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AN ARCHITECTURE FOR RADIO-INDEPENDENT WIRELESS ACCESS NETWORKS

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Abstract - This paper discusses a novel architecture for a Hybrid Fiber Radio (HFR) access network using Software Defined Radio (SDR) in a combined Base Station (BS) headend unit. While most of the current SDR approaches consider software radio to be used in the portable terminals to allow multi-mode operation, we propose a SDR-HFR based access network architecture. The combination of HFR and SDR allows smooth migration from current to future radio standards and realization of multi-standard networks by using the existing fiber infrastructure. In the first part of the paper trends in HFR and SDR as the two enabling technologies for radio-independence are theoretically investigated. The key components of a new multi-standard wireless access network are identified and some practical realization concepts are introduced. The focus of this paper is put on the availability and usability of SDR-HFR concepts from the network operator and the equipment manufacturer viewpoint.

I. INTRODUCTION

In the future wireless fixed or mobile broadband access for supplying multimedia services to the end user will be essential for public and private network providers (1-3). Some general network operators wishes are:

- ability to support a broad range of services
- preserving competition by flexibility
- protection of previous and future investments
- reliability and low maintenance costs
- seamless upgrade of the existing access network

Broadband services (bit-rate ≥ 2 Mbit/s) are supported by the future radio standards like UMTS / IMT-2000, MBS or ETSI BRAN. They will be based on different air interfaces for various telecommunication services. An overview on the occupied frequency spectrum, which ranges from ~1 to above 60 GHz, is given in Figure 1. These standards not only use different carrier frequencies but also different modulation formats, e.g. QPSK, nQAM or GMSK. Access techniques like FDMA and TDMA are combined with CSMA or wideband DS-CDMA. Future base stations and mobile terminals should allow:

- flexible control of the radio interface, adaptation to the different modulation and access formats
- easy adoption of new services and standards
- seamless roaming between different networks with different radio interfaces
- simultaneous support of several different radio standards

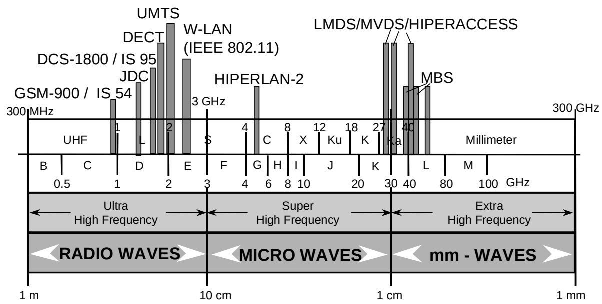

Figure 1 Radio spectrum used by current and future digital radio systems. The HIPERACCESS spectrum will be somewhere in the 3 GHz to 60 GHz range, e.g. in the DAVIC LMDS band

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II. ENABLING TECHNOLOGIES FOR RADIO-INDEPENDENCE

Hybrid Fiber Radio:

Microwave radio-frequency transport over fiber (1-2, 4-5) is a novel approach which allows the radio functionality of several base stations to be integrated in a centralized headend unit. Moreover, it offers fixed and mobile wireless broadband access with a radio-independent fiber access network. Different radio feeder concepts as Intermediate Frequency (IF) over fiber with electrical frequency up/down-conversion at the Remote Antenna Unit (RAU) or direct Radio Frequency (RF) transport are possible, as shown in Figure 2.

Radio frequency over fiber for GSM, W-LAN and video distribution systems have already been demonstrated (1-2, 4-5). There are different feeder concepts for HFR depending on the used radio frequency f_{RF}. For microwave transmission systems, e.g. the Local Multipoint Distribution System (LMDS) with 20 GHz < f_{RF} < 60 GHz, the most appealing solution is external modulation with single sideband or double sideband with suppressed carrier modulation, as chromatic dispersion penalties otherwise limit the usable fiber length (4).

