The intermediate module concept within the SATIN proposal for the S-UMTS air interface

[*]T. Severijns, [*]W. De Win, [*]M. Dieudonne, [♦]M.Karaliopoulos, [♦]K.Narenthiran, and [♦]B.G.Evans

[*]Agilent Technologies, Wingepark, 51 B-3110 Rotselaar, Belgium
Tel: +32 16 46 97 11, Fax: +32 16 44 54 81
Email: michael_dieudonne@agilent.com

[♦]CCSR, University of Surrey, Guildford, Surrey GU2 7XH, UK
Tel: +44(0) 1483 879131, Fax: +44(0) 1483 876011
Email: B.Evans@eim.surrey.ac.uk

ABSTRACT

This paper describes the *SATIN* ground repeater/ intermediate module repeater (*IMR*) concept, which is nowadays considered as way forward to target the mass market and gives bright future for *S-UMTS*. Different environmental scenarios for *IMR*s are highlighted and the expected services for each scenario are identified. Possible functionalities of *IMR* are brought up and the related cost and complexity issues of *IMR*s are investigated. SATIN simple repeater architecture is defined and expected characteristics architecture elements and possible difficulties in achieving them are discussed.

I. INTRODUCTION

For the satellite UMTS (*S-UMTS*), it is necessary to establish the critical mass of customers needed to provide affordable service. It is a common belief that the inability of satellite systems to provide urban and indoor coverage has prevented the mobile satellite systems (*MSS*) industry from achieving its potential success as a provider of competitive services to all areas, including rural and remote areas.

In order to overcome that problem, introducing ground repeaters/intermediate module repeaters (*IMR*) in urban, rural and highway is currently considered as solution. This proposed solution allows *S-UMTS* operators to extend multimedia services to indoor and urban areas, this way addressing a mass market in terms of coverage. It permits also to make *S-UMTS* terminals (*SMT*) more consumer-friendly and affordable. The attractiveness (in terms of cost mainly) of the *SMT* is anticipated to be a decisive factor for the *S-UMTS* success since the potential *UMTS* customer is not willing to pay much more than what he pays now for a 2G/2G+ terminal.

This paper explains the SATIN (IST project – "Satellite-UMTS IP-based Network") approach on *IMR* to provide multicast and broadcast services as terrestrial *UMTS* complement in a more efficient way to the mass market. Next section explains *IMR* concept in different environments. Section III discusses about the functionalities of *IMR* and the *IMR* architect issues are presented in section IV. Last section draws the conclusions and points out the future plans.

II. IMR ENVIRONMENTAL SCENARIOS

This section explains possible *IMR* scenarios, which can target the mass market and type of services each scenarios aiming for. The following issues may be different for different scenarios or may be same.

- *IMR* functions (e.g. just like a booster)
- Interfaces *SAT-IMR* and *IMR-SMT*.

A. Urban and Suburban environment

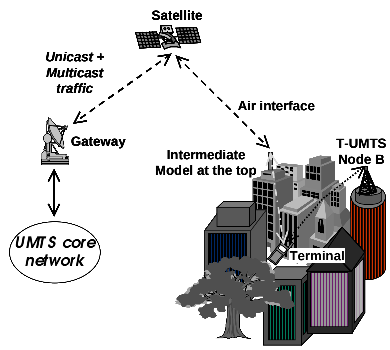


Figure 1: IMR in urban environment

Figure 1 shows the arrangement of an *IMR* capable of satellite reception inside the build up area and inside the buildings. There are two possible service scenarios, only broadcast and multicast services via satellite to the local users and full services via satellite to international roamers. However the *IMR* may also be just a repeater without incorporating any functions of *RNC* or *Node B*.

