

Mobile broadband everywhere : the satellite a solution for a rapid and large 3,9G deployment

Caroline BES and Christelle BOUSTIE

CNES (French Space Agency)
Toulouse, France

caroline.bes@cnes.fr, christelle.boustie@cnes.fr

Ari HULKKONEN*, Juha YLITALO*,
Ulla.ELSIILA* and Pekka PIRINEN[†]

* Elektrobit Wireless Communications
[†]University of Oulu, Centre for Wireless
Communications
Oulu, Finland

Ari.Hulkkonen@elektrobit.com ;

Juha.Ylitalo@elektrobit.com;

Ulla.Elsila@elektrobit.com ; pekkap@ee.oulu.fi

Abstract— The aim of this paper is to demonstrate the feasibility of the concept of a complementary Satellite Component to the LTE (3GPP Long-Term Evolution, also known as 3,9G) and/or WiMAX (Worldwide Inter-operability for Microwave Access) terrestrial network that mobile network operators intend to deploy to support a mass market offer of “Internet connectivity while on the move” and to show its benefit in ensuring truly global coverage.

In this paper, we show that the cohabitation of the terrestrial network and the satellite at the same frequency on the same global coverage is possible.

I. INTRODUCTION

Hybrid integrated system (associating satellite and terrestrial transmitters) is an opportunity for this sector to complete the coverage of current commercial mass market and to answer to governmental user needs.

“Integrated system” refers to a system composed of a LTE and/or WiMAX terrestrial network and a multibeam satellite component that re-uses the same frequency band than the terrestrial’s one. This integrated system improves the spectral efficiency of the overall system and spatially optimize the use of the frequency bands.

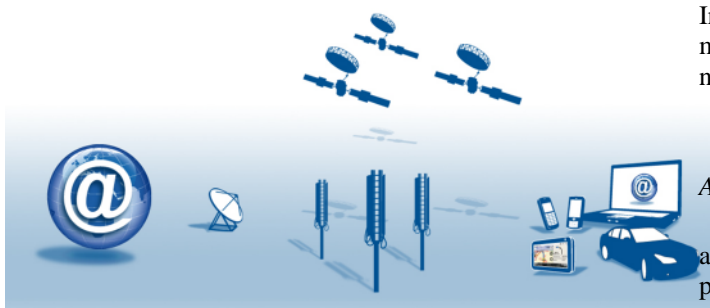


Figure 1. Hybrid integrated network

The main mission of this concept is then to offer a hybrid satellite and terrestrial variation of pure terrestrial technologies for commercial deployment of mobile broadband, with nomadic terminal (Ultra Mobile PC - UMPC) as main target. This axis appears promising since it provides a solution to commercial operators enabling them to cover rapidly a large chunk of the territory and not only 15 to 20% of the surface as it is foreseen for real mobile broadband (approximately 2 Mbps per user on a UMPC like terminal within a few years) deployment based on sole terrestrial components of LTE and/or WiMAX. It then gives the operators a real opportunity to make use of their spectrum beyond the first 15-20% of the territory (e.g.: spectrum usage of UMTS in the first 5 years).

Indeed, deploying more sites in rural areas would be so expensive for the parts of lowest density of population that another solution is now considered: CNES is working on a next-generation mobile satellite system quickly deployable, tightly integrated with terrestrial networks, and behaving as “terrestrial cells in the sky”. The terrestrial component will cover high density built-up areas and the satellite component will bring services to the rest of the coverage area.

The sharing of the terrestrial frequency bands with satellite component allows a better spectrum management mostly on rural zone. However, frequency reuse between terrestrial and satellite components may imply co-channel interferences between them.

In this paper, we show that the satellite component has a minimum impact in term of interference on terrestrial network and we present a solution of integrated system.

II. SATELLITE AND TERRESTRIAL SUB-SYSTEM

A. Satellite sub-system

Mobile satellite next generation system becomes an appropriate solution for rural coverage in terms of capacity performance thanks to the use of a large deployable antenna allowing (around 24 m of diameter) a large number of thin beams with between 100-160 km of diameter on ground. The beam densification is in favor of a better frequency reuse and of an increase of the capacity density.

