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IMR Specification Document

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Abstract:

This document contains the intermediate module repeater (IMR) specification. It will determine all requirements applying to the IMR for the SDMB commercial system.

Choice is made out of 3 different architectures, describing their pros and cons and illustrating the decision procedure.

Comprehensive Annex sections form the background for the decision,

Keyword list: SDMB IMR repeater specification

Executive Summary

(1) Embedding The IMR Specifications Into The SDMB

This is the 4th of 8 tasks in Work Package 6 – ”Architecture". The WP aims at the identification and definition of the technical requirements for the SDMB-system. It determines the SDMB architecture which is to inter-work with the 3GPP-architecture and all relevant system requirements.

Under this WP functions and interfaces of the SDMB and all sub-systems has been defined, in particular the user equipment, intermediate module repeaters (IMR), space segment, hub and service centre. In the following this paper is dedicated to the IMR.

(2) IMR Specifications And Requirements

The IMR specification generating Task 6.4 - matter of this document - determines all requirements applying to the SDMB intermediate module repeater (IMR) and evaluates the technical and economical implementations of the IMR functions and performance ensuring and taking into account, too, potential co-siting of the IMR with 3G base stations and other equipment.

This task delivers specifications for the hardware architecture of an IMR and its interfaces with respect to potential modifications of existing equipment and modules. In addition this task investigates new equipment to cope with synchronisation and one-directional I_{ub}-issues and/or optional I_{ur} issues, as well as GPS

Furthermore, Task 6.4 specifies the IMR hardware taking into account, if necessary, synchronisation and O&M requirements. This task produces engineering results allowing to choose between different types of IMR (cost linked to IMR itself but also to satellite/hub supplementary features to implement). In a subsequent paper it will provided some prices regarding RF-power, that allows to choose between many low power IMR versus a few high power ones. A special attention was also be paid to the possibility of co-existence of different IMR types in the project, and their possible succession in time if relevant.

(3) Document Overview

This paper contains of 9 chapters, where chapters 1 to 3 deal with the introduction, references, terms and definitions. Chapter 4 gives a view on SDMB system features and requirements relevant for the IMR specifications which then are executed in the subsequent chapter 5. Chapters 6 to 9 contain a collection of specifically investigated technical items and issues.

Figure 3 depicts a graphical view on the document. This document will continuously be updated during the **MAESTRO** project duration.

(4) Conclusions And Findings

The main issue and task of this deliverable can be seen in the technical selection of a specific terrestrial repeater type. Under discussion were repeaters acting as simple amplifiers (On-Channel, OCR), repeaters based on frequency conversion technology (FCR) and repeaters based on NodeB equipment.

The NodeB version had to be omitted, as synchronisation issues in combination with sharing problems caused high effort without guaranteeing reliable success. Thus depending on topology and environmental particularities the result of those investigations was a clear pro for the OCR and FCR technology and a con for the NodeB solution.

Nevertheless, it must be stated here that a NodeB based IMR application within **MAESTRO** still remains a challenging issue and for further research and investigations.

(5) Lessons Learnt

Though on the first glance the application of terrestrial repeaters should not cause serious problems, the converse becomes true. All type of investigated repeater architectures follows pros and cons strictly dependent on their application location, the environmental issues, synchronisation problems, etc. This requires individual solutions with specifically tailored applications. The main cons of such different architectures are:

For NodeB based solution: Enormous effort for national state-wide system synchronisation;

For the FCR-type: Not yet commercially available, and additionally its technological realisation burdened with some risky features;

For the OCR-type: Strict and careful de-coupling measures mandatory always under the danger of not controllable changing interfering environment.

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1 INTRODUCTION - DESCRIPTION ON SYSTEM LEVEL

1.1 Background - SDMB System Break-Down

Figure 1 [Mae0] gives a rough view on the operational context where the SDMB core system is embedded in. A brief description may help both to get a view on the whole SDMB system as well as identify finally the later working area environment of this deliverable D6-4.2.

Starting on right hand side a content provider exemplifies a data source whose data content is forwarded to the ground station (BM_SC) and subsequently fed into a satellite (SPACE) via the functional block accommodating the I_{ub}-generation and the transmission equipment (amplifiers, antennas, etc.). Both blocks together form the hub.

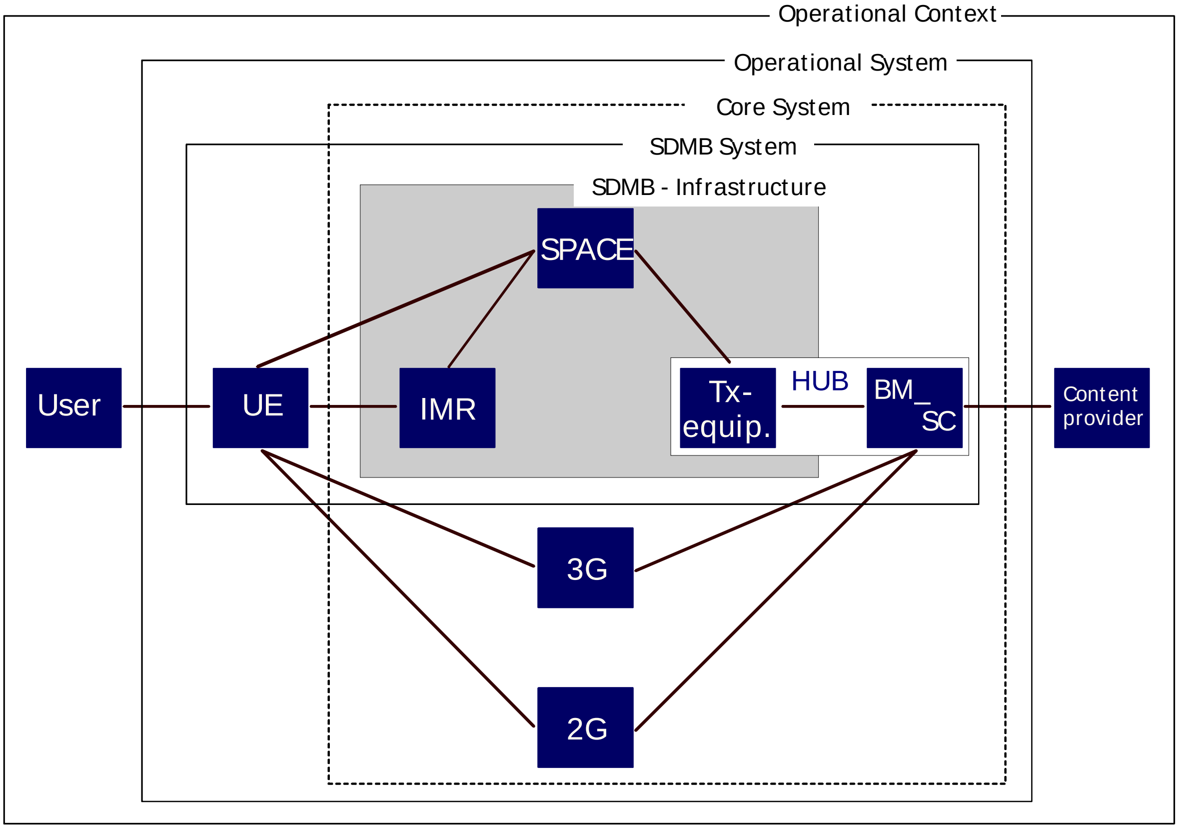


Figure 1: SDMB Architecture

The SPACE satellite beats down the received data, whereas the whole operational system to be covered by the satellite can be regarded (as an example reflecting the approximate dimensions) as at least nation wide. Transmission from satellite to the user equipment (UE) may occur principally across two different branches:

- direct broadcast from satellite to the UE;
- broadcast via IMR (Intermediate Repeater).

The former will be applied to links ranging from direct line of sight (LoS) connections (1Mb/s) to restricted coverage and thus throughput limitations (e.g., indoor 144kb/s), while the latter may be required in order to achieve full access even in those areas that are located in the satellite´s beam shadow.

Such gaps, explicitly more bad than the lowest level of LoS-type from above, are intended to be bridged by a number of terrestrial repeaters with differing architecture that may operate in different ways and some of them making use of and reusing the national communication infrastructure (e.g., existing private NodeBs, GSM/GPRS/UMTS infrastructure, etc.).

The fall-back on such networks is forced in particular by economical reasons. In particular Terrestrial Repeaters:

- may be deployed to increase service availability in areas subject to high blockage;
- are designed for smooth co-siting with existing 2G and 3G base stations;
- transmit the same signal as the one broadcast by the satellite;
- the NodeB and/or the RNS/RNC architecture shall not be modified significantly for the terrestrial repeater installation.

Application of IMR branches will follow two principles both to be further evaluated and investigated:

- The first one assumes a high degree of coverage and thus a rather small number of additionally applied repeaters. For this case the application of the IMR branch requires a high effort for a relative small user group.
- The second one is based on the users´ claims to receive the broadcast information more or less everywhere, reliably, full time and without short interruptions (e.g., tunnels, indoor, etc.). This user behaviour would require a high number of installed IMRs and, economical behaviour supposed, envisaged low cost per IMR item.

In any case, economical behaviour would force to keep the average cost per user as low as possible

The basic problem for solutions making use of a NodeB infrastructure is the synchronisation and delay balance of numerous signal streams; for this type of repeaters signals directly arriving from the satellite must comply with signals transported via one or more IMR configurations.

Such arriving various signal streams are regarded by the UE as being generated in a multiple propagation path environment. They must arrive within an extremely narrow time frame. Assuming similar conditions to standard UMTS their time delay difference may differ only approximately 20us which fits into the processing capability of a terminal Rake receiver.

Within this time segment the system has to cope also with all user movements, Doppler effect multiple path propagation, fading, variations in temperature etc.,

Additionally, all user terminals (UE) must be able to communicate within their national telecommunication environment; in particular they have to have communication links to their SDMB ground station (BM_SC) and thus to their Content Providers. In Figure 1 such links are denoted by the 3G and 2G – boxes indicating 2nd and 3rd generation equipment.

1.2 Fields Of Application

Based on Figure 1 the subsequent block diagram Figure 2 is to depict the working area for the IMR specification. The IMR is embedded between two interfaces (SPACE I/F and UE – I/F). For some IMR variants a number of specific measures have to be carried out. In particular additional effort has to be spent on synchronisation via GPS (bit, symbol, frame) and frame trip delay balance.

The maximum of processed channels depends on the Receiving Path-Searcher and thus on the number of Rake fingers. It has to be pointed out again that the time frame for correct reception is extremely narrow [20us].

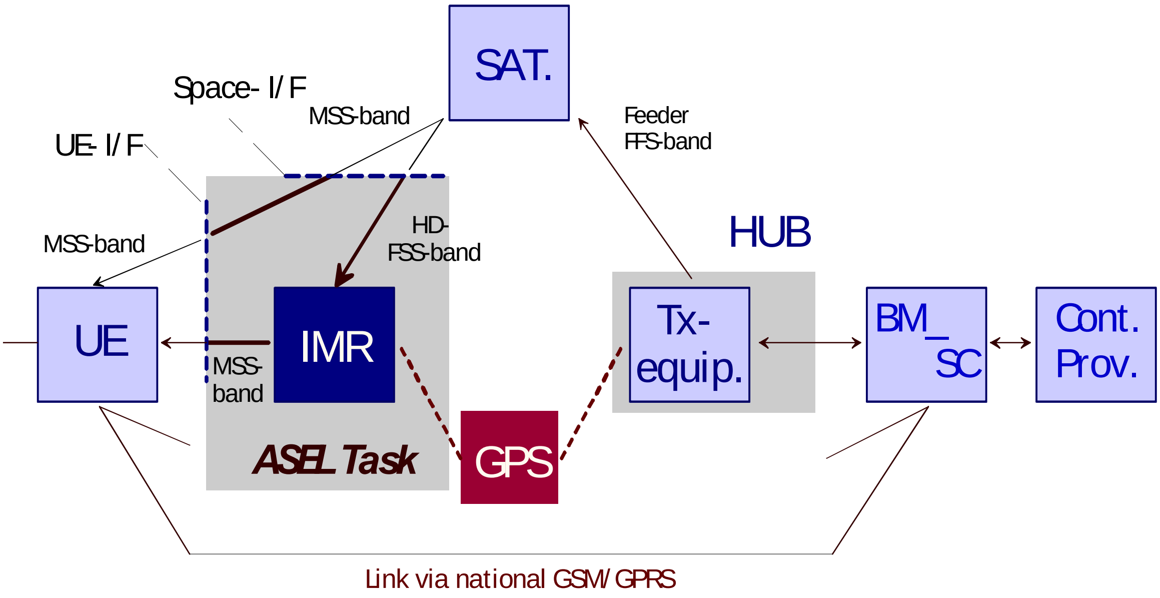


Figure 2: Underlying architecture for IMR-specification

1.3 Document Structure

The document structure follows the documentation tree depicted in Figure 3 and will be kept flexible and applicable for later versions, too.

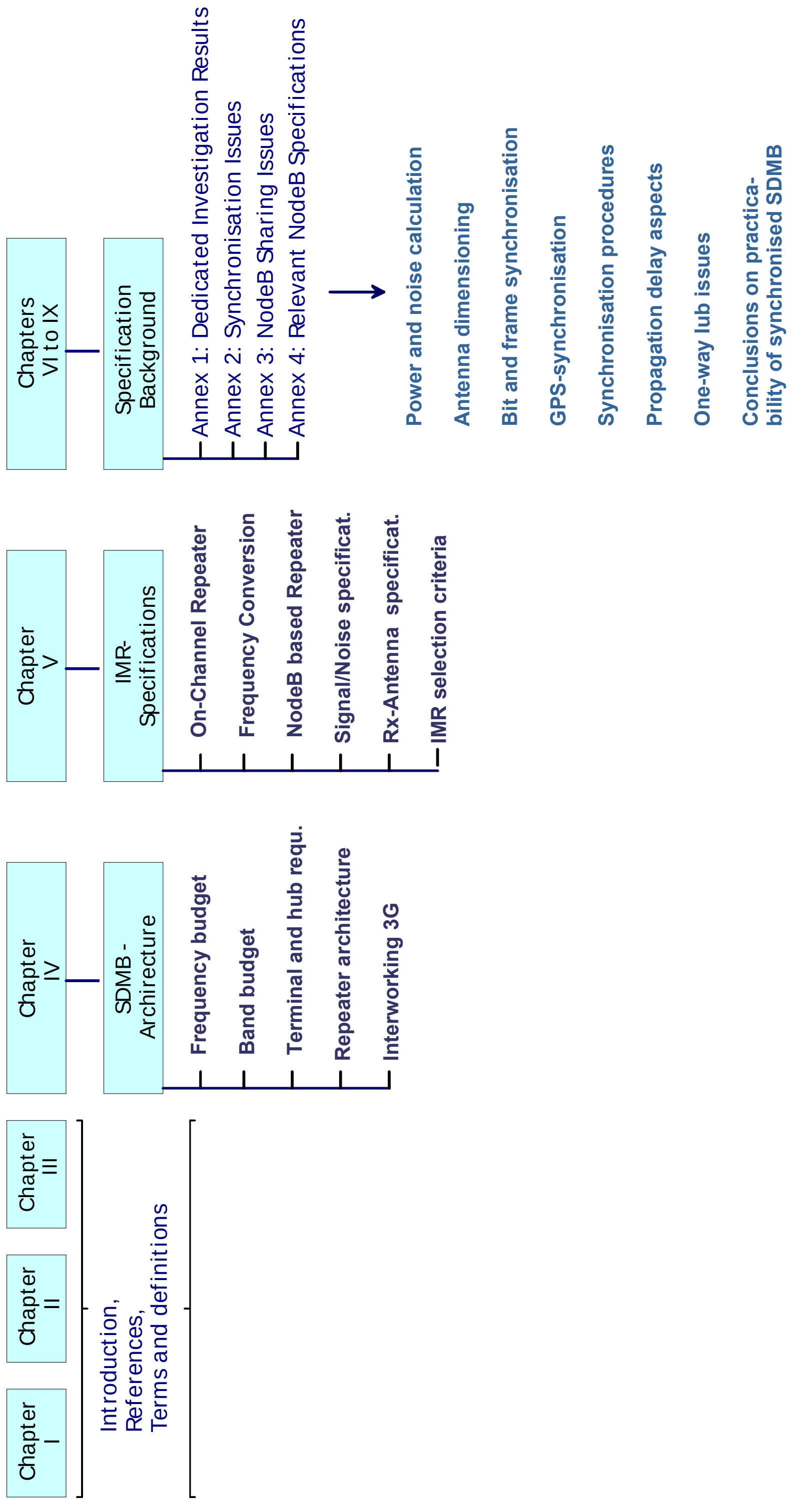


Figure 3: Deliverable D06-4.1 document tree

2 DOCUMENTARY REFERENCE SYSTEM

2.1 Reference Documents Applicable And Applied

- [ASP] ASP-03-TL/SR/A-9, November 18, 2003
- [TQZZA] 3DC 21151 0016 TQZZA, November 2003
- [Mae0] MAESTRO Glossary
- [Mae1] MAESTRO Deliverable D6-1: SDMB System Technical Requirement
- [Mae2] MAESTRO Deliverable D6-2: System Design Definition File
- [Mae3] MAESTRO Deliverable D3-1: S-DMB Access Layer definition

2.2 Norms And Standards

- [3GP5] 3GPP TS 25.104
- [3GP5] 3GPP TS 25.215
- [3GP1] 3GPP TS 25.402: “Synchronisation in UTRAN Stage 2”
- [3GP2] 3GPP TS 25.433: “UTRAN I_{ub} Interface NBAP Signalling”
- [3GP6] 3Gpp TS 25.923
- [3GP3] 3GPP TS 29.846: “Multimedia broadcast / multicast service; CN1 procedure description”, 1.2.0 (2004-02)
- [3GP4] 3GPP TS 23.246: “Multimedia Broadcast/Multicast Service (MBMS); Architecture and functional description”, V.6.1.0 (2003-12)

3 TERMS, DEFINITIONS, ABBREVIATED TERMS AND SYMBOLS

3GPP	:	Third Generation Partnership Project
APL	.	Additional Path Loss
AAL	:	ATM Adaptation Layer
ACLR	:	Adjacent Channel Leakage Power Ratio
ACS	:	Adjacent Channel Sensitivity
AGC	:	Automatic Gain Control
ALC	:	Automatic Level Control
ANRU	:	Alcatel NodeB antenna network
ARPU	:	Average Revenue Per User
BER	:	Bit Error Rate
BFN	:	NodeB Frame Number
BLER	:	Block Error Rate
BM-SC	:	Broadcast Multicast Service Centre
BP	:	Band Pass
BS	:	Base Station
BW	:	Band Width
CA	:	NodeB Connection Area
CFN	:	Cell Frame Number
CPICH	:	Common PIlot CHannel
CRNC	:	Controlling RNC
DC	:	Down Converter
DL	:	Down-Link
DoA	:	Direction of Arrival
DRM	:	Digital Rights Management
DVB	:	Digital Video Broadcast
EIRP	:	Equivalent Isotropic Radiated Power
EL	:	Elevation Angle
ETSI	:	European Telecommunications Standard Institute
ETSI TC SES	:	Technical Committee Satellite Earth Stations & Systems
EVM	:	Error Vector Magnitude
FCR	:	Frequency Conversion Repeater
FDD	:	Frequency Division Duplex
FDM	:	Frequency Division Multiplexing
FEC	:	Forward Error Correction
FSS	:	Fixed Satellite Service
G	:	Antenna Gainn
GSO	:	Geostationary Orbit
GPS	:	Global Positioning System
HDFSS	:	

IBS/IDR : Classical Satellite Modem
ID : Identification
IF : Intermediate Frequency
IMR : Intermediate Module Repeater
IPDL : Idle Period for Down Link
I_{ub} : Interface between RNC and BS
LCS : Location Services
LLI : Low Level Interface
LMU : Local Measurement Unit
LNA : Low Noise Amplifier
LO : Local Oscillator
LoS : Line Of Sight
LP : Low Pass
MBMS : Multimedia Broadcast/ Multicast Service
MCPA : Multi-Carrier Power Amplifier
MMS : Multimedia Messaging Service
MNO : Mobile Network Operator
MSC : Multiple Scrambling Code
MSS : Mobile Satellite Service
NGSO : Non GSO
OCR : On-Channel-Repeater
OCXO : Oven Controlled Oscillator
OMA : Open Mobile Alliance
OMC : Operation and Maintenance Centre
OTDOA . Observed Time Difference of Arrival
O&M : Operation and Maintenance
PA : Alcatel NodeB Linearised Power Amplifier
PAR : Peak to Average Ratio
PCDE : Peak Code Domain Error
PCF : Position Calculation Function
PHC : Phase Comparator
PL : Path Loss
QoS : Quality of Service
QPSK : Quadrature Phase Shift Keying
RF : Radio Frequency
RFN : RNC Specific Frame Number
RMA : Root Mean Square
RNC : Radio Network Controller
RRC : Root Raised Cosine
RTD : Round Trip Delay
RX : NodeB Receive Module
Rx : Receive Direction
SCF : Synchronisation Control Frame

SDMB	:	Satellite Digital Multimedia Broadcast
SF	:	Spreading Factor
SFN	:	Synchronisation Frame Number
SRI	:	Satellite Radio Interface
SSTD	:	Side Selection Time Diversity
STTD	:	
SUMU	:	Alcatel NodeB Station Unit Board
TDD	:	Time Division Duplex
TEU	:	NodeB Transmission Module
TM	:	Test Mobile
ToA	:	Time Of Arrival
TSTD	:	
TX	:	NodeB Transmit Module
Tx	:	Transmit Direction
UC	:	Up-Converter
UDD	:	Unconstrained Delay Data bearer service
UE	:	User Equipment
UARFCN	:	UTRA Absolute Radio Frequency Channel Number
UL	:	Up-link
UMTS	:	Universal Mobile Telecommunication System
USIM	:	Universal Subscriber Identity Module
UTRA(N)	:	UMTS Terrestrial Radio Access (Network)
VCO	:	Voltage Controlled Oscillator
VCXO	:	Programmable Voltage Controlled Oscillator
VSWR	:	Voltage Standing Waves Ratio
W-CDMA	:	Wide-band Code Division Multiple Access
WDS	:	Wide-band Distribution System
WI	:	Work Item

4 TERRESTRIAL REPEATERS

4.1 Some SDMB System Figures Relevant For The IMR-Design

The subsequent elaboration of IMR specifications cannot be done without respect to the actual system parameters and assumptions. Therefore, the following tables will list some of the main requirement parameters which might be not directly relevant for the IMR design but indirectly necessary for the specification work.

Table 1: Service requirements parameters

coverage	Outdoor and indoor
retransmission via terrestrial 2G/3G network	4,5% of users over 90% of service area,
	5% of average data volume user selected
service area over the European continent:	latitude : from 35°N to 65°N
	longitude : from 10°W to 30°E.

Table 2: Key features relevant for IMR

▪ satellite based broadcast layer full compliant with the MBMS , the same granularity of T-UMTS
▪ terrestrial repeaters may be co-sited with 3G base station to minimise deployment cost (---> Shared NodeB and/or Shared RNC).
▪ NodeB based terrestrial repeaters requires rights to re-use NodeB sites
▪ 3GPP UTRA FDD W-CDMA standardised technology
▪ 3GPP standardised handsets reception performances in IMT2000 satellite down-link frequency band (2.170 - 2.200GHz)
▪ recombination of signals received from the satellite and the terrestrial repeaters by rake r
▪ SDMB reception shall not prevent mobile network operations (idle mode: paging, location update; connected mode)
▪ standardised interfaces to 2G / 3G networks
▪ the hub controls the broadcast transmission in one or several spot beams
▪ the hub builds the 3GPP standardised W-CDMA down-link carriers
▪ the system is designed to allow several hubs to share the system capacity and several BM-SC to share the capacity managed by the hub

Table 3: IMR O&M aspects

▪ O&M requirements are strictly associated to the IMR type. At this point a selection of one ore more IMR architectures was not made yet.
▪ O&M requirements are also bound to the repeater application and location, e.g., located along a railway track side may advice to concentrate repeater maintenance in the railway control centre, while road applications may recommend maintenance together with the intelligent road signs.

4.2 View On Different Architectures Of Terrestrial Repeaters

The **MAESTRO** System is intended to apply different types of Terrestrial Repeaters according to the particular terrestrial topology and the identified system needs.

The subsequent investigations will give solid results for the preference of On-Channel (OCR) and Frequency-Conversion (FCR) repeaters. Thus the baseline for the system design i.e. for the hub and the IMR is to use Frequency-Conversion repeaters and On-Channel repeaters.

For the On-Channel repeater, there is no system trade-off to do since its use is always possible without impacting the hub.

Therefore the hub will first and preferably transmit only U_u interface. The I_{ub} transmission is a future system option but, with respect on the investigation results in chapter 5 and 6, with less probability to be introduced at all in the system.

Nevertheless, hub characteristics in combination with the transmitted UMTS channels may determine only a restricted number of IMR variants; in principle this will become a real issue when the decision has to be made up, either to transmit only the $U_{\underline{u}}$ via the satellite or the full set of e.g., U_u, I_{ub} and I_{ur} respectively.

Though only conceding an extreme low chance for any realisation of NodeB-based IMRs, the subsequent investigations and considerations will also respect this type of repeater until the final decision can be made to do without such an IMR type.

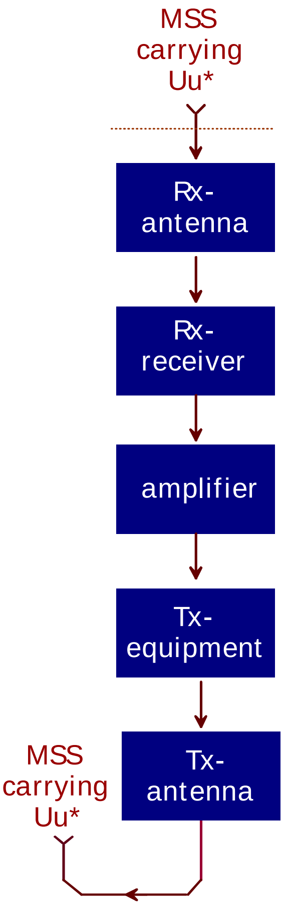
4.2.1 Stand-Alone Repeaters Without Sharing Available Infrastructure

This type of repeaters follows the scheme given in Figure 4 and Figure 5. A number of suitable terrestrial repeaters of this type is commercially available and applicable but all types are burdened with a set of specific issues by their own with respect to the envisaged SDMB system.

This paragraph will describe very briefly some principle type of repeaters which will described subsequently more detailed in context with their specifications. Due to their technical appearance such repeaters are fairly not suitable to use or re-use existing communication infrastructure (such as NodeBs, RNCs, etc). Two examples may be given to show the principles of such type of terrestrial repeaters.