B. Vehicular or Highway Environment

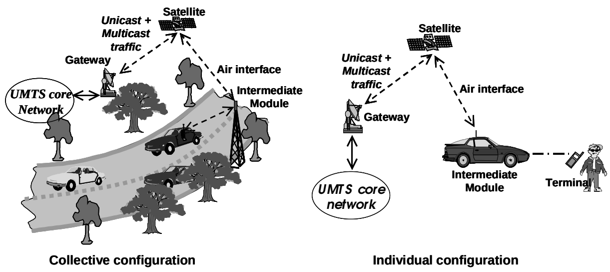


Figure 2: Vehicular or Highway Environment

IMR positions for the in-car application and the respective configurations have been shown in Figure 2. The *IMR* can be just a repeater and hence the terminal use the satellite mode or the *IMR* can translate the signal into terrestrial form so that the terminal can use the terrestrial mode.

C. Ship, plane and UMTS islands case

In this scenario (except UMTS islands), the *IMR* may feature *Node B* or simple repeater functionality. In the UMTS island case the satellite link represents the interface between the *UTRAN* and the *CN* (*Iu*).

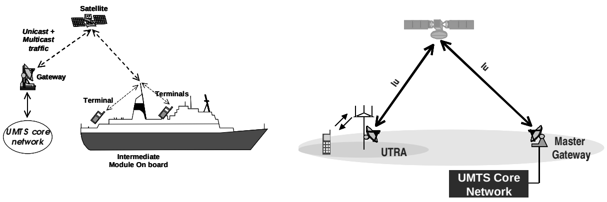


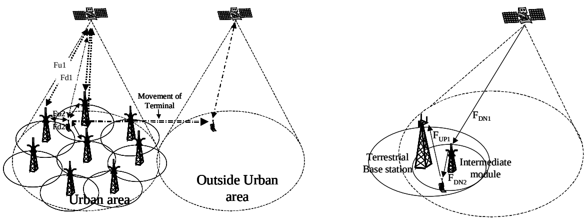
Figure 3: Remote environment (Ship, Plane and UMTS islands)

III. IMR POSSIBLE FUNCTIONALITIES

This section investigates different possibilities to define the functionalities of *IMR* and the interfaces *SAT-IMR* and *IMR-SMT* considering the following points.

1. Multicast and broadcast services can be well served by satellite.
2. Terminal complexity should not increase significantly due to the introduction of the *IMR*.
3. A big constraint experienced by the terrestrial system was placing the base stations in a cost effective and environment-friendly way. Therefore the satellite industry may also experience the same problem in installing the *IMR*s.

A. IMR as a simple repeater



Type I: Two way repeater

Type II: One way repeater

Figure 4: Simple repeater case

In this case the *IMR* acts as a simple repeater. The *IMR* receives the signal in the *S-UMTS* band from the satellite, amplifies and retransmits it towards the terminal. Similarly, it receives the signal from terminals and transmits it towards the satellite. The same frequency band may be used for both links, namely the *SAT-IMR* link and the *IMR-SMT*. Alternatively different bands may be used for each link, in the latter case the *IMR* features frequency conversion capability. Therefore the terminal can receive the same signal from two or more *IMR*s as shown in Figure 5 similar to multipath propagation. When the terminal moves out of coverage of the *IMR*, it can directly communicate with the satellite since the signal attenuation is very low outside the build up area. Hence the S-UMTS mode can be used at the terminal inside and outside the build up areas.

Contrary to the terrestrial case where the signal received from other cells is considered as interference, the signals transmitted by other *IMR*s can be considered as multipath signals except for the case that the *IMR*s are located in different spotbeam coverage area. Here a trade-off exists between *IMR* system cost and terminal complexity.

