shadowed areas as shown from our simulation results for HiperLAN2 according to the scenario in Figure 6a) in Figure 12. It can be seen that the radio range can be dramatically increased, especially, when using receive gain antennas at both MPs involved.

From both, Figures 11 and 12, it is apparent that the FWR based WMS architecture is scaling very well in that it is able to make available the traffic capacity of an AP to a small (pico) or much larger (micro) cell by using multi-hop communication. This consideration addresses the extension of the range of an AP to FWRs and does not say anything about the traffic capacity available to mobile terminals roaming around an AP or FWR.

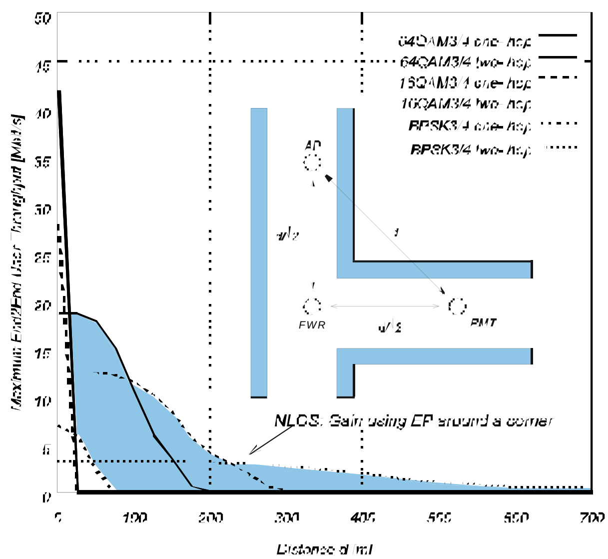

Figure 11: Fixed Wireless Router at the intersection (FMT) to extend the radio range of an AP "around the corner" into a shaded area to serve a remote mobile terminal (RMT)

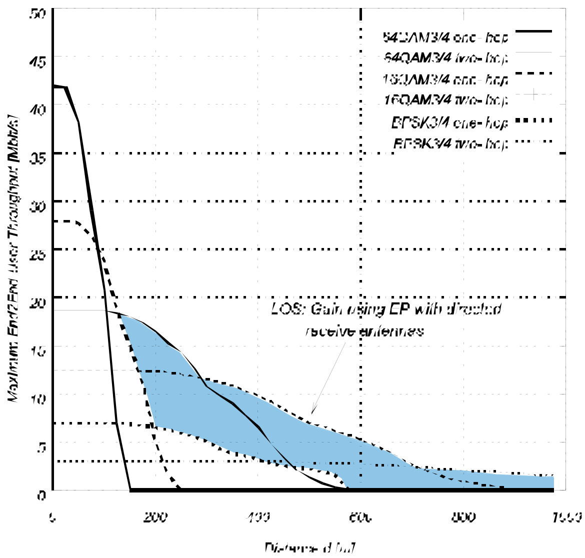

Figure 12: Maximum End2End throughput vs. Distance for Forwarding under LOS Conditions with directed receive antennas having a gain of 11 dB

2.3 Traffic Performance

A scenario according to Figure 5 (right) has been studied in [WX2001] where a new air interface developed for the so-called Wireless Channel oriented Ad-Hoc Multi-hop Broadband (W-CHAMB) system is used that was formally specified using SDL [ITU-T2000] and analysed using stochastic simulation of the traffic load. Multi-hop links are established in the time domain, cf. Figure 6a). Two types of traffic are considered competing for the transmit resources.

The packet sizes of the Available Bit Rate (ABR) traffic are read from an Ethernet trace file. Data rates are varied to model different loads. The Packet size of real-time Variable Bit Rate (rt-VBR) traffic is modelled by an autoregressive Markov process with a mean of 3060 bytes and a maximum of 6120 bytes. 24 packets are generated per second by each rt-VBR source. The multimedia traffic load consists of five download rt-VBR sessions and 10 download ABR sessions from AP to nodes, five upload ABR sessions from nodes to the AP, and five direct link ABR VCs from WS to WS. The min-hop routing algorithm is used to established a multi-hop route. The transmission rate is 24 Mbit/s using the modem specified in IEEE 802.11a. The connectivity is an important parameter in that it relates the number of direct neighbour nodes to the total number of nodes in the network:

$$c = \frac{1}{N(N+1)} \sum_{i=1}^{N} n_i \tag{1}$$

If c = 1.0 the network is fully meshed and no multi-hop links are needed to reach any other node or the AP. If c is small, say 0.34, under equal traffic distribution probability the mean number of hops would be about 3. Figure 13 (left) gives a comparison of the throughput performance over load for a network connectivity *c = 0.34 of the two concepts W-CHAMB and IEEE 802.11a*. The prioritised rt-VBR traffic is completely served at all load conditions by the W-CHAMB system, whereas the throughput of the rt-VBR traffic decreases with the increasing loads in IEEE 802.11a. The maximum throughput of ABR traffic is higher than with IEEE 802.11a. This underlines some weaknesses of this broadly accepted protocol. These results have been gained assuming no antenna gain at any node to connect to each other.

Much more interesting is the complementary distribution function of packet delay presented in Figure 13 (right) for both types systems under *c = 0.34* and variable total system load. It is visible that the W-CHAMB systen is able to guarantee a small delay for rt-VBR traffic even at a heavy overload situation of 0.5 (the saturation load is about 0.34 according to Figure 13 (left)). The curves of the complementary delay d.f. are quite similar under different load for W-CHAMB. Since IEEE 802.11a is not able to differentiate rt-VBR and ABR traffic, the delay performance degrades rapidly with a increasing load and gains unacceptable results even under very low load, say 0.25.
The traffic performance in Figure 13 addresses the extension of the range of an AP to wireless nodes and shows that multi-hop really is able to provide a high throughput to multi-hop routes. It does not say much about the traffic capacity available to mobile terminals roaming around any node. Investigations on that would need further development of the models used so far.