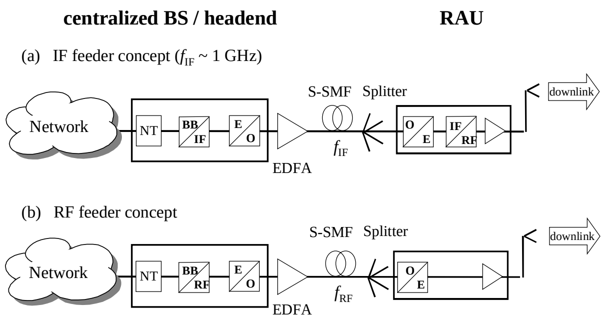

Figure 2 Block diagrams of optical feeder concepts for HFR downlink

Software Defined Radio:

The SDR concept allows the development of hardware independent radio transceivers by extensive use of digital signal processing. Ideal SDR assumes direct wideband ADC/DAC of a radio signal, which offers a programmable multi-band - multi-mode radio architecture (6). Current limitations in processors capabilities, memory capacity and ADC/DAC speed require hybrid solutions, where only a part of the radio modem is implemented in software, as shown in Figure 3. Nevertheless the advances in semiconductor technology, namely the progress in processing power, may enable pure SDR realizations in some years (7). SDR offers the following advantages:

- re-usability of radio hardware for new standards through reconfiguration by downloading signal processing software in a single radio / modem architecture
- reuse of the same base station design for different products – advantageous from a manufacturing viewpoint.
- reduced size, weight and power due to fewer radio units
- efficient usage of available radio spectrum by introducing new channel access modes into bands where existing modes are supposed to co-exist for a number of years

The maximum sampling frequency f_S and the Spurious-Free Dynamic Range (SFDR) may not be sufficient for some air interfaces in the BS. For example the DCS-1800 interface utilizes a bandwidth of 75 MHz for up or downlink, and requires a dynamic range of > 70 dB for different indoor and outdoor environmental conditions, see Reference (2). Possible realization approaches in order to soften the requirements on software radio are:

- parallel operation of multiple ADC/DAC and DSP
- automatic gain control in the analog receiver part to reduce the required dynamic range of the ADC
- integration of programmable hardware concepts

Although software radio is interesting for the mobile terminal and the network side, in this paper we are mainly interested in SDR base stations. This eases at least the restriction on size and power consumption compared to the mobile terminal.

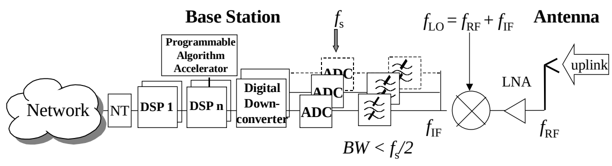

Figure 3 Sketch of a hybrid-SDR architecture

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III. ARCHITECTURES FOR MULTI-STANDARD BASE STATIONS

Our proposal is to use HFR technology in combination with hybrid-SDR as a wireless multi-standard access method. Figure 4 and Figure 5 show the concepts for the combined HFR hybrid-SDR architecture for the downlink and uplink respectively. In the following paragraphs the technical requirements and different concepts for realization of key components of the proposed architecture are analyzed.

Digital Signal Processing Unit: The DSP unit is required on the receiver and the transmitter side. Typical tasks are:

- filtering
- carrier and timing recovery
- modulation / demodulation and signal conditioning
- encoding and decoding

If using multiple ADC converters to extend the bandwidth, chip synchronization has to be performed. An interesting new approach is the integration of programmable hardware circuits like Field Programmable Gate Arrays (FPGAs). Many FPGA architectures are in system programmable and can therefore be reconfigured with new functionality during regular operation. The optimum partitioning between hardware and software components allows a reduction of the number of MIPS required without sacrificing flexibility (8).

