A Wireless Broadband Integrated Services Communications System at 60 GHz *

V. Aue, G. Fettweis, A. Finger, E. Förster, J. Hübner, H. Kaluzni, K. Kojucharow, R. Lehnert, W. Nowak, H. Nuszkowski, F. Poegel, M. Riedel, M. Sauer, B. Stantchev, J. Voigt, J. Wagner, S. Zimmermann

Dresden University of Technology, Communications Laboratory, 01062 Dresden

E-mail: inno@ifn.et.tu-dresden.de

Abstract: *The paper presents a wireless integrated services communications system for indoor and campus use. Whereas most current indoor wireless systems are distinct solutions for different services, our network, WISCS, covers the entire range from low-rate mobiles to high-speed portables. The system employs a picocellular structure in the 60 GHz band to provide capacity demanded by broadband services. The system concept and the employment of simple transponders connected via an optical fibre to a central base station allow a cost effective implementation. Virtual clustering of different number of cells is applied to allow coexistance of low rate mobile users and high rate portable users in one common system. WISCS uses adaptive modulation to yield an optimised performance in both the mobile and portable environment. The project is carried out at Communications Laboratory at Dresden University of Technology. Research includes new optical devices, flexible, efficient and error protected transmitting schemes, mm-wave circuits, antennas, and protocols. A demonstrator is currently under development.*

I. Introduction

In recent years, for the inhouse environment different wireless digital systems such as wireless LAN or digital cordless phone systems have emerged. Although being all wireless, as each system is optimised to meet different needs and to be as cost effective as possible, they are distinct solutions. A wireless LAN offers high data rate transmission, but, due to the cost involved for interference rejection and channel equalisation at this rate the user's mobility is often limited to portable use. A digital cordless phone system provides inhouse mobility to users allowed to transmit at a low data rate sufficient for toll voice quality, low rate file transfer, and fax. At present the Asynchronous-Transfer-Mode (ATM) is the preferred transmission technique of fixed networks integrating narrow- and broadband communication and data services (B-ISDN) [1]. An increasing number of terminals will be ATM based. Hence, a future wireless broadband system must not only integrate services offered by today's wireless communications and data systems, but also provide transparent access to the fixed ATM network (transparent in the sense of transparent to the ATM Adaption Layer).

The system presented here cost effectively integrates narrowband and broadband services and provides ATM access to public B-ISDN networks. Recognising that most high rate services are portable and usually stationary, a cost effective solution can trade-off mobility for higher bit rates as shown in Figure 1. WISCS provides an exhaustive solution that covers the entire range of low rate services with high mobility and high rate portable services. Users are allowed to virtually move inside and below the shaded region in Figure 1. For example, notebook computer hooked up to the network can use a high data rate for high rate file transfer as long as it is stationary. If the user starts moving, the connection falls back to a lower rate.

* The project is sponsored by German Research Council (DFG) under contract INK13

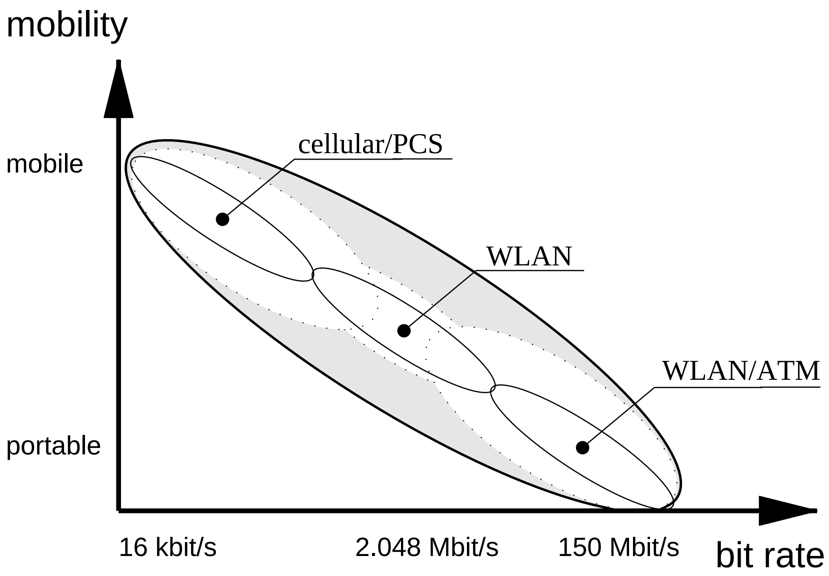


Figure 1: Mobility vs. bit rate.

High data rate applications and mobile low rate applications exhibit a great amount of heterogeneity in terms of bit rate, mobility, delay, tolerable bit error rate (BER), coverage, burstiness, and by the consumer acceptable equipment cost. Table 1 lists the capabilities and heterogeneous service support of WISCS.