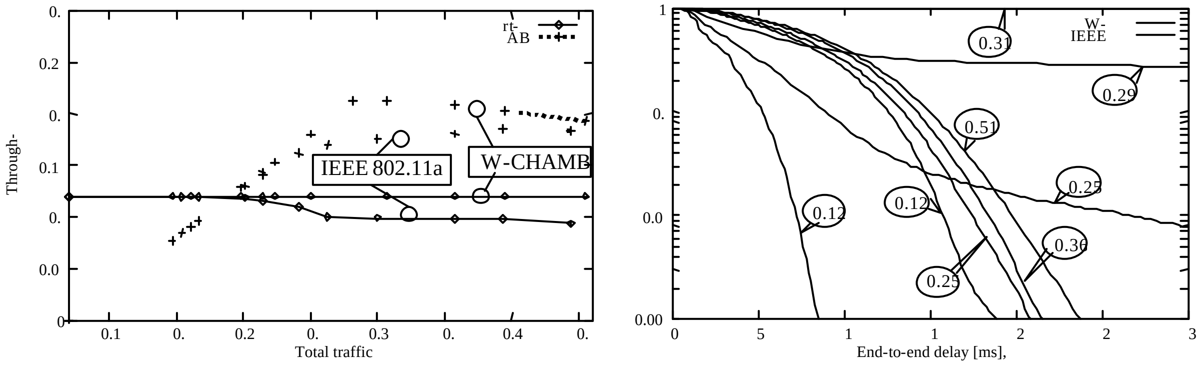

Figure 13: Multi-hop traffic performance under network connectivity c = 0.34 (about 3 hops on average); A throughput of 1.0 corresponds to 24 Mbit/s.**Capacity Analysis for the WMS**
In the following, the system capacity of the WMS with forwarding in the frequency domain (solutions B and C in Figure 6) is derived. For this purpose the buildings in Figure 7 are neglected as illustrated in Figure 14.

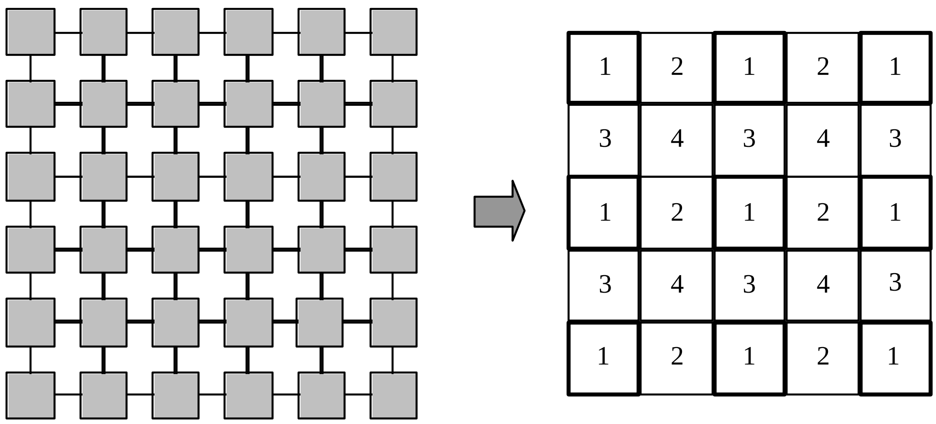

Figure 14 Square cell representation and frequency re-use distance

Each cell is served either by an AP or a FWR. A FWR is located in the middle of a cell and acts like an AP. In two neighboring cells a different frequency, rsp. frequency group is employed as indicated by the numbers in Figure 14. Therefore, operation in each cell is independent of each other. At which distance frequencies are re-used depends on the number of available frequencies, rsp. frequency groups. In Figure 14 four available frequencies, rsp. frequency groups have been assumed. In the following the capacity will be numerically calculated for a number of available frequencies/frequency groups of 4, 9 and 16.
The difference between system architectures B and C from Figure 6 is that in architecture B two neighboring FWRs (rsp. AP and FWR) are directly communicating with each other (via directed antennas with high gain), whereas in architecture C there is an additional FWR located on each border of two neighboring cells. These additional FWRs are not acting like APs but like normal WTs, which are participating in two cells and are designated as Forwarding Terminals (FTs) to distinguish them from

the FWRs in a middle of a cell that are acting as APs. The system capacity depends on, whether the FWRs (in architecture B), respectively the FTs (in architecture C) are equipped with multiple transceivers.
Exemplarily, the system capacity is calculated for system architecture C. If the FTs on the border of two neighboring cells were equipped with two transceivers, they could participate in the communication of both cells in parallel. If the FTs were equipped with only a single transceiver, they would have to periodically switch the frequency in order to alternately participate in the two cells. In this latter case the maximum forwarding capacity of a FT would only be half of the maximum cell capacity. However, this limited forwarding capacity would not be the limiting factor in the system capacity. What really determines the system capacity is the capacity of the central cell rsp. AP, which is serving a certain number of remote cells rsp. FWRs. As shown in Figure 7, the AP serves 4 remote cells in case of a single level FWR-hierarchy and already 12 remote cells in case of a 2-level FWR-hierarchy. With square cell representation the AP has to serve $2l(l+1)$ remote cells for an l-level FWR-hierarchy. The highest forwarding load has to be carried by the 4 innermost FTs, because the bundled traffic of several outer cells has to be forwarded. Even if each of the 4 innermost FTs has only a forwarding capacity of half of the AP capacity, there is no forwarding bottleneck, because the AP can assign not more than a quarter of its capacity to each of the four FTs.
On each level i of the FWR-hierarchy there are $4i$ FWRs. The FWRs of level i have to carry the traffic of all outer levels plus their own cell traffic. Assuming equally distributed user traffic and designating the user traffic of a cell with T, the total traffic T_i, a cell of level i has to carry, is given by:

$$T_i = \begin{cases} \left(\frac{1}{4i}\left(\sum_{j=i+1}^{l} 4j\right)+1\right)T = \frac{T}{2i}\left(l(l+1)-i(i-1)\right) & \text{für} \quad i \geq 1 \\ \left(\left(\sum_{j=1}^{l} 4j\right)+1\right)T = T\left(2l(l+1)+1\right) & \text{für} \quad i = 0 \end{cases} \tag{2}$$

Eq. (2) says that the highest traffic has to be carried by the central cell (with i=0), which therefore determines the system capacity.
In [HW2001, HW 2002] it has been shown that in an interference limited scenario the capacity T_{cell} of a cell is (almost) independent of the cell size. This is because the received signal strength as well as the interference at a given point depend in the same way on the cell size A_{cell}. Thus the signal to noise ratio E_s/N_0 is independent of the cell size, because A_{cell} can be cancelled down when dividing E_s by N_0 (if the background noise is neglected). The system capacity T_{system} of the WMS can be calculated by considering that the total load in the central cell has to correspond to the cell capacity T_{cell}:

$$T\left(2l(l+1)+1\right) = T_{cell} \tag{3}$$

The system capacity T_{system} is the product of the number of cells N_c and their throughput T leading to:

$$T_{system} = \frac{T_{cell} \cdot N_c}{\left(2l(l+1)+1\right)} \tag{4}$$

The question arises whether, at a given AP density r_{AP}, it is better to form larger cells with a few number of FWRs or smaller cells with consequently a larger number of FWRs. To answer this question we take into account that the AP density is given by:

$$r_{AP} = \frac{1}{A_{AP}} = \frac{1}{\left(2l(l+1)+1\right) \cdot A_{cell}} = \frac{N_c}{A \cdot \left(2l(l+1)+1\right)} \tag{5}$$