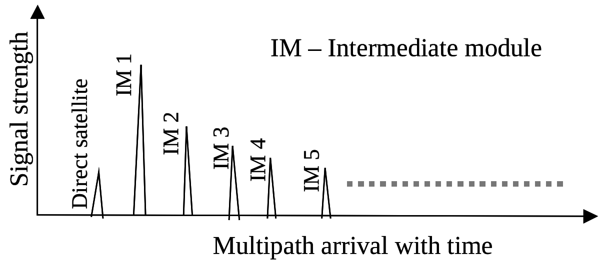


Figure 5: Same signal through different IMRs

The multipath arrival delays of signals coming from different *IMR*s will mostly be larger than the arrival delays of the multipaths caused by reflections etc. of the signal coming from the *IMR* closest to the terminal. Extending the *RAKE* search window (larger delay line) implies on one hand a more costly terminal, but on the other hand a similar amount of signal code power can be received with lower power *IMR*s or less dense distributed *IMR*s.

Two types of repeaters are considered based on the SATIN architecture concept [2]: bi-directional (Figure 6) and unidirectional (Figure 7) simple repeaters.

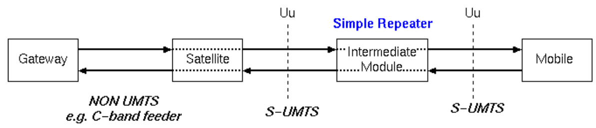


Figure 6: Bi-directional simple repeater

In bi-directional case, both downlink and uplink will use *S-UMTS* frequency bands. Positive aspects of this approach include:

- Creation of a multipath environment; a RAKE receiver in the terminal can exploit this and enhance the *SNIR* of the signal. Note that this is limited to urban areas, in rural environments the channel still has a Rice/LOS character.
- Effectively ‘everywhere/anytime’ coverage, because the terminal can communicate pseudo-directly to a satellite in an urban environment *and* directly in an open environment.

Negative aspects include:

- Only slow inner loop power control (*PC*) is possible due to large propagation delay between the *IMR* and the satellite[1]. *PCC* instructions will be given on a frame-to-frame basis (100 Hz instead of 1500 Hz as in *T-UMTS*). This will result in a serious decrease in the ability to compensate for fading channels.

- No possibility to implement any form of *PC*, to regulate the transmit level of the *IMR*s to mitigate intra-spotbeam interference.

- Terminals will have to be dual-mode for both the Tx and Rx chains, and hence more expensive.

Terminal considerations:

It seems difficult to design low cost *power effective handheld* terminals that can handle the full rate uplink straight to the satellite, as is the case in rural areas not covered by the *IMR*s. This does not necessarily mean that receive only scenario is the only option left. For low data rates the processing gain can be high enough to boost the uplink signal sufficiently at the satellite receiver. Hence an asymmetrical link scenario (Multicast/Broadcast) seems feasible for handheld terminals.

When aiming at the geographical complement goal of *S-UMTS*, handheld terminals will only be able to provide *low uplink bit rates*. A possible way to alter the uplink bit rate is to use an extension module with enough transmit power connected to the terminal (or laptop/PDA/etc.) with a short range wireless link or a cable or to use the nomadic terminal. The highest performance will probably be reached when using a vehicular *IMR* that can either be a simple repeater, or a short range wireless interface/*S-UMTS* converter, because in this case available Tx power will be highest.

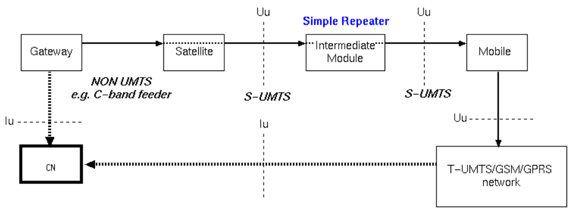


Figure 7: Unidirectional simple repeater

The unidirectional case has the following advantages compared to the bi-directional case:

- The *IMR* complexity (and cost) will be greatly reduced, because the *RF* front-end must only be capable of receiving from satellite and transmitting to the mobiles.

- The terminal complexity (and cost) can be made considerably lower because it must only be able to receive *S-UMTS*. The most cost-saving factor in that case is the considerably reduced complexity of the RF/IF part. Power consumption will be considerably less since no *S-UMTS* Tx in terminal.