Table 1: Capabilities and heterogeneous service support of WISCS.

basic bit rate (user class)	bandwidth efficiency	mobility	required SNR	hardware cost	antennas
low	low	mobile	low	low	omni
high	high	portable	high	medium	directed

Bit rates which have to be supported range over four orders of magnitude. A high antenna gain can be necessary for high rate users in order to achieve the required signal-to-noise which will be achieved by directed antennas. WISCS accommodates various services according to Figure1 in at least two ways: (1) Different bit rates are supported by using different amounts of bandwidth and different modulation techniques. For high data rate users a bandwidth efficient modulation scheme is used. Low rate users use a less bandwidth efficient but robust technique. This allows low rate users to extend their coverage region and allows for mobility. (2) Virtual cells of different sizes can be built by logical clustering of neighbouring physical cells significantly reducing the time constraints for hand-offs.

In Section II, we describe the network structure of WISCS, in Section III we show how multiple users share the system bandwidth and describe the modulation techniques and resource management. Conclusions are presented in Section IV.

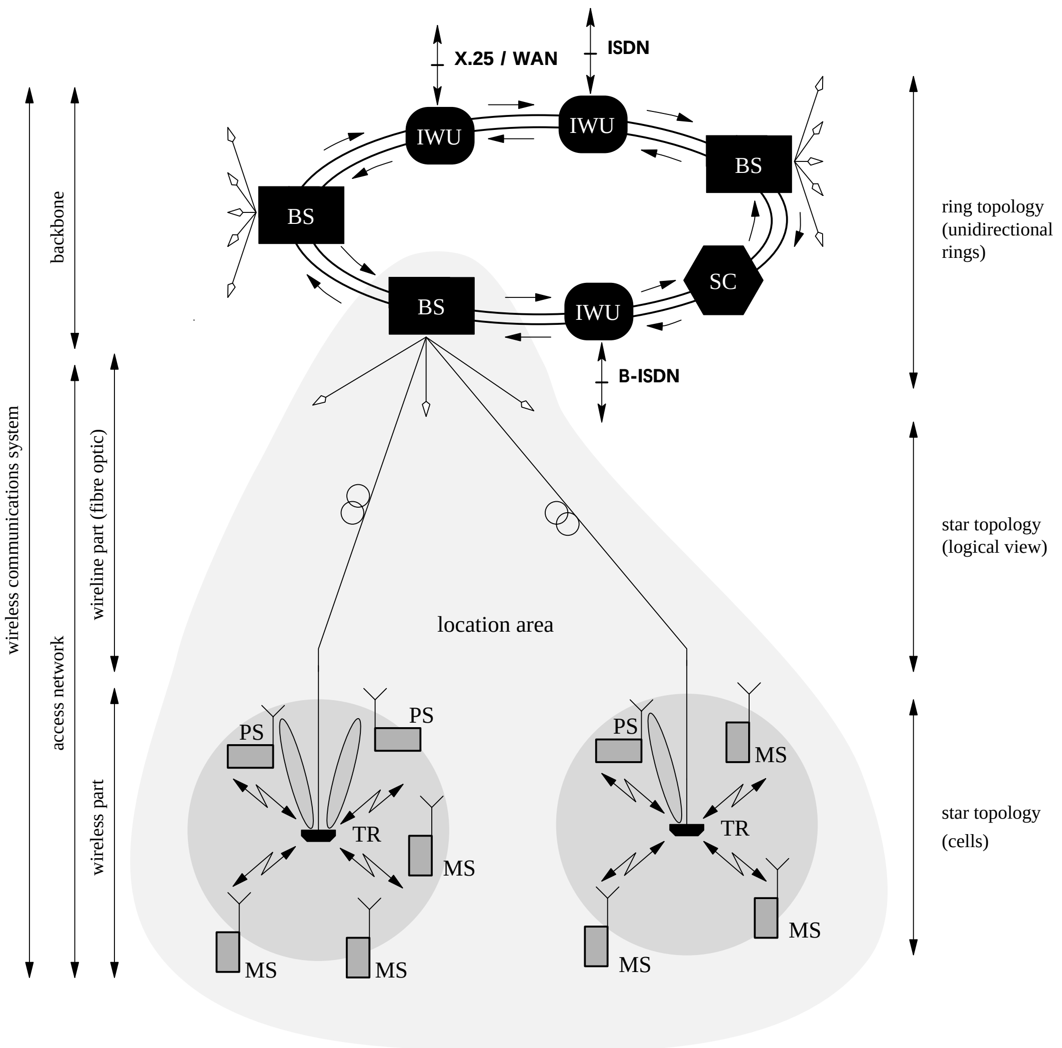
II. Network Structure

In office buildings, where many wireless terminals can be located in a single room, cell sizes up to a few meters in diameter are required. In order to keep interference originating from neighbouring cells (cochannel interference) low, WISCS uses carrier frequencies in the 60 GHz band, where the high attenuation of walls restrict cell sizes to sizes of rooms [2]. One GHz is available for both uplink and downlink. Transponders which convert electrical signals into optical and vice versa are employed in each cell. They are not involved in signal processing and protocol handling. This way the transponders are cheap and robust. For a large number of cells cost is substantially reduced.

