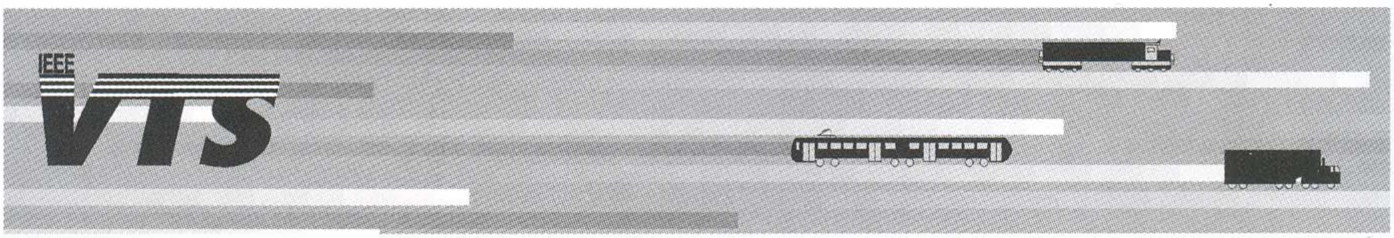

Mobile Broadband Systems: Research and Visions

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This article gives an overview of the European research on Mobile Broadband Systems (MBS), whose features range from WLANs type scenarios, allowing low mobility and medium data rates, up to public cellular MBS, where high mobility and data rates are foreseen, leading to plain ubiquity. Current trends in 4G systems are described leading to the definition of the MBS concept. Owing to high transmission data rate and spectrum limitations at lower frequency bands, MBS intend also to operate at millimetrewave frequency bands, namely the 40 and 60 GHz, offering improved system capacity. The MBS concept and the Trial Platform developed in the framework of the European ACTS-SAMBA and RACE-MBS projects are presented. Cellular planning aspects are discussed including a comparison between the 40GHz and 60GHz bands, considering services and applications, tele-traffic, and MBS optimisation based on economics aspects. Field trials results on the radio interface performance are presented, demonstrating MBS cellular operation feasibility at millimetrewave frequency bands.

Introduction

The paradigm behind 3G is the widespread provision of multimedia services and applications to users while on the move, therefore adding a multimedia flavor to the "anytime and anywhere" concept. In that regard, wideband and broadband radio technologies are necessary and a panoply of enhanced color displays, multimode, and multiband terminals will be required to satisfy market needs. The seamless transition between the respective environments, a good QoS (Quality of Service), and complete freedom, leading to full competition and new business models are other issues to be addressed and incorporated in future mobile systems. Further research and technology developments will contribute to an increase in the maximum transmission bit rates, to the convergence of the various access technologies associated with the seamless access paradigm, and to network evolution towards "all IP", which will reduce network deployment costs. Moreover, terminals will evolve to radio reconfigurability, allowing for operation on a family of access technologies and networks.

The large demand that is foreseen for really broadband mobile multimedia services in the next years and the current limitations on achievable data rates and system capacity, leads to the continuous research on mobile systems and eventually, to the deployment of cellular Mobile Broadband Systems (MBS) operating as well at millimetrewave bands [1]. In Fig. 1 an attempt is made to compare nowadays and future generation mobile systems in terms of data rates and mobility.

MBS are shown to exist in full operation beyond 4G and ending the "generation game" that today exists in the mobile communications industry. This idea is supported on the fact that after 4G there will be a full convergence of networks (fixed, mobile and wireless) and a complete integration of the different access technologies, leading to a completely ubiquitous telecommunications system. Extremely high data rates, approaching those nowadays available in fixed networks, combined with a high mobility, will be offered by MBS. These systems will operate in many frequency bands, including the millimetrewave ones, where bandwidth is not a serious issue as in lower frequency bands (around 1-2 GHz). It will exist everywhere providing seamless roaming between different access technologies to users, and enough capacity at low cost per bit, for the provision of huge amount of information, applications and broadband services to MBS users.

Historically, under the European RACE Programme initiatives in mobile cellular communication systems, a first definition of MBS and related systems was presented assuming that, in terms of terminal mobility and supported data rates, MBS operation will just begin where 3G ends. Reality has shown that another step is needed (the 4G) before we can have and experience MBS. The foundation of the MBS concept and its evolution is presented in [2].

MBS comprise a different set of integrated technologies, ranging from WLANs type environments, allowing low mobility and medium data rates, up to public cellular networks, where high mobility and high data rates are foreseen. The first MBS networks will use the lower frequency bands, and tend to address environments where mobility is low or just allowing portability. Therefore, MBS services will be first offered in WLAN type of scenarios.

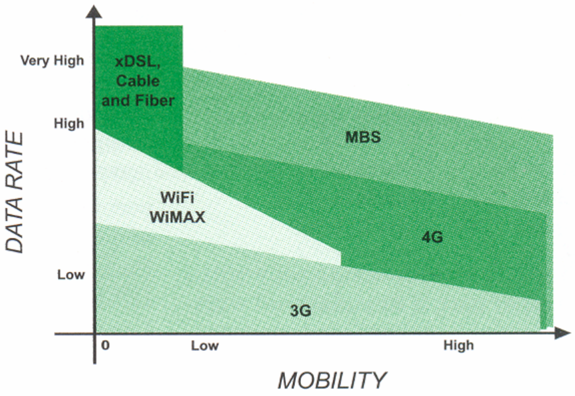

Figure 1. *3G, 4G and MBS capabilities.*

Later, when full deployment is required, there will be other possibilities in the 17, 40, and 60 GHz frequency bands. In these bands, high mobility, outdoor and indoor coverage will be supported.

This article focuses on MBS operating in the millimetre-wave frequency bands and is organised as follows: Section 2, makes a summary of the current research focus in Europe towards 4G. Section 3 presents the MBS millimetrewave bands key aspects and issues, while in Section 4, aspects of cellular coverage and frequency reuse are discussed from the point of view of large-scale cellular planning. Besides, aspects related to services and applications, tele-traffic, and cost/revenue optimisation issues of MBS are briefly addressed. In Section 5, the trial platform built up in the framework of the European SAMBA project is presented, namely the air interface and cell coverage issues. Results of the field trials in an outdoor scenario are presented, namely BER (Bit Error Rate), and received signal power. Conclusions are drawn in Section 6.

Current Research Directions

Due to the difficulties that the millimetrewave frequency bands present to mobile communication systems, and the actual cost of the required technology, current research focus exploits a wide variety of enhancements to 3G systems, applicable to bands up to about 6 GHz. These are the frequency bands expected for 4G systems operation. One of the most important projects contributing to the definition of the radio aspects of 4G systems in Europe is WINNER (Wireless World Initiative New Radio) [3].

The vision of WINNER for mobile radio communications beyond 3G is of a ubiquitous radio system concept, operating at frequencies lower than 6 GHz, and covering the full range of scenarios from short-range to wide-area, which provides a significant improvement compared to current systems in terms of performance, efficiency, coverage and flexibility. WINNER addresses a ubiquitous radio system concept based on common radio access technologies that will adapt to and be driven by different user needs and scenarios, by utilising advanced and flexible network topologies, physical layer technologies and frequency sharing methods. The ubiquitous radio system concept will make efficient use of the radio spectrum to minimise the cost-per-bit by utilising the technologies researched within the WINNER project and combining them in an efficient way.

Scenarios include:

- In building, with low mobility, small cell sizes.
- Public hotspot/area, with low-medium mobility, and cell range of ~ 100 m.
- Urban/suburban, where higher mobility is allowed in cells up to 500 m.
- Rural (high speed), where high mobility is allowed in cells that range from 1 to 10 km.

Link data rate will generally be up to 100 Mb/s, except in the case of the "in building" scenario, where it can reach 250 Mb/s. Cell throughput will be 1 Gb/s in low/medium mobility scenarios, and 1 Mb/s in higher mobility scenarios.

MBS at Millimetrewave Bands

Nowadays, while the wideband segment of mobile communications is being supported by UMTS and its enhancements (e.g., HSDPA, High Speed Downlink Packet Access), truly broadband requires MBS. Along the last decade, European research projects have given contributions that allowed for the creation of the MBS concept, and contributed for the developments of the new associated technologies. The RACE-MBS and ACTS-SAMBA projects developed different demonstrators for MBS evaluation. The RACE-MBS demonstrator operated at the 60 GHz band while the ACTS-SAMBA operated at the 40 GHz band.

The primary goal of ACTS-SAMBA project was to promote the development of a broadband cellular radio extension to the fixed broadband network, thus, allowing the use of fully interactive broadband multimedia services by mobile users. The project focused on a trial platform [4], which intended to demonstrate the MBS feasibility at the 40 GHz millimetrewave frequency band.

Owing to their high transmission data rate and due to the saturation of the spectrum at lower frequency bands, MBS are intended to operate in the millimetre waveband, offering improved performance in system capacity. At the millimetrewave bands, due to the specific characteristics of the radio channel, sophisticated mitigation techniques are required to improve the performance of MBS. The used data needs to be converted to a suitable form to keep the number of transmission errors at an acceptable level, taking into account for the specific frequency band used, the environment and mobility of terminals or obstacles. To mitigate the effects of shadowing, multipath propagation, and time variance due to motion (causing large-scale and small-scale fading), and to approach the system performance near to AWGN (Additive White Gaussian Noise) channel conditions, various possibilities were identified: adaptive equalisation techniques for single carrier modulation, multicarrier or OFDM (Orthogonal Frequency Division Multiplexing) modulation, error-correction coding, interleaving, robust modulation, utilisation of directive antennas, and diversity reception. An extensive discussion on the aspects of characterisation of the radio channel is presented in [5].

Due to the high path loss and obstacles opacity to the electromagnetic waves at high frequencies, LoS operation is normally required. This limitation can be reduced by the utilisation of multiple cell coverage configurations, e.g., two BSs allow to overcome the shadow regions. This solution requires however the installation of more BSs affecting directly the network cost [6].

The following specific bands are being considered for the implementation of MBS: [39.5, 43.5] and [62, 66] GHz, with an interval of 2 GHz in between 1 GHz bands, Fig. 2. Propagation characteristics are not the same in these two bands, with oxygen and rain presenting different values for their attenuation coefficients; moreover, these coefficients are not uniform within each of the bands. Since a larger attenuation leads to the possibility of reusing frequencies at a closer distance for approximately the same coverage (the attenuation is not substantial for short distances like the ones involved in cell coverage), the usage of one or the other frequency bands can have significant consequences on system capacity.

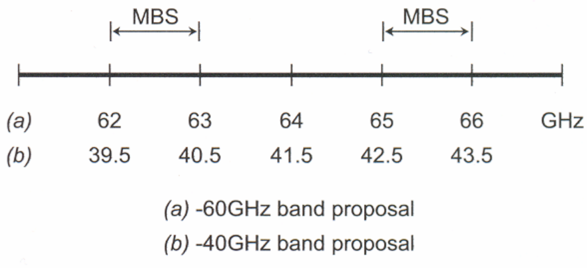

Figure 2. *Millimetrewave bands foreseen for MBS implementation.*

Cellular Planning at 40 GHz and 60GHz

The 40 and 60 GHz bands are different from the UHF bands, since the attenuation from atmospheric elements, namely rain and oxygen has to be taken into account. Besides, the desired high capacity leads, in conjunction with the low values for the achievable transmitter power, to micro-cellular architectures, employing a large number of cells, with BSs deployed at relatively low heights above ground level (e.g., around 5 m, in lamp posts). As a consequence of all these peculiarities, it makes sense to compare the two bands from the point of both cell coverage and frequency reuse.

Cell Geometries and Layouts

As propagation occurs essentially in line-of-sight (LOS) the shape of the cells and the co-channel interference are determined, to a large extent, by the location of the surrounding objects, buildings in particular (in urban outdoors scenarios). As a consequence, for cellular design purposes, an easy analytical treatment is only possible for environments with a regular structure as the linear and the "Manhattan grid" (planar regular) geometries.

For this regular geometries one can follow classical frequency reuse approaches that establish the correspondence between, on the one hand, the maximum coverage and reuse distances, R and D, and, on the other hand, the interference-to-noise ratio, I/N, and the carrier-to-interference ratio, C/I, for both bands, and extract conclusions about the range of coverage distances that allows us to obtain minimum values for the co-channel reuse factor (computed from D), and under which conditions it is preferable to use one band or another [7].

For urban irregular geometries, conclusions on the quantities of interest related to cellular design, such as urban coverage, achievable frequency reuse and system capacity, can be obtained from specific cellular layouts and environments (but typical, as much as possible). This can be done by using the interactive cellular planning tool (developed during the RACE-MBS project) to assist in the design procedure [8]. The planning tool allows for the interactive placement of BSs over a map of an area to be covered, determines the coverage area for each cell, and the interference among cells, taking LoS into account, through algorithms for the computation of visibility polygons/chains. These results can be fed into frequency assignment algorithms for the determination of the reuse factor and system capacity.

Average Received Power

At the millimetrewave bands the average power received at a distance d from a transmitter can be found by considering an almost free space received power, plus the attenuation due to oxygen and rain [9]. The crucial parameter for this model is the average power decay exponent, n, since all the others are well known. Values for n have been presented in the literature, ranging from 1.4 to 2.5 [10]. For an outdoor environment n is in the range [2.0, 2.5], a value of n = 2.3 being typically used [9]. There is only a small difference for the free space path loss between both bands, approximately equal to 20?log(60/40) = 3.5 dB; therefore, it is obvious that the difference between the two bands is not imposed by this parameter.

For the oxygen absorption, however, the difference is relevant. Using the equations of ITU-R [11] for $f < 57$ GHz and the formulas presented in [9] for $60 \leq f \leq 66$ GHz, one obtains the curves presented in Fig. 3, where the frequency scale is normalised in order to superimpose the 40 and 60 GHz bands in the same graph (-2 GHz corresponds then to the lower limit of each band, 39.5 or 62 GHz respectively, and 2 GHz to the upper one). In the 40 GHz band, go is almost constant and negligible (less than 0.07 dB/km), whereas, in the 60 GHz band, it has to be considered, decreasing from 14 dB/km (at 62 GHz) down to approximately 1 dB/km (at 66 GHz). In the case of the higher frequency band, the additional path loss caused by the oxygen absorption is negligible for short coverage distances, but it can present high values, larger than 10 dB, for typical reuse distances.

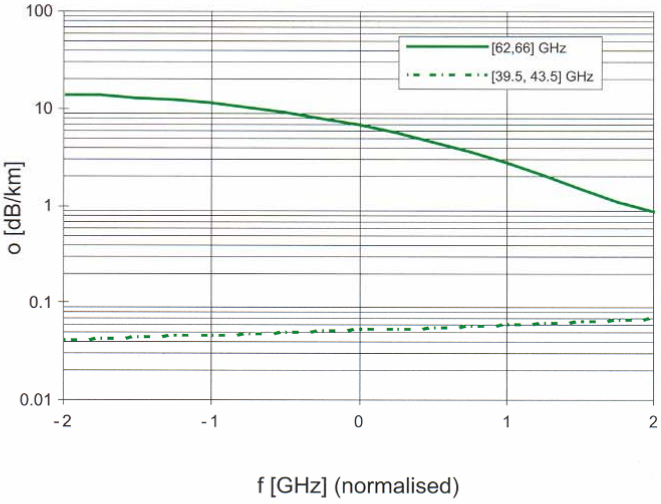

Figure 3. *Oxygen attenuation coefficient as a function of normalised frequency for the 40 and 60 GHz bands (0 corresponds to the central frequency of each band).*

Rain attenuation has also to be considered, and the model presented by ITU-R [12] has been used. For a rain intensity of 30 mm/h, which occurs in Europe with a probability less than 0.03% (circa 2 h 38 m per year), the rain attenuation is approximately 8 dB/km in the 40 GHz band, and it is slightly increasing through the band; in the 60 GHz band, the behaviour is similar, with a value of the order of 12 dB/km. Nevertheless, the difference between the two bands is not as significant as the one concerning oxygen. A more detailed analysis can be found in [7].

Comparison between the 40 and 60 GHz bands

It is well known that the attempt to reuse each frequency to a maximum in close cells is limited by the interference between co-channel cells. In regular structured environments it is important to establish the correspondence between the maximum coverage and reuse distances, R and D, and the CIR, C/I, for both bands, and to analyse the resulting consequences, in order to decide in which conditions is preferable to use one band or another. The simplest geometry to study the problem of frequency reuse in a cellular system is the one corresponding to a pair of cell, where only two co-cells exist with maximum coverage distance R and with their centres separated by a distance D (see Figure 4).

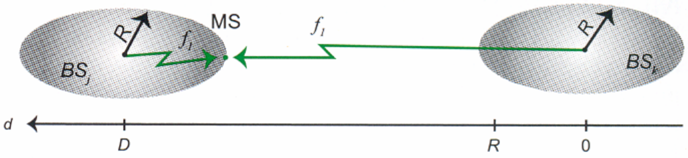

Figure 4. *Geometry for a pair of interfering cells.*

The C/I ratio has a direct influence on the co-channel reuse factor, rcc, and on system capacity. Considering two co-cells, the minimum value for C/I is given [9]

$$C/I_{[dB]} = y\bullet(r_{cc} - 2)\bullet R + 10\bullet n\bullet log(r_{cc} - 1), \quad (1)$$

where represents the attenuation by atmospheric elements, $= o + r$, and r_{cc} = D/R; the usual assumptions for C/I analysis have been considered (concerning transmitted power, antenna gains, and so on). In this ideal situation, where thermal noise is not considered, the dependence of C/I on rcc has, on one hand, a logarithmic term that depends on the average power decay exponent, and, on the other hand, a linear term that depends on the oxygen and rain attenuations, and on the coverage distance as well. As the same average power decay exponent is considered for both the 40 and 60 GHz bands [9], the difference between them is mainly due to different values of the oxygen and rain attenuation coefficients. At 40 GHz (where the oxygen absorption is negligible), if rain is not considered only the logarithmic term remains (Figure 5). A case of invariance to linear scaling of reuse and coverage distances will occur, since C/I will only depend on r_{cc} = D/R, presenting values of the order of 16 dB for r_{cc} = 6, both at 39.5 GHz and 43.5 GHz. These values and behaviour are similar to those found in the UHF band. In the other cases (40 GHz with rain, or 60 GHz – either with or without rain), however, the linear term will not be negligible, and the conclusions will be different. Details can be found in [7], where the analysis of the linear (the coverage of an indefinitely long street or highway) and "Manhattan grid" (a regular urban geometry with streets perpendicular to each other) regular structures is explored, too, and the simultaneous effect of noise and interference is analysed.

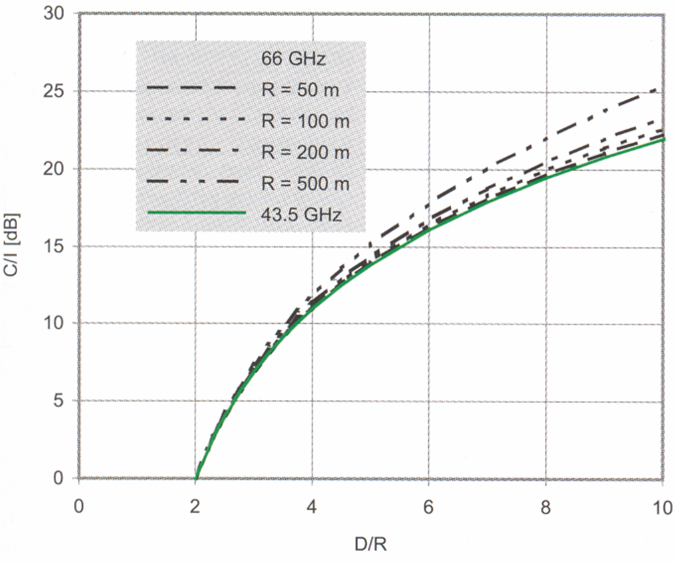

Figure 5. *Carrier-to-interference ratio in terms of the co-channel reuse factor, with R as a parameter, in the absence of rain.*

In this case, for both linear and planar regular geometries, different values for r_{cc} result at 43.5 and 66 GHz, being slightly higher for the former. However, for these regular geometries, as the co-channel reuse factor needs to be even, no practical difference exist on the values of co-channel reuse factor, and of the reuse pattern, K, between the two bands (r_{cc} = 6 and K = 3 in both) because the presence of obstructions decrease considerably the degree of interference between cells. A difference, however, exist in the achievable maximum coverage distances, values at 43.5 GHz being more than 20 % larger than at 66 GHz.

In [7], cellular planning results in specific irregular urban geometries were obtained using the planning tool developed during RACE-MBS [8]. An application was made to the coverage of part of Lisbon by MBS operating at the 40 and 60 GHz bands. Reuse patterns in the range 5-11 were obtained, with smaller values corresponding to smaller cell sizes, and vice-versa. The use of the 60 GHz band may lead to higher system capacity but it depends on the exact implementation to be done.

Services and Tele-traffic

In [13], MBS scenarios of operation were defined by incorporating a complete classification of MBS services and applications, their characterisation parameters, and available forecast information. As multi-service traffic analysis requires the definition of the main operation environments, the respective deployment scenarios were defined, with predictions of broadband applications usage in scenarios such as residential, business and industrial.

In MBS, cells will be confined to streets with dimensions of the order of a few hundreds of metres. The high mobility associated with it yields a tele-traffic analysis, where both new and handover connections traffic must be considered simultaneously. Research on traffic from mobility is available in [14], [15].

In packet switched networks the available resources are shared in a way that allows multiplexing of different traffic sources. As far as different sources do not take these peak values simultaneously, for a fixed number of users, the network can use less resources than would be required if resources were assigned according to their peak amounts required by each user, and a gain exists from this statistical multiplexing [16]. The identification of relevant models for the characterisation of voice, data and video traffic sources is needed, in view of finding a unified model to evaluate the QoS (Quality of Service), which depends on the aggregate traffic. Hence, keeping in mind that these models are needed for MBS cellular planning and optimisation purposes, the implementation feasibility of the aggregate traffic model is crucial in the choice of the basic model(s) for traffic sources. Results from research on multi-service traffic and system capacity determination can be found in [17], where the characterisation of services, applications, and scenarios is the one from [13]. As an analytical approach was sought, instead of a simulation one, the Bernoulli-Poisson-Pascal model was proposed for the computation of the blocking probability, and a user model had to be conceived to characterise the way an equivalent user of an application generates an actual service component user. From tables with results for the blocking probability (that generalise, in a way, the Erlang-B and Engset tables to multi-service traffic) it was possible to obtain the supported fraction of active users given the blocking/handover probability thresholds. While in the absence of mobility the average load of the mixture of applications is the most limiting factor, in the presence of mobility, the average velocity presents its limitation.

For the purpose of MBS optimisation, some useful cost/revenue models were developed, with an emphasis to MBS economic analysis incorporating multi-service [18]. A cost/revenue function was proposed, and some strategies were conceived for system deployment, in terms of the choice of the cell coverage distance, both in an initial phase of system deployment, when fewer users are foreseen, and in a medium term scenario, when more users have to be supported.

MBS Millimetrewave Trial Platform

Although OFDM may be a solution for the MBS radio interface, the approach from RACE-MBS (Mobile Broadband System) and ACTS-SAMBA (System for Advanced Mobile Broadband Applications) European Commission projects [19] was to assume TDMA/FDMA (Time / Frequency Division Multiple Access).

The SAMBA trial architecture was defined based on the state-of-the-art knowledge available when the specifications were frozen to start the design and manufacturing processes. The mission was to build an MBS demonstrator where the main functionality would be tested and evaluated. Since handover was seen as a key feature, the Trial Platform is composed of two Base Station Transceivers (BST) and one Base Station Controller (BSC) that interconnects to the fixed network. The architecture is shown in Fig. 6. Fig. 7 shows some pictures of the demonstrator (BST and Mobile Terminal). To facilitate the system's initial deployment the 40 GHz band was preferred instead of the 60 GHz [20].

This mini mobile system with two cells enables testing of many basic features, e.g., reliable transmission of information through the radio interface in a mobile radio environment (suffering from noise, co-channel and multipath interference), and also multiple access, dynamic resource allocation and mobility management, including seamless handover. It is, however, difficult to perform detailed studies of the impact of co-channel interference, and of the evaluation of more complex mobility management schemes. The availability of two MTs makes it possible to test the sharing, and dynamic assignment of bandwidth in a cell. This is an important feature due to the nature of broadband applications, which require asymmetry and variable transmission rate capabilities.

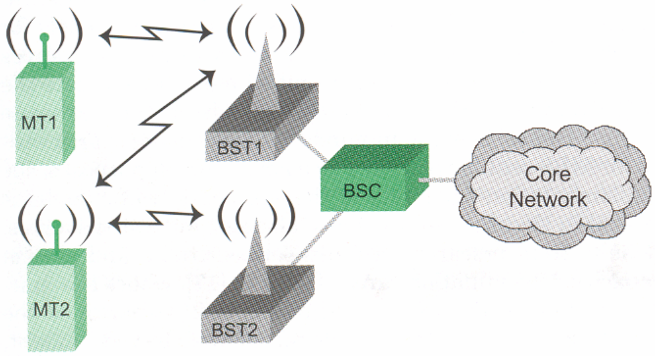

Figure 6. SAMBA Trial Platform.

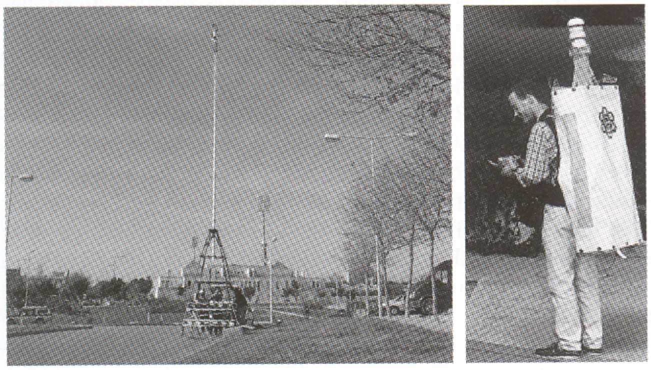

Figure 7. ACTS-SAMBA Base Station tower and MT operation.

Moreover, in order to increase capacity, for each MT, and for a particular instance, only the necessary bandwidth should be reserved. