Proceedings 10th Microcoll Conference, Microcoll'99, Budapest, Hungary, pp. 211-214, 21-24 March, 1999

Hybrid Fibre Radio Access: A Network Operators Approach and Requirements

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Abstract: This paper investigates the use of Hybrid Fibre Radio (HFR) for the transport of multiple radio signals to some distributed Remote Antenna Units (RAUs). From a network operator view, we expect the technique to be sufficiently mature to meet the requirements of current and future microwave radio systems like GSM-900, W-LANs and UMTS / IMT-2000. In this context HFR feeder technologies and wireless radio requirements on HFR have been investigated in order to understand HFR usability for future broadband wireless access. The main technical requirements investigated here are operating frequency, Dynamic Range (DR), and minimum-maximum cell size. The work described has resulted from EURESCOM Project P816, [1].

I. Introduction:

Wireless access is extremely popular, witnessed by the success of 2nd generation digital standards like DECT and GSM. Moreover, broadband systems as UMTS/IMT-2000, BRAN or MBS, for supplying wireless multimedia services will emerge in the future [2]. Some general network operators requirements 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

Microwave radio-frequency transport over fibre, [1], [3] - [7], is a novel approach which allows the radio functionality of several Base Stations (BS) to be integrated in a centralised headend unit. Moreover, it offers fixed and mobile wireless broadband access with a radio-independent fibre access network. Different radio feeder concepts such as Intermediate Frequency (IF) over fibre with electrical frequency conversion at the RAU or direct Radio Frequency (RF) transport are possible, as shown in Figure 1.

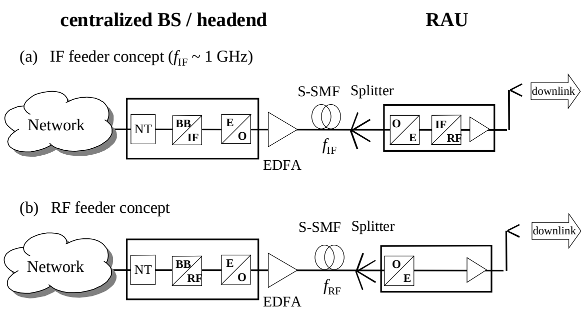

Figure 1 Block diagrams of optical feeder concepts for HFR downlink

II. Existing and planed radio interfaces:

Next some potential current and future wireless systems are highlighted considering some of their features.

<u>DECT</u> operates in 20 MHz of spectrum at around 1.9 GHz. It can supply narrowband access for indoor multi-cell cordless telephony, with indoor range from 20 up to 50 metres, and for outdoor Wireless Local Loop (WLL) with a radio range up to a few kilometres. DECT service provision for indoor applications is private, whereas DECT-WLL can be either public or private.

<u>GSM</u> operates in 25 MHz (35 MHz in extended range) of spectrum in the 900 MHz band and in 75 MHz of spectrum in the 1800 MHz band (DCS-1800). It provides narrowband access for speech and data services. Typical indoor DCS-1800 cell radius is from about 10 to 50 m and outdoor cell radius for GSM-900/DCS-1800 vary often between 50 to 1000 m with maximum cell radius up to more than 30 km. The GSM / DCS-1800 systems are public systems, owned by operators.

<u>W-LANs</u> (IEEE 802.11) currently operate in 80 MHz of spectrum using the 2.4 GHz ISM band. giving indoor access to high data rates, up to 2 Mbit/s, with coverage areas up to 250 m. W-LAN are privately owned networks. Future extension into the 5 GHz band (IEEE 802.11-a) will allow even higher data rates.

<u>UMTS</u> will operate at ~2 GHz with up to 60 MHz of spectrum. It can provide features like 2nd generation mobile systems but will also offer multi-media services like video telephony, up to 2 Mbit/s for low mobility. Supported cell sizes for indoor applications are up to ~100 metres, and for outdoor applications cell size can be up to a few tens of kilometres (suburban areas), by supporting different mobility features. UMTS will be a public operated system.

<u>ETSI BRAN</u> (Broadband Radio Access Networks) project is currently standardising HIPERLAN-2 and HIPERACCESS. HIPERLAN-2 will work in the 5 GHz band will give short range wireless access to local broadband networks (ATM or IP). The coverage range for an office environment will be up to 30 m and up to 150 m for outdoor applications. It will be a private system, owned and operated by the user. HIPERACCESS will offer outdoor fixed wireless broadband access (WLL) to households and enterprises. Its operating frequency has still to be decided, potential candidates offering enough free spectrum are the 30 and 40 GHz frequency

bands. HIPERACCESS will be able to cover a cell with a radius of 5 km. The system may be deployed by public or private operators.