- **On-Channel Repeater (OCR):**

This repeater type acts as a simple amplifier for the received signal. Specific measures have to be taken for keeping input and output signals strictly separated in order to avoid strong interference and feed-back. This repeater type is cheap but serviceable only in restricted areas (e.g., indoor application).



The simplest telecommunication solution would be the application of real UMTS-On-Channel-Repeaters. UMTS On-Channel Repeaters may provide in general a slight delay of the signal in the area of less than 6µs (according to product information).

If the UMTS-Repeaters are installed indoors only, the de-coupling measures for separating input and output signals may be a bit easier when using instead of smart antennas fibre links or coaxial cables for in-house distribution.

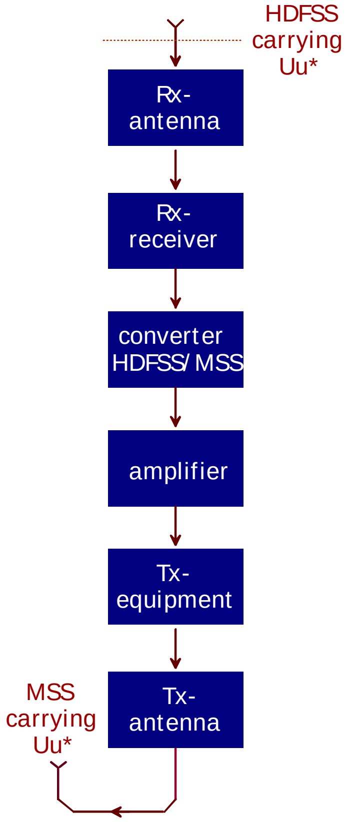
If a number of such repeaters – all sending and receiving on the same frequency - will be used in urban regions, the de-coupling problem will dramatically increase, as now the On-Channel-Repeaters operate in a "messy" environment, i.e., a mixture of original satellite signals, amplified repeater signals and any cases of reflections and phase shifts. In this case directed antennas may not suffice for a strict separation of input and output.

Figure 4: On-Channel repeater architecture

The great disadvantage of this repeater type is its vulnerability against interfering feed-back from output to input when used outdoors. An amplifier gain up to 100dB (taken from product description) requires measures in form of directed antennas with strict beam forming capabilities.

This solution applied in open weald would be far away from the plug´n´play philosophy which stands, among others, for cheap, economic and easy installations.

- **Frequency Conversion Repeater (FCR):**



This repeater type offers a reasonable technical concept in combination with a high degree of flexibility.

Input and output do not conflict; measures need not be taken to avoid interfering feed-back.

This type of repeater is of medium cost and its most suitable installation may be in more dens crowded areas.

In contrary to the On-Channel repeaters the frequency conversion repeaters make use of the satellite´s HDFSS band (19.7 – 20.2GHz) which is radiated down together with the MSS band.

This is the reason why feed-back interfering can be kept on a minimum.

Figure 5: Frequency converting repeater architecture

4.2.2 Repeater Sharing Available Infrastructure

(a) Issues

This repeater type will make use of available communication infrastructure and follows the scheme given in Figure 6. It can be said that this challenging broadcast system will suffer from – apart from a lot of other issues – trip delays, path delays, processing delays, etc. and their balance.

Furthermore, system synchronisation will play a strong role in the system which requires precise bit and frame synchronisation across both the satellite link and the supporting terrestrial links, in particular, when NodeBs and RNCs will be used. In that case the satellite beam meets a strict synchronous national/international network.

The propagation delay differences within the beam´s footprint spreads nearly 10ms (see Chapter 6) from north to south (latitude 35° to 65° north) and thus will not fit to the shared terrestrial network. Consequently, though the expected benefits of such a solution are high but there are serious doubts whether such really complex techniques and technologies will be able to compensate the mismatch.

(b) Architecture Sub-Variant For Based On NodeB IMR

Figure 6 represents the NodeB based IMR functional architecture, reusing an existing terrestrial mobile network base station for to comply with the requirement **MAE-D6-1.1-C-REQ-089**. In addition to the stand-alone repeaters the following functional equipment has to be added (see Figure 6):

- satellite reception equipment, providing the I_{ub} traffic coming from the hub via a satellite;
- I_{ub} signal routers and multiplexers merging and separating the unidirectional satellite I_{ub} traffic and the terrestrial I_{ub} traffic, respectively coming from the UMTS PLMN;
- NodeB upgrade for to use the IMT-2000 MSS satellite bands;
- equipment providing synchronisation;
- a GPS receiver, providing a time reference to the NodeB;
- OMC (Operational and Maintenance I/F) connected Node Set-up.
- RNS/RNC based repeater; t he decision on a repeater solution based on an RNS/RNC-infrastructure for the time being needs both further study and experience gain.

The IMR logical architecture must finally match one of the two logical architectures of the SDMB hub, represented in the hub design document.

A terrestrial repeater architecture as depicted in Figure 6 requires in any case the transmission of the I_{ub} – signals via satellite.

For the sake of free repeater choice, i.e., to keep the freedom for installing in parallel all three types of architecture (as shown in Figure 4 to Figure 6), the satellite must be able to handle both U_u and I_{ub} – signals.

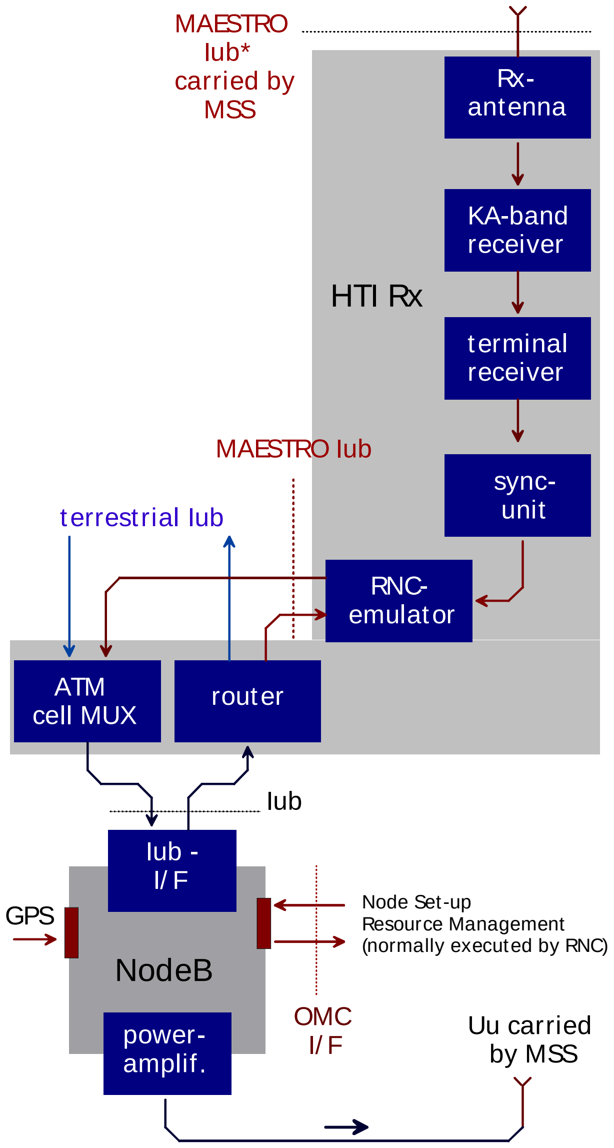


Figure 6: NodeB IMR functional architecture

(c) Inter-Working With Existing UMTS-Equipment

IMR types, whose architecture is depicted above, only would make sense, if the IMR cost can be decreased significantly. In order to tackle this target the IMR must be designed as the simplest upgrade of existing UTRAN equipment such, e.g., as the NodeB shown in Figure 6. On the other hand, the cost demands may only be fulfilled when making use of a NodeB belonging to an external network provider.

Apart from a lot of other problems which will be discussed in Chapter 6, sharing such node means to take the responsibility for reliable function of the **MAESTRO** hardware upgrade. For such inter-working two options could be identified:

Option 1: HTI-Rx Inserted On I_{ub}:

This option is shown in Figure 6. The drawback of this solution is that it might be difficult to be accepted by the network operator, because a failure of the HTI-Rx will have a serious impact on the UMTS terrestrial traffic.

Option 2: HTI-Rx Not Inserted On Iub But Connected To An ATM-Switch :

This option is shown in Figure 7. To overcome the problem of option 1, the HTI-Rx could be connected through the ATM switch forming part of the E1-interface. In this case, a failure of the HTI-Rx has no impact on the UMTS terrestrial traffic.

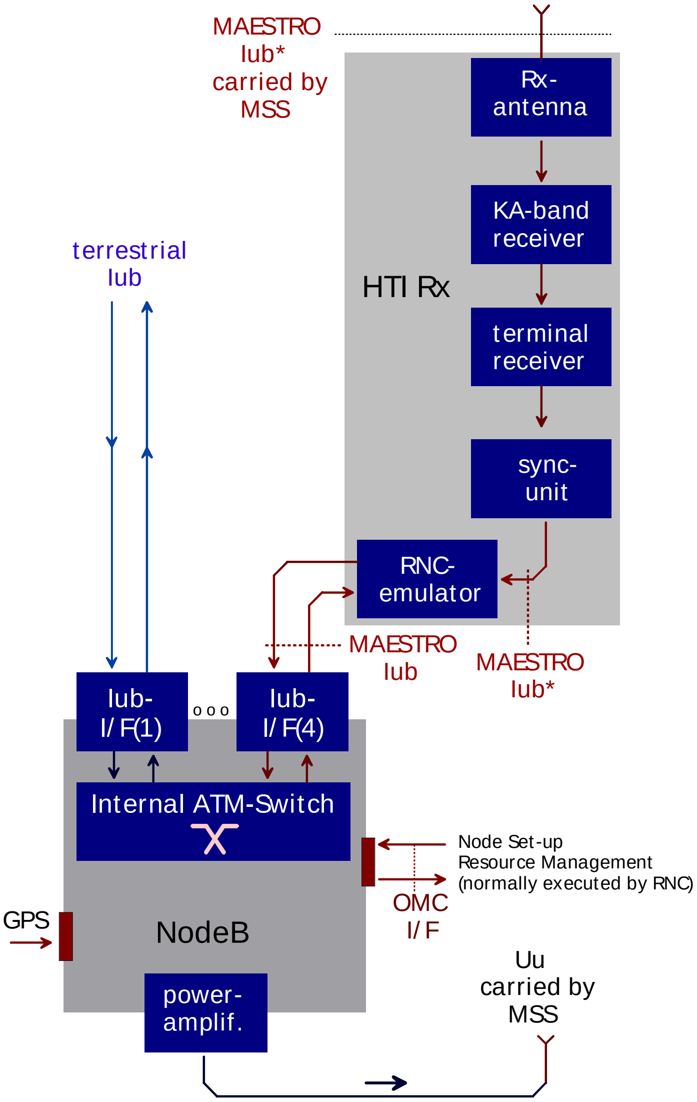


Figure 7: HTI Rx not inserted on I_{ub}

The I_{ub} traffic received from the satellite is fed into the ATM switch connecting the RNC to its NodeBs. This solution is economic, as it is not necessary to add an HTI-Rx and sets of antennas, etc. in each NodeB. Only one set of these devices need to be integrated in the RNC location. This will provide SDMB capability to the whole NodeBs connected to this RNC.

(d) Option 2 Refinement

In option 2, the I_{ub} traffic received from the satellite cannot be simply fed into the ATM switch as only one Q.2630 VC exists, and the AAL5 uses one ALCAP VC and one NBAP VC. Concerning the data traffic over AAL2, option 2 works as the ALCAP VCI and VPI can be changed.

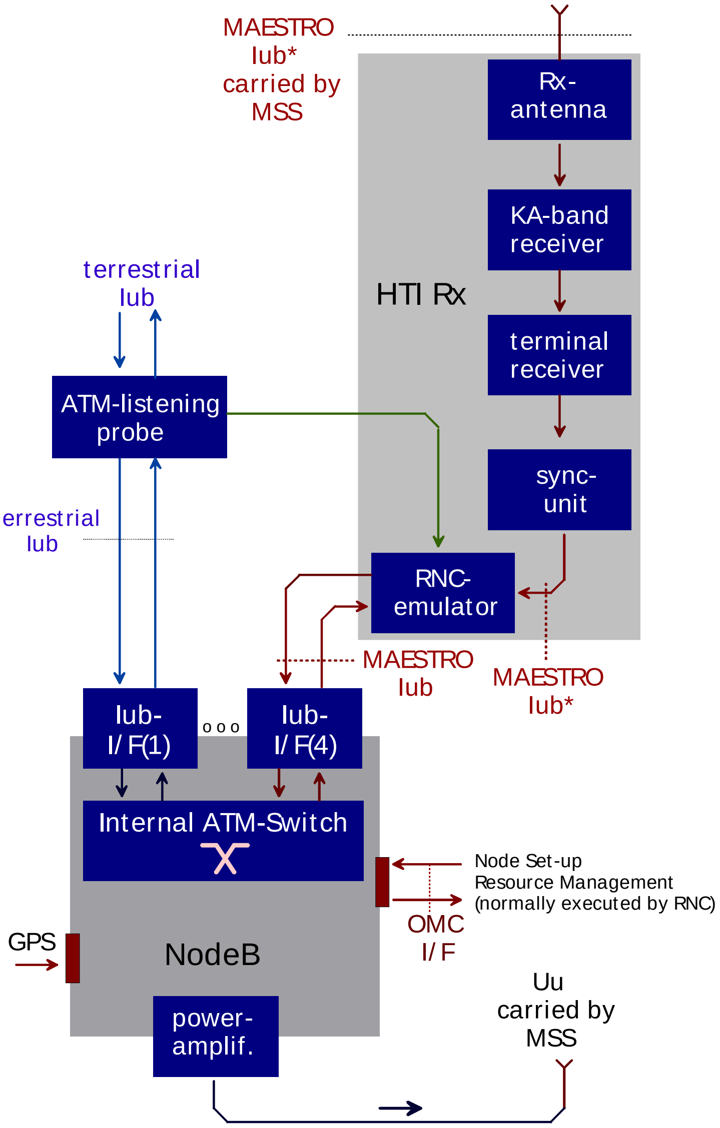


Figure 8: RNC based IMR as improvement for option 2

As shown in Figure 8, a listening probe close to the RNC could be inserted on I_{ub}. This probe enables the HTI-Rx to listen to the I_{ub} traffic exchanged with the RNC. This probe could be either a high-impedance listening probe inserted on E1/I_{ub}, or a feature of the ATM switch.

Another issue in this case is the synchronisation of the NodeBs connected to one HTI-Rx. As the HTI-Rx is only capable to synchronise one NodeB, the problem arises how and by what the other NodeBs can be synchronised, too.

5 IMR SPECIFICATIONS

5.1 Introduction

The following specifications for a terrestrial repeater are result of a comprehensive research work on different suitable terrestrial repeaters as well as a selection process for reducing a wide spread area of intermediate terrestrial repeaters to a manageable number of characteristic architectures. This was task in the previous paragraph. The result was a selection between three different architectures.

In order to keep it clear to the reader and depict the dependencies of such repeaters an IMR –"black-box" was defined, showing the necessary interfaces and the embedding of the repeaters.

Additionally it is noted which UMTS channels (U_u and/or I_{ub}) will be content of the MSS and optionally the HDFSS-band. The total number of required interfaces, in particular interfaces mandatory for synchronisation purposes, give an initial view on the expected effort and thus deliver initial decision criteria.

It is also target for the considerations made in this chapter, to reduce potential effort for infrastructure measures such as additional power lines, cabinets, antenna mast installations, sensitive reflectors and uncontrollable environment modifications by re-use and sharing of already existing devices.

Please note that in this chapter the IMR device specifications are tripartite into the very IMR device individual functional blocks, the receive antennas and the transmit antennas. The latter cannot be specified in advance, as their, among others, required gain and direction strictly depends on the future location, the necessary coverage, the interfering environment, topology, etc.

In case of the receiving antennas, their required gain was extracted from a compromise, namely the experience knowledge on suitable and manageable reflector sizes in combination with a required gain extracted from the power calculations. From both the technical and the economical point of view an reflector diameter of approximately 0.60m seemed reasonable. Proposed, however, is a flat patch panel antenna with a diameter (rectangle) of about 0.30m allowing flexibility of the internal IMR amplifier gains, noise figures and reliable S/N relations.

Another reason for this compromise was an expected solid mechanical installation of this reflector size largely resistant against wind, snow, hail, etc. Antenna with such reflector size are commercially available to medium cost.

The IMR devices are presented in a functional partitioning done and explained in the previous chapter. Kernel part of each IMR is an amplifier surrounded by a number of filters, frequency converters, receiver and transmitter networks, downconverters, etc.

5.2 Scheme For Embedding IMRs In An SDMB Environment

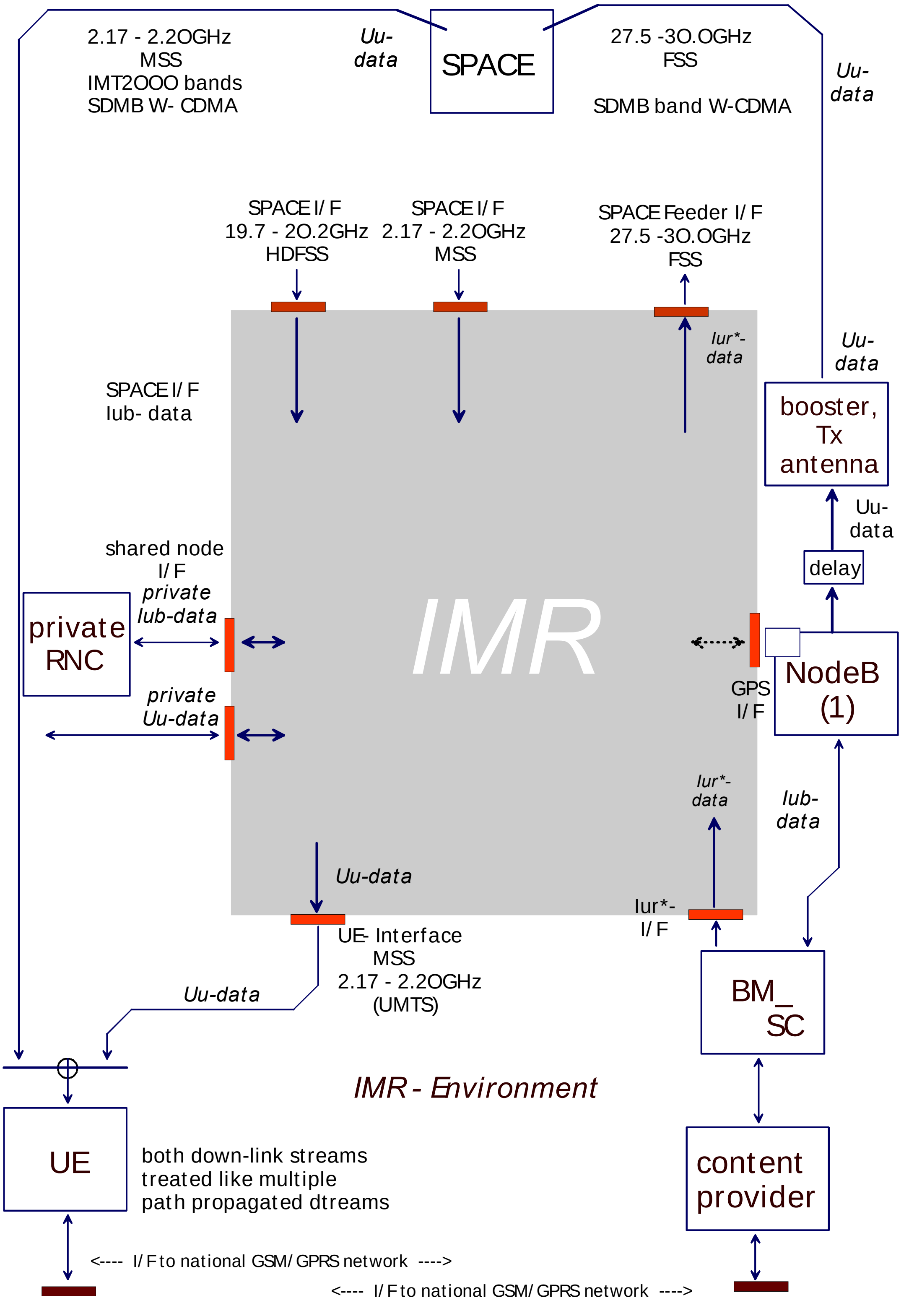


Figure 9: The Basic System – IMR Embedding

Figure 9 gives a rough view on the components of the envisaged SDMB broadcast and communication system, where the grey area will accommodate the different types of terrestrial repeaters. This figure follows the high-level architecture depicted in Figure 2 and (Figure 10).

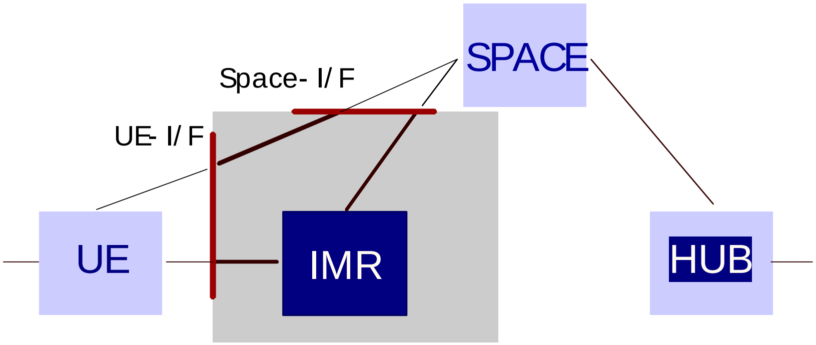


Figure 10: Basic system mapped on SDMB IMR architecture

With respect to Figure 9 the table below (Table 4) sub-summarises the applied bands, their adjacent frequencies and the carried UMTS data across the relevant IMR-interfaces. This table and its addressed three IMRs are advances of the later research results at the end of this chapter.

Table 4: Possible IMR connection bands c/t direct down-link

on-channel type (OCR)	**band**	**frequency**	**data**
direct down-link to UE	F_{MSS}	2.17 – 2.2GHz	U_u
down-link to repeater	F_{MSS}	2.17 – 2.2GHz	U_u
down-link from repeater to UE	F_{MSS}	2.17 – 2.2GHz	U_u

frequency conversion type (FCR)	**band**	**frequency**	**data**
direct down-link to UE	F_{MSS}	2.17 – 2.2GHz	U_u
down-link to repeater	F_{HDFSS}	19.7 – 20.2GHz	U_u
down-link from repeater to UE	F_{MSS}	2.17 – 2.2GHz	U_u

NodeB based type	**band**	**frequency**	**data**
direct down-link to UE	F_{MSS}	2.17 – 2.2GHz	U_u
down-link to repeater	F_{HDFSS}	19.7 – 20.2GHz	I_{Ur}
down-link from repeater to UE	F_{MSS}	2.17 – 2.2GHz	U_u
GPS synchronisation	GPS	1,575.42MHz	n/a

It was agreed that replacing and exchanging IMRs by other IMR types should not influence more than absolutely necessary the performance and specified parameters at both interfaces connecting the IMR to the SPACE and the UE respectively. This is one of the preconditions for an economical system deployment; the application of different IMR-architectures, too.

Following this philosophy and the architectural schemes from above, this requires to minimise the total number of interfaces connecting the IMR to the system. Such identified interfaces are the SPACE interface (SP-I/F) and the UE-interface (UE-I/F), the former working in the HDFSS-band (19.7 – 20.2GHz) and in the MSS-band (2.17 – 2.20GHz) respectively, while the latter operates in the SDMB W-CDMA MSS-band only.

Figure 9 represents the most simple SDMB-system solution under the assumption of a fully covered region without any relevant shadow problem zones; the system which can be regarded as basic and which performs the environment of the envisaged IMR items. Though strictly spoken it belongs to the system level, however, it may be described here very roughly, as it performs the basic system all IMR variants and components are embedded in.

Table 5: MAESTRO performance parameters

		unit
load per carrier and spot-beam	144	kb/s
spot-beam throughput	<1	Mb/s
terminal sensitivity [3GPP TS 25 101]	< -114	dBm
satellite based broadcast layer	8 - 384	kb/s
satellite frequency band for direct satellite path	5	MHz

Starting up-link the content provider box represents the broadcast data source; it contains a number of service relevant data bases, servers, etc. It may be of interest that the content provider is connected to the national GSM/GPRS network. Such connection is required to offer a terrestrial communication link from the SDMB-users and the content provider.

The content provider box is followed by the module, which mainly includes the RNC-functionality and delivers I_{ub}-data to the subsequent NodeB /1. This NodeB prepares U_u-data which is lead to ground equipment mainly consisting of amplifiers, up-converters and the directed Tx-antenna towards the satellite. Feeding transmission occurs in the 27.5 – 30GHz FSS SDMA bands (W-CDMA).

5.3 IMR On-Channel Solution – Description And Specs

5.3.1 On-Channel-IMR-Type (OCR) Embedding Scheme

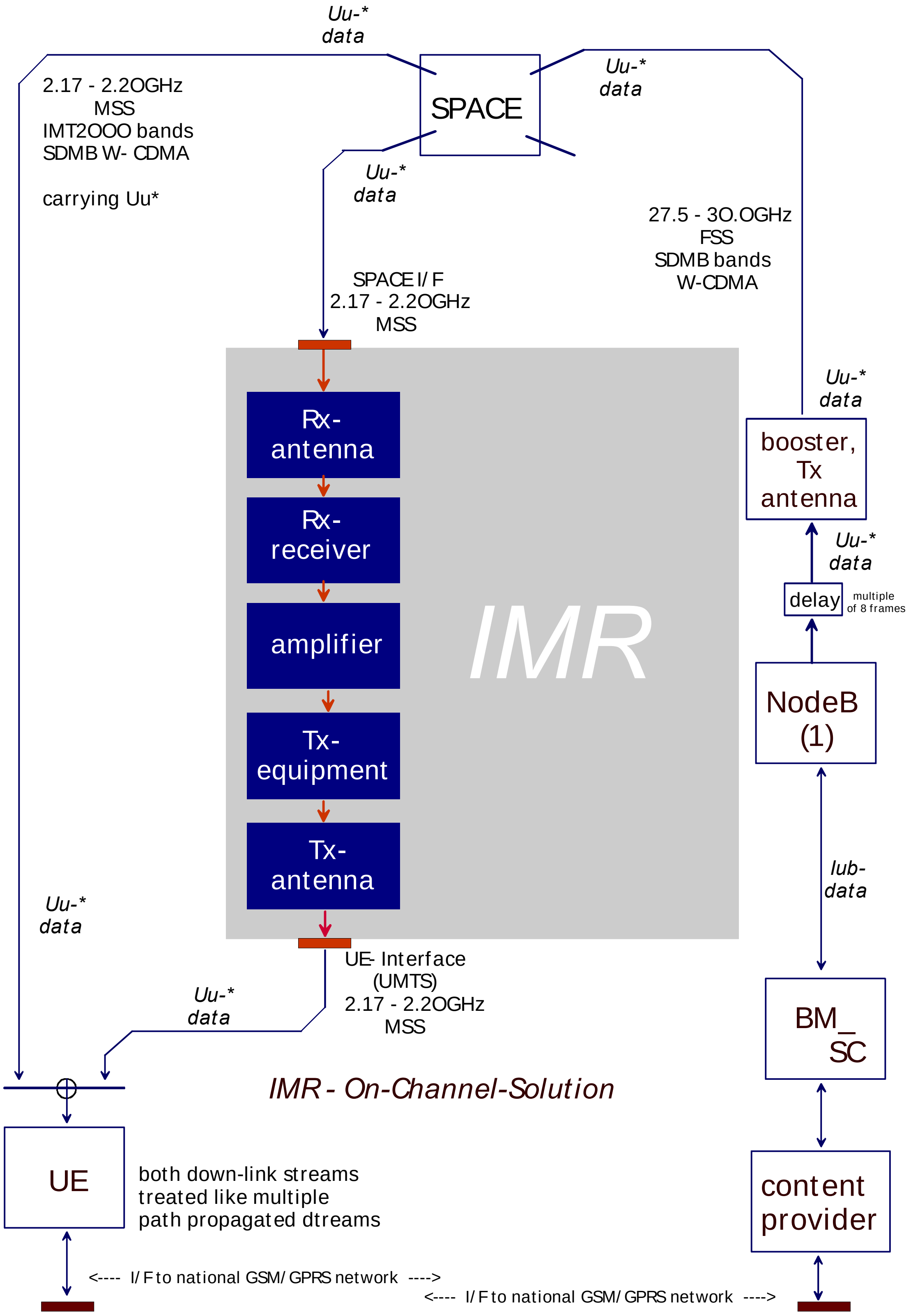


Figure 11: IMR – On-channel based repeater branch

5.3.2 OCR - Functions

This repeater type embedded in the terrestrial repeater link acts as a simple amplifier for the received signal. As the input frequency band (from the satellite) is the same as the amplified output frequency band towards the users, specific measures have to be taken for keeping input and output signals strictly separated either by fibres (only less suitable for this project) and/or by directed antennas in order to avoid strong feedback interference This repeater type is cheap but serviceable in areas with low interfering reflections (indoor application, far-off building sites, strong air traffic, etc.).

It is applicable for use in cellular and PCS wireless communication systems. Wireless RF network coverage problems can be addressed quickly and easily. In particular this repeater type is highly suitable for deployment in dense urban environments, tunnels, canyons, and other areas where physical structures cause low field strengths and poor multi propagation. It can also be used as an efficient and low-cost alternative to base stations in areas where coverage is more critical than additional capacity.

It is also suitable to extend base station coverage to shadow areas where signals can be obstructed. The repeater includes RF-enhancers for large area coverage, capacity, and high speed data. These primary network elements are ideal, too, for the first phase of the network rollout and for any subsequent phase where cost, coverage, and quality need to be optimised. This repeater does not only increase signal strength between a mobile and repeater in areas where high-quality voice or high-speed data service is not available, they also enhance air-interface capacity and increase the network data rate.

Such type of repeaters normally are channelised so that they repeat only the desired signal band without adding excess noise in adjacent bands. They can be used for both single carrier and multiple-carrier applications.

The IMR output specification follows as far as possible the specified figures for UTRA U_u I/F. In this document only a subset of such specs are addressed.

Table 6: On-Channel-Type-IMR Performance Parameters

frequency	down-link	2,170 – 2,200	MHz
CDMA-carriers	adjacent per module	1 – 3	
antenna isolation	min. for max gain	**>110**	dB

delay	w/o echo cancellation	stbd	us
OCR-gain	maximum	120 /automatic setting	dB
	adjust range	90 – 120	dB
return loss		> 15	dB
adjacent channel leakage	1st adjacent channel	-45	dBc
	2nd adjacent channel	-50	dBc
out of band gain (rejection)	opt.1	-40dB in 200	kHz
	opt.2	-70dB in 200	kHz
far-off selectivity		70	dB

Table 7: OCR-IMR power spec (operating on MSS)

	OCR
satellite EIRP (over 1.2°)	102dBm
path-loss	-190dB
additional path-loss	0dB
received signal (dBm)	-88dBm
thermal antenna noise (3.8MHz BW)	-108dBm
IMR-noise figure	4dB
receiving antenna gain (e.g., 30cm *30cm)	15dB

IMR-transmit gain (for local area application)	97dB

or:

IMR-transmit gain (for medium area applic,)	111dB

or:

IMR-transmit gain (for wide area application)	116db

Signal-To-Noise ratio S/N	**31dB**

IMR-output power (for local area application)	**24dBm**

or:

IMR-output power (for medium area applic,)	**38dBm**

or:

IMR-output power (for wide area application)	**43dBm**

Find below the spectrum emission mask at antenna reference point; this mask is valid for both the OCR and FCR repeater type output.

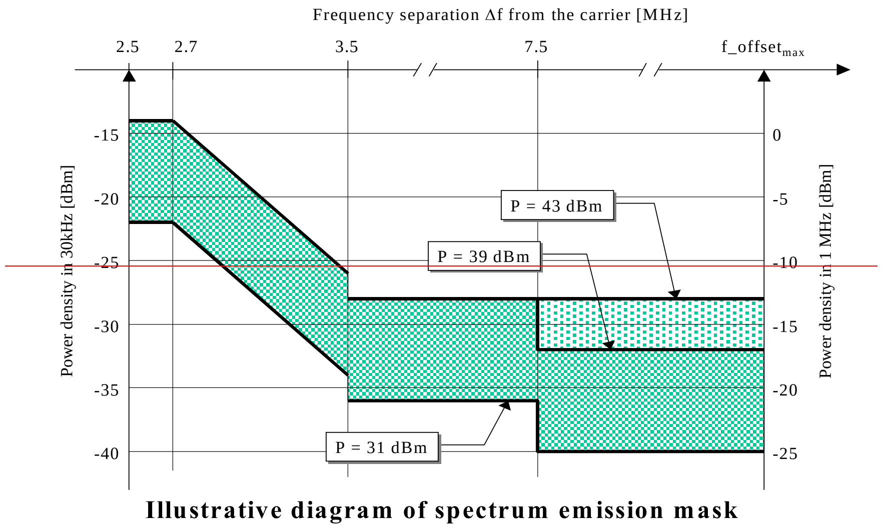


Figure 12: Spectrum emission mask at antenna reference point

5.3.3 Antennas Design For OCR

Reflector antenna can be considered only, if the diameter is higher than 4*wavelength. Since the wavelength is 15cm at 2GHz, then the minimum antenna diameter in S-band shall be higher than 60cm, that is non compliant with the operator requirement. Consequently, a reflector antenna cannot be considered for the receive OCR RF front end. Flat patch panel technology should rather be used.

Required antenna gain, RF-frequency as well as flat patch panel size form the basis for physical antenna design. In case of **MAESTRO** OCR repeater type only the MSS has to be considered. In chapter 6 calculations were done aiming in definition of the IMR input and output RF-figures. These calculations ended up with antenna gain requirements of 15dBi for the MSS connected OCR.

The flat patch panel antenna dimensioning was done in a way to achieve a gain of 15dBi. Rough estimations allow application of gain calculations by using the antenna gain calculations for reflector antennas. In this case the gain is defined as:

$$\mathbf{G[dBi]} = \eta^*(\pi^*\mathbf{d}/\lambda)^2 = \eta^*(\pi^*\mathbf{d}^*\mathbf{f}/\mathbf{c})^2$$

where: η = aperture efficiency (typical 0.55 for MSS)
d = reflector diameter / flat patch panel size ($330*10^{-3}$ m)
λ_{MSS} = RF-frequency wave length for MSS ($138*10^{-3}$ m)
f_{MSS} = RF carrier frequency for MSS (2.185GHz)
c = velocity of light ($3*10^{8}$ m/s)

The flat panel size calculations lead to a panel size of 0.33m for the MSS:

$$G_{MSS} = \eta*(\pi*d/\lambda)^2 = \eta*(\pi*d* 2.185\text{GHz}/c)^2 = \eta*(22.88)^2*d^2 = 288*d^2$$

$$G_{MSS}[\text{dB}] = 15 = 10*\log(288*d^2) \quad \text{--->} \quad \mathbf{d_{MSS} = 33cm}$$

	frequency *f*	**required gain *G***	**diameter *d***
MSS	2.185GHz	15dBi	33 *33cm

5.3.4 Decision Topics

pros for this repeater type:

- cheap
- simple and cheap indoor solution
- flexible against indoor and outdoor applications
- stand-alone capability
- no sharing issues
- already experience gained
- transparent amplifier
- no demodulation and no access of UMTS channels required
- only U_u over MSS

cons for this repeater type:

- strictly directed antenna set required
- difficult input/output de-coupling
- individual antenna installation mandatory
- no influence on environmental reflection interference
- infrastructure has to be built
- weak privacy security protection
- weak protection against content modification

The OCR-type repeater is a robust less complex solution for the IMR issue. By application of it no sharing issues will come up. This repeater type operates completely transparent.

However, as operating with the same input and output frequency, this repeater type is extremely sensitive against feed-back interference. Only a very individual tailored antenna concept with strict narrow beam forming can reduce this problem. Another measure for reducing feed-back interference can be seen in the strict local separation of receiving and transmission antennas.

Nevertheless, the repeater remains sensitive against multipath reflections caused by traffic, rain, building sites, etc.

This repeater type is only applicable in an environment which bears narrow beams and is protected against uncontrolled multipath radiation.

5.4 Frequency Conversion FCR-IMR Solution - Descriptions And Specs

5.4.1 FCR-IMR-Type Embedding Scheme

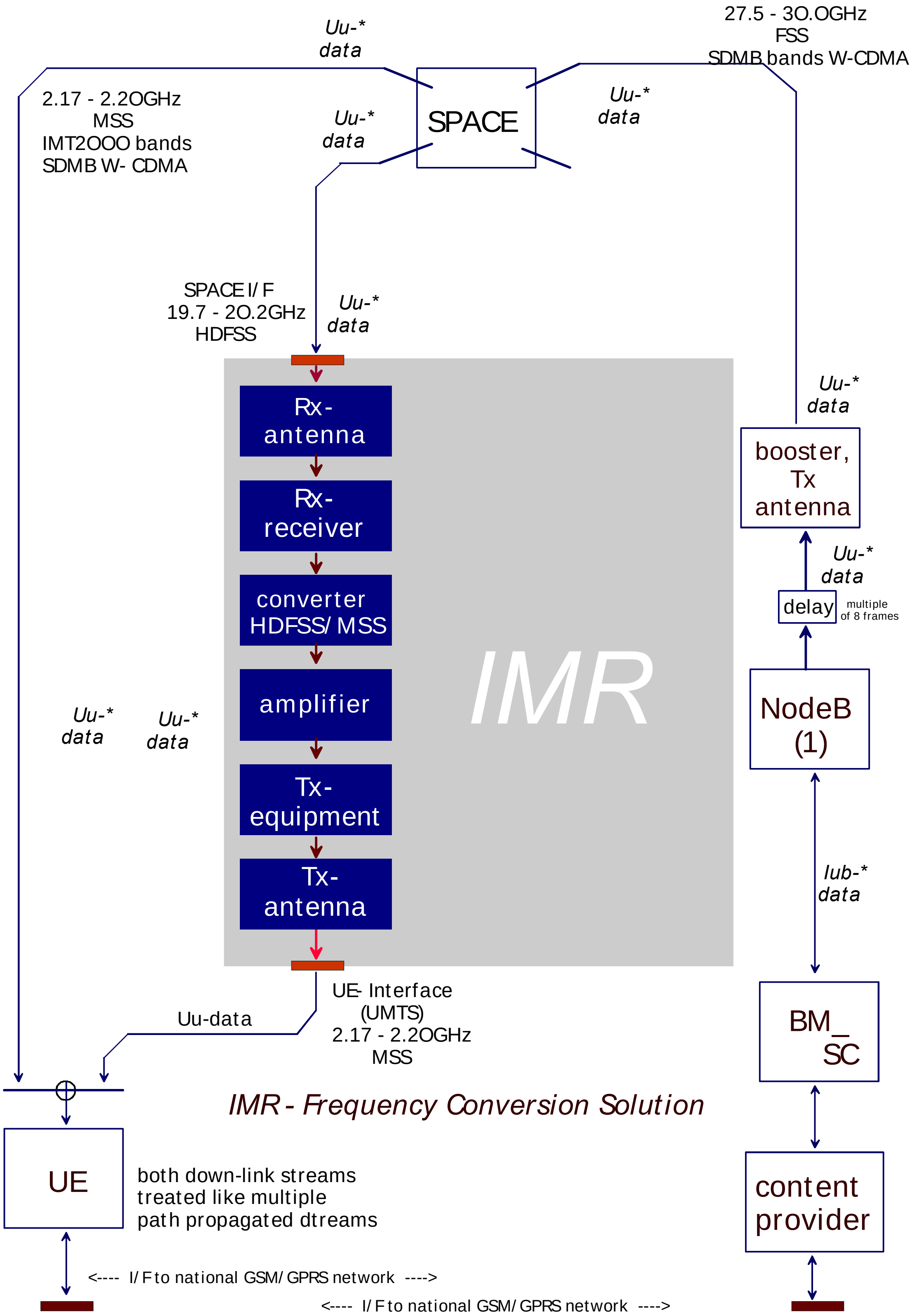


Figure 13: IMR – frequency conversion based repeater branch

5.4.2 FCR-Repeater-Type-Function

This repeater type embedded in the terrestrial repeater link obviously offers a reasonable technical concept in combination with a high degree of flexibility. This repeater type is divided into an up-converting part (normally within the satellite) and an down-converting part (from FSS to MSS) on the ground. The incoming high frequency band (FSS) from the satellite thus does not conflict with the down-converted MSS band transmitted to the users UE. No specific measures must be taken to avoid feed-back. This type of repeater is of medium cost and its most suitable installation may be in more dens crowded areas.

5.4.3 FCR-Repeater-Type-IMR Block Diagram

This repeater type stands for a group of flexible repeaters generally capable to be applied to all types of down-conversion tasks and up-conversion tasks using well introduced robust analogue frequency mixture techniques. Figure 14 gives a view on the block diagram of such a repeater (the frequencies indicated within Figure 14 serve as examples for accommodating a 500MHz window and a 30MHz window in the middle of the HDFSS and MSS respectively).

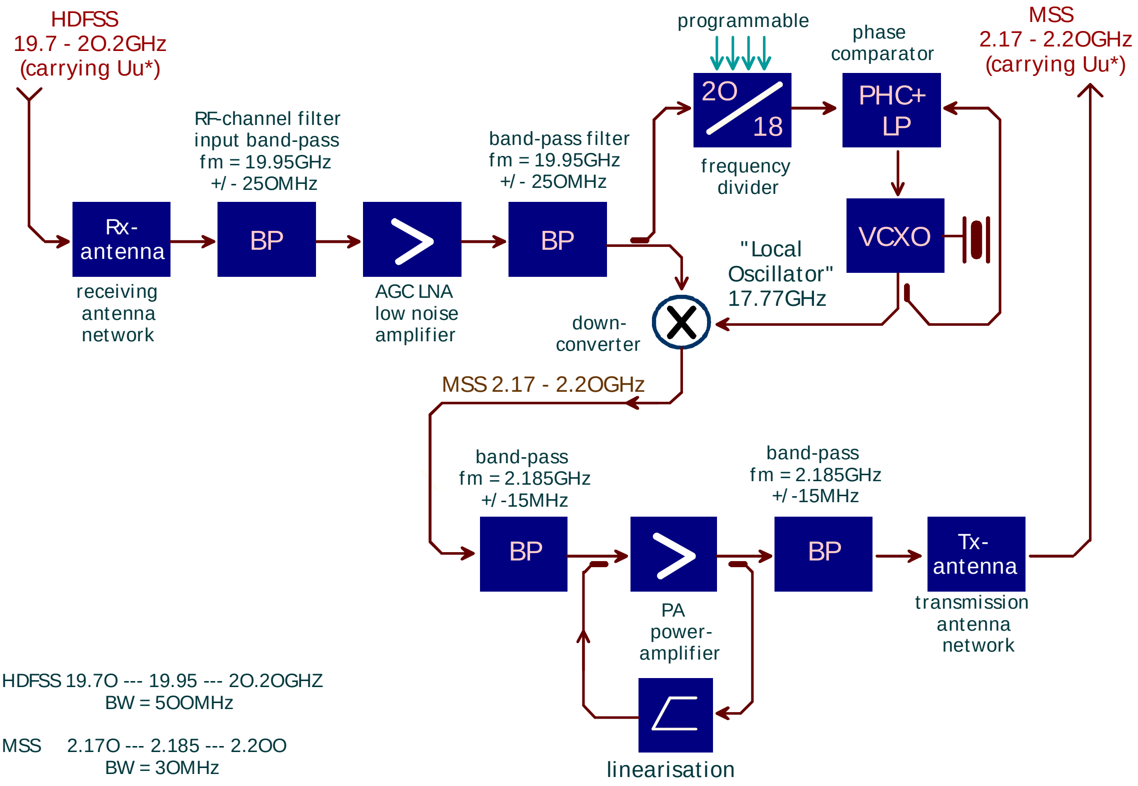


Figure 14: **Basic block diagram for a Frequency Conversion Repeater**

The receiving antenna is connected to the antenna network normally accommodating the diplexer filters and the VSWR-supervision, the former not applicable in the case of **MAESTRO** due to its strong unsymmetry of its input and output signal frequencies as well as potential antenna alignment.

The antenna network is followed by an RF-channel filter band pass (BP) with a centre frequency of 19,950MHz and a width of 500MHz (i.e.,19,950MHz ± 250MHz). This filter re-constructs the incoming HDFSS and, in general, it is to clean the incoming signal and prepare it for the subsequent amplification by a Low Noise Amplifier (LNA), among others equipped with an automatic gain control circuit (AGC).

Subsequently after amplification the signal is cleaned again by a band-pass-filter (BP) with the same characteristics from above in order to avoid unwanted down conversion interfering signal products.

In this suggestion for a Frequency Conversion Repeater (Figure 14) the local oscillator unit (LO) is coupled to the input frequency by a PLL-circuit consisting of a programmable divider, a phase-comparator (PHC) including a low-pass filter (LP) for the VCXO-control loop, and a voltage controlled VCXO oscillator. The loop input signal is extracted from the previous filter by a hybrid. This type of local oscillator coupling assists in avoiding frequency distortions (i.e., carrier offset) by phase and frequency lock.

A more simple configuration is shown in Figure 15, where the local oscillator consists of a high stable programmable VCXO; in this case fixed phase coupling is omitted. Simulations and onsite-measurements should give an answer to the emerged issue.

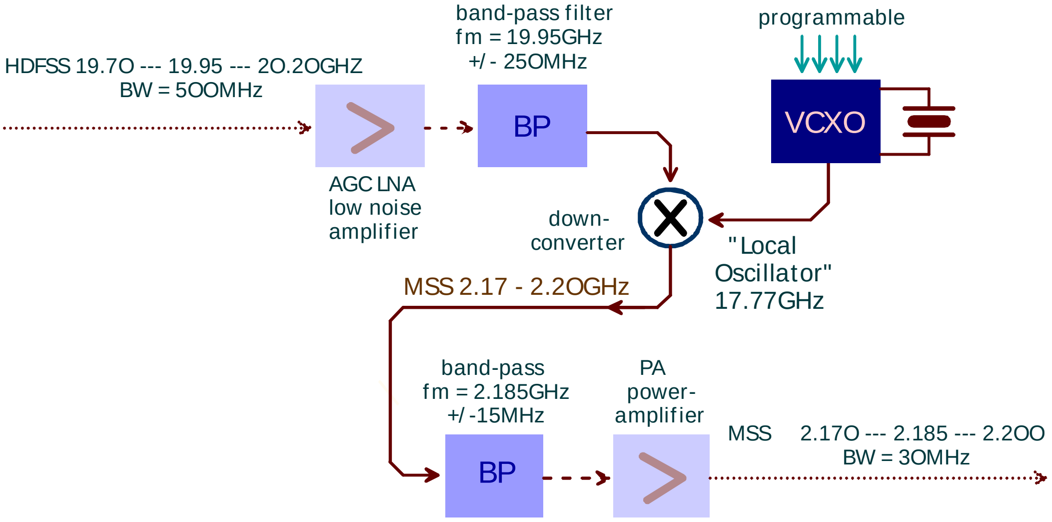


Figure 15: Free-running Local Oscillator

Following the example from above in any case the oscillator frequency must be exactly 17,770MHz in order to produce a MSS-signal accommodating a 30MHz window around the mid-frequency of 19,950MHz. Otherwise, for selection of a defined 30MHz-slot the LO-frequency has to be adjusted as detailed in the next section.

This down-converted signal is cleaned by a band-pass filter with a centre frequency of 2,185MHz and a window of ± 15MHz and afterwards forwarded to the power amplifier (PA), which, for better efficiency, is equipped with a linearisation-loop.

Thus the efficiency gain will be improved from originally 10% towards 15% (W-CDMA signal, 40W output power). A cleaning band-pass filter and the transmission antenna network including the antenna itself will conclude the Frequency Conversion Repeater suggestion. Possible channel mix and the frequency balance is described in the subsequent paragraph.

5.4.4 Frequency Balance

UMTS carried by HDFSS is enabled by an applicable 500MHz-window on the HDFSS capable to carry up to 17 slots of 30MHz size each (see Table 8). Each of these 30MHz slots may accommodate 6 UMTS-carriers. The window is positioned between the edge frequencies of 19,700MHz and 20,200MHz (i.e., resulting in a centre frequency of 19,950MHz ± 250MHz).

Table 8: UMTS over HDFSS

UMTS slot number	UMTS on HDFSS (centre frequency)
#1	19,715MHz
#2	19,745MHz
:	step-size 30MHz
#8	19,985MHz
:	step-size 30MHz
#17	20,185MHz

Down-conversion of those UMTS channels will occur by mixing with the Local Oscillator (LO) frequency (see Table 9). This depicts also a pre-step towards channel scalability described in next paragraph.

The 30MHz-UMTS over MSS is located in a window spreading from 2,170 – 2,200MHz, relating centre frequency is 2,185MHz. The input frequency divider of the LO-PLL must be adjustable in order to enable such a resulting MSS signal of precise 2,185MHz (± 15MHz).

Table 9: Local Oscillator (LO) stepwise programming

UMTS window number	**UMTS on HDFSS (centre frequency)**	**required LO-frequency**	**UMTS on MSS (centre frequency)**
#1	19,715MHz	17,530MHz	2,185MHz
#2	19,745MHz	17,560MHz	2,185MHz
:	**:**	**:**	**:**
:	step-size 30MHz	step-size 30MHz	:
:	**:**	**:**	**:**
#8	19,985MHz	17,800MHz	2,185MHz
:	**:**	**:**	**:**
#17	20,185MHz	18,000MHz	2,185MHz

5.4.5 FCR-Repeater Type Performance

Table 10: FCR-performance parameters

frequency	down-link	19,700 – 20,200	MHz
window size	down-link	500	MHz
CDMA-carriers	adjacent per module	1 – 6	
down-link output power	wide area application	43.0	dBm
	medium area application	40.0	dBm
	local area application	38.0	dBm
	output power step size	1	dB
	output power accuracy	±1.5	dB
down-link power	minimum at full output	-60	dBm
delay	w/o echo cancellation	stbd	us
gain	maximum	145 /automatic setting	dB
	adjust range	115 – 145	dB
return loss		> 15	dB
adjacent channel leakage	1st adjacent channel	-45	dBc
	2nd adjacent channel	-50	dBc
out of band gain (rejection)		-40dB in 200	kHz
far-off selectivity		70	dB

5.4.6 Summarised Parameter Table For FCR Type

Table 11: FCR - IMR signal parameters spec

	FCR
satellite EIRP (over 1.2°)	83dBm
path-loss	-210dB
additional path-loss	-3.5dB
received signal (dBm)	-130.5
thermal antenna noise (3.8MHz BW)	-108dBm
IMR-noise figure	4dB
receiving antenna gain (30*30cm))	34dB

IMR-transmit gain (for local area application)	120.5dB

or:

IMR-transmit gain (for medium area applic,)	134.5dB

or:

IMR-transmit gain (for wide area application)	139.5dB

Signal-To-Noise ratio S/N	**7.5dB**

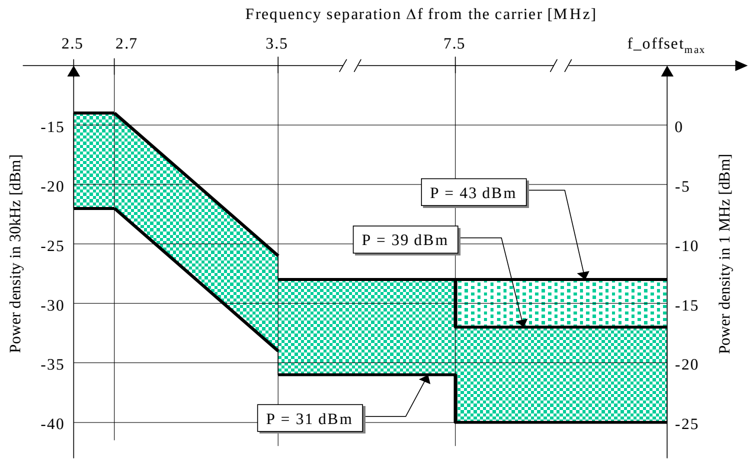
IMR-output power (for local area application)	**24dBm**

or:

IMR-output power (for medium area applic,)	**38dBm**

or:

IMR-output power (for wide area application)	**43dBm**



Illustrative diagram of spectrum emission mask

Figure 16: Spectrum emission mask at reference point

5.4.7 Antennas Design For FCR

For the same reasons as discussed in section 5.3, the Rx antenna size shall be limited to about 30cm. In contrary to the MSS application, for such frequency and diameter a dish antenna can be used. The gain for such diameter should be in the range of 34dB as calculated in chapter 6. The antenna gain (G, [dB]) is defined as:

$$\mathbf{G = \eta*(\pi*d/\lambda)^2 = \eta*(\pi*d*f/c)^2}$$

where:

η = aperture efficiency (typical 0.7 for this frequency)
d = reflector diameter
$\lambda_{\mathbf{HDFSS}}$ = RF-frequency wave length for HDFSS ($15*10^{-3}$)
$f_{\mathbf{HDFSS}}$ = RF carrier frequency for HDFSS (19.950GHz)
c = velocity of light ($3*10^{8}$ m/s)

On the basis of the formula above the diameter calculations lead to a reflector diameters of 0.29m for the HDFSS.