Programmable Up/Down Conversion: In the transmitter digital up-conversion of the baseband (BB) signal before transmission over the optical fiber may be either to IF or RF, as indicated in Figure 4. For the receiver frequency down-conversion using bandpass sampling is limited by ADC sampling speed. Multiple band sampling over e.g. the frequency band from 1.7 GHz to 2.2 GHz, which includes DCS-1800, IS-95, DECT and UMTS, may be possible in the future if ADCs for an IF input > 500 MHz and SFDR > 70 dB are available. Sampling and conversion can be performed by using parallel operation of multiple ADCs with corresponding bandpass filters. Specially designed commercial software radio chip sets for up- and down-conversion are available and can be used to relieve the multi-purpose DSP from the most computing intensive tasks. Examples are from Analog Devices the AD6622/AD6624 or from Harris Semiconductor the HSP50215/HSP50214B. These programmable devices can for example perform the tuning of the baseband signal to the desired digitized IF and vice versa.

ADC/DAC Converter: An attractive ADC solution for the receiver side is bandpass sampling with $f_S \geq 2\times$BW, where BW is the signal bandwidth. The converter is used to alias down the signal to baseband during the sampling process. The baseband signal is then fed into the DSP unit for further processing. Typical specifications are 12 to 14 bit ADC with IF input from 70 to 200 MHz, $f_S < 80$ MSPS with an in-band SFDR of > 80 dB over a digitized spectrum < 25 MHz. For the transmitter high linearity 14 bit DAC with conversion speeds up to 125 MSPS (SFDR > 70 dB for $f_{out} < 20$ MHz) are available. It should be mentioned that the current bottleneck in SDR design are the digital up- / down-converters, which requires especially for wideband modulation formats (W-CDMA) the use of programmable hardware.