- Benefit from the terrestrial uplink infrastructure features, like (fast) uplink *PC*, RAKE combining (*T-UMTS*), is feasible.

Negative aspects are:

- If *T-UMTS* is selected for the uplink, the geographical complement concept is violated; it is made clear though in [1] that SATIN adopts the service complement approach rather than the traditional, geographical complement one. If the up-link is *GSM/GPRS* the geographical complement goal is in a way achieved, since not many areas are outside *GSM/GPRS* coverage, but the up-link capabilities will of course be insufficient to support *full T-UMTS* services.

- *T-UMTS/GSM/GPRS* up-link gets some additional loading. This should however be very limited, since the targeted set of services are broadcast/ multicast.

This scenario seems to be the most interesting when geographical complement is not the main objective. However different types of terminals (in terms of *T/S-UMTS* capabilities) will probably be available in the market and customers need to pay more to get terminals with uplink *S-UMTS* capabilities (low rate).

B. IMR simple repeater with some functionalities of Node B

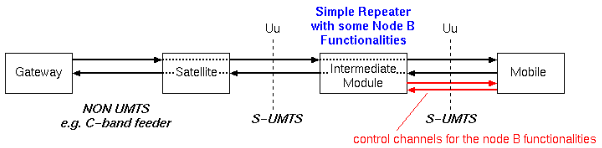


Figure 8: Repeater with some node B functionalities

Depending on the extra cost involved, some node B functionalities could be implemented in the *IMR*s. Functions of interest are:

- Power control

- Multipath reception (RAKE Rx)

As indicated in the Figure 8, the *IMR* will need to be able to communicate with the mobile in a direct and independent manner. One or more control channels per mobile user will need to be present to manage the envisaged functionalities. Inherently the *IMR* must be capable of doing demodulation and re-modulation of the control signal. This will place demand on the digital part, it's complexity depending on the functionalities to be included. The analogue part (RF) will also be more complex because some additional filtering, frequency conversion, amplification, and A/D - D/A conversion will be necessary.

It is important to note that the *IMR* is still a repeater, so the interface with the satellite is the same S-UMTS interface as between *IMR* and mobile. For most of the signals the *IMR* will be transparent.

[1] Note that the implied comparison is made with a case, where the intermediate module features some Node B or RNC functionality

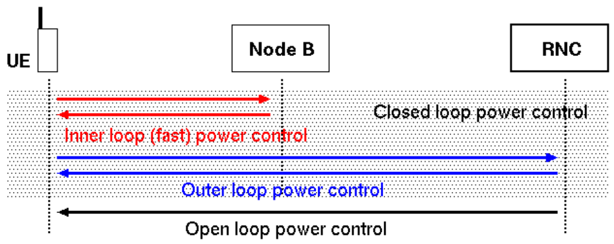


Figure 9: W-CDMA power control mechanisms

PC is an essential feature of any *CDMA* based cellular system. The mechanism to be considered in this scenario is the inner loop *PC* (both up-link and down-link). It continuously adjusts the terminal transmit levels in order to meet a specified *SNR* (depending on needed *QoS*) set by the outer loop *PC*. Open loop *PC* involves the *RNC* and is certainly not to be implemented in the *IMR*.

The main reason for implementing *PC* is the near-far problem, interference dependent capacity of the *WCDMA* system, limited power source of the terminal and the presence of fading channels. But only the latter would really require *fast* inner loop *PC* (1500 Hz). A frame-based *PC* (100 Hz) should be sufficient to effectively handle the other drawbacks. If the *PC* signal would only have to travel the distance between mobile and *IMR*, a *T-UMTS* like *PC* mechanism can be implemented and fading would be effectively mitigated.