$G_{\mathbf{HDFSS}} = \eta*(\pi*d/\lambda)^2 = \eta*(\pi*d*19.950\text{GHz}/c)^2 = \eta*(208.9)^{2*}d^2 = 30550*d^2$

$G_{\mathbf{HDFSS}}[\text{dB}] = 34 = 10*\log(30550*d^{2)}$ **--->** $\mathbf{d_{HDFSS}} = 0.29\text{m}$

	frequency f	required gain G	diameter d
HDFSS	19.950GHz	34dB	0,29m

5.4.8 FCR-Type Decision Topics

pros for this repeater type:

- clear technical concept allowing less effort for antenna design
- reliable input/output decoupling
- simple and cheap indoor and outdoor solution
- stand-alone capability
- mid complexity, low functionality
- operating without system synchronisation, demodulation and signal processing
- allows unified and less complex hub development
- scalability and extensions
- transparent operation

cons for this repeater type:

- installation cost (infrastructure to be built up)
- not yet available
- weak against content modifications and privacy protection
- privacy and security not satisfying
- no G3 inter-working
- Frequency extraction from the HDFss might become a problem, as the carrier may not be transmitted

The FCR repeater type appears as a reasonable technically solution with a high degree of flexibility Its technology is available (not the device yet) and proved in numerous applications. Its shop cost is expected to remain close to the OCR-type but less expensive as a nodeB. Its sensitivity against environmental changes is lower than for the OCR. The repeater is easy to extend by internally switched local oscillators.

This repeater type is ready to be applied fully flexible fairly without strict beam forming rules, variable reflections feed-back and multipath propagation.

Warning: 2MHz frequency derivation must occur from the 20GHz branch. As the 20GHz carrier is expected to be suppressed some further research effort must be spent for investigations of this issue

5.5 NodeB Based IMR Solution - Descriptions And Specs

5.5.1 NodeB Based-IMR Type Embedding Scheme

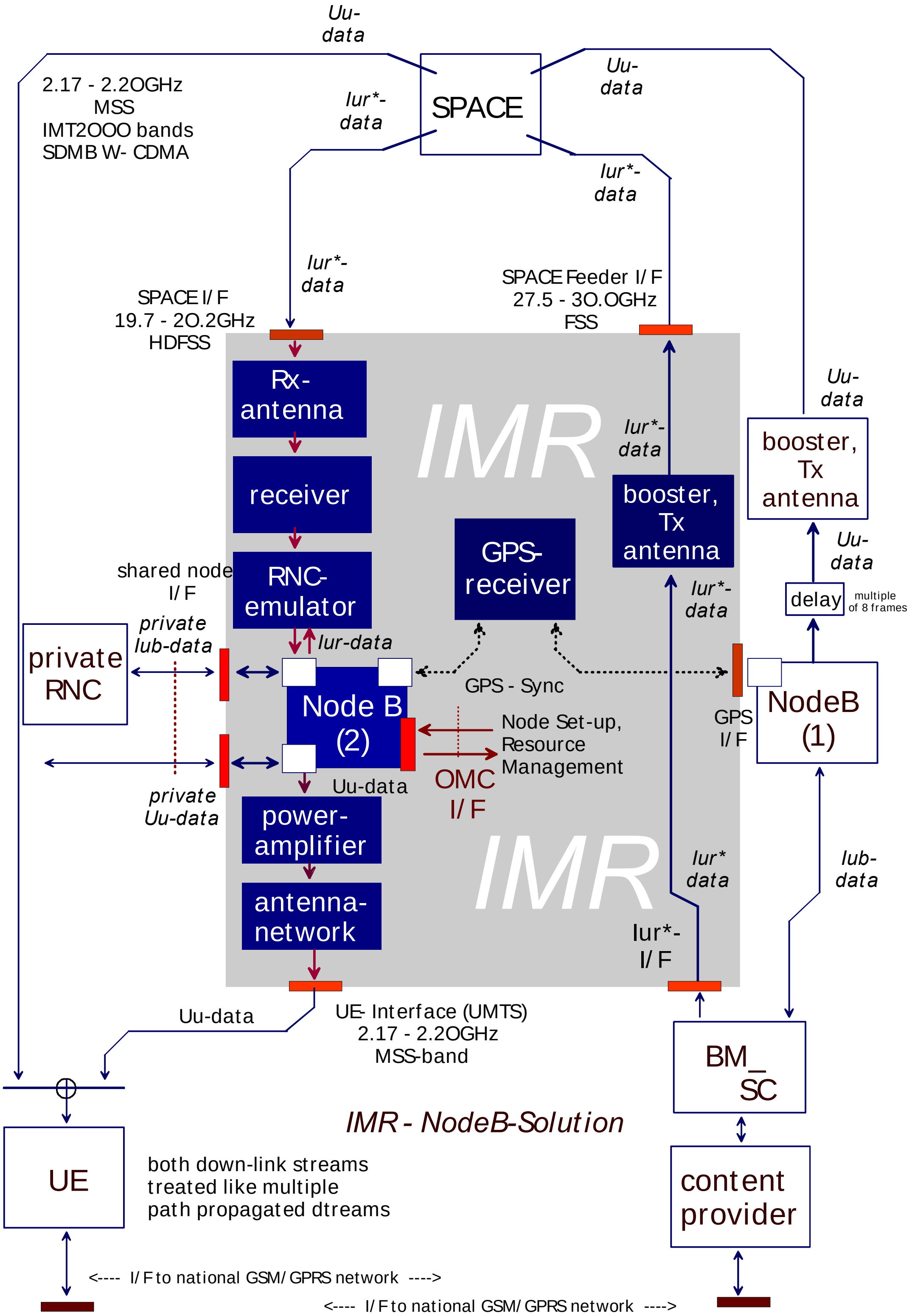


Figure 17: IMR scheme - NodeB based repeater branch

5.5.2 NodeB Based IMR Type Functionality

Figure 17 represents the NodeB based IMR functional architecture, reusing an existing terrestrial mobile network base station in the IMR-branch to comply with the requirement MAE-D6-1.1-C-REQ-089. Though the ambitious topic, **MAESTRO** to share an installed private NodeB with a private network provider, sounds reasonable for making use of the existing communication infrastructure, in equal measure this enlarges the number of additional issues sizably.

Of course, sharing existing NodeBs sounds charming and challenging, as one can act on the assumption that most installed NodeBs are neither fully equipped nor they are operating at the limit.

By applying and sharing a standard NodeB this repeater solution burdens the system concept with numerous technical issues, mainly in the area of synchronisation, propagation time delays and processing time delays.

This is illustrated in Figure 17 where a GPS receiver is assigned to the repeater branch and thus catering for bit synchronism and frame synchronism, between Hub and the repeater NodeB/2. This also requires a specific synchronisation access to the NodeB station unit (SUMU) on the I_{ub} – side. Such access is planned and prepared but not implemented yet and needs further HW and SW adaptation development.

Unfortunately, such synchronism is not sufficient, as propagation delay has to be balanced, too, in the repeater NodeB/2. This balance can only be executed correctly by sending both U_u-data and I_{ub}-data via satellite either to the UE directly as well as processed. The reason for this is that the U_u data has to be delayed within the Hub in order to meet later-on at the UE-interface frame number and assigned frame content timely correct. The required delay steps may be adjusted with steps of multiples of 8 frames duration.

Additionally caused by the large area to be covered satellite signals propagation delays result in up to nearly 10ms, when a satellite signal meets a strict synchronous national or supra-national communication system (calculations in Figure 20).

On the I_{ub} – side of the repeater NodeB/2 provisions have to be made to synchronise both the received data from the satellite as well as the data streams in the private part of the NodeB/2. Additionally private I_{ub}-data have to be multiplexed, at least functional, with the **MAESTRO** I_{ub}-data. As **MAESTRO** is a broadcast system, i.e., one-way I_{ub}-data, supplementary measures have to be taken to allow the NodeB/2 dialogues for cell set-up, common channel set-up, mismatch balance for UMTS frame synchronisation, ATM cell transmission, etc.

NodeB sharing also causes "political" issues, as adaptation to **MAESTRO** requirements goes together with serious restrictions (e.g., 3dB loss by splitters) for the network provider. Those sharing issues are addressed in Figure 28 to Figure 34.

5.5.3 Decision Topics

pros for this repeater type:	**cons for this repeater type:**
▪ re-use of NodeB infrastructure (power supply, etc.)	▪ rake requirements not fulfilled (20us window)
▪ suitable NodeB locations and positions good for node-sharing expected	▪ complete system synchronisation required
▪ required repeater position coincidence with base station location expected (same shadowing issues)	▪ additional satellite band for Iur /Iub transmission ---> different hub architectures
▪ great challenging task	▪ GPS Synchronisation required
▪ approved technology as applied world-wide	▪ conflict with synchronous national networks
▪ Robustness against threads and content modification	▪ not transparent but content processing necessary
▪ Privacy and security strongly protected	▪ unsatisfying system synchronisation required cost / benefit analysis
▪ Future safe	▪ NodeB sharing issue
▪ Available as standard product	▪ down-link demodulation
▪ Expected MTBF	▪ additional outsourced functionality
▪ Robustness against environmental changes	▪ U_u and I_{ub} transmission required
▪ Low additional installation cost	▪ high O&M effort

Though the IMR-type based on NodeB application obviously performs an extreme challenging communication item, the operation effort and the risks of complete failure due to synchronisation issues should be reasons enough for preventing such application.

The NodeB would require nearly an compete OCR-type only for down-link signal reception. The expected sharing issues would not be a serious problem for field trials or other research work but it will lead to perpetual fundamental discussions with the network provider within a commercial environment.

Therefore, as a consequence of most serious technical and commercial issues a NodeB based IMR cannot be recommended.

All further specifications and technical contributions will not any longer deal with NodeB type IMRs; Such repeater type will be only taken into account for interface specifications, as OCR and FCR have to meet the same I/F-requirements (e.g., tolerable, frequency errors, etc.).

5.6 Example Antenna Specifications

5.6.1 Features For the 1-ft GemFire Dish Antenna

The GemFireTM advances the state of the art in point-to-point radio antennas. Utilising proprietary design tools, the GemFireTM was developed to provide superior side-lobe and gain characteristics, while eliminating the conventional bulky shroud. The result is a smaller, more rugged, attractive antenna which outperforms competing designs. The slim GemFireTM profiles provide an excellent solution to rooftop and pole clutter. While these antennas are well suited for indoor mounting, they are designed to survive severe outdoor environments.

General Facts & Features:

- exceeds all FCC, ETSI and BAPT requirements.
- clean compact design.
- reduced wind-loading.
- feed input is ODU specified, other interfaces on request.
- designed for easy OEM ODU interface.
- meets or exceeds standards EIA-195-C and EIA-222-F.
- multiple mounting options.
- stainless steel hardware & components.
- easy to install and align.

Table 12: Mechanical specification

frequency range	17.70 – 23.60GHz
fine elevation	+/-20°
coarse elevation	+/-20°
fine azimuth	+/-20°
coarse azimuth	+/-180°
polarisation	V or H
dish diameter size	0.3m
pipe diameter	48 - 112mm

Table 13: Electrical Specifications

frequency	17.70 – 19.70 GHz	21.20 – 23.60 GHz
diameter	0.3m	0.3m
standards (see below)	c	d, e, f, g
gain at low	33.0dB	34.1dB
gain at mid	33.2dB	34.5dB

gain at high	33.8dB	35.0dB
nominal mid-band beam-width degrees	2.5^0	2.8^0
XPD	28dB	28dB
F/B ratio	55dB	60dB
VSWR max	1.5	1.5

c : ETSI Standard ETS 300-833 class 2
d : DTI Standard MPT-1409
e : ETSI Standard ETS 300-198
f : German BAPT 92/23 GHz
g : ETSI Standard ETS 300-833

5.6.2 Features For the (1-ft * 1-ft) Flat Patch Panel Antennas

A new generation of Point-to- Point antenna products exhibits wide bandwidth and high efficiency. They are currently available in 2.4GHz, 5GHz and 10GHz frequency bands.

Flat Panel Antennas are available in 0.15m, 0.3m and 0.6m sizes with a thickness of only 25 mm). The antennas small size and profile makes it an ideal choice when concealment of site antennas is necessary. For **MAESTRO** application a panel size of 30*30cm would be suitable.

In addition to the antenna’s size, it is easily concealed to blend into any architectural environment. These antennas are extremely easy to install and align.

The antenna input connector is located on the back of the panel. Two mount types are available for the Directional Flat Panel Antenna line:

- Mini-Mount standard on the 0.5 ft. and most 1 ft. models. The Mini-Mount mounts to a 1.9 in. (48 mm) to 4.5 in. (114 mm) O.D. mast pipe.
- Quick-Align Mount is Standard on the 2 ft. and is optional on the 1 ft.

General Facts & Features:

- lightweight and durable construction.
- quick and easy installation.
- input connector positioned on back of antenna assembly.
- meets or exceeds Standards EIA-195-C and EIA-222-F.
- antenna accommodates +/-20° elevation adjustment.
- antenna mounts to a 50 - 115 mm diameter
- vertical mast pipe.

Table 14: Electrical Specifications

frequency	2.30 – 2.5GHz
size	0.3*0.3m
standards (see below)	c
gain at low	16.2dB
gain at mid	16.5dB
gain at high	16.8dB
nominal mid-band beam-width degrees	22^0 / 21^o
XPD	28dB
F/B ratio	28dB
VSWR max	1.5

5.7 System Variants Evaluation Process

5.7.1 Selection Criteria (PRO&CON Matrix)

The subsequent evaluation table may be regarded as an attempt to find objective selection criteria as a pre-step for the later economical considerations. Unfortunately all addressed parameters have a close relationship to either each other or to the other IMR components; pros might balance cons and so far. The application of e.g On-Channel repeaters may be advantageous as far as satellite and Hub are concerned; it might be not to be the optimal solution, when the use of directed antenna configurations will be discussed.

From the specification work before a number of different criteria could be extracted but already during the pre-steps for understanding the system it became clear that classifying the applied IMR types is strictly bound to precise system application targets.

If, for reasons whatever, a strict synchronisation of 3G and 4G equipment is required (e.g., new types of networks, 4G+), then only and only the NodeB-type must be applied. In other cases the OCR and the FCR will be sufficient.

If indoor application is preferred, the OCR would mean the most efficient candidate. In this case a most stable environment will be required in order to keep input and output data streams strictly separated to each other.

If installation without much subsequent maintenance is wanted, then the FCR will play an advantageous role.

Though expectations in this decision matrix was extremely high, it soon became clear that the total number of freedom degrees and mutual dependencies is too high for forming the basis for a strict, complete and well founded decision procedure.

This is, roughly spoken, the start position for the subsequent table, where the attempt was made to extract equipment figures, put them into context and try to come to a decision. All criteria were made from the view of the IMR.

Selection criteria	**OCR**	**FCR**	**NdB**
Additionally required infrastructure (e.g., power supply)	–	–	**+**
Expected operation and maintenance effort	**0**	**0**	–
Installation issues	–	**+**	**++**
Installation cost factor (due to effort and equipment cost)	**++**	**0**	– –
Robustness against environmental changes (short-term, long-term)	– –	**+**	**++**
Expected MTBF	**+**	**+**	**++**
Synchronisation issues (general):	**++**	**++**	– –

in particular: GPS-coverage	**++**	**++**	–
In particular; GSM (GPRS) / UMTS Environment	**++**	**++**	– –
System complexity	**++**	**+**	– –
System flexibility	**0**	**0**	**0**
Robustness against regularity	**0**	**0**	**0**
Robustness against standards changes	**+**	**+**	**+**
Ability for equipment sharing	–	–	**+**
Privacy and security	– –	–	**++**
Robustness against threads and content modification	– –		**++**
Future safe:	–	**0**	**++**
in particular: extendable	**++**	**++**	**+**
in particular: adapted capacity /scalable	**++**	**++**	**+**
in particular: re-usability	–	–	**++**
Acceptance by external providers	**0**	**0**	– –
Acceptance by public	**0**	**0**	**0**
Availability	**+**	– –	**+**
Possible adaptation development effort (e., antenna decoupling)	**++**	**0**	
Efficiency (based on individually tailored concepts)	**0**	**0**	**0**
Adaptation development effort	–	– –	– –
Availability Of Suitable Equipment	**+**	– –	**++**
Satellite (U_U only; I_{ub} only, both)	**++**	**+**	–
Repeaters (replace effort)	**++**	**+**	–
Antennas (quality requirements, availability)	– –	**+**	**+**

OCR = On-Channel Repeater
FCR = Frequency Covnertion Repeater
NdB = NodeB based Repeater

– – **= extremely unfavourable**
– **= unfavourable**
0 = neither nor
+ = advantageous
++ = very advantageous

6 ANNEX 1 – DEDICATED INVESTIGATION RESULTS

6.1 Signal And Noise Calculations, Antenna

6.1.1 Purpose

This paragraph is intended to lay the basis for both the specification of the IMR-interfaces and, in this context, an optimal selection of IMR receive antennas. Such calculations are helpful, too, for giving a strong feed-back on the IMR-architecture and thus on the IMR selection criteria.

An actual example can be given for the remaining OCR and FCR-repeater type, where infavourable signal-noise conditions at the repeater entry might not allow a reliable operation and driving the subsequent UE as well.

At the time the S/N calculations were executed there was no final decision made yet whether the OCR, the FCR or both would remain candidates for an application within the **MAESTRO** System. The consequence of this fact is to make all S/N considerations separately for the OCR operating in the MSS-band and the FCR in the HDFSS-band respectively.

6.1.2 Loss Calculations From Satellite To IMR-Entry

(a) Contributing Feed And Loss Entities:

The subsequent paragraph lists contributing feed and loss sources and figures from satellite to earth´ surface distance. Some of the figures are average figures due to wide spread minimum and maximum values:

- EIPR (Effective Isotropic Radiated Power):

  The satellite transmission power is indicated as >71.0dBW to >72.5dBW (i.e, >101...>102.5dBm) both over an hotspot angle of 1.2º..[**MAESTRO** SDMB Overview, Jan. 2004]

- Path Loss (PL):

  Path Loss (PL) happens to the signal between the time it leaves the satellite antenna and the time it appears at the input devices of the IMR. Path loss is dependent of the satellite´s down-link frequency and the distance between satellite and earth´ surface.

- Additional Path Loss (APL):

  Additional path loss (APL) is caused by rain, snow, fog, etc. APL strongly depends on frequency and altitude angle, also on the consistence of precipitation, clouds density, etc.

(b) Path-Loss Calculation

Path-Loss (PL) is dependent of the satellite´s down-link transmission frequency and the distance between satellite and earth´ surface. The subsequent formula assists in path loss calculation (source: SeattleWireless):

$$\mathbf{PL = 20\ log_{10}\ (4 * \pi * \mathit{d}s\ /\ \lambda) = 20\ log\ (4 * \pi * \mathit{d}s * f\ /\ c)} \qquad \text{[formula 1]}$$

where: f : signal frequency depending on the transmission band
c : light speed ($c = 3*10^8$m/s)
λ : signal wavelength (c/f) depending on the transmission band
ds : distance between satellite and earth surface

According to their dependencies path loss calculations have to be executed separately for both the MSS and the HDFSS branch. Table 16 below totals the necessary parameters and the resulting path loss figures for the MSS and the HDFSS bands from satellite to IMR-entry. In the following the calculation parameters for path-loss parameters and calculations are listed for both the MSS and HDFSS.

Table 15: Path-Loss Calculation Parameters

	mid frequency f [MHz]	lower / upper edge b [MHz]	wave length λmid [m]	light speed c [m/s]	distance ds [m]
MSS	**2,185**	**± 15**	**$138*10^{-3}$**	**$3.0*10^8$**	**$3.6*10^7$**
HDFSS	**19,950**	**± 250**	**$15.0*10^{-3}$**	**$3.0*10^8$**	**$3.6*10^7$**

The above parameters inserted in [formula 1] deliver the path-loss results as shown in Table 16 below:

Table 16: Path-Loss (PL) calculation results

		MSS			**HDFSS**		
		lower edge	**mid**	**upper edge**	**lower edge**	**mid**	**upper edge**
frequency	[Hz]	$2,170*10^6$	$2,185*10^6$	$2,200*10^6$	$19,700*10^6$	$19,950*10^6$	$20,200*10^6$
λ	[m]	0.138	0.137	0.136	0.0152	0.0150	0,0149
PL	**[dB]**	**190.3**	**190.4**	**190.4**	**209.5**	**209.5**	**209.7**

For further calculations it will be sufficient to use the mid frequency and the mid-λ respectively.

Path-Loss PL = 190dB [for MSS]
Path Loss PL = 210dB [for HDFSS]

These figures from above form the basis for power budget calculations for both the MSS and the HDFSS-band; results are depicted in subsequent Table 17 and Table 18.

(c) Additional Path Loss Assumptions

Additional Path-Loss(APL) figures will be gained by assumptions based on a so called standard atmosphere and dependencies of frequency and elevation angle (see. Figure 18, source Maral/Bousquet, page 18). The standard atmosphere is defined as a mixture of snow, rain, fog, clouds, etc.), The related elevation angle (E) can be calculated to:

E = $90^{\underline{0}}$ – latitude = $90^{\underline{0}}$ – $49^{\underline{0}}$ = $41^{\underline{0}}$ (example Stuttgart)

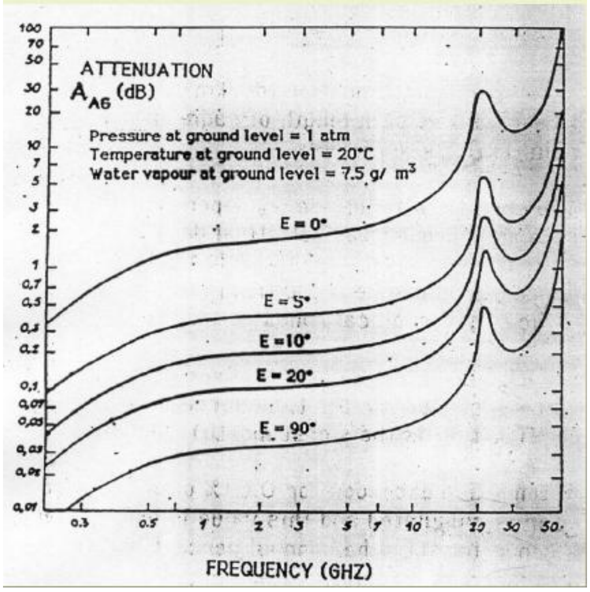


Figure 18: Curves for gaining Additional Path-Loss figures

This elevation angle together with the both MSS and HDFSS frequencies (as indicated in Figure 18 deliver additional loss figures of nearly 0dB in case of MSS and around 0.4dB for the HDFSS respectively. For reliability reasons fade margins will be introduced adding around 3.5dB additional loss to the path-loss figures. Based on a link availability of 99.5 %, the rain losses is in average of 2.9 dB and 0.6 dB for gas attenuation providing therefore an overall losses of 3.5 dB.

Additional Path-Loss APL = 0 dB	**[**for MSS**]**
Additional Path-Loss APL = 3.5dB	**[**for HDFSS**]**

It is important for all power link calculations to define an exact position of the receiving antenna, in particular the azimuth and elevation angle. Noise figures can change severely when directing the antenna to the (cold) space, the (hot and moving) sun and combinations of both as well as "men made noise" in the low elevation area.

(d) IMR S/N Ratio Calculations For MSS And HDFSS Connection

Table 17: Signal and noise course (for MSS-band)

	signal [dB]	noise [dB]	Σ signal [dBm]	Σ noise [dBm]	Line Nº
IMR-Air I/F					
satellite EIRP (over 1.2°)	102dBm		102.0		(#1)
path-loss	-190		-88.0		(#2)
additional path-loss	0		-885		(#3)
received signal (dBm)			-88		(#4)
receiving antenna					
thermal antenna noise (3.8MHz BW)		-108		-108	(#5)
receiving antenna gain (e.g., 0.3m diameter)	15		-73		(#6)
analogue IMR					
IMR-noise figure		4dB		-104	(#7)
IMR-transmit gain (for local area application)	97		**24**	**-7**	(#8)
or:					
IMR-transmit gain (for medium area applic,)	111		**38**	**+7**	(#9)
or:					
IMR-transmit gain (for wide area application)	116		**43**	**+12**	(#10)
the resulting S/N figures:					
S/N (for all applications):			**31dB**		(#11)

Discussion on Table 17 and Table 18:

Both tables above and below are to depict the IMR input and output specifications. The table is based on the preceding calculations of signal and noise power. It commences with an EIRP of:

<101...< 102...< 102.5dBm, line (#1) for MSS
< 82...< 83...< 83.5dBm, line (#1) or HDFSS.

This signal is attenuated by Path-Loss (PL) and Additional Path-Loss (APL) together –190dB in case of MSS, thus the received signal power will become–88dBm. In case of HDFSS Path-Loss and Additional Path-Loss will go up to –213.5dB and the received signal power will become –130.5dBm, lines (#2 to #4).

Table 18: Signal and noise course (for HDFSS-band)

	signal [dB]	noise [dB]	Σ signal [dBm]	Σ noise [dBm]	Line Nº
IMR-Air I/F					
satellite EIRP (over 1.2°)	83dBm		83.0		(#1)
path-loss	-210		-127.0		(#2)
additional path-loss	-3.5		-130.5		(#3)
received signal (dBm)			-130.5		(#4)
receiving antenna					
thermal antenna noise (3.8MHz BW)		-108		-108	(#5)
receiving antenna gain (0.3*0.3m diameter)	34		-96.5		(#6)
analogue IMR					
IMR-noise figure		4dB		-104	(#7)
IMR-transmit gain (for local area application)	120.5		**24**	**+16.5**	(#8)
or:					
IMR-transmit gain (for medium area applic,)	134.5		**38**	**+30.5**	(#9)
or:					
IMR-transmit gain (for wide area application)	139.5		**43**	**35.5**	(#10)
the resulting S/N figures:					
S/N (for all application):			**7.5dB**		(#11)

The thermal antenna noise related to a bandwidth of 3.8MHz would be –108dBm in both cases, line (#5).

As an realistic example for both cases, too, two different antenna types were applied. For the MSS a flat patch panel type was chosen, while for the HDFSS a 0.3m dish antenna was sufficient. The potential antenna diameter was chosen to 0.3*0.3m which results in an antenna gain figure of 15dB for MSS and 34dB for HDFSS respectively; the total signal power up to here is –88dBm (MSS) and –130.5dBm (HDFSS), line (#6).

