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Dynamic Channel Allocation in Wireless ATM Networks*

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Abstract — **During the last few years extensive research has been carried out to extend fixed ATM networks via the air interface. Several access protocols have been developed [1, 2] and international projects are building the first wireless ATM (WATM) demonstrators [3, 4]. Up to now nearly no research has been done in the area of dynamic channel allocation for WATM networks, which is an essential issue for a future broadband communication system. In case of a WATM system two different aspects have to be combined: on the one side the ATM like statistical multiplexing leads to a very dynamic assignment of capacity – on the other side dynamic channel allocation requires a steady behaviour. Due to these opposing requirements, conventional allocation schemes cannot be used. In this paper an efficient method is introduced to share the available capacity among the base stations in such a way that statistical multiplexing and dynamic channel allocation are supported.**

I. Introduction

After the success of the *asynchronous transfer mode* (ATM) in the area of multimedia networks during the last years, a lot of research has been carried out to integrate wireless ATM terminals into the ATM network [5, 6, 7]. Currently many international projects are building demonstrators, which will be finished during the next years [3, 4].

To fulfil the requirements of the mobile users, the ATM like statistical multiplexing has to be extended to the air interface (Fig. 1). This can be done by using a TDMA scheme to divide the physical channel into slots which are able to carry one or several ATM cells. The base station (BS) as a central instance co-ordinates the access of the wireless terminals (WTs) to the common physical channel. It has to share the available channel capacity fairly between the WTs according to the negotiated *Quality of Service* (QoS) parameters and its capacity requests.

The BS assigns these slots to the WTs on a slot to slot basis and informs the WTs by transmitting reservation messages in a special signalling burst. The assigned slots build together with the signalling burst the so called signalling period. Its length is variable and varies over the time. The principle of the resulting signalling scheme in case of time division duplexing (TDD) is shown in figure 2. Further details can be found in [1].

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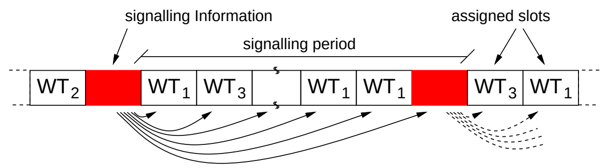

Figure 2: Structure of the signalling period

This kind of signalling scheme is used by different Medium Access Control (MAC) protocols such as DSA++[1]/MASCARA[2] and is currently discussed at ETSI BRAN to be standardised as the signalling scheme for future WATM systems.

The statistical multiplexing which is performed via the air interface leads to a very dynamic assignment of capacity to the terminals. Since the capacity assignment changes from period to period, there is no prediction of future slot assignments possible.

Conventional dynamic channel allocations are based on circuit switched connections. Decentralised algorithms measure the current channel situation an perform on these measurements a prediction of the future situation (free or busy channels). Therefore dynamic channel allocation algorithms are only able to work effectively, if there is a certain steadiness in the allocated channels. In this paper we present a solution to solve the contrast between the requirements for DCA and WATM-MAC.

This paper is organised as follows. In section 2 it is explained why common methodes to share capacity between terminals cannot be used in case of wireless ATM. In the following section a DCA scheme for wireless ATM is introduced. The used simulation scenario is described in section 4, followed by simulation results (section 5).

II. Conventional Channel Allocation Schemes

For conventional cellular systems (TDMA/FDMA) there are in principle two methods: Fixed Channel Allocation (FCA) and Dynamic Channel Allocation (DCA). Due to the micro-cellular structure and the dynamic behaviour of the load situation a dynamic channel allocation seems to be most promising for an efficient usage of the available capacity.

Sharing the available capacity can be done by allocating complete frequencies or channels (periodically used slots). Allocating a frequency has the advantage that no synchronisation between the BSs is necessary. Such a proposal using a dynamic frequency assignment to avoid frequency planning can be found in [8]. For