where A is the total area to be covered and A_{AP} is the area that is served by one AP. Inserting Equ. (5) into Equ. (4) yields:

$$T_{system} = T_{cell} \cdot r_{AP} \cdot A \tag{6}$$

Equation (6) illustrates that the system capacity does only depend on the number of APs (rsp. the AP density if the area to be covered is given). The cell capacity is constant and especially independent of the depth l of the FWR architecture. This is due to the fact that the cell-size has no influence on the cell capacity. The cell capacity does only depend on the number of available frequencies rsp. the frequency-cluster size, which is assumed to be given. It is most appropriate to compare system architectures with constant installation cost rather than constant AP density. The installation cost can be assumed to be proportional not only to the AP density r_{AP} but also to the FWR density r_{FWR}:

$$C = A \cdot C_{AP} \left(r_{AP} + a \cdot r_{FWR} \right) \tag{7}$$

In Equ. (7) C_{AP} is the cost of an AP and a is the ratio between the cost of a FWR and the cost of an AP. The FWR density can be expressed as a function of the AP density and the hierarchy depth l of the architecture:

$$r_{FWR} = 2l(l+1) \cdot r_{AP} \tag{8}$$

Inserting Equ. (8) into Equ. (7) yields

$$C = A \cdot C_{AP} \cdot r_{AP} \left(1 + a\, 2l(l+1) \right) \tag{9}$$

From Equ. (9) it can be derived that, at the same cost, one can substitute APs by FWRs or vice versa. However, replacing APs by FWRs reduces the system capacity as can be seen when inserting Equ. (9) into Equ. (6).

$$T_{system} = \frac{T_{cell} \cdot C}{C_{AP} \left(1 + a\, 2l(l+1) \right)} \tag{10}$$

Note that T_{cell}, C, C_{AP} and a are constants. Equ. (10) shows that in order to minimize the cost per bit, the number of FWRs, rsp. hops should be kept as small as possible. Nevertheless there is a situation, where it makes sense to install FWRs: If the cost target C is very low and no FWRs are installed (l=0) to optimize the cost per bit, the cost target can only be reached by reducing the AP density $r_{,}$, cf. Equ. (9). However, if seamless coverage is aimed at, the AP density can not be reduced beyond a certain minimum value (given by the transmission range of the terminals). In such a situation the seamless coverage can only be guaranteed by installing FWRs. This is because, for a given cost, the cell size A_{cell} can be reduced by increasing the depth l of the hierarchy, rsp. the number of FWRs (cf. Equ. (5), rsp. Equ. (11)). Note that a is smaller than 1.

$$A_{cell} = \frac{1}{r_{AP} \left(1 + 2l(l+1) \right)} = \frac{A \cdot C_{AP} \left(1 + a\, 2l(l+1) \right)}{C \left(1 + 2l(l+1) \right)} \tag{11}$$

The design rule should be that, for a given system cost target C, the depth of the FWR hierarchy should be chosen according to Equ. (11) such that the maximum cell size, at which seamless coverage can be guaranteed, is just reached. However, the number of FWRs should not be increased beyond this level, because this would only increase the cost per bit.

To conclude, for the system capacity it does not matter whether larger cells with a small number of FWRs or bigger cells with a higher number of FWRs are built as long as the positions of the APs are not changed. Beside the cost considerations, if one considers that the end-to-end delay increases with the number of hops, it seems recommendable to use as few FWRs as physically possible. The minimum number of necessary FWRs depends on the distance of the APs and their maximum transmission range. On the other hand it has to be taken into account that with increasing transmission range (rsp.

transmitted power) of the APs and terminals the exposure of humans to electromagnetic radiation is increased. Therefore, the introduction of FWRs does not only appear as a solution to realize systems with very low cost targets (by reducing the AP density at the expense of system capacity) but also as a means to reduce the exposure of humans to electromagnetic radiation.

2.5 Solution to increase the system capacity

The system capacity can be increased by assigning the number of available frequency channels (or spreading codes) according to the total traffic, that each cell has to carry. In order to be able to guarantee a constant frequency re-use distance despite the unequal channel distribution, the FWR hierarchy would have to be aligned with the number of channel groups. As an example the 2-level FWR network architecture could be modified in order to align it with a frequency-cluster size of 9. This can be achieved by reducing the number of FWRs on level 2 according to Figure 15.

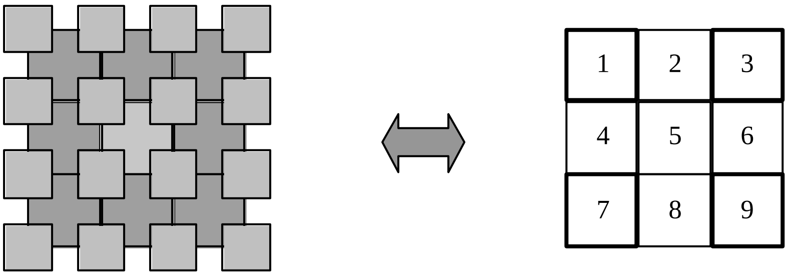

Figure 15 Modified FWR network architecture

With this architecture there are only 4 FWRs on level 2 (namely the cells in the four corners). Each of the four level-2 FWRs has to carry only its traffic *T*. The four FWRs on level 1 have to carry a traffic of 2*T* each and the central cell carries a traffic of 9*T*. By dividing the number of available frequency channels into 9 groups, the channel distribution can be aligned with the FWR architecture (cf. Figure 15). In this example the optimal fraction p_i of the totally available frequency channels (or codes) that should be assigned to the group used in a level-*i* cell is given by:

$$\begin{aligned} p_0 &= \frac{9T}{4T+8T+9T} = \frac{9}{21} \\ p_1 &= \frac{1}{4}\cdot\frac{8T}{4T+8T+9T} = \frac{2}{21} \\ p_2 &= \frac{1}{4}\cdot\frac{4T}{4T+8T+9T} = \frac{1}{21} \end{aligned} \tag{12}$$

Assuming an available bandwidth of *B*, a bandwidth of 9/21 *B* has to be consequently assigned to the central cell. As the cell capacity T_{cell} is proportional to the available bandwidth within the cell, the system capacity of the optimized system is given by:

$$T_{system}^{opt} = T_{cell}^{opt}\cdot r_{AP}^{opt}\cdot A = n\cdot\frac{9}{21}\cdot B\cdot r_{AP}^{opt}\cdot A \tag{13}$$

with a constant factor *n* that only depends on the frequency re-use distance (frequency-cluster size). This capacity has to be compared to the capacity of the original system, where 1/9 of the bandwidth is assigned to the central cell:

$$T_{system} = T_{cell}\cdot r_{AP}\cdot A = n\cdot\frac{1}{9}\cdot B\cdot r_{AP}\cdot A \tag{14}$$