MBS (Mobile Broadband System) aims to give mobile users access to the range of broadband services available for fixed users of B-ISDN. Candidates for the operating frequency are in the 40 and 60 GHz frequency bands Multimedia with high-quality video transmission is one of the major driving forces for such a high capacity system. The system will be for indoor and outdoor applications, covering ranges of up to 200 metres. MBS systems may be public or privately owned.

Figure 2 gives an overview of the operation frequency for different radio systems from 0.8 GHz to 70 GHz, including the ones treated above.

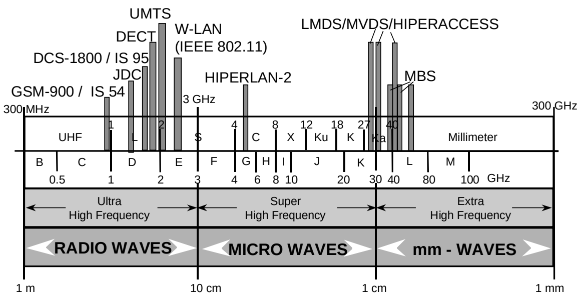

Figure 2 Radio spectrum used by current and future digital radio systems.

III. HFR access architectures: For radio frequency over fibre, the complete BS system is located at the headend, with minimum components necessary at the antenna side. Centralisation of components and functionality in the headend will save costs and makes the system more compact and reliable. The architecture may also depend on the existing fibre network. In Europe the distance between switching centres in the metropolitan area is < 5 km for 50 % of the links. The fibre installed is mainly Standard-Single Mode Fibres (S-SMF) which offers low attenuation and a bandwidth of about 2 THz in the 'erbium window' around 1550nm.

Service/application scenarios for HFR access can be offices, warehouses, industry, homes, hospitals, universities campus, airports, metropolitan areas, etc. In general the services supplied by HFR may depend on the supported radio standards as discussed above.

The reference architecture definition consists of the location of the Network Termination (NT), and the HFR technology used. For each supported radio standard/service, different reference configurations would be possible, but in general the final goal will be to have an architecture independent of the wireless service.

Access architectures for outdoor and indoor applications are shown in Figure 3 and Figure 4 respectively. For the outdoor applications a distributed star and bus antenna architecture are shown. For the bus architecture passive fibre couplers with EDFAs may be used. A bus or star architecture may be also used for the indoor architecture shown in Figure 4, which extends wireless access into complex places where it is often difficult to get coverage, e.g. in radio dark places like tunnels, underground railway stations, garages, where there is no line of sight to the donor cell and a coaxial cable has too much attenuation. The bus architecture if possible is preferred as just one fibre is needed, but on the other hand puts some additional technical constraints on the optical feeder system, if transmitting many radio standards simultaneously.

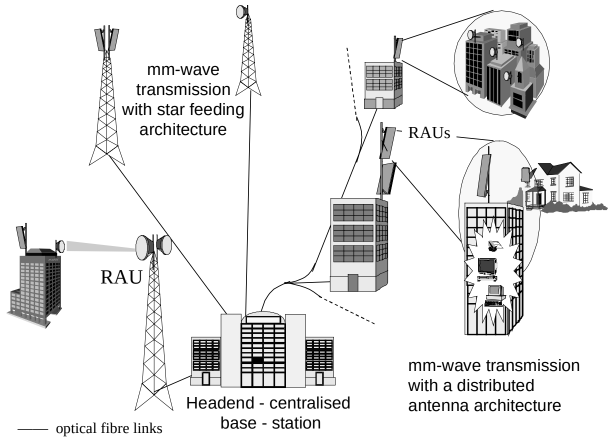

Figure 3 Outdoor distributed bus or star antenna architecture for HFR.

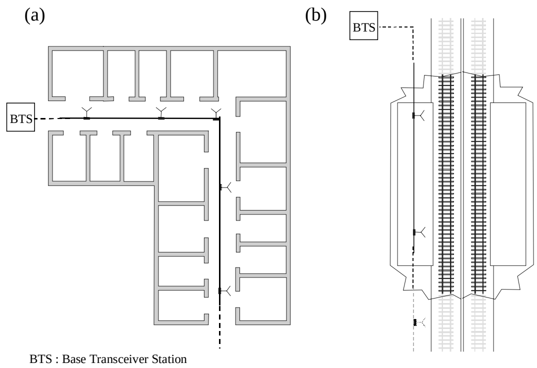

Figure 4 Indoor HFR distributed antenna system. In (a) for an office environment and in (b) for a underground railway station.