When in uplink mode, the transponder down-converts a received signal from the 60 GHz band to an intermediate frequency of 2.4 GHz. The signal is then converted into an optical signal and transmitted via an optical fibre to the base station. In the base station, this signal is converted back to an electrical signal and down converted into baseband. In the downlink, signals are upconverted to IF first, before they are transmitted on the optical fibre. The transponder upconverts the optical signals to the 60 GHz band. A single tone carrier (master oscillator) is added to the optical signal thus eliminating the need for local oscillators at each transponder side. Each transponder is capable of converting the entire system bandwidth of one GHz.

For the optical feeder system connecting the base station and the transponders, a fibre bus system employing dense wavelength division multiplexing (DWDM) is used. Such a system simplifies installing effort and is very easy to extend. All optical channels (each feeding a transponder) are multiplexed at once at the base station, whereas only one channel is dropped off the fibre at the transponders. Cheap, compact and low-loss devices will be developed shortly. Add-drop-multiplexers using fibre Bragg gratings are excellent candidates [3]. They are of extremely small bandwidth permitting a narrow channel spacing and meet the conditions mentioned above.

The entire system can consist of several basestations each of which supports a different number of transponders. A possible system setup is shown in Figure 2. Asynchronous operation between cells is possible such that base stations do not have to be synchronised.



BS *base station*, IWU *interworking unit*, MS *mobile station*, PS *portable station*, SC *switching centre*,

TR *transponder*

Figure 2: Logical network architecture.

III. Multiple Access Scheme and Modulation

Since the dynamic range is limited by the transponders, WISCS shares a frequency band using time-division multiple access (TDMA). Five to seven frequency bands exist, each having a bandwidth of 140 to 200 MHz. One cell is assigned to one band. Frequency allocation is done during system initialisation and can be rearranged during operation. Dynamic time-division duplexing is used to facilitate decoupling of transmitter and receiver. A frame consists of slots containing signalling information, slots for uplink and downlink. The slot duration is of about 150 µs including a guard interval, the frame duration is 3 ms, respectively. The slot duration lies inside the coherence time such that adaptation to the channel is facilitated. Each user is assigned one or multiple slots inside a frame of the time-division multiplex. Figure 3 depicts the organisation of a frame inside the time-division multiplex.

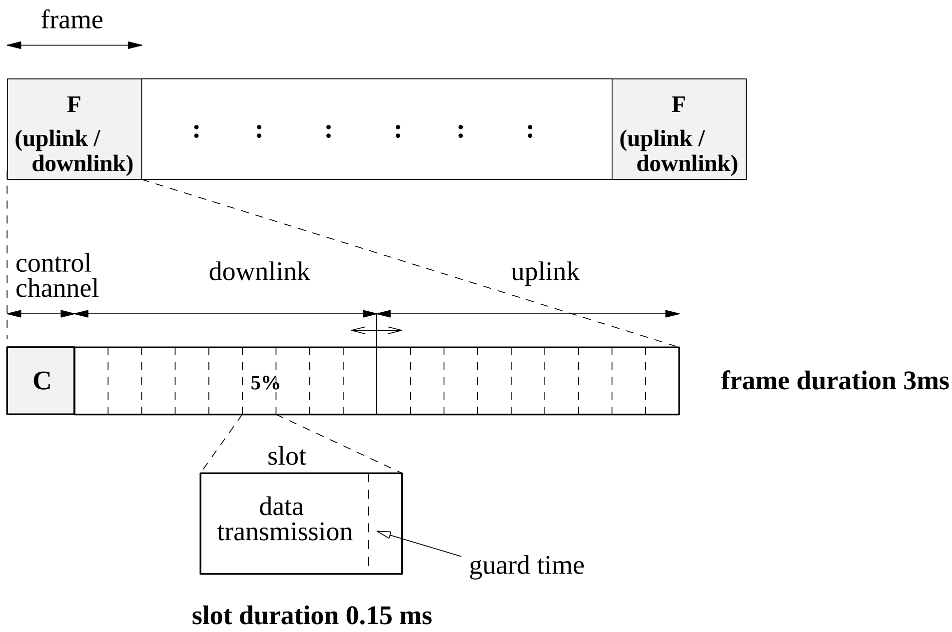


Figure 3: Organisation of a frame inside the time-division multiplex.