Here again, for a fair comparison, the system variants should be compared at the same system cost. The cost of the optimized system variant is given by:

$$C^{opt} = A\cdot C_{AP}\cdot r_{AP}^{opt}\left(1+8a\right) \tag{15}$$

Equating the cost of the two system variants leads to:

$$r_{AP}^{opt} = \frac{1 + a\,2l(l+1)}{1+8a} r_{AP} \tag{16}$$

Equations (13), (14) and (16) finally give the capacity of the optimized system as a function of the capacity of the original system:

$$T_{system}^{opt} = \frac{27}{7} \cdot \frac{1 + a\,2l(l+1)}{1+8a} \cdot T_{system} \tag{17}$$

As we are considering one specific example of an optimized system, we should compare it with the specific version of the original architecture, which implies the same packet delay, rsp. average number of hops. The average number of FWR-hops h^{opt} of the optimized system is given by:

$$h^{opt} = \frac{4}{9} \cdot 2 + \frac{4}{9} \cdot 1 + \frac{1}{9} \cdot 0 = \frac{4}{3} \tag{18}$$

The average number of FWR-hops of the original architecture can be calculated to:

$$h = \sum_{i=1}^{l} \left(\frac{4i}{2l(l+1)+1} \cdot i \right) = \frac{2l(l+1)(2l+1)}{3\left(2l(l+1)+1\right)} \tag{19}$$

Equating the two average hop numbers determines the depth l of an equivalent non-optimized architecture to be l=1.715. Inserting this value into Equ. (17) leads to the final formula:

$$T_{system}^{opt} = \frac{27}{7} \cdot \frac{1+9.3a}{1+8a} \cdot T_{system} \tag{17}$$

In Table 1 the performance gain of the non-uniform spectrum allocation is summarized for different values of a. A performance gain can also be achieved by the non-uniform spectrum allocation for architectures with a different depth of the FWR hierarchy.

Table 1 Performance gain due to non-uniform spectrum allocation

a	**Performance gain [%]**
0	386
0.1	414
0.5	436
1	441

2.6 Point-to-Multipoint Radio to feed Media Points

A MP would need a very high transmission rate of multiples of 100 Mbps that it supports at the air interface of an AP using multiple carriers. Since no fibre can be assumed existent at intersections and other locations useful to position an AP, Point-to-Multipoint (PTM) line-of-sight (LOS) radio or High Altitude Platform Stations (HAPS) could be used to connect MPs to the fixed telecommunications network as shown in Figures 2 and 13. Since a LOS radio system has a limited capacity, a tandem of two air-interfaces, each one in its respective frequency band, need to be implemented – one for the PTM system and the other one for the mobile broadband system. The PTM system capacity is made available to the MPs only when needed to serve mobile broadband terminals.

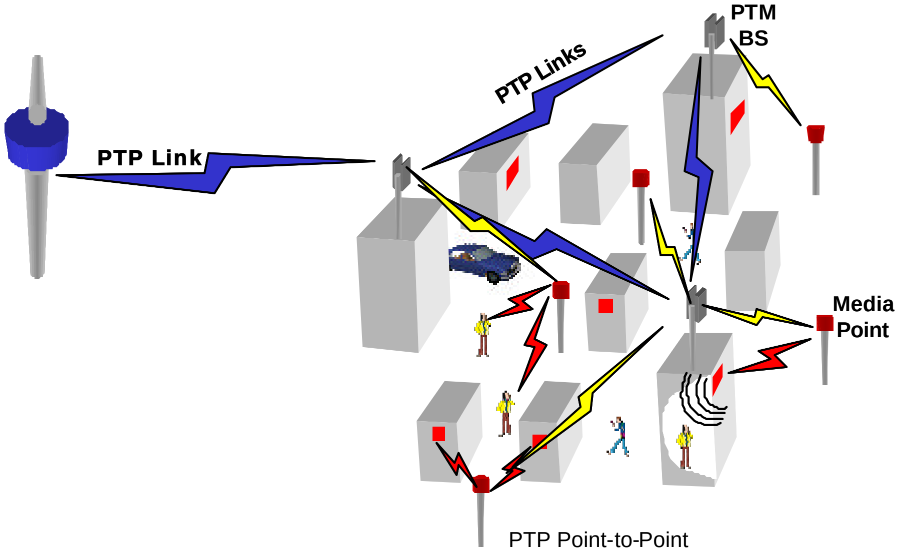

Figure 13: PTM LOS radio to connect Access Points to the Fixed Network [BW1999]

Smart antenna technology would increase the capacity of the PTM system to feed the fixed located MPs. Radio coverage in buildings could be provided through FWRs mounted at windows and served from outdoor APs. The dark coloured squares shown at the buildings in Figure 13 represent these FWRs. High gain antennas might be useful to connect base stations and the FWRs.
The radio exposure of humans from the PTM LOS radio system thereby can be kept very small. The PTP LOS microwave radio network above roof-tops will apply highly directive antennas and the radio exposure of humans will therefore be very small.

3 Service Architecture

3.1 Intelligent Service Control of the Wireless Media System

The core network of the Wireless Media System (WMS) applies an Intelligent Service Control (ISC) to ensure that data communicated over the various radio access networks is continuously made available to a Mobile Terminal (MT) even if the radio connectivity to the WMS is interrupted time-wise owing to the discontinuous radio coverage available from the WMS. The ISC simulates to user applications a continuous connectivity of the MT to the WMS by making extensive use of caching at MTs and MPs or their nearby controllers. Spontaneous access via the WMS to contents data is typically executed with a situation-specific delay, since the respective MT must wait until it has reached an area with WMS radio supply – optionally the service might be provided from the mobile radio system, immediately.
A MT associated to the WMS, when reaching an MP served area refers to the session already established earlier with its remote application, receives the data it had requested earlier at a very high data rate from the cache of the respective MP controller and caches it locally for later use. The quantity of data transmitted should be large enough to accommodate the expected duration of the local processing while a terminal might not be connected to the system (e.g., mailbox content, MP3 music file or other large data file). An MT transmits all data waiting for transmission to the MP as soon as it reaches its coverage area.
MTs may use all services known from cellular networks and the Internet, i.e., voice, data transmission, reception of broadcast transmissions etc. and may operate interactive multimedia connections. The ISC uses the mobility management and localization function of the advanced 3G radio system and dynamically tunnels data across fixed networks. Handover between adjacent cells served by MPs is replaced by fast re-association to the next MP.

A simplified version of Figure 2 is shown in Figure 15 where two sub-networks of a WMS are shown, each with its Media Point Controller (MPC) comprising the cache storage for all the MPs in the sub-network. The dotted curve relates to the route of a car that originally had used the mobile radio system, e.g., to transmit a request for large volume data and later is roaming through MP-sub-networks where

it crosses a number of areas served by MPs of the WMS. The ISC will provide as much data as possible at the downlink, according what was requested by the terminal in the car.
It is clear from Figure 15 that multicast data could optimally be broadcast from the base stations of the hexagonal cells, namely via the cellular radio system. One other possibility is to realize a multicast based service in the WMS by caching the respective data in the MPCs and pushing a copy down to an MT as soon as it shows-up at one of the related MPs. This would allow a perfect selective multicast service in that only pico-cellular MP capacity is used to reach the MTs that have subscribed to a multicast service.
The ISC supervises and controls all of the sessions of any mobile terminal in the combined systems of cellular mobile radio and the WMS. Its purpose is to control in an optimal way how to provide communication services related data to mobile terminals. The ISC is a logical unit that co-ordinates and comprises the following functions

- mobility management of all of the terminals,
- localization of the terminals in both, the mobile network and WMS,
- subscriber identity module (SIM) common with cellular radio network,
- dynamic tunneling of data through core networks involved to serve a mobile terminal,
- authentication, authorization, accounting and encryption,
- caching of data for mobile users,
- self-learning algorithms to understand the behaviour of an user and to take advantage of knowledge on the type of MT and applications running on it,
- quality of service (QoS) support depending on the used network.

The ISC may be a centralized or decentralized unit. It simulates a continuous broadband access service to mobile terminals although the radio network coverage of the WMS is discontinuous only.

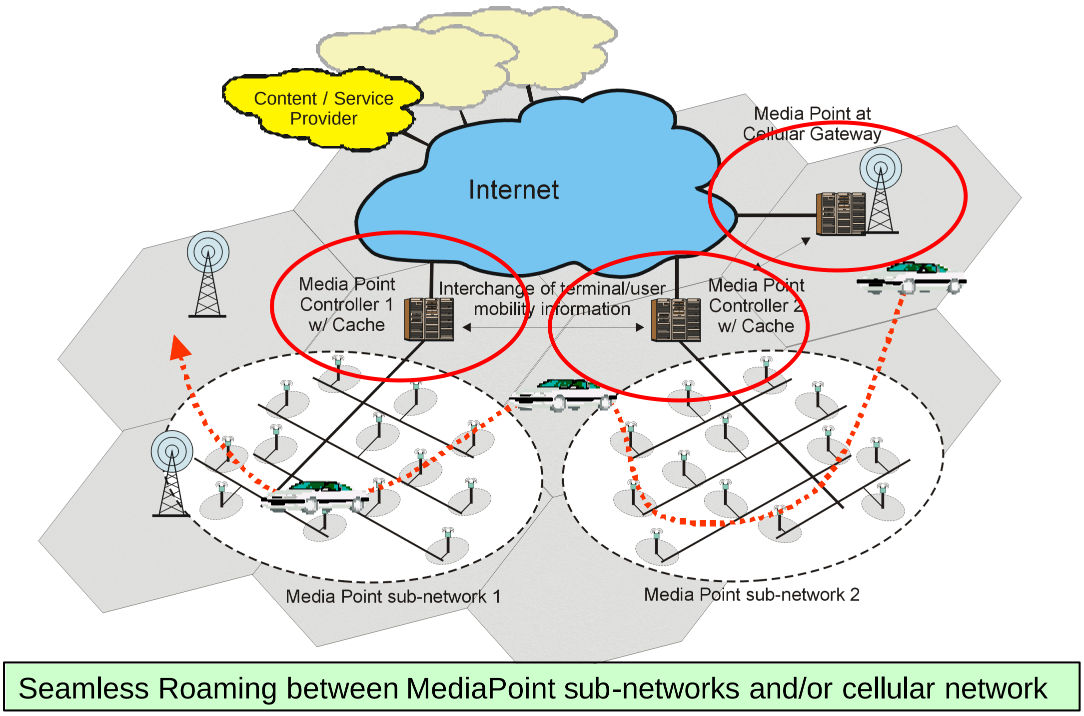

Figure 15: Media Point Controllers (as part of the ISC) to cache broadband data in preparation for download to mobile terminals

4. Multimedia Applications and Usage Scenarios

Broadband wireless access for mobile (moving) terminals, e.g. for terminals installed in vehicles, poses higher system requirements than for stationary terminals. It has been found that multi-media (MM) services to mobile users in many application scenarios could be satisfied by a much more cost-effective network architecture than known from cellular mobile radio systems, which then basically serve as a back-up system to provide services like voice and data that must be brought instantaneously to users without any cost concern [BW2000-1],[BW2001-1]. This architecture is realized by the WMS approach. Only a perfect combination between a very high bit-rate wireless communication system and an ISC in terminal and network, that takes the terminal, application and network specific data into account to provide MM contents to mobile users at specific wireless access points, would lead to a success of the WMS.

4.1 Basic Service Concepts

The WMS is designed to realize the concept of a wireless bi-directionally transmitting communication network for MM applications characterized by the following properties:

- High bit-rate wireless transmission of media data via Media Points (MP) that connect mobile terminals to the Internet and to MM servers, which are locally distributed according to the expected user/terminal density, and in total do not enable a ubiquitous but only a discontinuous radio coverage and radio connectivity. An MP is realized by a base station with a broadband radio interface or by an FWR connected wirelessly to an AP.
- Continuous use of media (in spite of discontinuous radio coverage) whereby the application running on the MT in co-operation with the ISC of the WMS transfers data at each MP between the network and the MT as much as required for the expected processing and consumption within a planned time horizon, e.g., 20 min. By sending commands to the network, ISC will predict and determine what media data should be transmitted next to which MP to be predicted to be visited by the MT in the near future. In the meantime other local data is consumed or processed offline at the MT, and the results may be transferred to the network at the next MP.

An example scenario is shown in Figure 16 (left) with two MPs and their transmit and receive devices (transceivers) mounted on two gantries over the highway. Each MP is equipped with a control unit that is connected to the Internet or local MM server via the ISC of the network. The coverage area of an MP is depicted as a grey elliptic surface. As long as a vehicle resides in a coverage area, a MT in the vehicle can set-up a connection with the local MP to request and download its application data wirelessly, or to send data, that has been prepared earlier, e.g., video recordings. When the vehicle leaves the coverage area or does not reside in any of the coverage areas, no radio link and thus no data transmission in absence of a contact to an MP exists anymore. In another scenario depicted in Figure 16 (right) the transceivers of the MPs are mounted on signal posts at intersections (or street lamps) within a residential area. Beside a MM terminal in a vehicle, pedestrians using a portable MM terminal may set-up a radio link to an MP and transmit the data wirelessly with high bit rate, as long as he/she stays within the corresponding coverage area.

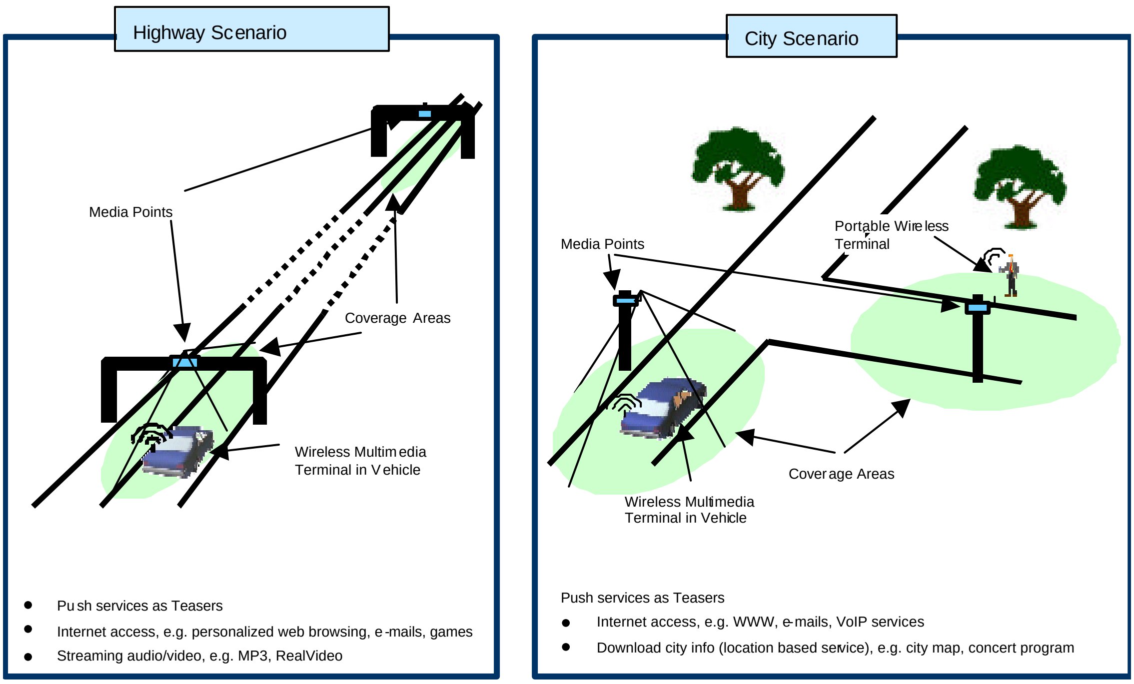

Figure 16: Continuous media use with discontinuous wireless data transmission for mobile terminals

4.2 Provision of personalised data by Wireless Media System in City Areas

Nowadays many cellular operators begin to extend their cellular networks with WLAN hotspots in public areas like train and bus stations, shopping malls, campus or downtown areas as they recognize the importance of a low-cost and broadband wireless Internet access for their customers. Figure 17 depicts the envisioned scenario in a city area where a user can access the Internet via a WMS access point (AP) or Fixed Wireless Router (FWR) that is mounted invisibly at a street lamp. We consider such Media Point (MP) availability in our WMS city scenario, which is described in the following.

In the city scenario many WMS hotspots are available at strategic public areas. Users with suitable wireless equipments can "hop" from one MP island to another to get high-speed Internet access. One main issue WMS has to deal with is to be aware of the presence status and location of each mobile terminal. Personalized data like e-mails or subscribed contents (news, movie trailers, no.1 song of the day, etc.) should be brought or pushed to the user each time new data is available and the terminal is in reach of the WMS and the user is online (according to user's preferences). Since the dwell time of the mobile user within a MP coverage area is limited and the push session could therefore be interrupted, the ISC of the WMS must support fast and reliable session re-establishment and continuation at the next MP. To explain one of the technical approaches applied by the ISC we consider the WMS network architecture shown in Figure 18.

The Intelligent Service Control (ISC) acts as a local central entity, whose main functions are to monitor the presence status and location of each active user and to cache personalised user data. ISC is connected via broadband Intra- or Internet to a number of Media Point Controllers (MPCs) with large cache capacity. Each MPC administers a group of MPs that are usually located in close geographical proximity and establish the hotspots in city areas.

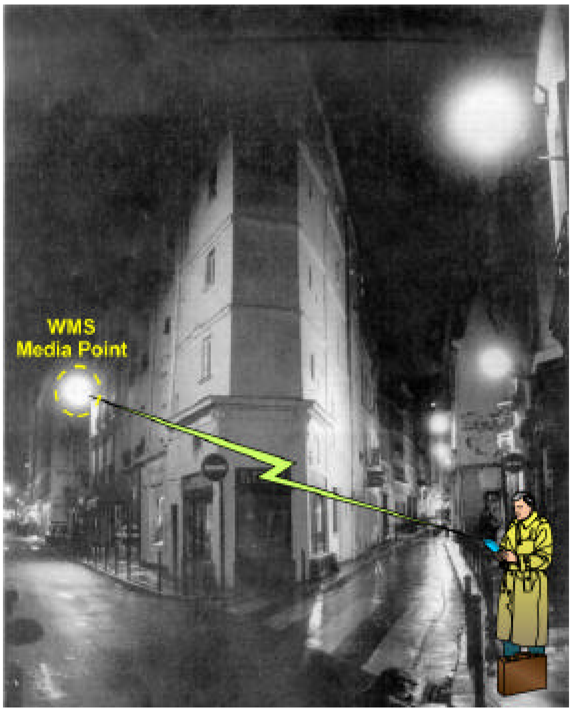

Figure 17: Media Points at hotspots in city areas

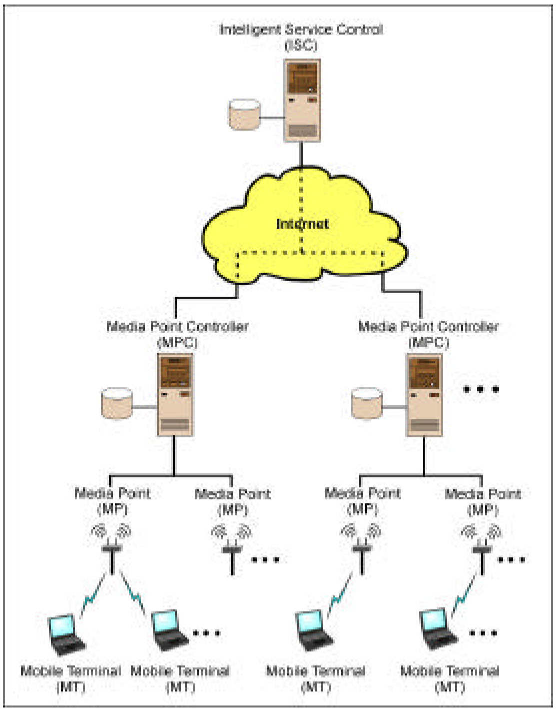

Figure 18: WMS network architecture

We consider the Session Initiation Protocol (SIP) [Ro2002] as a suitable protocol for handling the mobility management [WS1999] of each user terminal and the signalling between the system components for push sessions. SIP has been standardised within the Internet Engineering Task Force (IETF) as a norm for the creation and termination of multimedia sessions. SIP is an application-layer control protocol designed to be independent of the lower-layer transport protocol. Presently UDP is preferred as the default transport protocol but TCP is supported as well. Within the SIP context each (mobile) user is uniquely identified by his or her global SIP address. The SIP-based signalling in WMS is depicted in Figure 19.

The presence status of each user terminal is stored in the so-called Presence Server (PS)[3] [Ro2001]. ISC requests for the user's presence status by sending a SUBSCRIBE message to PS on a regular basis since the message expires after a defined time. In case PS accepts the subscription, the current presence information [S2002] about the user is included in a NOTIFY message and sent back to ISC. Each time the presence status of the user changes the ISC will be notified. On the other side, after the mobile terminal (MT) has entered a hotspot area and set up a connection with a MP[4], MT sends a REGISTER message to the administering MPC, which in turn forwards the message to PS. This way PS knows the current presence status of the user and via which MPC the user can be contacted.

If any personalised data for the online user is known available to the ISC, a new push session between ISC and the MPC is initiated with an INVITE message. The session is described using the Session Description Protocol (SDP) [HJ1998]. After the session is established ISC sends a list of data (by means of the MESSAGE method [C2002]) that MPC can pull (download) and cache for the user. Instead of "true push" we apply the "smart pull" method for WMS since it gives MPC more flexibility on how and when the data should be downloaded depending on the capability of each MPC, e.g., cache/storage size, computer power, link quality. The session is terminated by means of BYE message after all data has been pulled or after timeout. The identical SIP-controlled "smart pull" session is carried out between MPC and MT via the established wireless connection. Each time a data has been pulled by the MT an acknowledgment is sent back to MPC and ISC and the data is removed from their caches. In case that the "smart pull" session is interrupted, e.g., due to lost of access point connection, MPC keeps the remaining data in its cache until timeout. The session can be resumed by the MT with the same MPC (e.g. via the same or another access point of the same group) or another MPC.

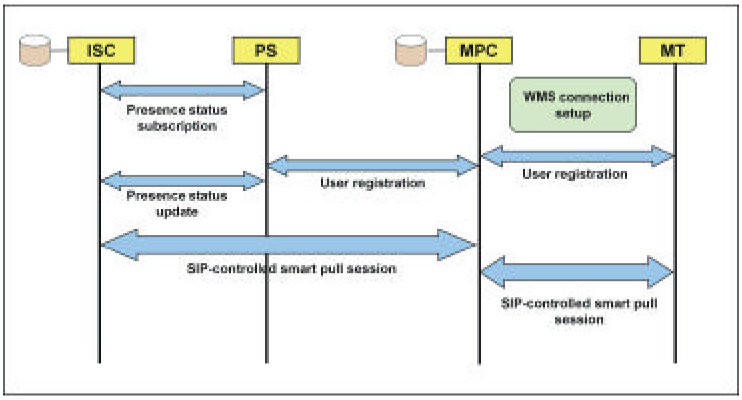

Figure 19: SIP-based signalling in WMS for pushing personalised data to a mobile terminal

The strategy to cache user data in MPCs before it is pulled by the user becomes more advantageous when the link capacity between ISC and MPCs is limited (e.g. due to high Internet traffic) and the data can be cached in an MPC before the users has entered one of the administered MP coverage areas. This requires sophisticated localisation methods that can be realised by integrating the WMS with a mobile radio network.
Mobile IP is not used in the SIP based solution discussed above. This would mean that any type of fixed network could be used.

4.3 System Characteristics and Functions

In order to enable a continuous media use in spite of discontinuous radio coverage, the mobile terminals are equipped so that they can predict and determine in cooperation with the ISC in the network, which MPs they will pass by in a foreseeable time span next, and which media data they are going to download there. Since this prediction may only be made with a certain precision regarding the time and location, the network thus keeps the requested and other supplementary information available at

[3] The Presence Server might be co-located with MPC
[4] including the assignment of an IP address in case DHCP (Dynamic Host Configuration Protocol) is used

several such MPs, that are foreseen by the terminals and the network as potential MPs to be passed by. Because the mobile terminals always maintain a virtual connection to the network, they can refer to the preceding communication context at subsequent MPs. The interworking between the wireless broadband terminals and the service control in network is coordinated so that the terminal's user gets the impression his/her terminal would always have a continuous connection to the network, although it is only connected via radio with the network from time to time. The mobile terminals possess a large internal storage capacity to receive or transfer the data wirelessly via an MP. If no free storage is available in the terminal to download data from an MP, the radio link will be released and communication will be resumed at one of the subsequent MPs by referring to the existing virtual connection.
Furthermore, by means of an extrapolation of the requested data or the corresponding application, e.g., playback of video clips or MP3 music, etc., the ISC extrapolates, which or what kind of data would be needed by the mobile terminal in the future, to assure a continuous data provision for the application. The data that has been requested by the terminal and made available by the network at a certain MP will be deleted if the terminal does not download the data within a certain period of time. The control unit of the MP can keep such media data, that are statistically very often requested by many mobile terminals, in its local storage permanently or at least for some time period, in order to minimize transmission delays between MPs and the Internet or multimedia servers via the ISC.
To support the prediction of the locations where supplementary data will have to be provided, the routes of the streets or highways are used to determine the reachable MPs, that are located on the streets. The terminals deliver terminal and vehicle specific data, such as GPS data, vehicle's speed or user-chosen route, etc., via the MPs to the network, which then evaluates the data and uses it in cooperation with the ISC for the prediction and determination of the MPs to be passed by the terminals/vehicles. For this purpose, information about the sequence of the access points passed by the terminals so far, which is stored and updated regularly in the network, will also be evaluated in combination with the location specific characteristics of each MP. Further a regularly updated display on the mobile terminal may indicate the locations of the nearest MPs, via which the network can be accessed. The display on the terminal may inform the user or the application about the amount of application specific data remaining on the storage and suggest a move direction for the mobile terminal, so that it could reach the next MP in time.
During a radio connection with an MP the terminal displays the actual capacity level of the local storage for the media data to the user, so that he/she could adjust the move speed to satisfy the data needs of the application. Other MPs near to the current MP will also be displayed on the terminal properly, so that the user, who can estimate his/her own move speed, can also estimate how much data he/she has to download at one time so that no lack of application data until arriving at the next MP occurs. Since not all MPs have the same transmission capacity and same traffic load (caused by the served terminals), the terminal's display informs also about the capacity and workload of the neighbouring and other MPs, that are specifically requested by the terminal. This information might be used by the user or the terminal internal agent to organize the future route of the terminal and the consumption of the data stored locally.
To achieve this functionality, MP system protocols operate on top of the radio network and fixed telecommunication network (Internet) that allow a closely harmonized interaction between the network elements like mobile terminal, MP, ISC and Internet based servers, see Figure 20.