IV Technical requirements for HFR: One of the most important parameters for the optical feeder system is the Spurious Free Dynamic Range (SFDR), which is defined as the highest achievable signal to noise ratio. The maximum power level is limited by system non-linearities which cause distortion and the minimum power level is limited by the noise floor. In general a higher SFDR is needed for the uplink than the downlink as the BS must be able to receive a wide range of signal powers from mobile terminals. In this section the

DR requirements for different cell sizes and environments will be computed and in Section V the possible SFDR for different optical feeder systems will be evaluated.

The path loss in a radio system depends on a range of factors such as environmental conditions (e.g. building structure, rain attenuation), antenna type, antenna height, frequency, etc [8]. There are different models available ranging from simple Line-of-Sight (LOS) path loss models to more sophisticated computer supported three dimensional ray tracing models. As we are only interested in DR and not the absolute path loss, a simple empirical equation for the LOS and Non-Line-of-Sight (NLOS) condition has been used. The DR combining path loss for LOS and NLOS as a function of distance, *d*, between transmitting and receiving antennas can be written as [8],

$$DR(dB) = 20 \cdot \log_{10}\left(\frac{d_{LOS}}{d_{\min}}\right) + 10 \cdot n_{NLOS} \cdot \log_{10}\left(\frac{d}{d_{LOS}}\right) \quad (1)$$

for far-field region and $d \geq d_{LOS} \geq d_{min}$.

In general d_{LOS} is a reference power distance which in our case has been calculated at some LOS distance, d_{min} is some minimum allowed distance, and n_{NLOS} is the path loss exponent which takes into account antenna height and propagation environment, as shown in Table 1. It occurs that there is no frequency dependence in Equation (1) as we are calculating the power difference between some minimum and maximum distance, however the path loss exponents given in Table 1 are mainly obtained from measurements in the frequency range below 10 GHz. Figure 5 shows the calculated DRs using Equation (1) for different environmental conditions and cell sizes. The maximum and minimum cell sizes for the pico- micro and macro-cell used for calculation of the DR are given in the figure. Some approximate LOS condition have been assumed which are: 3 metre for the pico-cell indoor application, 0.1 km for the micro-cell and 1 km for the macro-cell, covering urban and suburban areas. The NLOS attenuation factors used for the different cell sizes represent:

• pico-cell:	1.6 to 2 for in-building/factory with LOS condition. 2 to 4 for indoor open plan, obstructed sight and 4 to 6 for indoor one to three floor separation, obstructed within residential building
• micro-cell:	2.5 to 3.8 for 10 to 50 meter antenna height and up to 5 for shadowed urban areas
• macro-cell:	2.1 to 2.5 for antenna heights between 50 and 100 meter and up to 5 for shadowed urban areas

Table 1 Typical values of path loss exponent, n_{NLOS}, in mobile radio channels, [8] to [10].

Further factors which may be considered for the wireless path loss are:

- by increasing the minimum distance, DR can be further reduced which maybe especially interesting for some indoor pico-cell systems.
- the actual antenna radiation profile as there is often a near distance shadowing region (depending e.g. on the antenna height), may be used in a positive sense.
- the DRs plotted in Figure 5 show the expected mean values. In order to count for frequency dependent material losses, multi-path fading, shadowing effects which may change with position and time, a confidence level of $\sigma = \pm$ 8 dB may be taken as the standard deviation around the mean with a uniform distribution.

The DR values calculated here agree quite well, within σ, with reported measurements for different indoor and outdoor environments in the microwave range, [8] to [10].

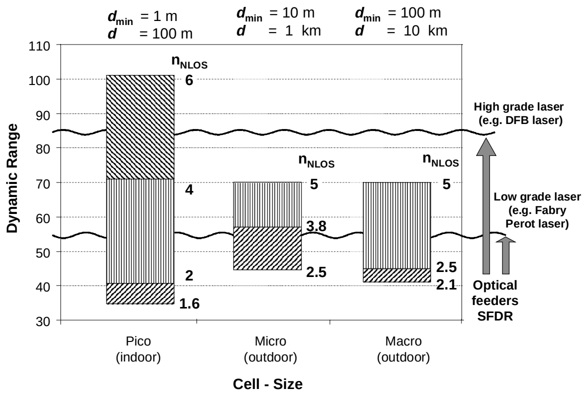

Figure 5 Dynamic range requirements for indoor and outdoor wireless systems as a function of cell size and n_{NLOS}. There is also an indication about HFR feeders possible SFDR, calculated for a signal bandwidth of 200 kHz

V HFR technologies: Optical feeder concepts and their performance parameters are considered next.