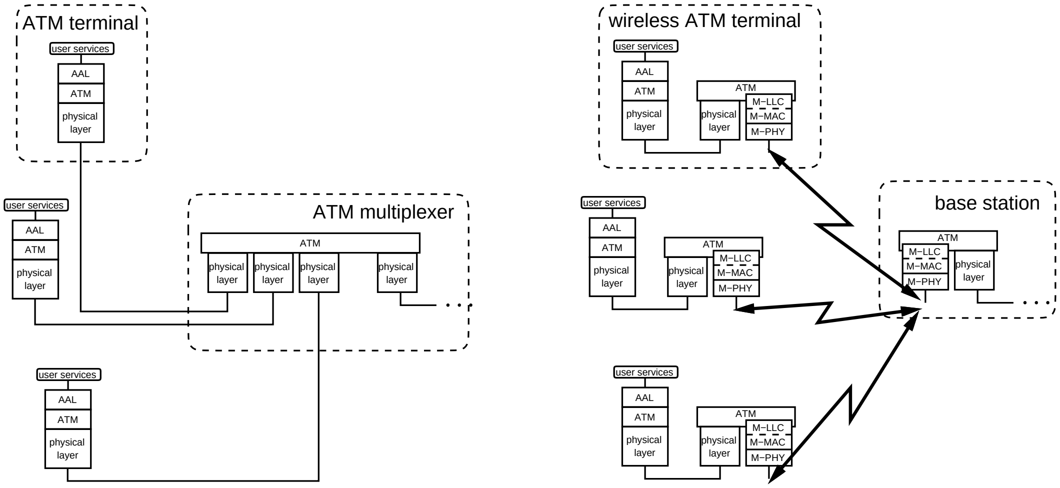

Figure 1: Correspondence between radio cell and ATM multiplexer

WATM systems only a limited bandwidth is available up to now [9]. Using a frequency allocation scheme, the foreseen spectrum will not be sufficient to build up a cellular system. Furthermore this scheme results in a very ineffective usage of the available bandwidth since the WTs served by a BS will normally require only a fraction of the capacity which is offered by a frequency and the remaining capacity will be lost. Even if the BS does not serve any WTs, it has to allocate a whole frequency.

On the other side, capacity can be assigned to terminals by dividing the physical channel into slots which are allocated to the same mobile terminal in each frame. Based on this scheme, some systems (e.g. DECT) have a dynamic assignment of channels at each BS. This scheme would require a completely new MAC protocol and does not support the statistical multiplexing. Due to the wide range of applications (wide range of bandwidth and QoS requirements) this scheme would result in a very dynamic channel allocation in case of WATM and therefore in a bad performance, because the critical situation in DCA-algorithms is the allocation of a new channel. At this time other connections could be disturbed due to the additional load on the spectrum.

For a wireless ATM system a new definition of a *channel* has to be introduced which fulfills the requirements of the dynamic channel allocation (long term prediction must be possible) and allows the statistical multiplexing of different terminals. Furthermore the resulting allocation scheme must be able to live with a limited number of frequencies and must use the available capacity most efficient.

III. DYNAMIC CHANNEL ALLOCATION FOR WIRELESS ATM

To use the capacity effectively, the BS has to be able to allocate capacity according to the requests of its WTs, so that the remaining capacity can be used by other BSs. A continuous dynamic capacity allocation cannot be co-ordinated in a distributed system but a stepwise allocation can be realised with a stepsize much smaller than the capacity offered by one physical channel. This means that the capacity has to be divided into small parts, which will be called *containers* in the following. The containers are generated by using a TDMA scheme. A fixed number of containers build a frame which is repeated periodically (Fig. 3).

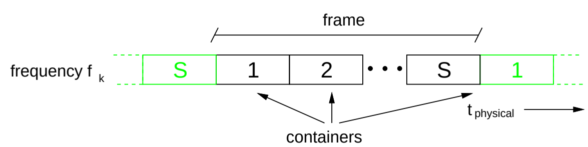

Figure 3: Frame and container structure on a physical channel

To simplify the handling, the containers are of equal length. The BS is able to allocate one or several containers of a frame according to the capacity requested of its WTs (Fig. 5). These containers are hold for a relatively long time (the BS uses the same containers over many frames) to provide the required steadiness for the DCA. Inside the allocated containers, the access of the BS and the WTs on the physical channel is co-ordinated using a *standard* MAC protocol as described in [1, 2] and briefly explained in the introduction. The signalling periods of the MAC protocol are mapped on the allocated containers (cf. Fig. 4). It has to be pointed out, that there is no fixed relation between a signalling period and a container – a signalling period may consist of several containers.