The subsequent calculations are based on an reasonable assumption, namely that the IMR output should show the same power behaviour like a down-link NodeB antenna specified in 3GPP (TS25 104). Three cases can there be distinguished:

wide area		+43dBm
medium range	<	+38dBm
local area	<	+ 24dBm

Such three power classes are defined as $P_{\mathbf{max}}$ of the base station; It is the mean power level per carrier measured at the antenna connector. With respect to the role the IMRs are playing in the **MAESTRO** project, the "wide area case" may not be applied as the purpose of the IMR is to cater for signal reception in rather narrow shadowed areas; consequently the "local area case" might be the most applied one.

Assumptions were also made on the noise figure of an analogue IMR, taking into account experience with analogue amplifiers and signal processors. A realistic value for the IMR noise figure will be about 4dB, line (#7).

In order to meet the three 3GPP-power classes, in case of MSS an IMR internal amplification gain of 97...111...117dB is required leading to output power figures of 24...38...43dBm as specified in 3GPP, lines (#8), (#9), (#10). The internal amplification gain maybe kept adjustable with respect to the wanted gain.

In case of HDFSS the amplification gain must be set to 120.5...134.5...139.5dB in order to come up with the same output figures as achieved by the MSS version.

With these figures the signal to noise ratio remains positive with more than 6dB signal over noise, i.e., correct operation can be expected. The S/N figures are 31dB in case of MSS, while in case of HDFSS the relation goes down to 7.5dB, line (#11).

(e) Conclusions From The S/N-Calculation

MSS for OCR:

- On-Channel-Repeater (OCR) applicable
- directed antennas for strict input/output separation mandatory
- receive antenna gain 15dB
- noise figures excellent S/N = 31dB
- internal gain adjustable 97...111...116dB
- meets 3GPP power classes for down-link base stations

HDFSS for FCR:

- Frequency-Conversion-Repeater (FCR) applicable
- directed antennas recommended
- receive antenna gain 34dB
- noise figures satisfying S/N = 7.5dB
- internal gain adjustable 120.5...134.5...139.5dB
- meets 3GPP power classes for down-link base stations

(f) Summarised RF-Parameter Table For OCR And FCR Types

Table 19: IMR RF-signal parameters spec

	OCR	**FCR**
satellite EIRP (over 1.2°)	102dBm	83dBm
path-loss	-190dB	-210dB
additional path-loss	0dB	-3.5dB
received signal (dBm)	-88dBm	-131dBm
thermal antenna noise (3.8MHz BW)	-108dBm	-108
IMR-noise figure	4dB	4dB
receiving antenna gain ()	15dB	34dB

IMR-transmit gain (for local area application)	97dB	120.5dB

or:

IMR-transmit gain (for medium area applic,)	111dB	134.5dB

or:

IMR-transmit gain (for wide area application)	116db	139.5dB

Signal-To-Noise ratio S/N	**31dB**	**7.5dB**

IMR-output power (for local area application)	**24dBm**

or:

IMR-output power (for medium area applic,)	**38dBm**

or:

IMR-output power (for wide area application)	**43dBm**

6.1.3 Antennas Design

Required antenna gain, RF-frequency, reflector diameter as well as flat patch panel size form the basis for physical antenna design. As shown in chapter 5, in case of **MAESTRO** OCR type repeaters connected to the MSS will require a flat patch panel antenna, while the FCR type connected to the HDFSS will do with dish antenna technology.

The following calculations were done aiming at the definition of the IMR input and output RF-figures. These calculations ended up with antenna gain requirements of 15dBi for the MSS connected OCR and 34dBi in case of HDFSS connected FCR.

Rough estimations allow application of gain calculations also for flat patch panel typs by using the same antenna gain calculations for reflector antennas. The antenna gain G is defined as:

$$\mathbf{G = \eta*(\pi*d/\lambda)^{2} = \eta*(\pi*d*f/c)^{2}}$$

where:

η_{MSS} = aperture efficiency (typical 0.55)
η_{HDFSS} = aperture efficiency (typical 0.7)
d = reflector diameter (30cm) / flat panel size (30*30cm)
λ_{MSS} = RF-frequency wave length for MSS ($138*10^{3}$ m
λ_{HDFSS} = RF-frequency wave length for HDFSS ($15*10^{3}$)
f_{MSS} = RF carrier frequency for MSS (2.185GHz)
f_{HDFSS} = RF carrier frequency for HDFSS (19.950GHz)
c = velocity of light ($3*10^{8}$ m/s)

On the basis of the formula above the diameter calculations lead to a patch panel size of 30*30cm respectively a reflector diameters of 0.3m for the MSS and the HDFSS respectively.

$$G_{MSS} = \eta_{MSS}*(\pi*d/\lambda)^{2} = \eta_{MSS}*(\pi*d*\ 2.185GHz/c)^{2} = \eta_{MSS}*(22.88)^{2}*d^{2}$$
$$= 288*d^{2}$$

$$G_{HDFSS} = \eta_{HDFSS}*(\pi*d/\lambda)^{2} = \eta_{HDFSS}*(\pi*d*19.950GHz/c)^{2} = \eta_{HDFSS}*(208.9)^{2*}d^{2}$$
$$= 30550*d^{2}$$

G_{MSS}[dB] 15 = $10*\log(288*d^{2)}$ **ˉ-- ---> d_{MSS} =** 0.3*0.3m (panel size)
G_{HDFSS}[dB] 34 = $10*\log(3055*d^{2}$**)** **-----> d_{HDFSS} =** 0.29m (diameter)

	frequency *f*	**required gain *G***	**diameter d**
MSS	2.185GHz	15dB	0,3*0.3m (panel size)
HDFSS	19.950GHz	34	0.29m (diameter)

6.2 Distance And Delay Considerations

6.2.1 Distance Consideration Between Direct Link And IMR Link

In addition to the compensation of HTI and IMR NodeB processing time described in the previous section, which is performed at frame level, the signal coming directly from the satellite must be aligned with precision with the signal coming through the IMR.

As shown in, Figure 19 the geo stationary satellite being at ds = 36,000km from the earth, it can be estimate that:

- ds - di < dt; - di induces a fixed reception delay (or advance) D1, of maximum 10 / 300,000 = 33µs, if dt = 10km.
- D1 is constant and depends on the location of the IMR relatively to its satellite.

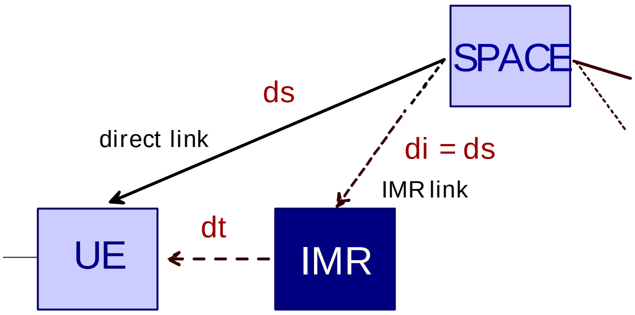


Figure 19: Distances through direct link and IMR link

In addition, a variable delay D2 is provoked by the distance dt between the UE and the IMR. The reception of two identical signals with a time difference more than the rake window duration (20us) causes interference and then degrades the reception performance.

Considering that the rake receiver in the UE can recombine signals received with a time difference of up to 20 µs, the IMR transmission power should be limited to cover a defined maximum distance. The approximate cell size can be calculated by:

DRake = 20 µs x 300,000km/s = 6km.

DRake seems compatible with the fact that the IMRs will be installed in dense urban areas, where the goal is not to cover a very large cell.

6.2.2 Distance Considerations (between north and south beam limits)

(a) "Beam Delay" Variants

This briefly explained issue is only relevant for a synchronised IMR application. In this concept the RNCs and NodeBs together with the GPS cater for bit- and frame synchronism and additional forced frame content delays. This fact requires a fully synchronised network of RNCs and NodeBs, i.e., a time delayed satellite beam has to operate with a fully synchronised network.

Depending on the actual delay time – as calculated below – the propagation delay time of the beam may fit into those time constraints or not. As these different propagation delay is a physical phenomena and can only be adjusted (in the hub) once for the whole system, no additional balance can be applied.

It is now subject of the subsequent considerations to find out whether propagation delay variants will support/skip the synchronous system concept.

(b) Simplified Model By Neglecting The Longitude

In order to give a first overview on the delay problem an initial simplification is applied. The restriction is made by calculating only in a two dimensional sphere which might be sufficient for the first batch. Depending on the outcome results a three-dimensional calculation can be added, if necessary. Subsequent Figure 20 gives a view on the relevant parameters and distances.

The satellite SAT is assumed to be positioned in orbit on the equatorial line in a distance ***d*s** of 36,000km. Its Cartesian co-ordinates are [xSAT │0]. The earth radius R is assumed to 6,366km.

The satellite´s beam covers an latitude area between 35 (α1)and 65 (α2) degrees north represented by the Surface Points **SF1** and **SF2** with its co-ordinates [x1│y1] and [x2│y2].

Caused by the deflection of the earth surface the distances between satellite and **SF1** (**ds*1***) differ to that between satellite and **SF2** (**ds*2***).

It is now matter of this investigation to prove that all UEs on the curve between **SF1** and **SF2** receive the broadcast data stream within the Rake´s tolerance frame of about 20us. Increasing this value would mean that the UEs cannot combine the received signals; they will be regarded as non-correlated signals.

The simplification is made by neglecting the longitudinal angles 10 to 30 degrees and thus not calculating in a three-dimensional space.

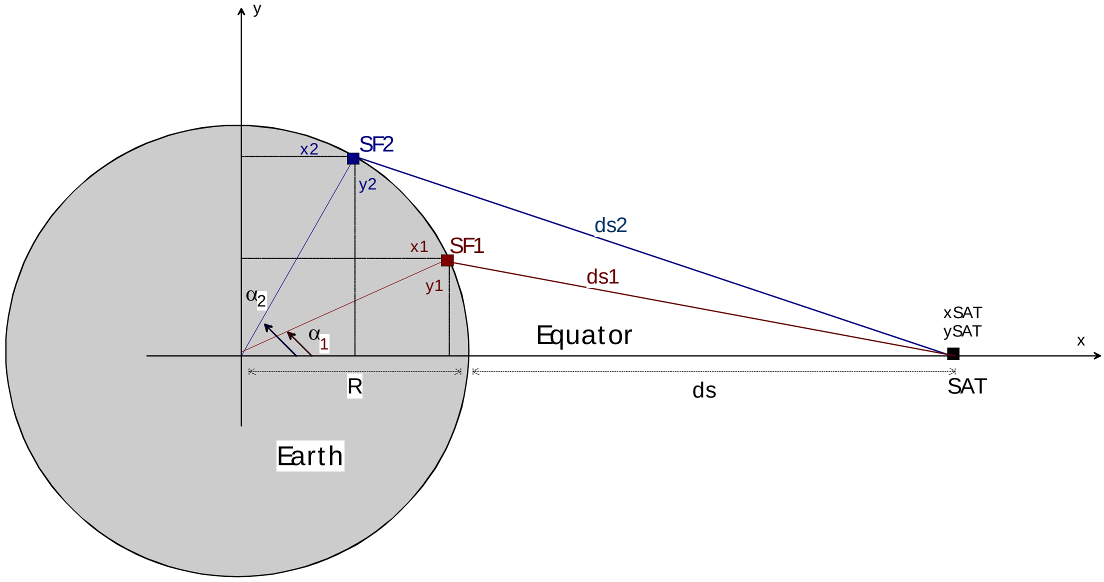


Figure 20: Propagation delay variants

(c) Assumptions And Calculations

- Earth radius : **R** = 6,366km
- Satellite distance : **D** = ***ds*** = 36,000km
- Latitude : α_1 = 35°
  α_2 = 65°
- Co-ordinates : **SAT** = [R+D | 0]
  SF1 = [R cosα_1 | R sinα_1]
  SF2 = [R cosα_2 | R sinα_2]

Taking the figures from above the distance difference between most south (***ds*1** from **SAT** to **SF1**) and most north (***ds*2** from **SAT** to **SF2**) surface points can be calculated by:

$$d1 = \sqrt{(R + D - R\cos\alpha_1)^2 + (R\sin\alpha_1)^2}$$

$$d2 = \sqrt{(R + D - R\cos\alpha_2)^2 + (R\sin\alpha_2)^2}$$

Inserting the parameters from above the distances will result in:

$$d1 = 37{,}331km$$

$$d2 = 40{,}090km$$

The two-dimensional distance between the both north and south surface points can thus be calculated to:

$$\delta d = d2 - d1 = 40{,}090km - 37{,}331km = 2{,}759km$$

6.2.3 Conclusions Gained In Distance And Delay Considerations

The above calculations can offer a granularity of 66.6us, while the UE-RAKE receiver normally accepts only a 20us maximum window.

- As also further explained in Chapter 6.3, the resulting granularity of the standard UMTS to adjust the timings consequently is not sufficient enough.

The addressed 20us limitation was originally based on a measurement regulation bearing in mind narrow cell sizes. This rule might be overcome, in particular for a demonstration system, but anyway, quality decrease has to be expected.

The reason can be seen in the functionality principle of the Rake, as this device gathers **all** received signals as long as the window is open and thus the size of the sampling window decides on the quantity and, finally, quality of the re-combined signals.

- One solution could be seen in the upgrade of the 3GPP-specifcations in order to enable time adjustments with a granularity below 66µs.

Another issue, apart from sharing problems, complicates the application of a NodeB as terrestrial repeater. For a given frame, the NodeB frame number (BFN) in the Hub NodeB and the BFN in the IMR NodeB must be equal (the BFN is used to transmit the SFN to the UEs). The BFN depends on each NodeB start-up time, and cannot be controlled; therefore, the BFN in the Hub and in the IMR will be different.

- One solution could be to upgrade the 3GPP specifications a second time and thus enabling BFN setting through the I_{ub}.

This would result in 460 cells along the borderline (6km cell size assumed) or, for the whole three-dimensional area in total 211,600 cells.

The above calculations result in a time delay difference of 9.2ms between the most north and the most south beam-point within the beam-covered area, even, like in this example, a simplified model (only two dimensional) is applied. Otherwise the results would have to be multiplied by $\sqrt{2}$, which in any case might be too large to enable broadcast and node-sharing in an area of synchronised NodeBs.

- The severely differing propagation delay times within the covered area (9.2ms) will probably force the system concept to desist from synchronised broadcast systems such as **MAESTRO**.

It should be mentioned again that such 9.2ms delay variation within the covered surface have nothing to do with the Rake particularities but with the synchronism of the underlaying national or inter-national communication systems.

7 ANNEX 2: SYNCHRONISATION

All in the following discussed synchronisation issues are mandatory for a **MAESTRO** system based on synchronous NodeB infrastructure. They are not relevant when basing the system on OCR and FCR repeater architectures.

7.1 Synchronisation Issue Studies Between Hub And IMR

7.1.1 Usage Of UMTS And NodeB Based Repeaters

Application of UMTS-Repeaters of On-Channel type and/or Frequency Conversion type requires no specific synchronisation measures, as they operate in independently in stand alone mode.

Data streams sent by the hub and radiated by the satellite can be received everywhere (apart from shadowed areas) without any remarkable time delay; processing delay within the repeater must be kept below the 20us limit, as otherwise the UE-rake receiver will no be in a position to combine the different signals originated in the satellite and in the repeater.

In principle the subsequent issues only arise, if the transmitted U_u is going to be re-generated on the basis of an I_{ub} and/or I_{ur} signal. From this point on strict synchronisation between the hub-NodeB, the IMR-NodeB and, in general with a fully synchronised communication environment.

7.1.2 Synchronisation Of NodeB Based Repeaters

(a) Mandatory Synchronisation

Obviously, applying a NodeB to the IMR-branch and, additionally use it for shared traffic, will cause higher-than-average problems. As an application of a NodeB based repeater only makes sense for sharing NodeBs with a private network provider, a huge amount of synchronisation effort has to be spent for synchronising the **MAESTRO** broadcast data with the data from the private providers, and this at least nation-wide. Six different types of synchronisation targets between the hub, the repeaters and the private NodeBs have to be aspired:

- Bit-synchronism
- Frame-synchronism (SFN and CFN)
- Synchronisation between the RNC and its NodeBs;
- Synchronisation of NodeBs among each other;
- Frame-content balance
- Propagation delay balance

Bit-synchronism and frame-synchronism can be achieved by applying a GPS system, while synchronisation between RNC and its NodeBs respectively NodeBs among each other can be achieved by the regular I_{ub} and I_{ur} interfaces. Nevertheless, the issues how to synchronise the frame content and how to balance propagation delay times in the area of ms shall be discussed subsequently.

(b) Summary On Existing Procedures For Frame Content Balance

The SFNs of both NodeBs (hub NodeB and shared **MAESTRO** NodeB) are not synchronous. This is the main difference to the synchronisation of radio links in the soft hand-over situation, where corresponding Cell Frame Numbers (CFNs) are equal. As the terminal does not see the frame numbers, it is the RNC which could recalculate the appropriate BFN/SFN for the 2nd NodeB thus the content is delivered time-synchronous over different SFNs of the two NodeB's S-CCPCH.

Furthermore the application of the existing procedures would require for the UE to provide a larger window for the processing of the two signal streams.

(c) Synchronisation Procedure

Synchronisation of and by means of NodeBs aims at the achievement of common timing references among different nodes. Though normally not required, for some specific applications (like IMR inter-working / inter-operation) such synchronisation will become mandatory.

In order to avoid buffer-times and thus speeding up the transmission delay, it could be suitable to estimate the timing differences between RNC and NodeB without the need to compensate the phase differences within the NodeB´s internal counters. This is the reason why UTRAN provides this three synchronisation mechanisms over I_{ub} as mentioned above:

- synchronisation between the RNC and its NodeBs;
- synchronisation of NodeBs among each other;
- frame synchronisation.

The synchronisation between the RNC and its NodeBs is shown in Figure 21. The Round Trip Delay (RTD) is calculated [3GP1]:

RTD = T2 ... T1 and T4 ... T3

- **T1**-specific frame number (RFN) indicates the time when RNC sends the down-link Node Sync Control Frame (DL-NSCF) through SAP to transport layer.
- **T2**-NodeB specific frame number (BFN) indicates the time when NodeB receives the correspondent DL-NSCF through SAP from transport layer.
- **T3**-NodeB specific frame number (BFN) indicates the time when NodeB sends the DL-NSCF through SAP to transport layer.
- **T4**-RNC specific frame number (RFN) indicates the time when the RNC re ceives the up-link UL-NSCF Node Sync Control frame.

Each T1, T2 and T3 covers a range between 0 – 40,959.875ms with a step size of 0.125ms; T4 is not standardised yet.

The node synchronisation between the RNC and NodeB can be used to detect differing timing references between the UTRAN nodes (RFN in RNC and BFN in NodeB); in particular, synchronisation is required for the transport channels between RNC and their connected Nodes both for determination of up-link and down-link offset values.

Measured values of timing relationships between those nodes are gained by the RNC-NodeB Synchronisation Procedure. This procedure is defined in the user plane protocols for I_{ub} (DCH, DSCH, and FACH/PCH) and I_{ur} (DCH).

When used from RNC over the DCH user plane, this procedure also allows to detect the actual round-trip-delay, as the Node Sync Control Frames (NSCF) are transferred the same way as the DCH frames).

The procedure may also be carried out **over** a high priority transport bearer. Measurements of node offsets can be made at start or re-start as well as during normal operation to supervise the stability of the nodes.

Though an **accurate** Reference Timing Signal (RTC) is used, there still might remain a low frequency deviation between the nodes.

If **no accurate** RTS is available, the local node reference oscillator must be relied upon. In such cases the RNC-NodeB node synchronisation procedure can be used as a background process for detecting the frequency deviation between the nodes.

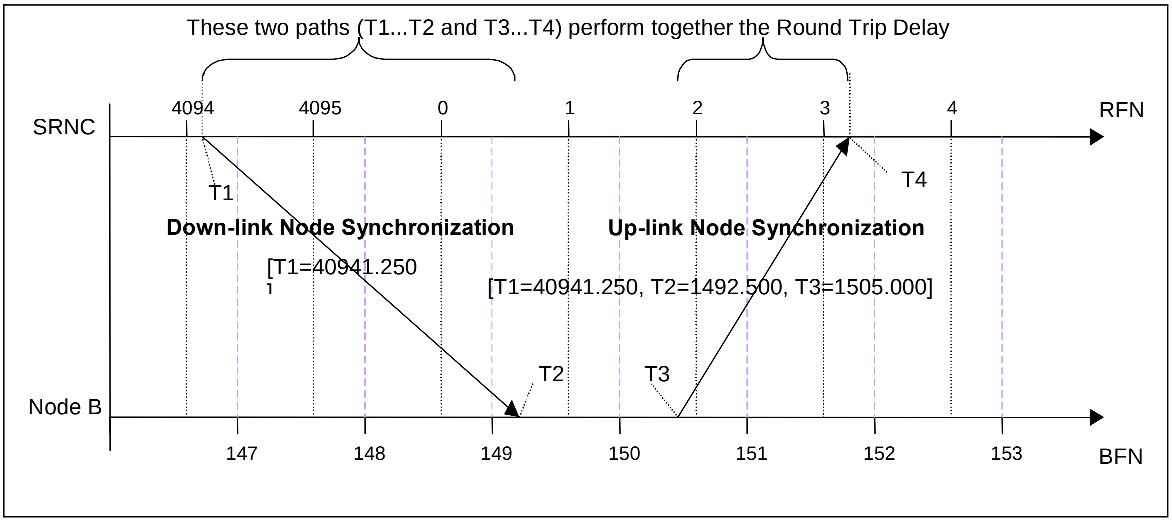


Figure 21: RNC-NodeB synchronisation

In the RNC-NodeB node synchronisation procedure, the RNC sends a DL-NSCF to the NodeB containing the parameter T1. Upon reception of a DL-NSCF, the NodeB shall respond with UL-NSCF indicating T2 and T3, as well as T1 which was indicated in the initiating NodeB DL-NSCF (Figure 21).

For monitoring the ToA when no down-link data frames are sent, a synchronisation procedure is defined in the I_{ub}/I_{ur} frame protocols ([4],[5]). This procedure makes use of UL and DL-SCF (see Figure 22).

The SRNC sends DL-SCF containing the CFN in which the control frame should be received by the NodeB. When the NodeB receives the DL-SCF, it always replies with an up-link UL-SCF containing the ToA, even if the DL Control Frame is received within the receiving window as shown in Figure 22.

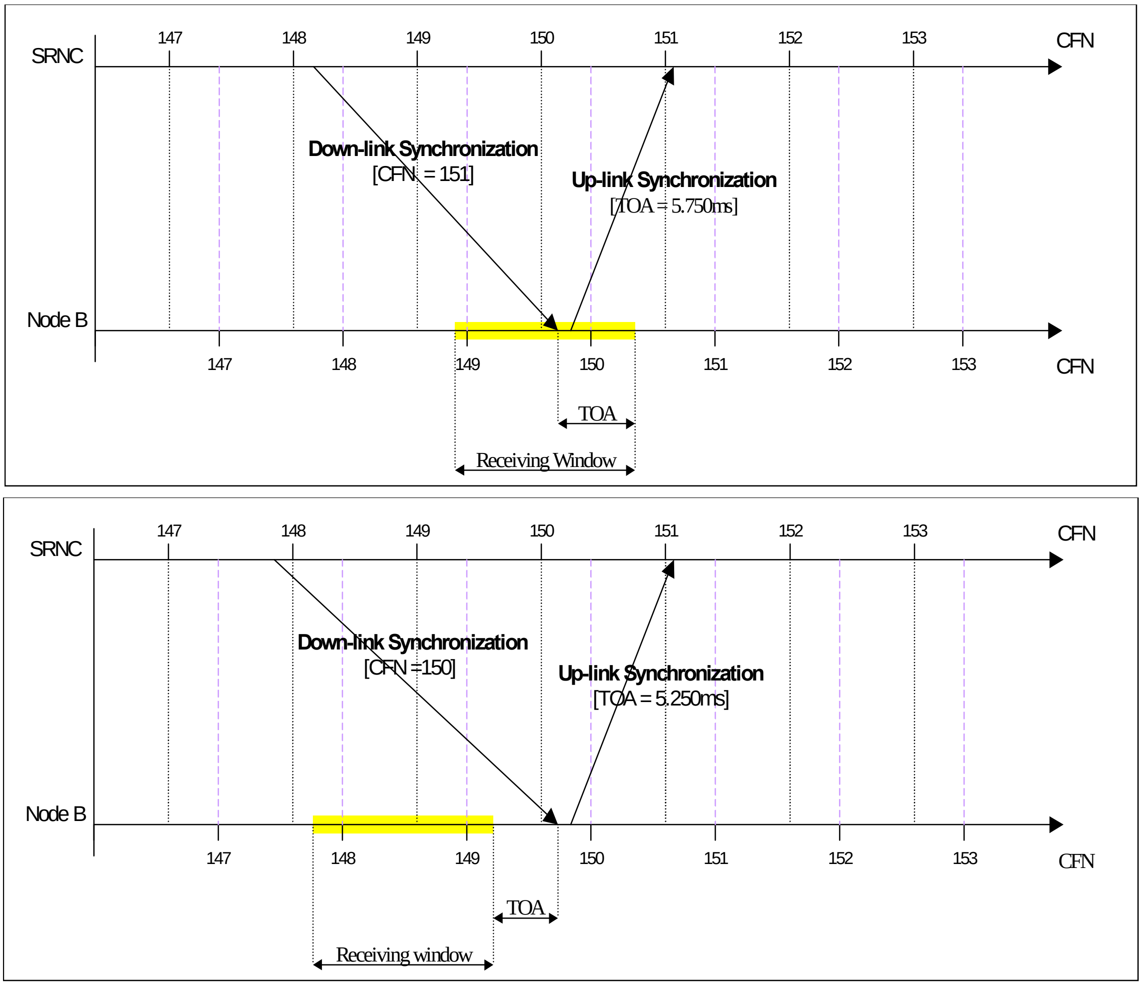


Figure 22: ToA monitoring

ToA-monitoring is executed through Frame Protocol Synchronisation procedure (ToA >0, ToA <0 as shown in Figure 22.

(d) Features Provided In UMTS For Timing Adjustment:

The channels to be synchronised and used for SDMB are shown in Figure 23. The Secondary Common Control Physical CHannel (S-CCPCH) is the only common physical channel that can be aligned on a multiple of 256 chips, as shown in Figure 24 The other common physical channels are aligned on the 10ms frame structure.

As one radio frame takes 10ms and contains 15 slots of 2,560chips, thus 256chips last 10ms / 15 /10 = 66.6µs. Therefore, the S-CCPCH can be aligned with a granularity of 66.6µs only. But aligning the S-CCPCH alone is not enough: the other physical channels (SCH, CPICH and P-CCPCH) must be aligned, too.