The channel between the mobile and satellite does not usually have Rayleigh multipath characteristics. However the satellite environment with *IMR* can be seen as multipath environment, the same way as in *T-UMTS*. These multipath characteristics can be exploited by incorporating a RAKE receiver into the module. An advantage of putting a RAKE receiver already into the *IMR* as opposed to only having a RAKE in the gateway is that the *IMR* would demand less transmitted power. Putting a RAKE receiver in the gateway makes it possible to exploit macro diversity (from different *IMR*s). If the *IMR* uplink transmitted power is not really an issue, there is probably no considerable benefit since the path between *IMR* and gateway should not really distort the signal (only path loss) so the multipath characteristics of the signal prevail and can be exploited by a RAKE in the gateway.

However, the strong increase in complexity and hence cost outweigh the gain in implementing *PC* in the *IMR*. Implementing *PC* implies (de)modulating capabilities and some decision-making software. Also the analogue part (RF/IF) will become more complex and thus expensive. The only actual gain is better fading mitigation.

Implementing a RAKE receiver in the *IMR*s seems only beneficial if *IMR*s uplink Tx power is a critical factor.

C. IMR acts as Node B

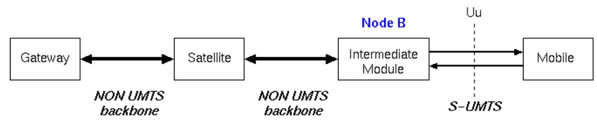


Figure 10: IMR with Node B functionality

This case is similar to the *T-UMTS* island case, with the difference that it is going to use the *S-UMTS* band instead of the *T-UMTS* band. ICO proposed a system similar to the one explained to handle the coverage in the urban environment. It is known as Ancillary Terrestrial Component (*ATC*). It is important to note that the satellite only acts as a backbone network or as shown in Figure 11 there is no satellite involvement at all except both satellite and *ATC* share the frequency band as shown in the case below. It has been mentioned in the ICO proposal that there should be a single entity responsible for fully integrated operation of the MSS network in order to reduce the interference and share the spectrum.

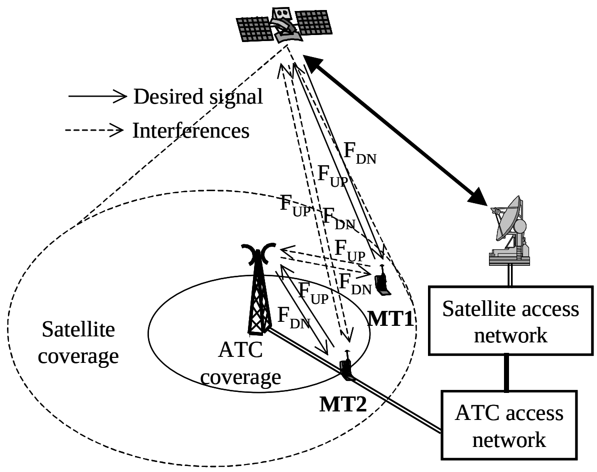


Figure 11: ICO Forward Band Sharing Mode

G. IMR acts as Node B and RNC

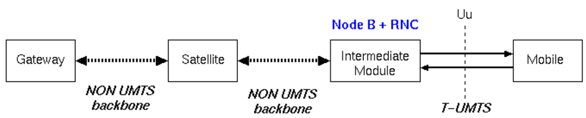


Figure 12: IMR with Node B and RNC functionality

This set-up could be interesting for the 'UMTS island' scenario in the sense that the satellite link is responsible for the interface between the 'island' and the *UMTS* core network. In some cases this could be much cheaper than connecting the 'island' to the *CN* with cables. An 'island' can be a remote, though relatively dense populated area, it can be a ship, stadium etc.

IV. IMR ARCHITECTURE

The overview of some basic architecture issues for the unidirectional simple repeater is given below.

A. IMR functional elements

The *IMR*s functions are limited to receiving, amplifying and re-transmitting the signal coming from the satellite towards the mobile. Therefore, the entire module can be kept analogue, since only RF-related functions have to be implemented.