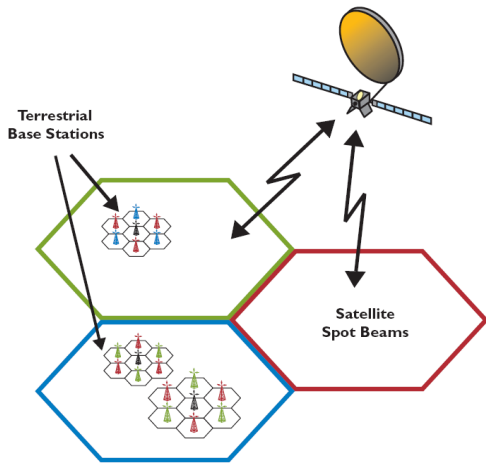


Figure 2. Example of hybrid integrated system deployment on earth

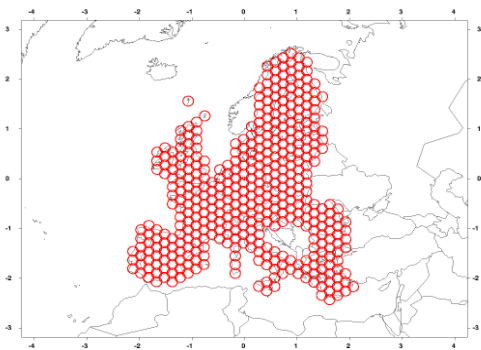


Figure 3. Example of satellite European coverage (around 400 beams)

At our latitude, geostationary orbits are seen at low elevation angle (between 30° and 40°) and require high shadowing margin to have a good availability of the service. The choice of Highly inclined Earth Orbit (HEO) for next-generation mobile satellite system allows a high geographical availability at our latitude even in suburban zone thanks to the fact that the satellite elevation is better than 60° everywhere on the satellite coverage zone. This better propagation condition (less shadowing margin) promotes the use of better spectral efficiency modulations and improves the global capacity.

B. Terrestrial sub-system

The integration of the satellite component and the terrestrial component of the radio network is performed at the physical layer. Therefore, the physical layer of the satellite component is following either the LTE or the WiMAX standard. Some modifications may be required, though.

1) Cellular standards

a) LTE

The 3rd Generation Partnership project (3GPP) has standardized LTE (3GPP Long Term Evolution) to meet the

demand of rapidly growing mobile user data traffic. LTE applies in downlink the orthogonal frequency division multiple access (OFDMA) technique to enable efficient time-frequency radio resource allocation for improved system performance. OFDMA is a multiple access technique based on orthogonal frequency division multiplexing (OFDM), a digital multi-carrier modulation scheme that is widely used in wireless systems but relatively new to cellular.

b) WiMAX

WiMAX is also an OFDMA based broadband technology especially for high-speed internet data access. It applies OFDM modulation both in downlink and uplink. From the physical layer point of view, the mobile WiMAX (IEEE802.16e) applies the adaptive radio link techniques in a similar manner as LTE.

c) Fractional Frequency reuse

However, OFDM does have some disadvantages. The subcarriers are closely spaced making OFDM sensitive to frequency errors and phase noise. For the same reason, OFDM is also sensitive to Doppler shift, which causes interference between the subcarriers. It is known that OFDM will be more difficult to operate than CDMA at the edge of cells. Therefore, some form of frequency planning at the cell edges will be required as shown in the Figure 4.

Different bandwidths can be allocated to cell edges and to cell centers and the band division can be either hard or soft. Several subbands can be reused at the cell edges to avoid inter-cell interference and, moreover, the powers for cell edges and cell centers can be controlled to guarantee users QoS requirement and further reduce the inter-cell interference (Figure 4).

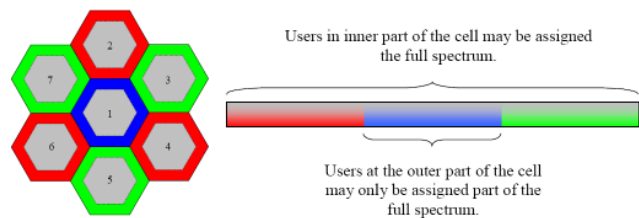


Figure 4. Frequency planning in OFDM

LTE and WiMAX are aimed at frequency reuse 1 scheme. This target is facilitated by several link and system level features, which introduce techniques for mitigating and coordinating intra- and inter-cell interference.

2) Interference mitigation in the terrestrial system

These next generations of cellular network aim to provide an increase of their capacity by maximising the use of the frequency spectrum. This implies the use of sophisticated interference mitigation techniques.

These techniques are classified into three major categories such as interference cancellation through receiver processing, interference randomization by frequency hopping, and interference avoidance achieved by restrictions imposed in resource usage in terms of resource partitioning and power allocation. The benefits of these techniques are mutually exclusive, and hence, a combination of these approaches is likely to be employed in the system.