The subsequent Figure 23 gives a view on the subset of channels used and applied in the envisaged SDMB-System, while Figure 24 depicts the timing of both types of Common Control Channels.

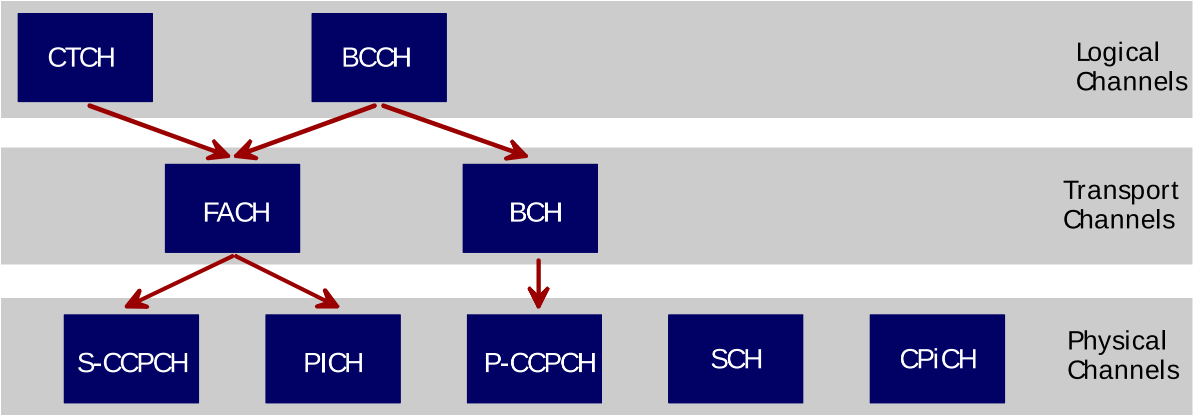


Figure 23: Channel types applied to SDMB

In NBAP T_{CELL} the timing delay is used for defining start of SCH, CPICH and the down-link scrambling code(s) in a cell relative BFN. The resolution of T_{CELL} is 256 chips.

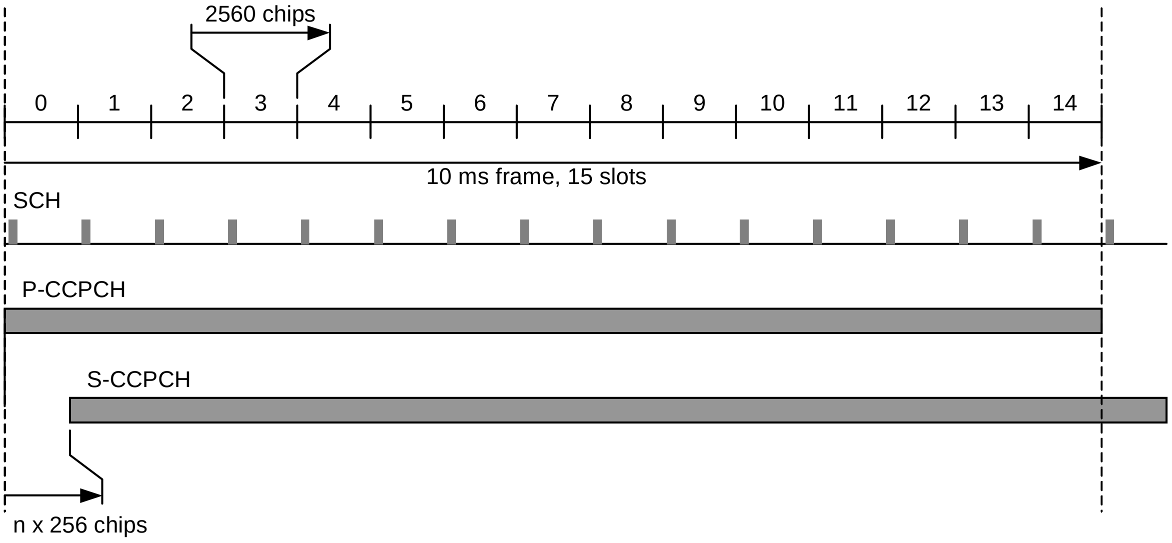


Figure 24: Timing of P-CCPCH and S-CCPCH

(e) Compensation Of HTI And IMR NodeB Processing Time

The architecture in Figure 25 illustrates the different links within the SDMB system where propagation delay is produced and thus be compensated.

The hub (SDMB RNC) in relation with the IMR (HTI Rx) ensures that both satellite W-CDMA signal and terrestrial repeater's W-CDMA signal are received by the SDMB enabled handset (UE) within its rake window (20us) to ensure coherent re-combination.

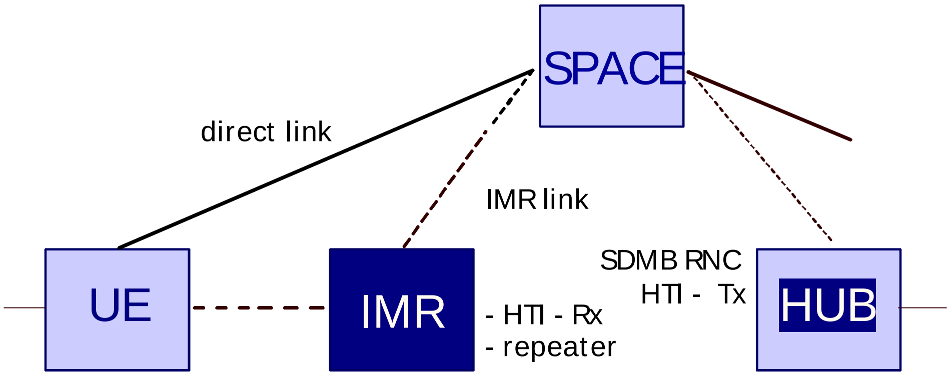


Figure 25: Direct link and IMR link

The SDMB RNC shall delay the information/signal transmitted by the SDMB NodeB to take into account the maximum processing time of the HTI Tx + HTI Rx + 'enabled S-DMB' NodeB (repeater), illustrated in Figure 25.

The HTI Rx will synchronise the information/signal transmitted by the 'enabled SDMB' NodeB to achieve time alignment between both signals from the satellite and from the terrestrial repeater at the UE side. For that, a cache memory is needed to absorb the worst case time difference [500ms].

The use of a common clock reference in the hub and in the IMR is required to adjust the IMR's nodeB modem time reference with regards to time reference sent by the HTI Tx/SDMB RNC.

(f) Alignment Of The Satellite And IMR Signals

The synchronisation issues may be fairly solved by applying a GPS receiver to the NodeBs. This synchronisation is intended to control both clock frequency and phase. Unfortunately this synchronisation mechanism, as described in [3GP1], section 6.1.2.1, is intended only for TDD and cannot applied here one-to-one.

The Alcatel NodeB intended to be used in **MAESTRO**, however, is already equipped with add-on synchronisation ports but the software does not handle it yet. One solution could be an upgrading adaptation development of the NodeB software.

The RNC should itself be synchronised, too, e.g., by implementing a procedure to loop-back the NodeB´s GPS-synchronised clock - see [3GP5] section 5.2.9, used for LCS - Location Services - described in [3GP6]

Additionally, the standard UMTS granularity to adjust the timings is not sufficient: it is of 66µs only, and the UE-rake receiver accepts 20 µs maximum. Therefore, the 3GPP specifications should be upgraded to enable time adjustments with a granularity below 66µs.

For a given frame, the BFN (NodeB frame number) in the Hub NodeB and the BFN in the IMR NodeB must be equal (the BFN is used to transmit the SFN to the UEs). The BFN depends on each NodeB start-up time, and cannot be controlled; therefore, the BFN in the Hub and in the IMR will be different. One solution could be to upgrade the 3GPP specifications and thus enabling BFN setting through the I_{ub}..

(g) Conclusions

Though the foreseen Alcatel NodeB applied in **MAESTRO** is already equipped with add-on synchronisation ports but the current software does neither support nor handle it yet.

- One solution could be an upgrading adaptation development of the NodeB software.
- The RNC should itself be synchronised, too, e.g., by implementing a procedure which enables to loop-back the NodeB´s GPS-synchronised clock as indicated in [3GP5] section 5.2.9, and actually used for LCS - Location Services [3GP6]

Additionally, the standard UMTS granularity to adjust the timings is not sufficient: it is of 66µs only, and the UE rake receiver accepts 20 µs maximum.

- Therefore, the 3GPP specifications should be upgraded to enable time adjustments with a granularity below 66µs.

For a given frame, the BFN (NodeB frame number) in the Hub NodeB and the BFN in the IMR NodeB must be equal (the BFN is used to transmit the SFN to the UEs). The BFN depends on each NodeB start-up time, and cannot be controlled; therefore, the BFN in the Hub and in the IMR will be different to each other.

- One solution could be to upgrade the 3GPP specifications and thus enabling BFN setting through the I_{ub}.

7.2 Synchronisation Based On GPS

7.2.1 GPS Application On The SDMB Core System

The synchronisation of the Hub NodeB (NodeB/1) becomes mandatory for the case that the IMR´s core will consist of a NodeB/2, independent whether this Node will be shared with a private user. This synchronisation could be done by synchronisation to the same transport network. Formerly initial consideration were made for this issue but restricted to a test-bed application only, where the NodeB/1 played the role of a satellite emulator.

The actual problem for the **MAESTRO** application is now the supplementary synchronisation of the NodeB/1 (Hub NodeB) in the Hub branch and, additionally, the extreme precise handling of the required propagation delay balance of the I_{ub} and U_u data streams.

For the case that no significant attempt is planned and made to enhance the current functionality of the NodeB and the surrounding network, the GPS alternative seems to be suitable for the first to tackle the most exigent synchronisation issues. Synchronisation by GPS means on I_{ub}-side bit-synchronisation and frame (-begin) synchronisation.

7.2.2 GPS Receiver Connection To The NodeB

The NodeB´s Connection Area (CA) provides remote access to the NodeB´s external interface and thus the later connection of an optional GPS receiver module. This module delivers the time and position data which is used for alarm and performance measurement time stamping, OCXO clock and frame number synchronisation.

The Alcatel GPS receiver consists of two parts, a receiver connection board proprietary printed board for connecting the GPS receiver to the NodeB; and the GPS receiver itself, a commercial product from Trimble (Lassen SK II) and Wharton. The Wharton 488GPS receiver system is designed to allow 482 series master clocks to be automatically synchronised from the GPS satellite time transmissions

7.2.3 The GPS Receiver Components

(a) Antenna Module

The satellites transmit highly accurate, real time world-wide, navigation information at a frequency of 1,575.42MHz that is free for reception by anyone and thus use to identify their position together with a precise local time.

The active antenna module is a low-profile disc shaped unit, 10cm diameter and 3.5cm high, specifically designed for GPS use. GPS signals are received by the antenna, amplified within the antenna assembly and then relayed to the GPS receiver for processing.

The antenna should be horizontally mounted with a clear view of 75% of the sky. If the sky view is reduced, the interval between ‘switch-on’ and system time synchronisation will be considerably increased.

The antenna module transmits the received GPS signals and receives power (5V DC @ 25mA) from the GPS receiver/decoder module via a single 6m RG58 coaxial cable. A post mounting clamp is supplied to enable the antenna to be fixed to a suitable horizontal or vertical post of up to 2m diameter.

(b) GPS Receiver/Decoder Module:

The GPS receiver/decoder module contains an advanced 6-Channel parallel receiver, a power supply and a microprocessor based communications interface. This module should be mounted in a protected location within 6m of the antenna.

To ensure ease of operation and to remove the possibility of operator error the 488GPS system is designed to self initialise without the necessity of operator data input.

When the accurate satellite time information is available, synchronising time signals are transmitted every minute from the receiver/decoder module to the master clock using W482 time code. This code provides UTC time and date information and may be used to synchronise any 482 series master clock.

The 482 series master clock will automatically convert the UTC time to local time using operator pre-programmed time offset conditions. When the 482 master clock is synchronised with the GPS receiver/decoder module, all transmitter signals are accurate to within ± 1us. Higher accuracy is available on request.

7.2.4 GPS-Clock Based Synchronisation Procedure

The introduction of the GPS into the **MAESTRO** system would increase the capabilities of the NodeB with a reasonable effort. This approach would synchronise both NodeBs on the same BFN. It has to be defined, how both NodeBs select (or are provided with) the same absolute time to start with BFN = 0:

- The BFN is reset to 0 after 4096 * 10ms = 40,960s.
- The absolute time sent by GPS is given in weeks and seconds of weeks after Jan 6th 1980. So a possible synchronisation would be, if the BFN counter is reset to 0, when GPS_time_in_seconds modulo 4096 (or 1024) equals 0.
- The BFN could also be set to (GPS_time_in_seconds *100) modulo 4096.
- The roll-over period of the weeks can be neglected, because this again is 1024 and thus does not influence the calculation.
- Furthermore mechanisms have to be defined, how a NodeB can synchronise after recovery. Essentially the same method to calculate a re-synchronisation time can be applied here.

It will still be a problem, that the recovery with GPS synchronisation means a longer NodeB outage than an un-synchronous recovery.

For the NodeB synchronisation a number of questions and open points still remain:

- The BFN should be assigned before telecom application are set up and before the connection to the RNC is established.
- Can the use of the transport network clock or the use of the GPS clock provide better synchronisation?
- What will happen, if for any reasons GPS is not available over some time?
- Is it sufficient, if the clock is also synchronised via GPS.
- The distance of about 1km (cell size) between two NodeBs should not cause a delay between the GPS signal reception at both NodeBs.
- If one of these NodeB synchronisation methods is applied, the cells and SCCPCHs for both NodeBs have to be set-up with the same T_Cell and SCCPCH_FrameOffset values.

7.2.5 Identified Problems For The GPS Synchronisation

- It is necessary to start the GPS receiver independently from the NodeB, because the GPS receiver needs about 15 minutes to calculate its position and the actual time from the GPS signals (the whole GPS information is transmitted in 12.5min.
- The GPS time in seconds is repeated every 6 seconds.). After this time the GPS time can be used to deduce the BFN for the NodeB.
- The modification of the BFN will generate a NodeB re-start caused by the telecom application, if already active. Only for the purpose of the field trial, this should not be a problem.
- When a NodeB has to be re-started in an already deployed network, there will be a delay of availability depending on the availability of the exact GPS time and the delay to start frame synchronisation with a new calculated BFN.

7.2.6 Conclusions

Inter-node synchronisation by means of GPS looks promising but is still burdened with a number of technical issues and political particularities, mainly in the field of availability:

- A GPS synchronised system is fully dependent of the GPS availability.
- GPS receiver start set-up requires apprx. 15 minutes forerun.
- The modification of the BFN will generate a NodeB restart caused by the telecom application, if already active. This will become a problem when entering the commercial application of **MAESTRO**.
- Re-start of a NodeB in an already deployed network means a delay of availability depending on both the availability of the exact GPS time and the delay to start frame synchronisation with a new calculated BFN.
- BFN assignment is required before telecom applications are set up and before the connection to the RNC is established.
- It might be that the use of the transport network clock and/or the use of the GPS clock provides better synchronisation.
- The distance of about 1km (cell size) between two NodeBs may not cause a delay between the GPS signal reception at both NodeBs.

If one of these NodeB synchronisation methods is applied, the cells and SCCPCHs for both NodeBs have to be set-up with the same T_Cell and SCCPCH_FrameOffset values.

7.3 NodeB-I_{ub} And U_u Synchronisation Considerations

7.3.1 Issue Description

If the concept considerations lead to the application of a NodeB in the terrestrial repeater branch, then significant synchronisation problems will emerge; synchronisation problems between the Hub-NodeB ("satellite NodeB") and the potentially co-sited repeater NodeB. ("terrestrial NodeB"). Still more, the UMTS standard does not provide synchronisation rules and applications for absolute synchronisation in FDD.

The situation will grow more bad when the "terrestrial" NodeB has to be shared with a private provider, who may not like to be touched by specific **MAESTRO** requirements and potential QoS issues.

Taking into account the standard I_{ub}/NBAP procedures for common channels, the only achievable synchronisation can be gained on frame level which may not be sufficient. The NodeB uses the frame number received from the RNC to transmit the data block at the indicated time (1 frame = 10ms).

Subsequent Figure 26 was taken from 3GPP TS 25.211 and describes summarising the timing relationships between the down-link channels of one NodeB as required for the **MAESTRO** concept.

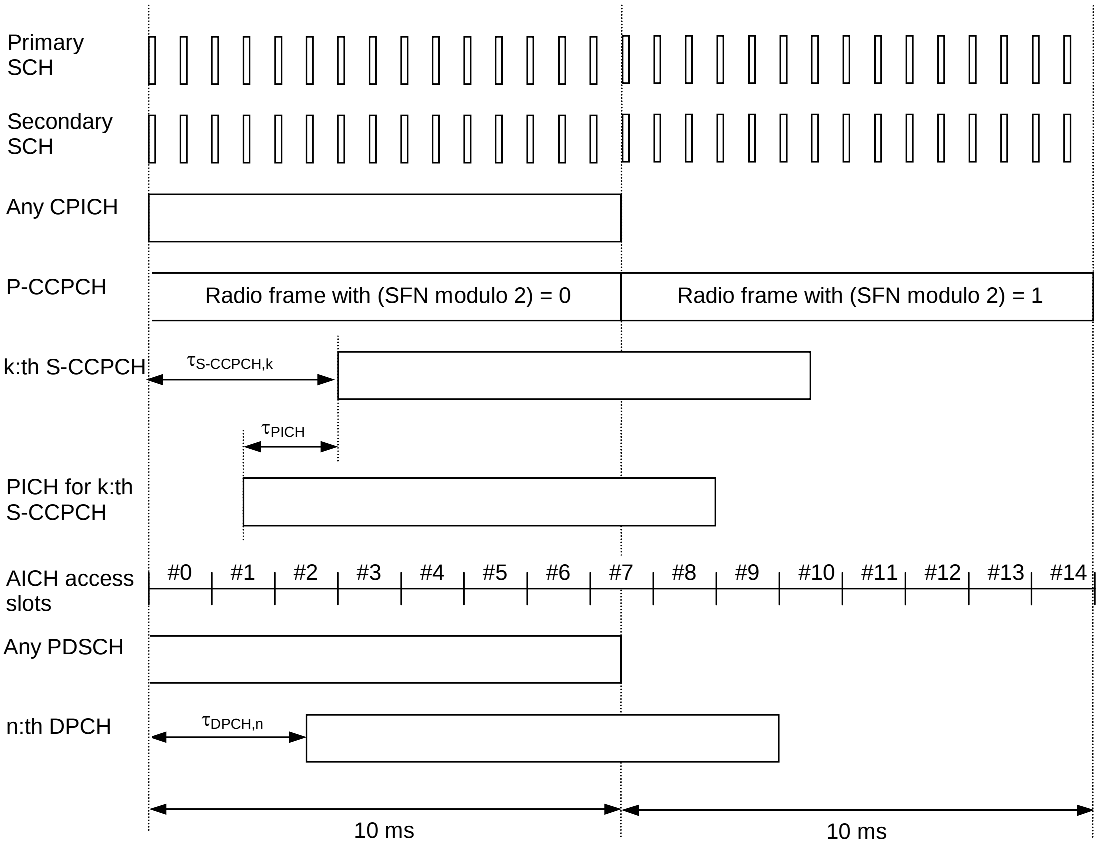


Figure 26: DL-physical channels - radio frame and access slot timing

To achieve a synchronisation on chip or bit level, a radio interface sync-procedure is required similar to the one defined for dedicated channels and soft hand-over feature.

Though not standardised, a similar procedure for common channels should be implemented for SDMB. The synchronisation mechanisms used for the Alcatel NodeB are compliant to the 3GPP specifications, as far as they exist.

7.3.2 MAESTRO Synchronisation Requirements

The SCCPCHs bearing the broadcast FACHs of the different NodeBs should be synchronised, i.e., the FACH of the "terrestrial NodeB"s should be started synchronously with the FACH of the "satellite- NodeB".

The terminal should see the FACH channels like ordinary dedicated channels being in a macro diversity (softer hand-over situation). This is necessary, if the terminal has to synchronise signals in its rake window of 80 chips (i.e., 20µs).

7.3.3 Node And Network Synchronisation

(a) Node Synchronisation

The Node synchronisation procedure is used to get a timing reference of the NodeB in the C-RNC. Node Synchronisation relates to the estimation and compensation of timing differences among UTRAN nodes. The procedure is as follows:

- The CRNC sends a **down-link Node Synchronisation Control Frame** to the NodeB reporting an RNC frame number when it was sent.
- The NodeB replies with an **up-link Node Synchronisation Frame**, indicating a NodeB frame number at the reception of the down-link frame, and another frame number at sending back the up-link frame.

This procedure is supported on the specific high priority VC on which only one AAL2 connection is established for this purpose.

Here only the "RNC - NodeB" Node-synchronisation is considered. This Node synchronisation allows to get knowledge of the timing differences between RNC and its NodeBs, and thus to estimate the phase difference between RFN and BFN of these nodes. The estimated phase difference is used in the down-link data transmission (i.e., Tx direction) in order to minimise the transmission delay and the buffering time.

For the Alcatel NodeB this procedure is performed at NodeB re-start, and periodically (e.g. once a day) after that.

(b) Network Synchronisation

Network Synchronisation relates to the distribution of synchronisation references to the UTRAN Nodes and the stability of the clocks in the UTRAN (and performance requirements on UTRAN internal interfaces).

The distribution of an accurate frequency reference to the network elements in the UTRAN is related to the main issue to provide a synchronisation reference with a frequency accuracy better than 0.05 ppm at the NodeB in order to properly generate signals on the radio interface.

For the time being this synchronisation is achieved for the Alcatel NodeB by synchronisation to the (ATM) transport network.

If the transmission network can provide the required frequency accuracy, the NodeB V2 is synchronised on it. In case of e.g. an ATM network unable to provide this accuracy, the NodeB will switch to the free run mode.

Normally the NodeB is basically synchronised on the transmission network, if the network can provide the required frequency accuracy (in normal conditions better than 0.05 ppm).

The NodeB´s local oscillator permanently monitors the quality of the clock delivered by the network. For the case of a loss of incoming signal or if a clock drift is detected, the NodeB then switches to its local clock mode. After the fault has disappeared the NodeB will switch back to the transmission line synchronisation source.

When the I_{ub} is supported on several E1 links, the NodeB performs its synchronisation on the first E1, and in case of failure of this E1, it switches to the second one and so on.

The Alcatel NodeB clock is compliant with 3GPP TS 25.104 (0.05 ppm) [3GP5]. The NodeB synchronises:

- **on I_{ub} link**--->when the clock delivered by this link is of good quality,
- **on the OCXO** (Oven Controlled Oscillator) ----> when the clock delivered by the I_{ub} link has bad quality.
- **Future option: on an external GPS** clock, as the NodeB architecture allows to synchronise the OCXO via an external GPS clock.

7.3.4 Down-Link Synchronisation

(a) Transport Channel Synchronisation:

The Transport Channel Synchronisation mechanism defines synchronisation of the frame transport between RNC and NodeB, considering radio interface timing.

This procedure is used by CRNC to adjust the transmission time for data frames on FACH and PCH FP. The C-RNC sends a down-link Synchronisation Control Frame indicating the target CFN value. The NodeB replies with an up-link Synchronisation Frame indicating the ToA for the down-link frame, and the CFN value received in the down-link frame.

(b) Timing Adjustment

The Time Alignment Handling procedure over Iu relates to the control of the down-link transmission timing in the CN nodes in order to minimise the buffer delay in SRNC. This procedure is controlled by SRNC.

This procedure is used by the NodeB to report to the CRNC an incorrect arrival time of a down-link data frame in the NodeB. It is initiated by the NodeB when a down-link frame arrives outside of the defined arrival window.

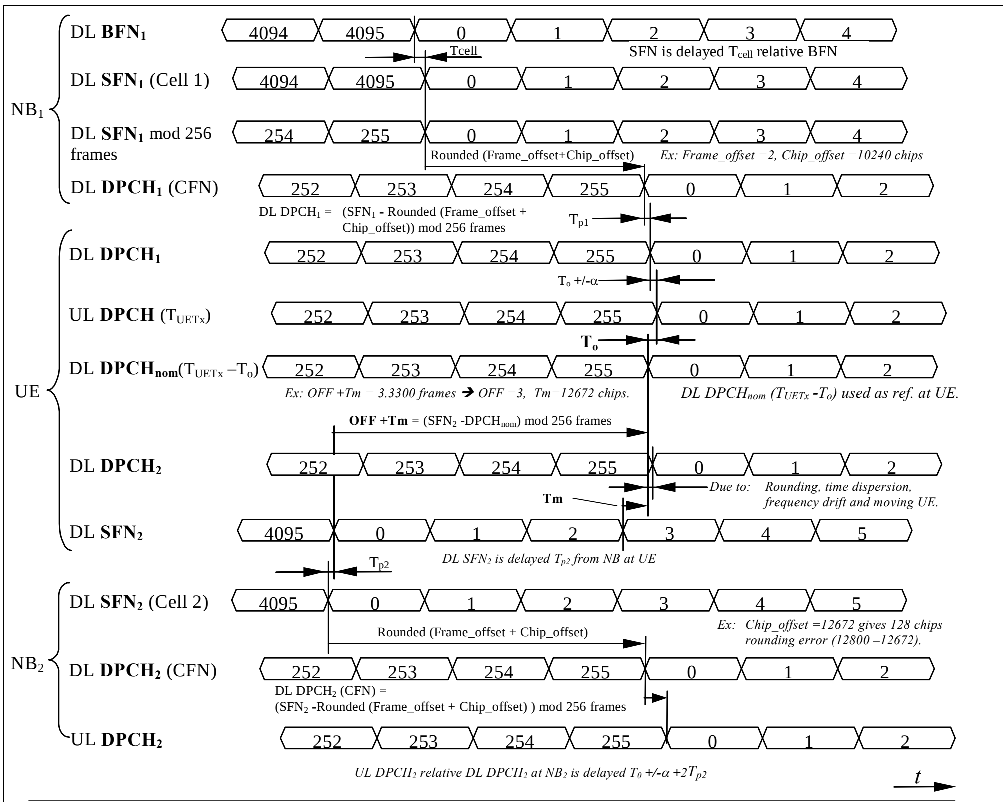
7.3.5 Radio Interface Synchronisation (U_u)

The radio Interface synchronisation relates to the timing of the radio frame transmission in down-link [FDD]. In FDD Radio Interface synchronisation is necessary to assure that the terminal receives radio frames synchronously from different cells, in order to minimise terminal buffers.