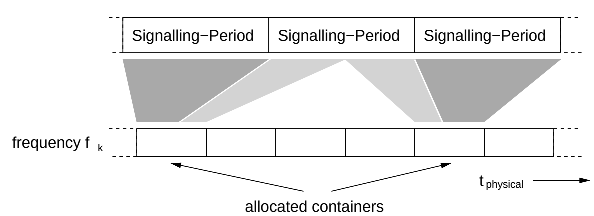

Figure 4: Mapping of signalling periods into containers

This results in a two level multiplexing. Inside the allocated containers the BS performs a multiplexing of the traffic of its WTs, which results in a very dynamic capacity assignment to the WTs. The multiplexing of BSs (the use of different containers by different BSs) on the same physical channel happens with reduced dynamic, since the capacity requirements of a BS are steadier. By allocating a container the BS defines a channel like in a circuit switched connection. This enables the use of connection oriented DCA-Algorithms for allocating a container.

If a simple scheme is used to mark allocated containers (e.g. energy signals at the beginning of a container), it would even be possible to run different systems of different providers in the same frequency band.

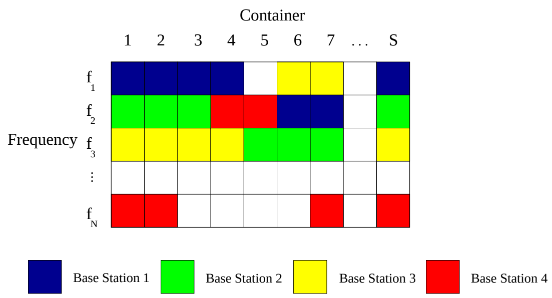

Figure 5: Allocation of containers on different frequencies

This DCA scheme offers a high variety of parameters:

Number of containers per frame: One important issue is the number of containers per frame. The BS is only able to allocate the capacity stepwise. The step size c_{step} is calculated as follows, with c_{total} as the capacity of one frequency and S is the number of containers per frame[1].

$$c_{step} = \frac{c_{total}}{S} \tag{1}$$

It can be seen, that a higher number of containers leads to a more precise allocation of capacity. To take advantage of the smaller size, the containers have to be allocated/released just in time/immediately.

Since it takes some time until a released container is detected as free and allocating a free container disturbs with a certain probability other BSs, a high rate of allocating/releasing leads to a waste of capacity. Also the total length of a frame impacts the minimum delay if a BS has allocated only a few containers.

Thus, a certain number of containers per frame leads to an optimum usage of the available radio resources. This optimum is also influenced by other parameters such as the container length and the DCA algorithm.

Container Length: The length of a container influences the frame length. A certain number of containers per frame is required to share the capacity efficiently. Since the frame length is limited, the container length has to be adapted. Since each container has a fixed overhead (guard-time, signalling information), a shorter container length decreases the load which can be carried by the system.

Container Allocation: A main problem is, how the allocation of a container is recognised by a BS and when new containers are allocated.

The allocation/release of containers depends not only on the load of the BS but also on the service classes. In case of time critical services the capacity is required immediately. If the BS handles any low priority traffic (like ABR), this capacity can be used; otherwise new containers have to be allocated.

If several containers are available, it has to be decided at which position within a frame and on which frequency a container should be allocated. Different frequencies are an advantage in case of fading but lead to difficulties because of the frequency switching time.

Cell Size: Using power control, the cell size can be adapted. A smaller cell size leads to a shorter frequency reuse distance which increases the available channel capacity. Wireless ATM networks perform statistical multiplexing via the air interface. Therefore, if a *standard* MAC protocol is used, all WTs of a BS can be addressed in each container. Thus, each container has to cover the whole service area of the BS.

IV. Simulation Model

The proposed scheme was simulated with a WATM simulator using a scenario which consists of 19 radio cells whose inner 7 cells were evaluated to reduce the border effects (cf. Fig. 6). In each cell 50 WTs were uniformly distributed.