In traditional interference avoidance, inter-cell interference is handled by the classical clustering technique. However, while this technique reduces interference for the cell edge user terminals, it compromises system throughput due to resource partitioning.

As stated before, LTE and WiMAX networks have been designed for a reuse factor of 1 and downlink transmissions are based on OFDM. In addition to data allocation in both time and frequency domains, it creates new possibilities to utilize the available spectrum by flexible and intelligent subcarriers allocation, which is based on both frequency and time domain utilization. In case of a single frequency network this would be one of the ways to avoid interference from the satellite spot beams operating on the same frequency sub-band.

III. RESULTS

A. Influence of the satellite in term of power

The power flux density (PFD) emitted by the satellite is considered as constant upon all the coverage of the Satellite system: -104 dBW/m²/MHz. This PFD is considered as interference from the terrestrial point of view and causes a decrease of the LTE/WiMAX cell size.

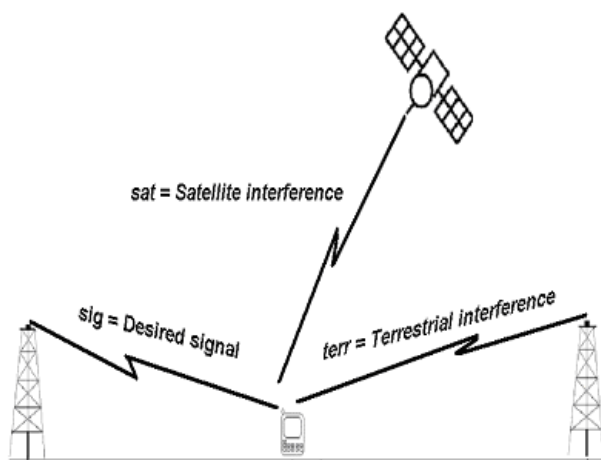


Figure 5. System topology for LTE simulation

Figure 5 presents the system configuration and Figure 6 shows different diameters of a single cell with a given emitted power of the base station 1. Diameter for the cell alone (without interference) 2. Diameter with the influence

of a neighbour cell 3. Diameter with the influence of a neighbour terrestrial cell and the satellite spot beam.

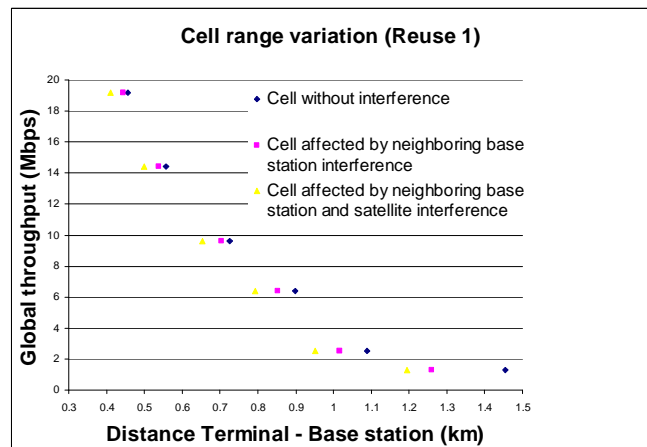


Figure 6

B. STUDY OF THE INFLUENCE OF THE SATELLITE

1) Influence of the satellite on LTE/WiMAX network

Tolerating the high interference levels that occur in reuse 1 networks is based on both adaptive 2-dimensional scheduling, which can utilize the radio channel characteristics in an optimum way. In addition, interference cancellation is improved with multiantenna receivers. Considering all this, it seemed possible that LTE would provide acceptable performance with satellite overlay scenario without major design or network level changes.

The downlink of both LTE and WiMAX systems is based on multicarrier modulation and it occupies relatively wide bandwidth. The terrestrial radio channel, on the other hand, introduces quite strong frequency selective fading, which means that an advanced multi-dimensional scheduling can allocate dynamically the best slot in both time and frequency domain to each user. Therefore, the HSDPA time domain scheduling principles are valid also in LTE [1]. As the radio channels between an individual mobile user, base stations and the satellite are non-correlating, a good slot can almost certainly be found for each user.

This study also investigated the affect of optimal scheduling. This gave an upper bound on the throughput performance at the cell edge of an LTE link. As a lower bound, the full band average signal to interference plus noise ratio (SINR) was also calculated. Three scenarios are compared: 1) no interference, 2) terrestrial interference only, and 3) terrestrial and satellite overlay interference.