7.4 Standard Synchronisation Procedures In Detail

7.4.1 Parameters And Functionality

The subsequent Figure 27 gives a view over the radio interface timing synchronisation details:



α	1st received DL DPCH finger relative DL $DPCH_{nom}$	T_{cell}	Specifies the SFN delay relative BFN
BFN	Node B Frame Number (counter)	T_m	Measured by UE at HO, T_m has a range from 0 to 38399 chips.
CFN	Connection Frame Number (DPCH related)		
DPCH	Dedicated Physical Channel (CFN related)	T_o	Is a constant of 1024 chips, is the nominal difference between first received DPCH finger (DL $DPCH_{nom}$) and T_{UETx} at UE.
HO	Handover		
NB_x	Node B (x: 1=source, 2=target)		
OFF	Offset with a range from 0 to 255 frames	T_{pX}	Propagation delay (one way), UE to Cell X
RFN	RNC Frame Number (counter)	T_{UETx}	The time when UE transmits an UL Dedicated Physical Channel.
RNC	Radio Network Controller		
SFN	System Frame Number (counter)		

Figure 27: FDD Radio interface synchronisation timing diagram

The k^{th} S-CCPCH has a timing offset of T_k * 256chips in relation to the P_CCPCH, where T_k is an integer of {0, 1, ..., 149} and may differ for different S_CCPCHs. The offset is set by the Common_Transport_Channel_set-up with the parameter SCCPCH_Offset.

The offset for a cell (in magnitudes of 256chips) in relation to the NodeB frame number BFN is defined in the parameter T_Cell of the Cell_set-up procedure (3GPP 25.402). Thus the offset of a S-CCPCH in relation to the BFN is (T_Cell + SCCPCH_Offset) * 256 (chips) or (T_Cell + SCCPCH_Offset) * 66,7us.

If the difference between both SFNs can be measured, synchronisation of the S_CCPCH of the second (terrestrial) NodeB is possible by calculating the right T_Cell parameter for the Cell_set-up and the right SCCPCH Offset parameter for the S_CCPCH-set-up.

For the synchronisation of dedicated channels a procedure is described in 3GPP TS 25 402 chapter 8. It is based on the measurements of the terminal on the time difference between its DPCH and its SFN, which is calculated by the RNC in terms of Frame Offset and Chip Offset and communicated to the NodeB.

In **MAESTRO**´s case there is no up-link from the terminal to the RNC. In addition, the interest is in synchronising the common channel. For this we require the time difference between the SFN and the S_CCPCH (which is the SCCPCH_Offset value from the S_CCPCH set-up). From the Node synchronisation the RNC knows the BFN and the phase difference of both NodeBs since NodeB restart.

On the basis of the existing capabilities of the NodeB there are two approaches to set up a S_CCPCH on a second NodeB, which is nearly synchronous to the S_CCPCH of the first NodeB. Nevertheless, the NodeB synchronisation is not sufficient for the **MAESTRO** application, neither for option 1 (on I_{ub} link) nor 0ption 2 (on the OCXO).

7.4.2 Using NodeB - RNC Synchronisation

Based on the knowledge of the phase differences PD:

$$\mathbf{BFN = [RFN + PD]\ modulo\ 4096}$$

between both NodeBs, it is possible to map the BFN of one cell on a BFN of the other cell:

$$\mathbf{BFN_{Ter} = [BFN_{Sat} + PD_{Ter} - PD_{Sat}]\ modulo\ 4096.}$$

It is also possible to do the same calculation for the SFNs:

$$\mathbf{SFN_{Ter} = SFN_{Sat} + [PD_{Ter} - PD_{Sat} - TCell_{Sat} + TCell_{Ter}]\ modulo\ 256}$$

Please note, that in both cases the calculations are simplified; they do not take into account, that the phase differences do not represent whole frames, but also offsets, which normally are discarded by rounding. This can be used to calculate the SCCPCH_Offset.

This approach can only be applied, when the NodeBs are controlled by the same RNC. As basis for calculation of the phase difference, the BFN and the RFN at sending / response time are taken. The quality of the measurements depends also on the delays of the used ATM network. The granularity of the measured time is given in ms with 125us-steps.

This is twice as much as the granularity of the SCCPCH_Offset between two S_CCPCH channels. If the two S_CCPCHs would be synchronised using this information, the terminal must provide a rake window of about 125us.

8 ANNEX 3 SHARING ISSUES IN CONTEXT WITH NODEB

8.1 General Considerations

In order to install and operate the **MAESTRO** – System at a minimum of cost, it seems plausible to make use of nationally installed (e.g., NodeB) telecommunication equipment; in particular, if it is under-utilised or, for expansion purposes, the rack only partly equipped and in use.

It should be also noted that in context of NodeB application as terrestrial repeater it makes only sense to share a NodeB with another network or service provider (in the following called owner). Pure stand alone NodeB solutions will fail because of its cost.

For all further considerations in this paragraph it is assumed that only Alcatel NodeB base stations will be applied. This reduces the number of other potential candidates strictly. Furthermore, as starting scenario it is assumed, too, that commercial network providers have established an UMTS network with UMTS NodeBs, which do not operate at full capacity with both data traffic and physical expansion states. This means, **MAESTRO** has to be invited to share the base station and:

- add the equipment of its own (additional boards, SW extensions, etc.);
- does not touch (i.e., modify) the equipment of the owner;
- does not touch and influence sections operated by the owner;
- modifies the base station only by removable add-ons.

The issues on physical level, additionally emerging from the NodeB sharing philosophy, can be grouped into 5 problem areas:

- U_u-side antenna connection and antenna configuration;
  - adding a second TX-module with an antenna by its own
  - adding a second TX–module but connected it by combiner to the VSWR-coupler
  - adding an antenna to the NodeB antenna via combiner
- I_{ub}-side GPS synchronisation connected to local maintenance plug:
  - bit synchronisation and frame synchronisation
- I_{ub}-side **MAESTRO** RNC connection
  - via I_{ub}
  - via I_{ur}
- I_{ub}-side RNC I_{ub} response emulator;
- I_{ub}-side RNC-data multiplexer/router and/or timely control of different I_{ub} data flows.

Apart from a pure antenna sharing, the above 5 areas will have to be worked on, when NodeB sharing is applied.

8.2 Analogue Physical Issue

8.2.1 The RF-Front-End And Its Standard U_u-Interface In Brief

The subsequent Figure 28 is to facilitate a better understanding of the radio part and the shared NodeB U_u-side issues. The figure shows two radio modules capable of 2-antenna diversity operation. The boxes left hand side and right hand side accommodate the linearised power amplifier (PA), its controlling feed-back and pre-distortion path, clipping, up-converter and transmission (Tx) filters.

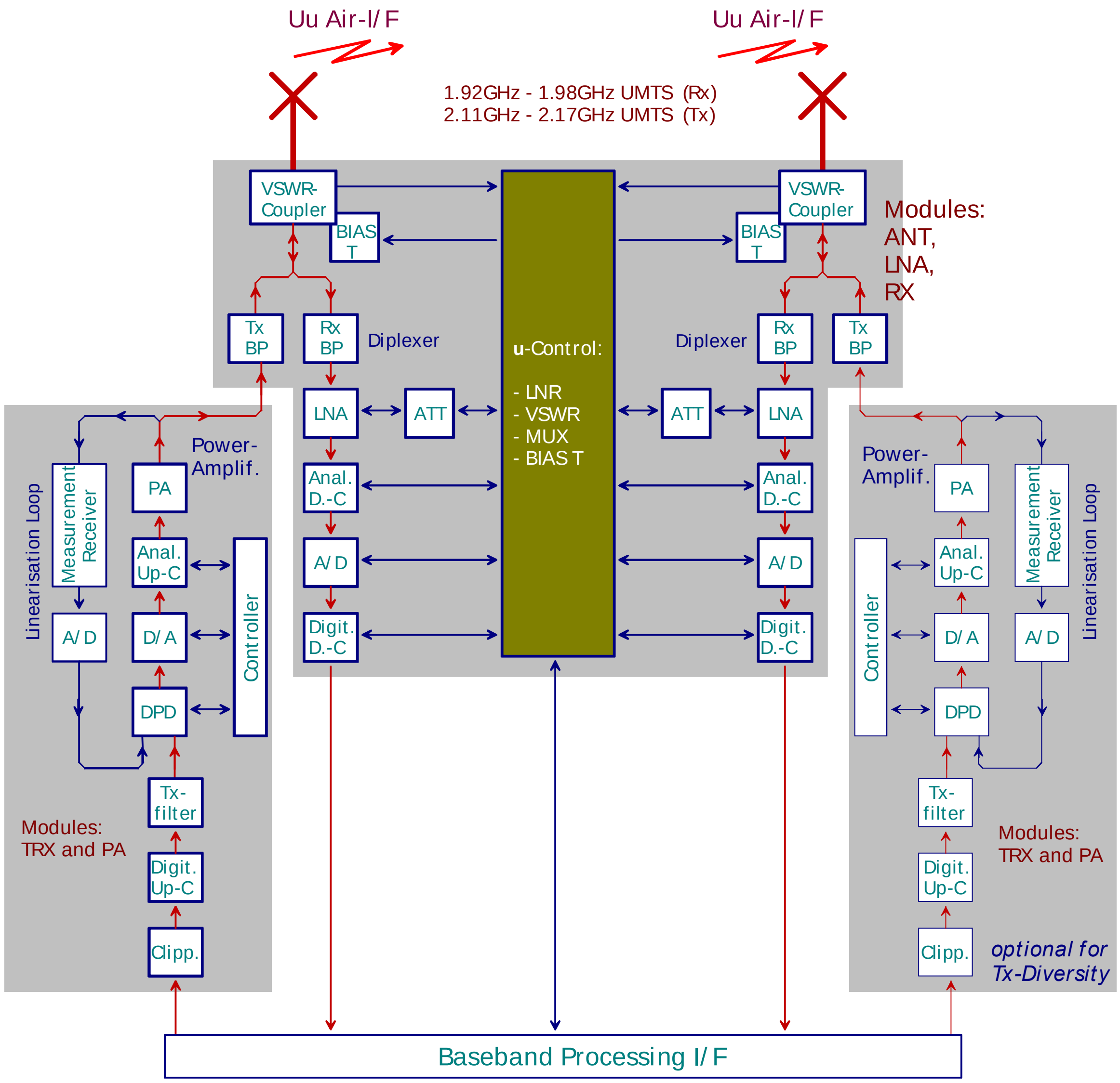


Figure 28: NodeB´s standard radio front-end

The down-link path is capable to handle up to four UMTS frequency channels. They may be accommodated within any consecutive 20MHz sub-band of the overall 60MHz UMTS transmit frequency band. The antenna network (ANT) module allows the connection of two transmitters in case of transmit diversity.

Connection to the mobile terminal is done across the U_u - interface (for UMTS FDD). This UMTS radio interface backs up the FDD mode air interface for transport channels compliant to 3GPP-R-99 and R4. It also supports channel coding up to 384kb/s with turbo-coding or convolutional coding/decoding and all layer 1 error indication mechanisms as well, Table 20 below summarises the U_u -interface functionality.

Table 20: U_u - UMTS standard radio interface functionality

supports: Transport Channels compliant to 3GPP-R-99 and R4F; FDD mode air interface	- RACH, FACH, DCH - **DSCH** (all combinations involving DSCH supported) - P-SCH, S-SCH (sync channels, primary/secondary) - CPCH, **BCH**, **PCH**, **DCH** (DRAC)
supports: Physical Channels	- DPDCH, DPCCH, PDSCH, - P-CCPCH, S-CCPC (carries PCH and FACH) - CPICH, AICH, CSICH, PRACH (physical RACH) - PCPCH, AP-AICH, CA/CD-AICH, PICH (pag.-indic.)
supports: Channel Coding turbo or convolutional up to 384kb/s	- one transport bearer per CCTrCH - multiple transport bearers per CCTrCH

For the specific **MAESTRO** system concept only a restricted set of down-link transport channels will be applied, such as PCH (Paging)-, BCH (Broadcast)- DSCH (Down-Link Shared)- and DCH (Dedicated)-Channels.

With respect to the slightly differing transmission frequency band (instead UMTS 2.11 – 2.17GHz now the **MAESTRO** 2.17 – 2.20GHz) some additional measures have to be taken (marked in by dark blue boxes) in Figure 29 and Figure 30:

- The Diplexer Receiver Band-Pass (Rx BP) has to be removed in order to avoid UMTS noise reception;
- The Diplexer transmission band-pass (Tx BP, mid-frequency 2.14GHz) has to be replaced by one with a mid-frequency of 2.185GHz);
- The local oscillator within the Analogue Up-Converter has to be replaced by one operating at a 20MHz higher frequency; the same with the Tx-filter in this block.

8.2.2 RF Analogue Front End Measures For NodeB Sharing

(a) Adding An Extra Complete Tx-Board

Sharing a NodeB commonly with a private network provider can be done in different ways. One of those is depicted in Figure 29 This way is only possible for the case that the base station does not operate at full capacity, in particular, when the racks and sub-racks are not fully equipped. Making use of sharing the Node means, for the first solution, to install a complete Tx-branch from the Base-band interface up to the antenna.

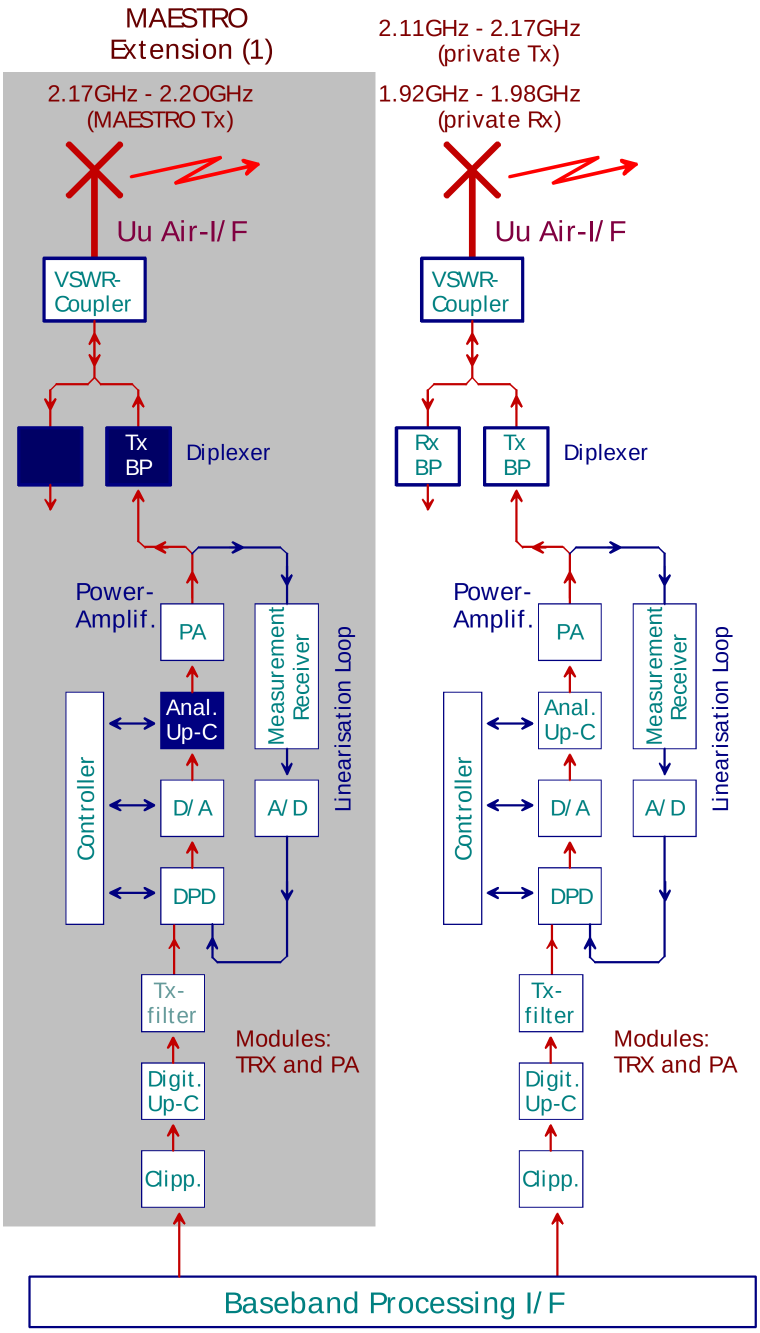


Figure 29: MAESTRO add-on extension (1) for NodeB sharing

(b) Adding An Extra Tx-Board Without Extra Antenna

This variant for the U_u is depicted in Figure 30. In order to save cable and installation cost (e.g., approximately 150 € per meter) it is possible, too, to re-use the installed UMTS-antenna together with the private network provider. However, in this case the **MAESTRO** Tx-branch as shown in Figure 30 and Figure 29 has to be connected to the UMTS-antenna by a Combiner, Splitter or directional coupler. All the connection types will attenuate both the UMTS and the **MAESTRO** signals by 3dB. This is either to be accepted or can be partly balanced by power amplifiers with higher power figures and/or better linearisation. This means in both cases additional effort and cost for the private network provider.

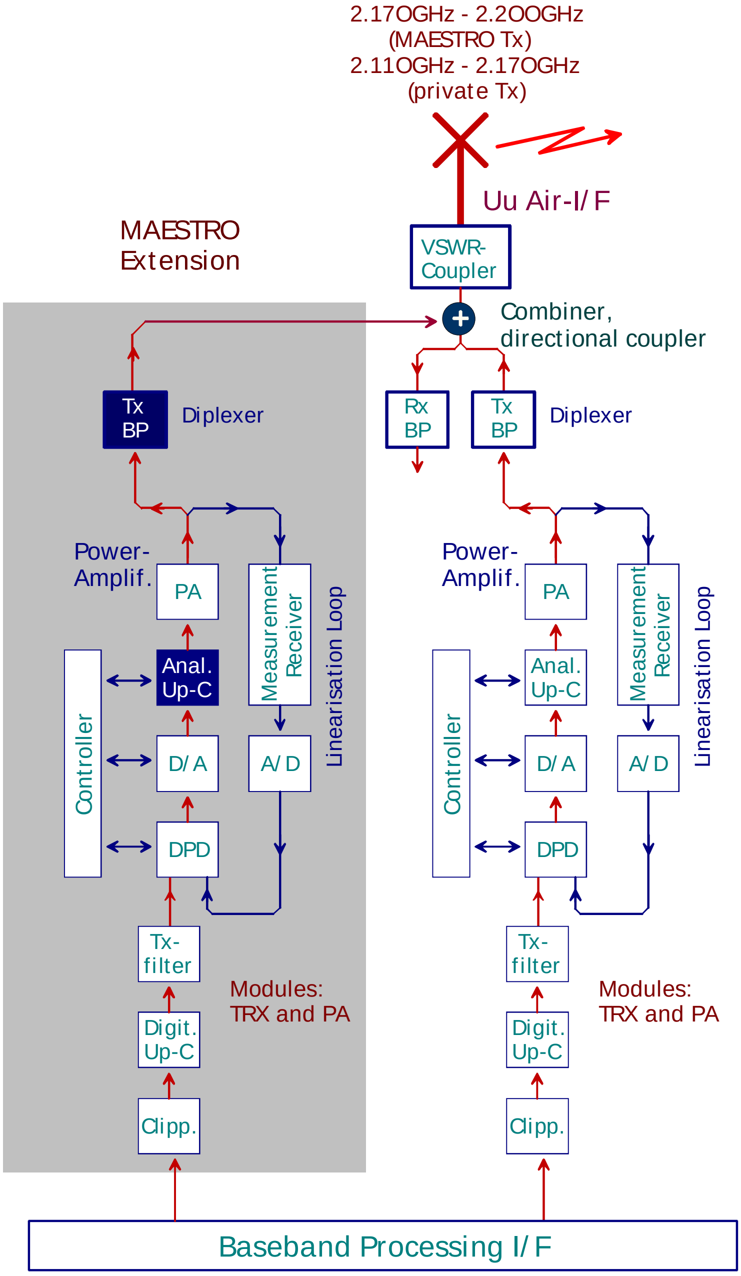


Figure 30: MAESTRO add-on extension (2) for NodeB sharing

(c) Connecting MAESTRO Signals Via Splitter To Private Antenna

Instead of sharing a complete NodeB with all issues and effort described above, it may be sufficient to share only the pure antenna system [3GPP TS 25 867]. The subsequent technical proposal is based on summarised results of a feasibility study about inclusion of Wideband Distribution Systems (WDS) as part of third generation networks in 3GPP standards. It seems applicable in the **MAESTRO** project, as re-use of existing telecommunication environment is foreseen.

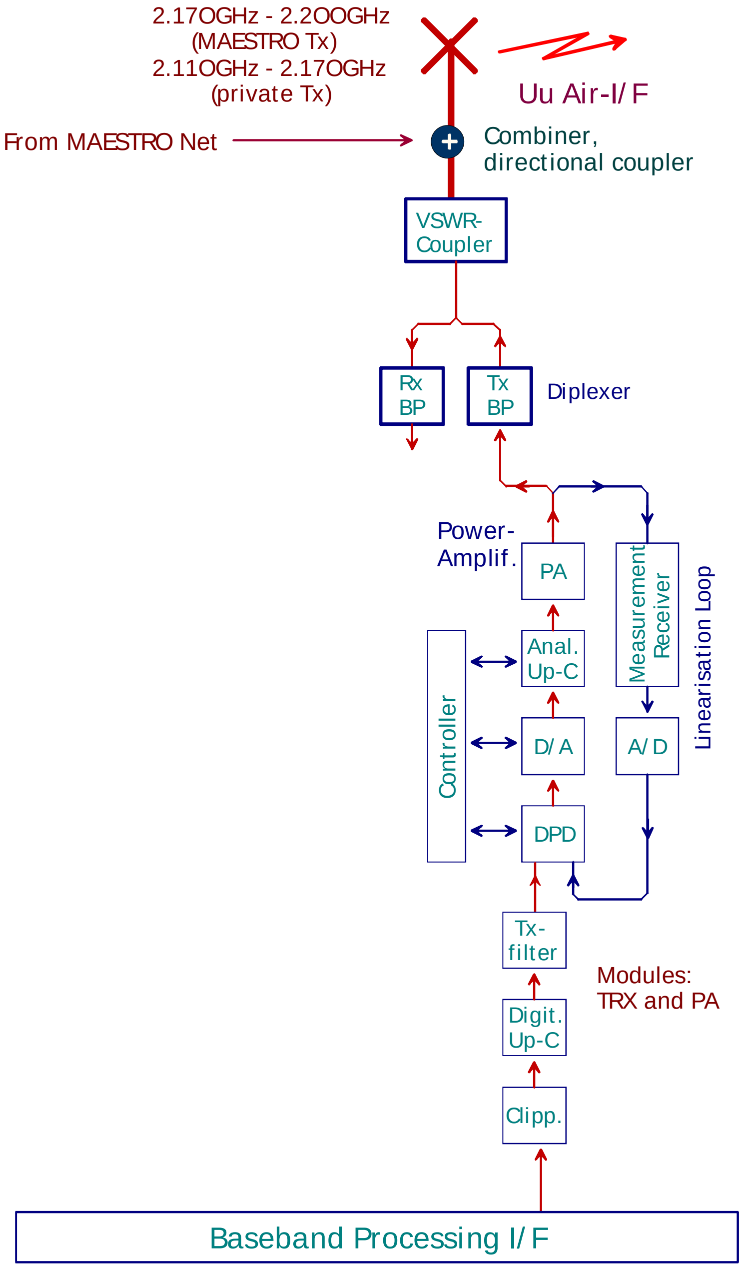


Figure 31: MAESTRO add-on extension (3) for NodeB sharing

8.2.3 Analogue Extension Candidate For MAESTRO Re-Use:

The above described possible add-on extension for NodeB sharing looks promising for application in **MAESTRO**. Though the cost savings are not that much, it is the only method to re-use at least real antennas without spending enormous effort for system synchronisation. Nevertheless, here, too, it is not possible to get around the 3dB splitter loss.

(a) Issue Description

Bearing in mind re-use of already existing telecommunication environment, re-use may be made of installed ancillary equipment like masthead amplifiers or remote radio heads, that may add flexibility and reduce cost of installation. These solutions are embedded in the NodeB as ancillary RF amplifiers and are therefore seen as integral part of it in a single-vendor deployment scenario.

In order to improve flexibility of radio access network solution and decrease installation cost of a second (i.e., **MAESTRO**) system, a new type of equipment is proposed, here called Wideband Distribution System (WDS).

WDS are altogether similar devices, capable of remotisation of NodeB RF.front-end interface, but offering flexible and multiple RF interface to one or more NodeBs or sub-equipped base-stations. The so-defined WDS shall include one or multiple RF front-ends, RF transmission, and interfaces capable of supporting one or multiple base stations (BS).

The degree of performance impact shall be assessed in this chapter to understand the effect on multiple-carrier W-CDMA signals in order to maintain compliance to the relevant standard in the coverage area. The test and simulation scenarios in this report are made with the assumption that of no impact from any passive distribution system. Therefore the results are of an ideal nature and may need to be adjusted to suit the class of base station utilised for deployment.

The specifically tailored solution for NodeB described above became matter of standardisation in a slightly differing configuration [3GPP TR 25 867].

(b) Architecture

The key attribute of WDS is its capability to enable the radio interface of a number of BS to be remote, and hence support a distributed multi-carrier and multi-operator network. WDS is in general an active device and includes, but is not limited to, one or multiple RF front-end (LNA, MCPA) and RF transmission interfaces capable of supporting one or multiple base station. Other ancillary functions may be included as required for best system integration. It also includes O&M facilities and interfaces in order to fulfil any supervision requirements. WDS generally include a number of functions that are required for correct operation. Those functions are listed and described in Table 21 here below:

Table 21: WDS-functions list

Function Definition	Function Description
Centralised multi-operator RF_interface	Provision of RF independent interface to multiple base stations belonging to different networks. It must include provisions such as RF isolation (>30dB), power threshold detectors, and ALC to prevent that any malfunctioning at one network may affect other networks. Transmit RF power at the base station interface can be as low as a fraction of a Watt
Transmission	Provision of correct wide-band links to a number of remotely placed sites that host suitable RF amplifiers and other devices.
RF transmit MCPA	Amplification of all available RF channels in the down-link direction, and therefore shall offer suitable in a multiple-carrier scenario. Power classes can be defined on a wide range, and amplifier technology shall accordingly change to maintain best efficiency
RF receive LNA	Amplification of up-link signals before they are fed back to the base station receivers. Its dimensioning is basic in order to optimise uplink dynamic range (NF, Intermodulations, Blocking, etc.)
RF filtering/diplexing	Provision of a common TX/RX antenna connector at the remote site, and includes proper selectivity for achieving interference protection as required in the various deployment scenarios

(c) WDS Benefits

WDS may bring technical and economical advantages as summarised here:

1. Possible base station and RNC co-location in centralised equipment locations allowing shared facilities, increased implementation flexibility and trunking efficiency.
2. Distributed RF wide-band micro-cellular heads, with lower RF transmission power to cope with most stringent environmental compatibility and scalable traffic capacity requirements.
3. Better and easier flexibility in network planning and upgrading, and on capacity and location systems implementation
4. Sharing opportunities, leading to cost reduction and reduced visual impact for cell sites with the added possibility of increased protection from co-channel and adjacent channel (intra-networks) interference
5. Faster and easier network rollout and maintenance in currently established transmission infrastructures
6. Enabling network manufacturers to shipping base stations and other network elements more quickly

8.3 Digital Physical Issues

8.3.1 I_{ub}-Front-Measures For NodeB Sharing

(a) The Main Issue:

Apart from all synchronisation effort, the operation of a Terrestrial Repeater on NodeB basis within a "shared" environment generates enormous problems in the field of synchronisation, re-use of external equipment and system control.