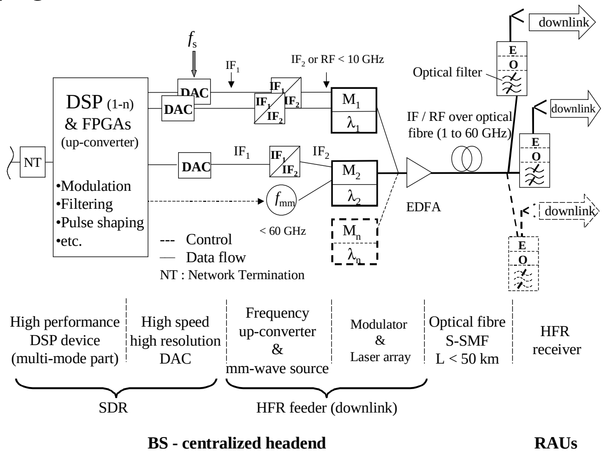

Figure 4 Downlink architecture for HFR and hybrid - SDR

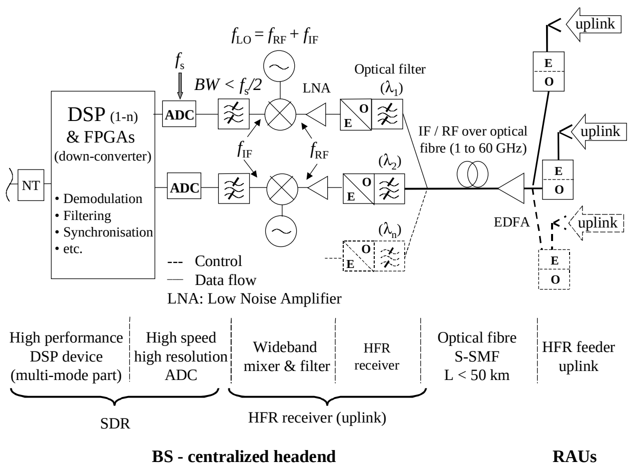

Figure 5 Uplink architecture for HFR and hybrid - SDR

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Headend HFR Feeder and Receiver: Optical receivers up to frequencies of ~ 60 GHz and with responsivity > 0.1 A/W are available. External modulation of narrowband lasers up to 50 GHz, in order to generate the radio carrier wave, is state of the art. For higher modulation frequencies double sideband with suppressed carrier modulation may be used, doubling the modulation frequency (4). The magnitude of the dominant noise and non-linearity penalties - in addition to the those arising from the free space radio link - depend on the optical feeder concept and modulation format used. Of these, the most problematical are laser phase noise, non-linearities caused by the transmitter modulation, optical amplifier noise such as Erbium Doped Fiber Amplifier (EDFA) signal-amplified spontaneous emission, fiber dispersion causing destructive interference in the generated radio wave at the receiver end and receiver thermal noise. However, the most severe penalties are in the free space radio link, e.g. propagation loss or multipath fading penalties.

The different services indicated in Figure 1 may be fed into the fiber by using:

- different subcarriers, for direct/external modulation of the same DFB laser
- different laser wavelengths, e.g. WDM laser array with direct/external modulation

The latter has the advantage that the different services can be separated in the optical domain by using optical filters at the receiver side. This can reduce the fiber count but adds extra cost and complexity to the system.

Optical Fiber: Standard-Single Mode Fiber (S-SMF) is the choice as there are millions of kilometers installed worldwide. S-SMF designed for 1.3 µm operation has at 1.55 µm an attenuation of ~0.25 to 0.3 dB/km but a relatively large chromatic dispersion of ~ 17 ps/nm/km. This limits the radio wave transmission for f_{RF} > 5 GHz to fiber lengths < 50 km, if no dispersion compensation or a modulation format with suppressed carrier or single sideband modulation are used (4). The fiber delay determined by the propagation speed (2 x 10^8 m/s) in the fiber has to be considered as well when using HFR. For GSM the maximum allowed radio delay is ~ 220 µs, therefore the HFR network has to obey: fiber delay + radio path delay < 220 µs.

RAU HFR Feeder and Receiver: The optical feeder / receiver located at the RAU site has basically the same functionality as the feeder / receiver at the headend. Transmitting IF over fiber requires analog frequency up-conversion at the downlink side. For the return link (uplink) the radio-wave carrier may be extracted from the received signal, saving a local oscillator (LO) at the RAU. For strong asymmetric traffic, like in video distribution systems, a direct modulated laser at the RAU side may be used for the uplink. Down and uplink can be physically separated by using two fibers or using a single fiber with WDM technology, e.g. downlink at 1.55 µm and uplink at 1.3 µm.

A novel design for the RAU transceiver has been demonstrated in Reference (5) by using an electro-absorption-modulator for direct electrical-to-optical and optical-to-electrical conversion. However, the radio range, due to low conversion efficiency is < 50 meters, for a DCS-1800 system, if not using some electrical amplification (1).

IV. CONCLUDING REMARKS AND FUTURE WORK

We have shown a novel architecture combining state of the art HFR concepts with hybrid-SDR. Possible applications for the proposed architecture are telecom mobile and access networks as well as in-building wireless LAN infrastructures. There are several advantages for network operators, customers and equipment manufacturers.

HFR using IF / RF over fiber can reduce complexity at the remote antenna side and allows the concentration of the radio related functions of several radio cells in a single centralized BS. The huge bandwidth of the optical fiber offers the possibility of transmission of multiple radio standards simultaneously, over the same feeder network. The generation of the different radio signals, modulation/demodulation, filtering, etc, could be done in general by conventional analogue techniques. However, the centralized BS concept of the proposed HFR – hybrid-SDR architecture allows flexible upgrade approaches, which are essential for the rollout of new mobile network services like UMTS/IMT-2000. By shifting radio functionality to a centralized location at the headend equipment cost and investment risks can be reduced. For the realization of the proposed architecture future research is required, e.g.:

- analysis of the power budget, dispersion penalties and overall noise accumulation
- nonlinearity penalties (SFDR)
- development of fast DSP algorithms for the multi-mode radio transceivers
- implementation and integration of efficient multi-band SDR architectures
- cost analysis of the RAU and of the centralized BS - headend side due to the use of HFR and SDR

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