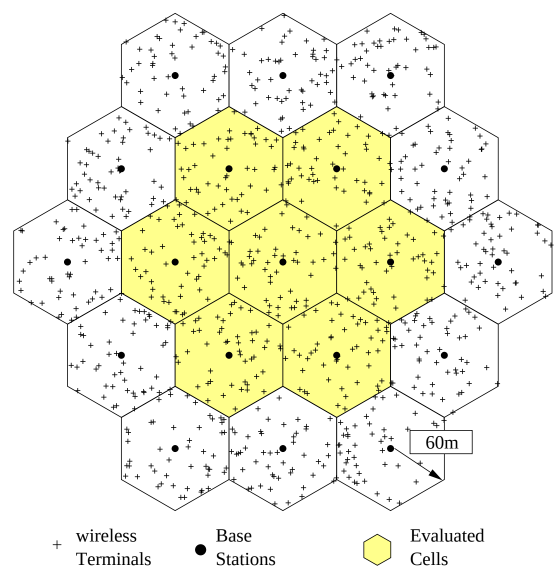

Figure 6: Simulation scenario

Each terminal was modelled as a two state machine (cf. Fig. 7). During the `active` state the terminal generates ATM cells using a Poisson arrival process with a mean rate of 5% (referred to the capacity offered by one physical channel), while during the `passive` state no cells were generated at all.

The rate μ was chosen so that the terminal stays with a mean of $10s$ in the `active` state, while the duration of stay in the `passive` state was adjusted to receive a certain load.

The propagation conditions for the simulations were based on the following formula of the pathloss. All

[1]One container per frame would result in a Dynamic Frequency Allocation[8]. This is only a special case of our concept.

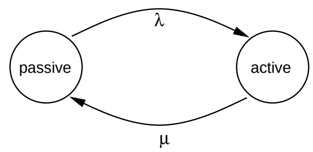

Figure 7: Model for a wireless terminal

BS/WT had omnidirectional antennas with no additional antenna gain. The hight of the antenna was not considered.

$$L = -40(1 + \log_{10} D) \quad (2)$$

The carrier-to-interference ratio was calculated for each slot with all terminals (BS/WT) sending on the same frequency. Therefore any interference caused by adjacent channels were neglected. Based on the carrier-to-interference ratio the BER (bit error rate) for non-coherent FSK and the resulting PER (packet error rate) could be obtained. In our simulations an Reed-Solomon (65,55) FEC (forward error correction) was used to reduce the BER on the air interface. Each slot was able to carry one ATM-cell plus additional signalling information (55 bytes). In figure 8 the resulting curves can be seen. Due to the reason that no additional fading was added, we used a fading margin of 3dB.

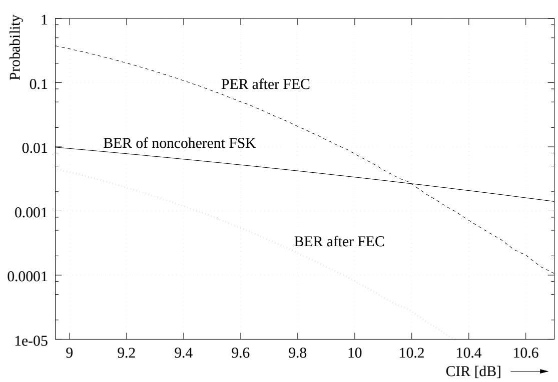

Figure 8: BER and PER

All simulations were performed with four frequencies and a transmission power of the terminals (BS/WT) of 20 dBm. The choice of a DCA-algorithm[2] offers a wide research field, but is not in the scope of this paper. Therefore a very simple scheme was used for the allocation of a new *free* container. The most quiet container was used as long as the noise power was below -105 dBm. The noise level of a container was determined by peak and hold over a whole container. This is necessary due to the large variance of possible disturbers inside one container.

The modulation scheme, FEC, etc., of future WATM system are still under discussion and it is likely that they are different compared to the assumption which were made for the simulations. Nevertheless it is possible to indentify the influence of different parameters.

All simulations shown in the paper were carried out with a fixed frame length of $3.2ms$ (= 160 slots) and four frequencies were available for the whole system.

[2]The algorithm, which chooses the next container to allocate. This has to be separated from the proposed DCA scheme.

V. Simulation Results

A. Containers per Frame

A higher number of containers per frame allows the BS to allocate capacity more precisely and results therefore in a higher load which can be carried. The *Grade of Service (GoS)*[10] was used to determine the maximum load which can be carried. A small value of the GoS means a good grade of service for the system. A GoS of less than 1% seems to be acceptable for a mobile communication system.

$$GoS = \frac{blocked\ setup\ trials + 10 \cdot lost\ calls}{total\ number\ of\ calls} \quad (3)$$

Figure 9 shows the GoS depending on the average load per BS and the number of containers per frame. The average load of the BSs is referred to the capacity offered by one physical channel.