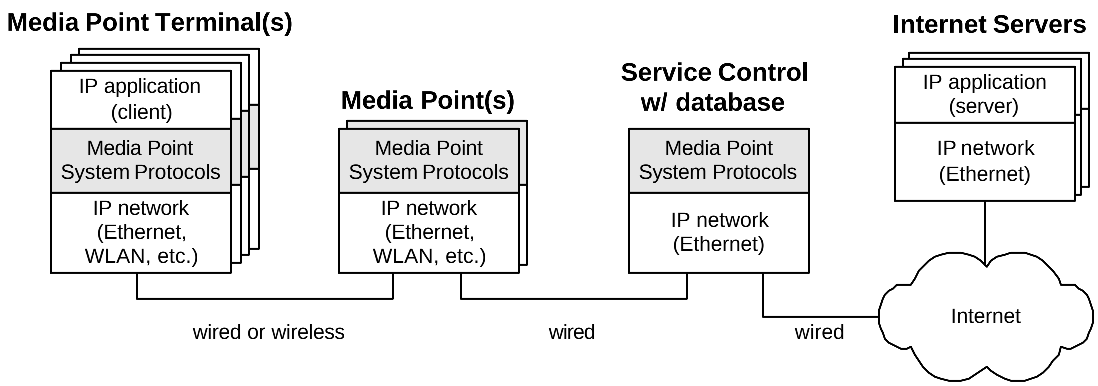

Figure 20: Media Point system protocol architecture

Since the QoS parameters achievable from a WMS will determine its acceptance as a next generation system, it demands a careful performance evaluation of the protocols and of the whole system design. For that purpose suitable performance evaluation scenarios concerning the type of applications, user behaviour, number of terminals, number of MPs, terminal mobility, etc. will have to be considered. The performance evaluation will cover the time behaviour (e.g. session establish/re-establishment time), data caching (i.e. proactive vs. reactive data transfer), coverage range, and QoS provided. Scenarios like in a city with stationary and slow-moving wireless terminals and with terminals moving in a car will need to be considered.

4.4 Broadcast and Single cast combined

Broadcast of data substantially reduces radio exposure of humans compared to single cast. Services characterised by highly asymmetric traffic with large data volumes on the downlink and error tolerance are well suited for broadcasting. These characteristics are typical for streaming services. Broadcast services advantageously can be combined with single cast services, e.g., as a "push-pull service combination". The service specific data is "pushed" to a mobile terminal according to the subscription of the user. In reaction to the pushed contents the user with a high probability might "pull" data via a micro-cell base station, see Figure 21. To optimise the number of users reached the data can be broadcast either via utilising public services based on DVB-T/ DAB or by broadcast from macro cells of a 3G network. Research is aimed at content engineering, development of an appropriate billing system and the further development of protocols to allow for dual-watch over macro- and micro-cells in 3G systems.

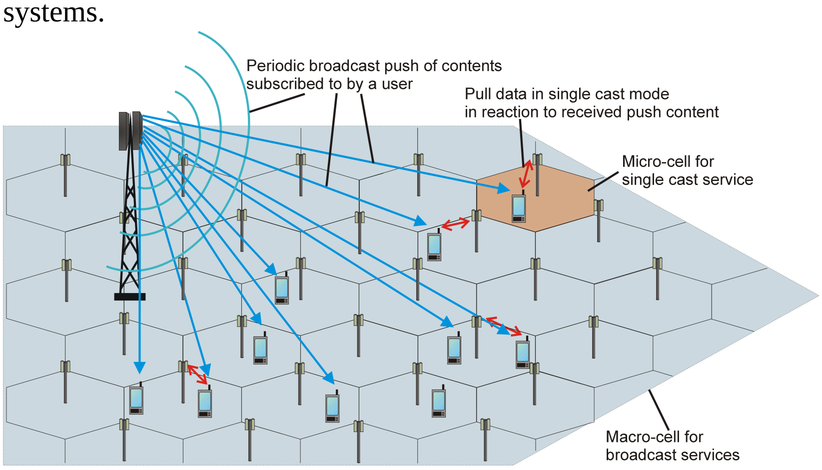

Figure 21: Push-Pull service scenario in an integrated broadcast/multicast/single cast system

4.5 Ad-hoc Network Operation in the WMS Access Network

An ad-hoc network has a completely distributed architecture with dynamic allocation of network and network node identifiers. In contrast to a wired network, self-organizing networks using the same radio channel cannot be separated from one another. The range of any node is restricted and networks can be fragmented under unfavourable propagation conditions. Independent ad-hoc networks do not communicate to each other and do not share the same communications medium, i.e. there is no interference between the networks. Overlapping ad-hoc networks share the same medium and contain some nodes being in the receive or interference range of the respective other network. Hidden stations can cause unpredictable interference that is difficult to control. Nodes may receive data with network IDs of a foreign network.

Multi-hop ad-hoc networks contain some nodes able to perform the function of routers. 4th generation systems will transmit packets multi-hop across mobile routers under multiple access conditions. Hidden stations are part of the concept.

Applications running on nodes of ad-hoc networks in most cases need to be connected to wired networks to make a sense. This affects the network layer (routing) protocols.

ETSI-BRAN/HIPERLAN_1 and IEEE 802.11 contain the elements to operate ad-hoc networks, esp. addressing, forwarding, power conservation, security, routing information exchange, Hello procedures, topology control, multipoint relay functions. ETSI/HiperLAN_2 in the Home Extension contains an ad-hoc mode of operation that allows the nodes to agree on a Central Controller (CC) to take

the role of an AP in a cluster of nodes, but no multi-hop functions are specified so far. Multi-hop operation based on wireless routers that operate alternating on different frequency channels to connect neighboured clusters has been proven to be workable, too [HW2002]. In the HiperLAN_2 basic mode (using an AP) it has been shown that multi-hop operation is easy to perform without changing the standard [ES2001]. ETSI/BRAN has not taken up ad-hoc networks so far as a working issue but has postponed the respective studies for later.
Neither measures to organize the coexistence of ad-hoc networks in a proper and well-defined way nor the network layer functions to be able to guarantee some quality of service are available so far; some first work on this has been published recently [MHCN2001], [M2002].
Studies on radio based ad-hoc networks for packet radio applications range back to the 70-ies, e.g., [TK1975], studies for telecommunication applications range back to the 80-ies, e.g., [WB1985]. Besides others recent results have been published in [WBL1998], [T1997] and [X2002].
The WMS will allow an ad-hoc component of operation for its mobile terminals.

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