<u>The optical feeder concepts</u> may be classified into four categorises, by considering the operating frequency, the NT location and technical maturity.

1. Baseband (BB) transmission over fibre. The NT is in the RAU where all the radio functionality is located
2. IF transmission over fibre. The NT is at the headend with frequency up-conversion at the RAU, Figure 1 (a)
3. RF transmission (microwave) over fibre with $f_{RF} \leq 10$ GHz. The NT is at the headend, Figure 1 (b)
4. RF transmission (mm-wave) over fibre with 10 GHz < f_{RF} < 70 GHz. The NT is at the headend, Figure 1 (b)

We are mainly interested in the last three feeder concepts as they comply with many of the network operator requirements, by removing radio complexity from the RAU. Multiple radio services, Figure 2, may be fed into the fibre by using:

- different sub-carriers at the same optical wavelength (SCM).
- different optical wavelengths, (WDM).

For microwave HFR a laser may be driven either direct or the CW laser output may be modulated using an external modulator. The first has the advantage of saving components and offering a larger DR whereas the last has the advantage of higher possible modulation speed and less laser linewidth broadening.

For mm-wave HFR chromatic dispersion penalties can be severe and new techniques are needed for the optical source. Some promising techniques are optical heterodyne [3], optical single sideband [4] and double sideband suppressed carrier [5]. Much of this technology, including the optical receiver at the RAU, will not be mature enough for several years however.

Although technology for microwave HFR is relatively mature, there is still a question about dynamic range performance. Requirements have been calculated for a range of environments (shown in Figure 5) and these results must be compared with measured HFR link performance. For direct laser modulation, SFDR values between 90 $dBHz^{2/3}$ and 120 $dBHz^{2/3}$ can be obtained depending on the type (and cost) of the laser used [6]. For the example of a GSM carrier (200 kHz), these values equate to dynamic ranges between 55 dB and 85 dB. For the case of external modulation, electroabsorption modulators can have very good performance if an appropriate bias point is chosen. This is because the optical transfer characteristic of this device can have several very linear spots (over small variations of bias) where the third-order intermodulation terms are at a minimum. A SFDR of 123 $dBHz^{4/5}$ has been reported (in this case the dominant intermodulation products are fifth-order) [7]. For a GSM carrier, this equates to a dynamic range of 81 dB. By contrast, simple Mach-Zehnder modulators (MZMs) do not have comparable linear regions in their transfer characteristics and are therefore not as suitable for high dynamic range systems. Schemes using more than one MZM have been proposed to overcome this limitation, but this adds considerably to system complexity.

For completeness it should be also noted here, that some mobile systems like GSM have implemented power control, which also helps to relax optical feeder SFDR requirements.

VI Conclusion: HFR using RF over fibre can reduce complexity at the remote antenna site and allows the concentration of the radio related functions of several radio cells in a single centralised BS. This enables reduction of equipment cost and investment risks.

Radio operating frequency, DR requirements and minimum - maximum cell size are critical parameters for the implementation of HFR access. We have found that microwave optical feeder systems, which are quite mature and offer high SFDR, can be used for wireless access in different indoor/outdoor environmental conditions, except for some high loss indoor pico cell conditions. The laser may be modulated using either direct or external laser modulation, for radio frequencies up to 10 GHz. It has been shown that radio DR requirements may be further relaxed by increasing the minimum allowed distance between transmitting and receiving antenna. For mm-wave transmission chromatic dispersion penalties are quite severe. This makes it necessary to use some quite complex optical feeder techniques which, including the receiver at the RAU, will not be commercial mature enough for the next few years.

Future work within the EURESCOM project P816 [1] will evaluate optical feeders performance values and optical feeders component costs.

ACKNOWLEDGMENT: This document is based on the results achieved in a EURESCOM project, this does not imply that it reflects the common technical position of all EURESCOM shareholders/parties. The authors greatly acknowledges the support of EURESCOM for carrying out this work. The author wishes to thank P816 Task 2 participants for their contribution to the project.

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