2) Simulation methodology

The simulation aim is to investigate the affect of interference on the LTE throughput (the effect on a WiMAX system would be very similar).

In short, the mobile user is spread in a region that includes both sides of the cell edge. The transmit power is set to 20 W on a 5 MHz bandwidth and the antenna gain is 15 dBi. The carrier frequency is 3.45 GHz and the terminal noise - 107.5 dBm. The spread is repeated for a number of channel impulse response (IR) realizations generated by the IMT-A [2] channel model generator. Each channel snapshot corresponds to a random snapshot of the defined scenario's propagation conditions. Thus, with a sufficient number of snapshots (or drops) we obtain a statistically stable average of the channel conditions.

For each channel snapshot, the IR is converted to a frequency response from which the SINR is calculated, both across the entire bandwidth and for each LTE resource block individually. LTE resource scheduling is emulated by choosing the resource block (RB) that produces the highest SINR as the scheduled RB. This should give a good upper-bound on the performance enhancement from scheduling. As a lower bound, the full band SINR, which is the average SINR of the RB, is considered.

On Figure 7, the minimum throughput is plotted for the "scheduled" resource blocks as a function of the mobile user location. This analysis takes into account the pilot overhead and the discrete coding and modulation schemes in the LTE downlink. The modulation and coding schemes and their respective SINR requirements are taken from [3].

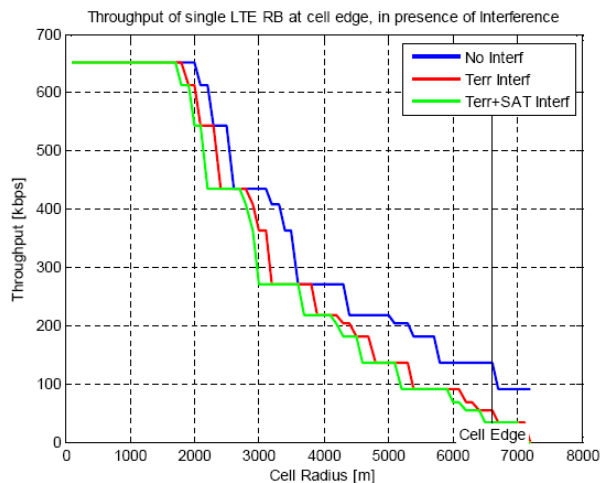


Figure 7 Single Ressource Block throughput in presence of interference

To calculate the cell capacity in terms of throughput, 25 users were placed randomly from 0.1km up to 6km from the eNodeB and a single resource block was allocated for each user.

The cell centre capacity for 5 MHz bandwidth was then obtained for the users at a distance of 0-3km from the eNodeB from the throughput simulation values shown in Figure 7. Correspondingly, the cell edge capacity was

obtained from the throughput values for users at 3-6km from the eNodeB. 10000 simulation rounds with 25 different random UE positions in each round were performed for achieving average throughput values. Results are presented on Table 1.

Interference scenario	5 MHz throughput in cell (Mbps)		
	Cell	Cell centre	Cell edge
No interference	10.7	15.12	6.43
Intercell interferences	9.63	14.69	4.74
Intercell + satellite interf.	9.36	14.44	4.46

Table 1 Average throughput values in an LTE cell (5MHz bandwidth)

The simulation results show that it is the inter-cell interference which dominates the throughput loss while the satellite interference plays a minor role. In fact, the loss due to the satellite interference is only at about 2.8%, 1.7%, and 5.9% levels at entire cell, cell centre, and cell edge, respectively. Thus the impact is at largest at cell edge, as expected.

IV. CONCLUSIONS

Based on the simulations it seems that introducing a satellite overlay network on top of a terrestrial LTE or WiMAX network will not introduce a significant interference issue in the case sophisticated interference compensation techniques are used. LTE has been designed to handle reuse 1 scenario, which means the entire network is using the same operating frequency band. This creates a high intercell interference level, which must be handled anyway. Adaptive mechanisms are supported by LTE and also WiMAX thus enabling efficient interference avoidance and compensation. The satellite overlay component does not increase the total interference level significantly and it was estimated that the capacity loss in a cell is only less than 1% and even at the cell edges the performance criteria will be met. The study clearly shows that a satellite overlay component can be introduced and integrated to LTE or WiMAX terrestrial network.

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