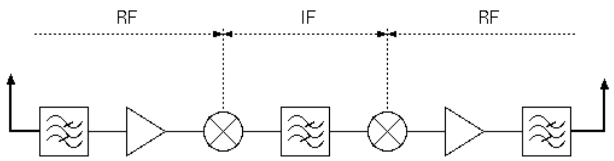


Figure 13: Architecture for unidirectional simple repeater

Figure 13 displays a simple model of a possible architecture. The components of this repeater type are limited:

- *Donor antenna:* the repeater antenna directed towards the satellite, picking up the downlink signal. This antenna should be highly directional.
- *Service antenna:* omni-directional antenna to cover the service area.
- *RF band pass filters:* determine the frequency range for operational configuration
- *IF band pass filter:* defines the actual pass band and is a determining factor in important issues like out-of-band-gain, delay, Error Vector Magnitude (*EVM*), etc. for which a compromise will have to be made.
- *Mixers*
- *Local oscillators*
- *Low noise amplifier (input)*
- *Power amplifier (output)*

Typical characteristics (partially based on *T-UMTS* repeaters):

- *Gain:* 70 dB - 90 dB
- *Maximum output power:* 30 dBm
- *Rx antenna gain:* 28 dBi
- *Noise figure:* 3.5 dB (G/T=2.5dB)
- Most repeaters feature *Auto Limit Control (ALC)* or *Automatic Gain Control (AGC)*, an adjustable limit for the output power to be able to inhibit out of band gain and emissions, and to prevent self-oscillation.
- *Mechanical characteristics:*
    - *Size* in cm: 40H x 35W x 30D
    - *Weight:* <20 kg

C. Remarks on frequency separation of donor link and service link

High power repeaters used for large coverage areas might imply a frequency separation of both links, because the antenna isolation requirement can become too strict. So, for high power repeaters a trade-off exists between extra effort in antenna isolation (shielding, highly directional Rx antenna pattern, etc.) and the need for extra spectrum. The increase in repeater complexity as a consequence of the need for frequency conversion will be negligible.

Using a GEO constellation, highly directional antennas are possible and because the majority of repeaters will probably not be large coverage area oriented, the most favourable option with respect to efficient spectrum usage seems to be a single-frequency repeater.

D. Special cases

Indoor reception will already be greatly improved by the outdoor repeaters. Still, coverage dead zones might exist (e.g. in tunnels, underground parking lots, etc.). The repeater will take the outside received signal and retransmits it inside a building. These repeaters will be similar to the outdoor ones but will need less gain and less output power.

Another remark is to be made concerning moving *IMR*s (on a ship, train, etc.). The presence of Doppler frequency shifts due to the relative motion with respect to the satellite will most likely not ask for a different type of *IMR*, since the shifts will be very small with respect to the signal bandwidth (for ships, trains, etc.). Some extra attention should be given to the IF filter characteristics. In the case of moving *IMR*s it can be better to use a wider although steeper filter characteristic to tolerate a slightly frequency shifted signal with a minimum amount of distortion. The Doppler frequency shift will be removed in the user equipment.

V. CONCLUSION AND FUTURE DIRECTION

Three distinct environmental scenarios (urban, vehicular and remote) for *IMR* are identified and possible services in each case are given. Selection of functionalities of *IMR*s are discussed considering the cost and complexity and it is decided that unidirectional simple repeater is cost effective and less complex one. Characteristics IMR architecture elements are discussed and the difficulties in incorporating these characteristics in reality are also investigated. Antenna isolation in high power *IMR*s and Doppler effect in moving *IMR*s are identified some key issued to tackle.

Future work will mainly concentrate in *IMR* distribution (*IMR* cell planning).

REFERENCES

[1] *SATIN Project, 'S-UMTS IP-Specific Service Requirements' Del. No. 2, October 2001*

[2] *SATIN Project, 'SATIN Architecture specifications' Del. No. 3, 28 Feb 2002.*