Sharing the I_{ub} or the I_{ur}-interface with an external (private) provider requires specific measures within the **MAESTRO** branch, as both interfaces are bi-directional interfaces and the NodeB expects some response when communicating with the RNC.

Thus a specific piece of equipment has to be introduced consisting of e type of RNC-emulator and a Termination unit for responded I_{ub}-data.

(b) The Original I_{ub}

On network side the NodeB is inter-linked to the radio network controller (RNC) via the I_{ub} interface. The physical part of this interface supports I_{ub} redundancy, ATM protection switching and ATM protocol termination management as well as transmission protocols (e.g., IP and ATM); Table 22 summarises the I_{ub} I/F functionality

The bi-directional I_{ub} interface is accommodated in the Station Unit board. In standard NodeBs this interface is of E1-type. For interconnection with a fibre optic STM1 configuration an additional adaptation unit will be required. Data transmission across this interface occurs with ATM cells supporting AAL2 or AAL5.

Table 22: I_{ub}-interface functionality

supports: **physical interfaces**	I_{ub} redundancy with load sharing (optional)
	ATM protection switching according to ITU-T Rec. I.630
	ATM termination mgmt according to ATM Forum UNI3.1 specs

supports: **transmission protocols**	IP with MLPPP on E1/T1 (HW ready, SW upgrade needed)
	ATM with IMA on E1/T1
	IP over Ethernet10/100 (HW ready, SW upgrade needed)
	ATM or IP over STM1/OC3 or E3/T3/J2

supports: **platform configurations**	chain
	ring
	star

(c) Shared I_{ub}-Interface With External HW-Equipment

Sharing the I_{ub} interface with a private provider causes some more serious issues than sharing the U_u. For sharing the I_{ub} additional functional blocks will be required as shown in Figure 32.

Crucial point is that the normal I_{ub} is a bi-directional interface for data exchange with the assigned RNC. Data content can be cell set-up, correction of erroneous frame positions, mismatch of frame synchronisation, different I_{ub}-data flow, common channel set-up etc. This function is performed in the **MAESTRO** RNC-Emulator. This block terminates the up-link cells and generates response for down-link control.

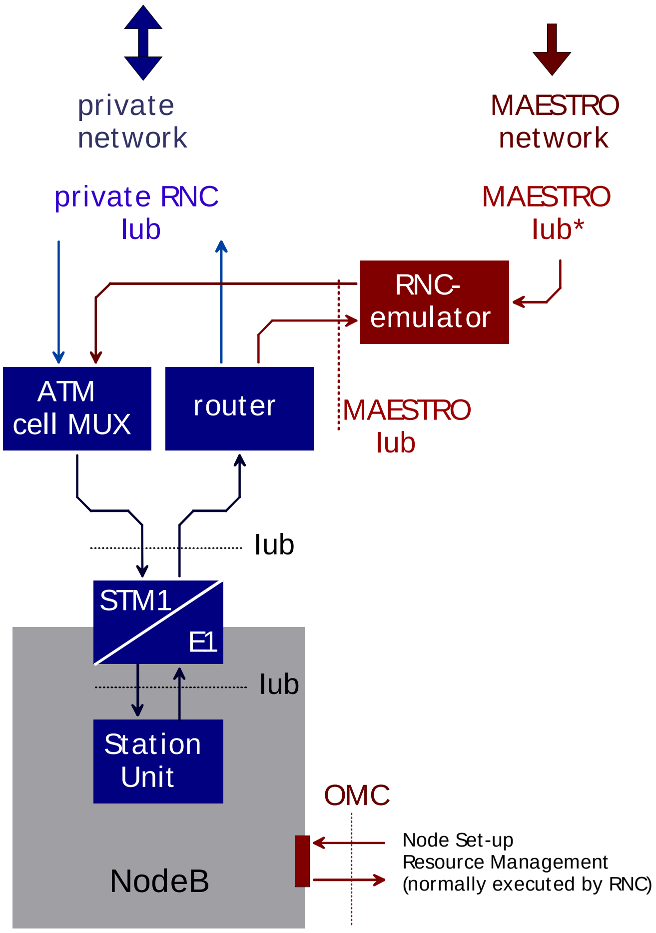


Figure 32: Addendum for I_{ub}-sharing

In a next step RNC-Emulator generated ATM cells will be multiplexed with cells originated in the private RNC, subsequently modified from STM1 format to E1 and fed into the Station Unit block.

The other way round is similar; here a cell router caters for cell distribution depending on their header addresses. Cells will be routed either to the private RNC or to the **MAESTRO** RNC Emulator.

(d) Shared I_{ub}-Interface Using Internal ATM-Switch

This circuit variant looks promising, if external hardware upgrade necessary for **MAESTRO** functionality accommodation is regarded to be too risky for parallel operations executed by both the network provider (owner of the shared NodeB) and the **MAESTRO-**system.

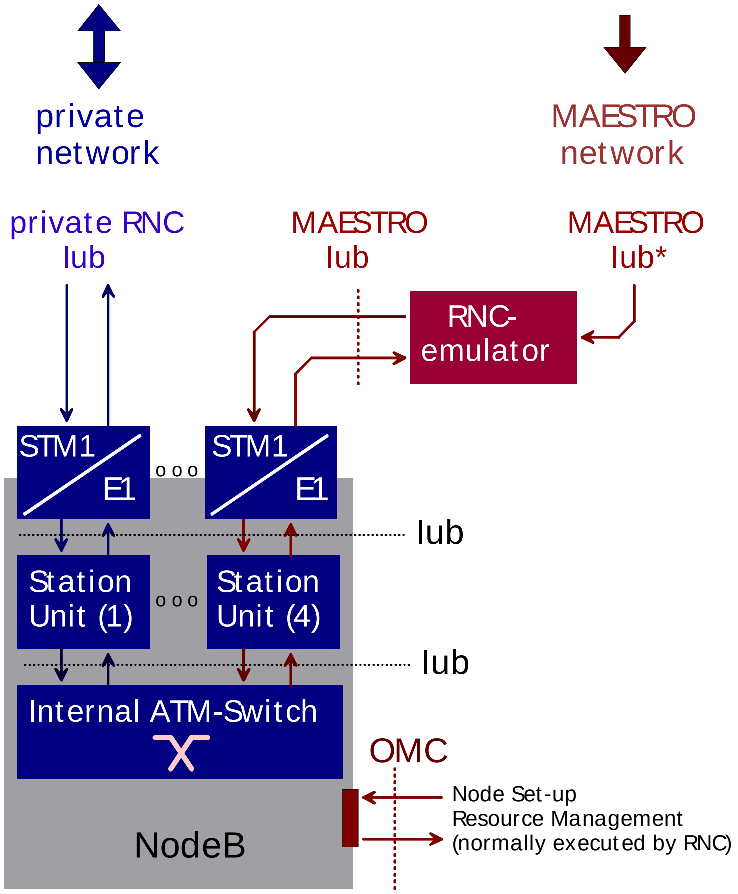


Figure 33: I_{ub}-sharing with NodeB internal ATM-switch

(e) Shared I_{ur} Interface

It is still under study whether the I_{ub} allows direct access to relevant channels, as assumed in Figure 32 and Figure 33. If this is not possible, access has to be provided to the I_{ur} interface as depicted in Figure 34.

In this case the private RNC operates as a C-RNC and enables data exchange with the RNC-Emulator via the I_{ur} interface. The RNC-Emulator and the protocol termination is required to serve the C-RNC with the expected bi-directional I_{ur}.

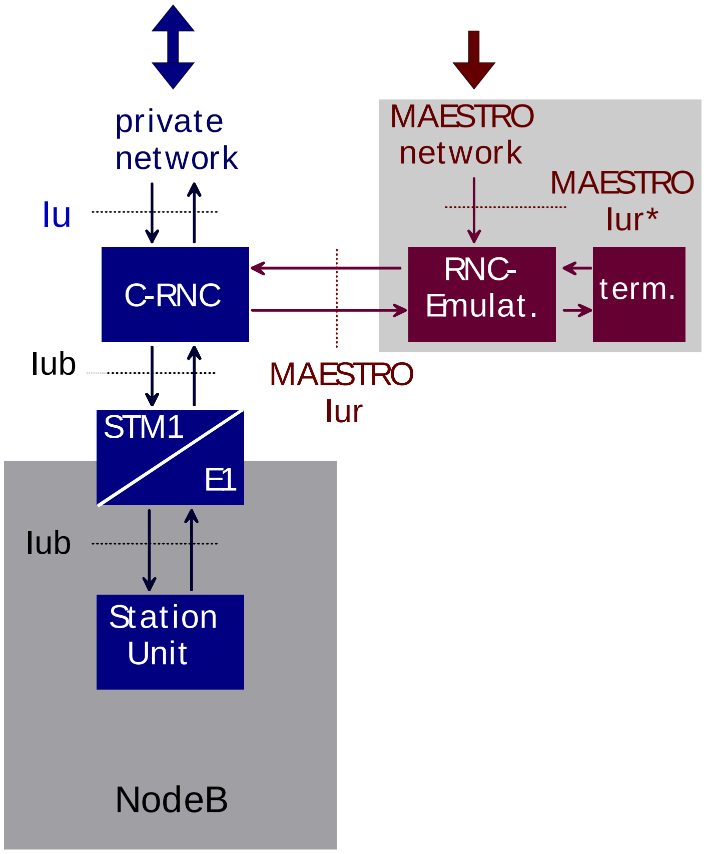


Figure 34: Addendum for I_{ur}-sharing

In principle both of the introduced sharing schemes are – roughly spoken – applicable. While I_{ub} sharing requires the NodeB management (e.g., resource management, node set-up, etc.) executed from outside via the OMC interface, the I_{ur} sharing administration can be executed by the RNC module.

9 ANNEX 4 – RELEVANT NODEB-SPECIFICATIONS

9.1 Selected NodeB Specifications As Far As Relevant For IMR

9.1.1 General For Transmit Path Of NodeB

In principle the NodeB down-link specification figures should not differ from the respective figures of the OCR and FCR. Both repeater types could be regarded as transparent, i.e., specifications could concentrate on analogue issues.

In contrary to them, the NodeB requires a lot of signal processing specifications and recommendations.

9.1.2 NodeB Capacity Considerations And Calculations

Table 23: NodeB General Radio And Power Parameters

Tx-power [3GPP TS25.104]	24dBm (for local area application)	
	38dBm (for medium area application)	
	43dBm (for wide area application)	
reference sensitivity	-123dBm at 12.2kb/s (Alcatel); -114dBm (3GPP),	
	SF = 64	
	BER less or equal10^{-3}	
channel bandwidth	5MHz (i.e., 3.8MHz + 1.2MHz role off	
transmit frequency band (terr)	2,110MHz – 2,170MHz	(terrestrial UMTS)
transmit frequency band (sat)	2,170MHz – 2,200MHz	(UMTS-satellite band)
Tx-mid-frequency (terr)	2,140MHz	(terrestrial UMTS)
Tx-mid-frequency (sat)	2,185MHz	(UMTS-satellite band)

Table 24: NodeB Channel Space And Channel Raster:

Channel spacing	5MHz
Channel raster	200kHz, i.e., channel centre frequency must be an integer multiple of 200kHz.
UARFCN	multiplying the corresponding Tx channel centre frequency by five

UARFCN = UTRA absolute radio frequency channel number

Table 25: NodeB Capacity:

	number of users	available data rates
today	75	1.536Mb/s
future	120	1.920Mb/s
fully equipped	1,215	25.920Mb/s

Remarks to Table 5:

The NodeB is built to support up to 120 users within 1.920Mb/s per cell. This capacity cannot be achieved today but will be target for the next future.

Fully equipped the NodeB may handle up to 1,215 users (18 x 0.75 x 0.75 x 120 users) within a maximum of 25.920Mb/s.

The today base-band processing per cell allows support up to 75 users within 1.536Mb/s per cell.

For traffic-mix-models the following rough estimation for Base Band processing-dimensioning can be made:

$$\mathbf{K} + \mathbf{L} + \mathbf{M} + \mathbf{N} \leq \mathbf{75\ User\ Channels}$$
$$\mathbf{K} \times \mathbf{12.2kb/s} + \mathbf{L} \times \mathbf{64kb/s} + \mathbf{M} \times \mathbf{128kb/s} + \mathbf{N} \times \mathbf{384kb/s} \leq \mathbf{1,536\ kb/s}$$

where:

- K = number of AMR users
- L = number of 64kb/s- channel users
- M = number of 128kb/s- channel users
- N = number of 384kb/s- channel users

Base-band processing capacity serves as pooled resource for the whole platform. So the distribution of users in the BB-pool is independent from the number of the carriers or sectors.

The limit for one basis band processing board is the support of a 6x2 configuration in the future. BB dimensioning is independent from the RF configuration with the following limits per Node:

- min. configuration : up to 16 users and 384kb/s + necessary CCH
- max. configuration: up to 675 users and 13.824Mb/s+necessary CCH
- (---> assuming max 12 cells, 75 % load)

9.1.3 Frequency Error

All frequencies and clocks within the Node shall be derived from the same source. The modulated carrier frequency is measured over a period of one power control group (one radio timeslot of 666.6us). The following effects may contribute to the modulated carrier frequency error:

- stability of the common frequency source (master oscillator of the Node, which determines the long-term stability of the carrier frequency. If the master oscillator is locked to the clock from the I_{ub} interface, then clock stability will refer to the stability of the I_{ub} clock.
- clock distribution within the platform´s cabinet. Low frequency noise and spurs up to several kHz contribute to the frequency error. To minimise these effects, a clock cleanup circuit shall be used within the transmission module with a loop bandwidth of less than 10Hz.

Table 26 below allocates the allowed overall frequency error to the different sources.

Table 26: Tx frequency errors

Tx frequency error budget	error [+/- ppm]	error at RF [+/- Hz]
platform master oscillator	0.020	29.5
clock distribution inside cabinet	0.005	44.7
TX-module	0.025	1.5
calculated platform frequency error	0.050	43.2
required platform frequency error	0.050	44.7

9.1.4 Adjacent Channel Leakage Ratio (ACLR)

Adjacent Channel Leakage power Ratio (ACLR) is the ratio of the average power centred on the assigned channel frequency to the average power centred on an adjacent channel frequency. In both cases the average power is measured with a filter that has Root Raised Cosine (RRC) filter response with roll-off factor 0.22 and a bandwidth equal to the chip rate.

The requirements below shall apply for all configurations of TRx (single carrier / multiple carrier) and for all operating modes.

Table 27: Adjacent channel leakage ratio at TX and platform output

adjacent channel offset below the first or above the last carrier frequency used	ACLR limit	ACLR typ
5MHz	45dB	48dB
10MHz	50dB	53dB

9.1.5 Output RF-Spectrum Emissions

The RF-spectrum emission requirements are complicated by the fact that the terrestrial UMTS–band (2,110 – 2,170MHz) slightly differs to the satellite UMTS-band (2,170 – 2,200MHz). In this case the Tx-transmit module has to fulfil the output requirements, as the Tx-output filter does not provide any additional suppression beside the normal in-band insertion loss.

- for the **MAESTRO** application the Tx-filter requires a shift of the filter mid-frequency from 2,140 to 2,185MHz.

Occupied bandwidth is a measure of the bandwidth containing 99% of the total integrated power for transmitted spectrum and is centred on the assigned channel frequency. The occupied channel bandwidth shall be less than 5MHz at TX output.

The platforms Tx-emissions shall not exceed the maximum level specified in Table 28 and also shown in Figure 35 for the appropriate maximum output power, in the frequency range from Δf = 2.5MHz to f_$_{\mathbf{offsetmax}}$ from the carrier frequency, where:

- Δf is the separation between the carrier frequency and the nominal -3dB point of the measuring filter closest to the carrier frequency.
- f_$_{\mathbf{offset}}$ is the separation between the carrier frequency and the centre of the measuring filter.
- f_ $_{\mathbf{offsetmax}}$ is either 12.5MHz or the offset to the UMTS-Tx-band edge.

Table 28: Spectrum emission mask values for different output power

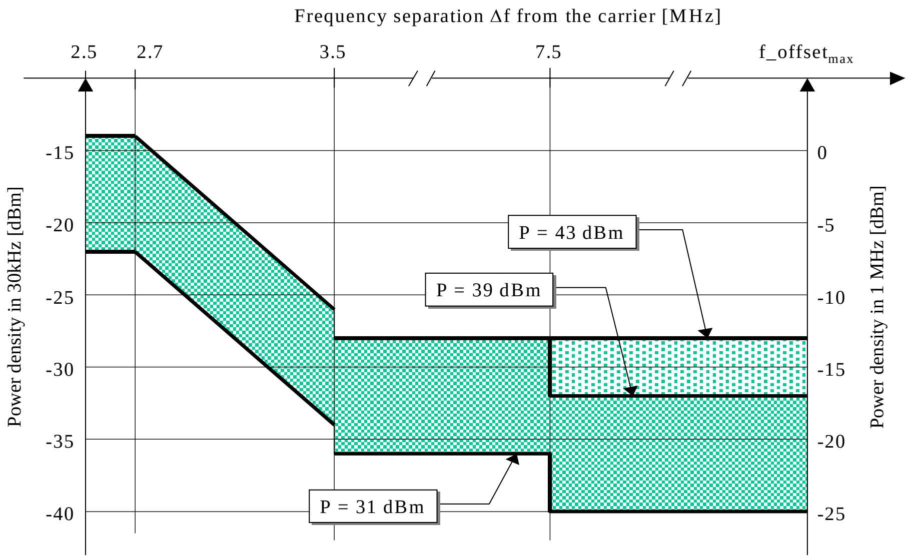
spectrum emission mask values for output power P<43dBm				
frequency offset of measurement filter –3dB-point, Δf	**frequency offset of measurement filter centre frequency f_offset**	**maximum level at TRx-output**	**maximum level at antenna output**	**Measure. bandwidth**
2,5 < Δf <2.7MHz	2.515 < f_offset < 2.715MHz	-13.15dBm	-14dBm	30kHz
2,7 < Δf <3.5MHz	2.715 < f_offset<3.515MHz	-13.15 - 15 (f_offset-2.715)dBm	-14 - 1.5 (f_offset-2.715)dBm	30kHz
see note below	3.515 < f_offset<4.000MHz	-25.15dBm	-26dBm	30kHz
3.5 < Δf MHz	4.000 <f_offset<f_offset max	-12.15dBm	-13dBm	1MHz

spectrum emission mask values for output power P>43dBm				
2,5 < Δ f < 2.7MHz	2.515 < f_offset < 2.715MHz	-13.15dBm	-14dBm	30kHz
2,7 < Δf < 3.5MHz	2.715 < f_offset < 3.515MHz	-13.15-15 (f_offset-2.715)dBm	-14-1.5 (f_offset-2.715)dBm	30kHz
see note below	3.515 < f_offset < 4.000MHz	-25.15dBm	-26dBm	30kHz
3.5 <Δf < 7,5MHz	4 < f_offset < 8MHz	-12.15dBm	-13dBm	1MHz
7.5 <Δf MHz	8 < f_offset < f_offset max	P - 55.15dBm	P - 56dBm	1MHz

spectrum emission mask values for output power 31 < P < 39dBm				
2,5 < Δf <2.7MHz	2.515 < f_offset < 2.715MHz	P - 52.15dBm	P - 53dBm	30kHz
2,7 < Δf < 3.5MHz	2.715 < f_offset < 3.515MHz	P - 52.15-15 (f_offset-2.715)dBm	P-14-1.5 (f_offset-2.715)dBm	30kHz
see note below	3.515 < f_offset < 4.000MHz	P - 64.15dBm	P - 65dBm	30kHz
3.5 < Δ f < 7,5MHz	4 <f_offset < 8MHz	P - 51.15dBm	P - 52dBm	1MHz
7.5 < Δf MHz	8 < f_offset < f_offset max	P - 55.15dBm	P - 56dBm	1MHz

spectrum emission mask values for output power P < 31dBm				
2,5 < Δf < 2.7MHz	2.515 < f_offset < 2.715MHz	- 21.15dBm	- 22dBm	30kHz
2,7 < Δf < 3.5MHz	2.715 < f_offset < 3.515MHz	P - 52.15-15 (f_offset-2.715)dBm	P-22-1.5 (f_offset-2.715)dBm	30kHz
see note below	3.515 < f_offset < 4.000MHz	-33,15dBm	- 34dBm	30kHz
3.5 < Δf < 7,5MHz	4 <f _offset < 8MHz	- 20.15dBm	P 21dBm	1MHz
7.5<Δf MHz	8 < f_offset < f_offset max	- 24.15dBm	- 25dBm	1MHz

Note:a minimum insertion loss of 0.85dB is assumed for the TX to antenna connector



Illustrative diagram of spectrum emission mask

Figure 35: Spectrum emission mask at reference point

9.1.6 Transmit Pulse Shape Filter:

The transmit pulse-shaping filter is a root-raised cosine (RRC) with roll-off $\alpha = 0.22$ in the frequency domain. The impulse response of the chip impulse filter RC0(t) is:

$$RC_0(t) = \frac{\sin\left(\pi \frac{t}{T_C}(1-\alpha)\right) + 4\alpha \frac{t}{T_C}\cos\left(\pi \frac{t}{T_C}(1+\alpha)\right)}{\pi \frac{t}{T_C}\left(1-\left(4\alpha \frac{t}{T_C}\right)^2\right)}$$

where the roll-off factor $\alpha = 0.22$ and the chip duration:

$$T_C = \frac{1}{chiprate} \approx 0.26042\mu\mathrm{s}$$

9.1.7 Transmit Inter-Modulation

The transmit inter-modulation performance is a measure of the transmitter capability to inhibit the generation of signals in its non linear elements caused by presence of the wanted signal and an interfering signal arriving via the antenna.

The transmit inter-modulation level is the power of the inter-modulation products when a W-CDMA modulated interference signal is injected into the antenna connector at a level of 30dB lower than that of the subject signal. The interference frequency shall be ±5MHz, ±10MHz and ±15MHz offset from the subject signal.

9.1.8 Transmit Modulation

Transmit modulation is specified in three parts, Frequency Error, Error Vector Magnitude and Peak Code Domain Error. These specifications are made with reference to a theoretical modulated waveform.

The theoretical modulated waveform is created by modulating a carrier at the assigned carrier frequency using the same data as was used to generate the measured waveform. The chip modulation rate for the theoretical waveform shall be exactly 3.84Mc/s. The code powers of the theoretical waveform shall be the same as the measured waveform, rather than the nominal code powers used to generate the test signal. In the platform the modulation is performed within the digital part of TX. Modulation errors are due to:

- minor truncation effects in the digital signal processing part of TX (limited number of bits and transmit pulse shape filter length).
- the clipping algorithm within TX which is needed to improve the signal peak to average ratio (PAR) of the unclipped signal. A low PAR is required in order to have a good power amplifier efficiency. Most of the allowed modulation errors should be allocated to the clipping process.
- D/A, up-converter and power amplifier imperfections inside the TX-module.
- the transmit filter imperfections like amplitude ripple and group delay variations within the Antenna Network ANT / ANRU module.

9.1.9 Error Vector Magnitude (EVM)

The error vector magnitude (EVM) is a measure of the difference between the reference waveform and the measured waveform. This difference is called the error vector. Both waveforms pass through a matched Root Raised Cosine filter with bandwidth 3.84MHz and roll-off $\alpha = 0.22$.

Both waveforms are then further modified by selecting the frequency, absolute phase, absolute amplitude and chip clock timing so as to minimise the error vector. The EVM result is defined as the square root of the ratio of the mean error vector power to the mean reference power expressed as a %. The measurement interval is one timeslot as defined by the C-PICH (when present) otherwise the measurement interval is one timeslot starting with the beginning of the SCH.

Table 29: Error vector magnitude (EVM) requirements

EVM_{TRX}	EVM_{ANT}	EVM_{total}
16.80%	4.1%	17.3%

For the platform on Node B basis the total allowed EVM is allocated to the different modules as shown in Table 29 above. It is assumed that the EVM of the individual modules is independent so that the overall EVM is the RMS-value of the individual contributions.

9.1.10 Peak Code Domain Error (PCDE)

The Peak Code Domain Error (PCDE) is computed by projecting the power of the error vector onto the code domain at a specified spreading factor. The Code Domain Error for every code in the domain is defined as the ratio of the mean power of the projection onto that code to the mean power of the composite reference waveform.

The PCD Error (ratio expressed in dB) is defined as the maximum value for the Code Domain Error for all codes. The measurement interval is one timeslot as defined by the C-PICH (when present) otherwise the measurement interval is one timeslot starting with the beginning of the SCH. The requirement is valid over the total power dynamic range.

Table 30: Peak code domain error (PCDE) requirements

$EVM_{\mathbf{TRX}}$	$PCDE_{\mathbf{ANT}}$	$PCDE_{\mathbf{total}}$
16.80%	4.1%	17.3%

The spreading factor for the peak code domain requirement is 256.

10 FINAL CONCLUSION ON IMR ARCHITECTURE

NodeB based IMR, though technically challenging, requires enormous synchronisation effort and thus high cost. Thanks to the sharing application power supply and other cabling is already provided and thus gives a low cost balance. With respect to the complex synchronisation effort it is not clear up to now whether such a construction will ever work reliably.

The frequency converting IMR (FCR) is technically easy to handle and shows a good cost-performance relation. Though not yet commercially available, the technical concept is reasonable and reliable. Sensitivity against environmental interference is low.

The On-Channel IMR (OCR) is technically more complicated to handle, as precise effort has to be spent for de-coupling entry and output. Sensitivity against multipath interference is very high, the same for environmental interference. As this IMR type accommodates a relatively simple technology, operation is expected to be reliable; for the same reasons this type has a good cost-performance relation.

Both the OCR and FRC can be applied to the **MAESTRO** system depending on requirements coming from the external environment. Both types have a right for exist and it will be a matter of further research and investigation to determine application locations, technology constraints, and other details (cost, reliability, potential manufacturers) for a wide spread area of application.