WISCS accommodates various services, according to Figure 1, by using a different modulation technique for each service. A parametrical linear modulator and demodulator at the base station is capable of generating different M-ary pulse amplitude keying (PAM) phase-shift keying (PSK) signalling schemes for different number of M [4][5]. Using a scaleable FFT/IFFT, the system can furthermore employ orthogonal frequency shift keying (OFDM) for different number of carriers and continuous phase frequency-shift keying (CPFSK). Which modulation technique is used to transmit the data for each service depends on the channel and on the capabilities of the terminal, and is negotiated during call initiation. A stationary user with a high signal-to-noise ratio can use a highly bandwidth efficient modulation scheme with high indices M. Data rates up to 150 Mbit/s can be easily accommodated inside the transmission bandwidth [6]. A mobile user employs a robust modulation technique such as differentially encoded minimum shift keying (MSK). A fallback from a higher rate modulation scheme to a more robust modulation is possible. The signalling channel uses the most robust modulation technique in order to be detectable even in worst channel scenarios. Channel coding is applied to reduce the bit error rate and to reduce the required transmission power.

Resources at the air interface are dynamically assigned to the active connections in accordance to

- traffic parameters negotiated at connection set-up,
- traffic load of the connection,
- traffic history of the connection,
- traffic mix of the corresponding cell,

- load of the corresponding cell.

As the number of active connections within one cell is small and the ratio between connection's peak rate and the bandwidth of the entire radio channel is too large, a blind multiplexing scheme cannot be employed. Therefore, the timeslots are deterministically assigned to the connections. This is achieved by two controllers, a dynamic slot assignment scheduler and a dynamic slot access controller, and appropriate signalling on the air interface. These controllers are realised as distributed entities located at the base station and at modem connected to the mobile.

Three traffic classes with different priorities are supported by WISCS. Connections belonging to a traffic class with lower priority are only served, if no data of higher prioritised connections are ready for transmission. Within one traffic class available, bandwidth is assigned in proportion to weights or in a round robin manner.

IV. Conclusions

The paper presents a pico-cellular system which cost-effectively integrates existing wireless services ranging from mobile services with low data rates to portable services at high rates. This is accomplished by using a flexible modulation technique which can be adapted to match the channel characteristics and meet the needs of each service. Small cell sizes are required to provide for capacity which is needed to accommodate high rate users as in a WLAN office environment. Large cell sizes, however, are needed to reduce the number of hand-offs for mobile users. Our system uses adaptable cell-sizes by virtual clustering, thus allowing low rate mobile users and high rate portable users to coexist in one common network. Employing the resource allocation, modulation, and multiple access techniques described in the previous sections allows WISCS to efficiently accommodate different heterogeneous services in one system.

A demonstrator will be built up in two phases. In phase 1 we will demonstrate the function of the physical layer, phase 2 demonstration includes higher layers. Phase 1 and phase 2 are scheduled to end in 1997 and 1999, respectively.

V. References

[1] R. Händel, M.-N. Huber, and S. Schröder, ATM Networks: Concepts, Protocols, Applications. Addison-Wesley, 1994

[2] K. Sato, T. Manabe, J. Polivka, T. Ihara, Y. Kasashima, and K. Yamaki: "Measurement of the Complex Refractive Index of Concrete at 57.5 GHz", IEEE Trans. Antennas & Propagation, vol. 44, pp. 35-40, Jan. 1996

[3] I. Baumann and W. Nowak: "Advantages of optical FDM using fiber Bragg gratings in broadband passive fiber bus systems", MIOP 95, pp. 638-642, Sindelfingen, May 1995

[4] John G. Proakis, Digital Communications, 2nd Edition, McGraw-Hill, 1989

[5] W. T. Webb and R. Steele, "Variable rate QAM for mobile radio", IEEE Transactions on Communications, pp. 2223 - 2229, July 1995.

[6] Ziemer, R.; Peterson, R.: Digital Communications, Macmillian Publishing Company (1992)

[7] Gejji, R. R.: "Mobile Multimedia Scenario Using ATM and Microcellular Technologies", IEEE Transactions on Vehicular Technology, VOL. 43, No. 3, pp. 699 ff, August 1994.

[8] Schäfer, R.: "European R & D Activities in Mobile Multimedia Communications and Expectations on Future Services", IEICE Transactions on Communications, VOL. E77-B, No. 9, pp. 1083 ff., September 1994

[9] Goodman, D. J., and Wei, S. X., "Efficiency of Packet Reservation Multiple Access", IEEE Transactions on Vehicular Technology, VOL. 40, No. 1, pp. 170 ff, February 1991.