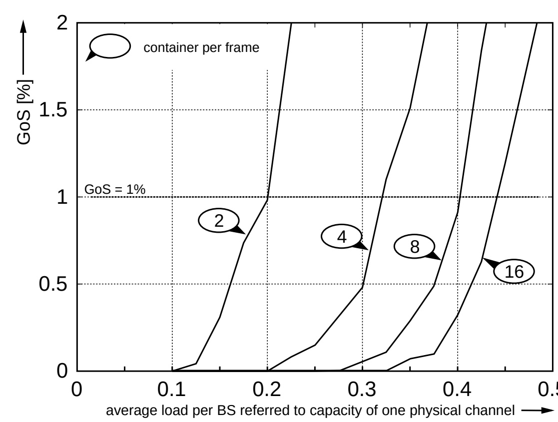

Figure 9: Containers per Frame versus GoS

It can be seen that a higher number of containers per frame leads to a more efficient usage of the available bandwidth and the average load which can be carried increases significant.

It has to be pointed out that several BSs are transmitting on the same frequency and that therefore an average load of e.g. 40% does not mean that the remaining 60% are lost.

B. Capacity allocation and transmission delay

The transmission delay over the air interface is a critical item. In the proposed DCA scheme reduces the bandwidth used by a BS which certainly has an impact of the transmission delay. The following simulations were performed with 16 containers per frame. Figure 10 shows the complementary distribution function (CDF) of the transmission delay in case that the BS allocates capacity according to the mean-rate of its connections plus 3% as a safty margin.

It can be seen that the transmission delay depends highly on the the allocated capacity. The delay decreases with increasing load, which is unusual for a communication system. If the load increases, the BS allocates more capacity and the decrease of the transmission delay results from the multiplexing gain. Due to

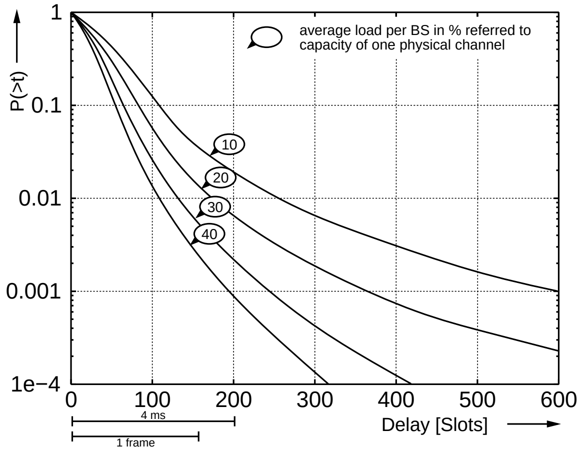

Figure 10: CDF of the transmission delay (allocated capacity: mean-rate+3%)

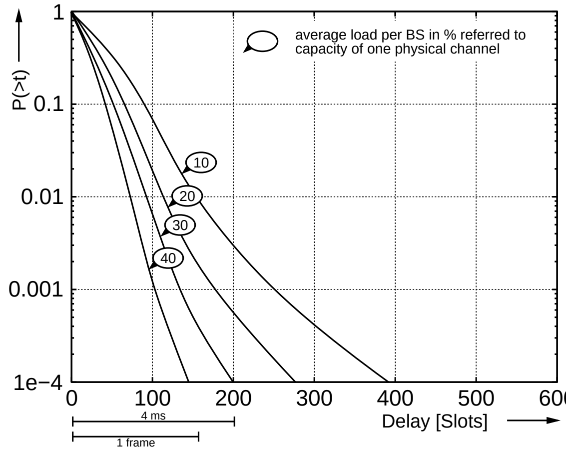

Figure 11: CDF of the transmission delay (allocated capacity: mean-rate+10%)

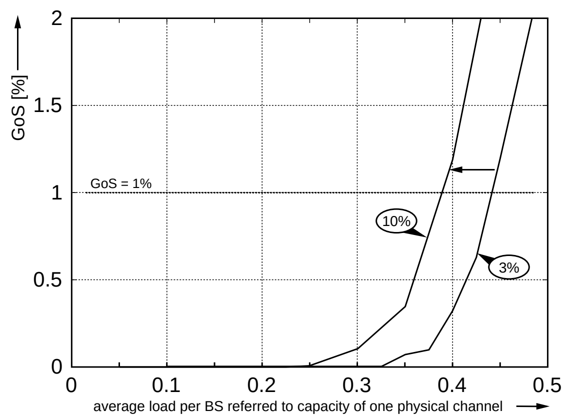

Figure 12: Reduction of the load which can be carried due to allocation of additional capacity

the restrictive capacity allocation the transmission delay is quite high and many cells require more than one frame until they were transmitted. A restricitve allocation can be used for non realtime services classes (e.g. ABR) and increases the load which can be carried by the system.

In case of real-time services, like CBR and rt-VBR, the transmission delay has to be reduced drastically. This can be achived by allocating more capacity than required according to the mean rate of the connections (cf. Fig. 11). On the other side, the maximum load per BS decreases (cf. Fig. 12).

Further reduction of the transmission delay can be achived, if the distribution of the allocated containers within a frame is considered. A uniform distribution reduces the transmission delay compared to *clumped* containers.

Two conclusion can be draw out of these results:

To be able to provide the same QoS independent from the load situation of the BS the total load has to be considered when determing the required capacity. A simply overbooking by a certain percentage (e.g. always 5%) is not suitable.

Services which require short transmission delays (e.g. real time services) can be supported, if this is considered by the capacity allocation. These services requires more bandwidth to garantee short delays over the air interface. In case of a traffic mixture, the additional capacity required to fulfil the QoS demands can be reduced, since the capacity can be *borrowed* from non real-time services (e.g. ABR).

VI. Conclusion

In this paper a solution for dynamic channel assignment was presented. This scheme enables future WATM systems to use the frequency spectrum in an efficient way, which was shown by simulations. Nevertheless many improvements are still in evaluation, like the more uniform distribution of the containers inside a frame to reduce the delay. One other important point of our current research is the enhancement of the capacity. Here are still many topics, which can lead to a higher efficiency.

VII. References

[1] D. Petras and A. Krämling, “Wireless ATM: Performance Evaluation of a DSA++ MAC Protocol with Fast Collision Resolution by a Probing Algorithm,” *Int. J. of Wireless Information Networks*, vol. 4, no. 4, 1997.

[2] F. Bauchot, S. Decrauzat, G. Marmigère, L. Merakos, and N. Passas, “MASCARA, a MAC Protocol for Wireless ATM,” in *ACTS Mobile Summit*, (Spain, Granada), pp. 647–651, Nov. 96.

[3] M. Dinis, V. Lagarto, M. Prögler, and J. Zubrzycki, “SAMBA: a Step to Bring MBS to the People,” in *ACTS Mobile Summit*, (Denmark, Aalborg), pp. 495–500, Oct. 97.

[4] J. Mikkonen and J. Kruys, “The Magic WAND: a wireless ATM access system,” in *ACTS Mobile Summit*, (Spain, Granada), pp. 535–542, Nov. 96.

[5] F. Priscoli, “Medium Access Control for the MEDIAN System,” in *ACTS Mobile Summit 1996*, (Granada, Spain), pp. 631–638, Nov. 1996.

[6] D. Petras, A. Krämling, and A. Hettich, “Design Principles for a MAC Protocol of an ATM Air Interface,” in *ACTS Mobile Summit 1996*, (Granada, Spain), pp. 639–646, Nov. 1996.

[7] L. French and D. Raychaudhur, “WATMnet: A prototype wireless ATM system for multimedia personal communications,” in *Proceedings of Wireless ATM Workshop*, (Espoo, Finland), Sept. 1996.

[8] K. Degenhard, M. Litzenburger, H. Bakker, and W. Schödel, “Design Issues of a Cellular Broadband ATM Access Network,” in *Proceedings of The Second European Personal Mobile Communications Conference (EPMCC’97)*, (Bonn, Germany), pp. 165–171, Sept. 1997.

[9] ETSI RES10, “HIgh PErformance Radio Local Area Network (HIPERLAN), Requirements and Architectures for Wireless ATM Access and Interconnection,” TR 101 031, ETSI, Apr. 1997.

[10] ETSI, “Digital European Cordless Telecommunications (DECT): Traffic capacity and spectrum requirements for multi-system and multi-service DECT applications co-existing in a common frequency band,” 1996. ETR 310.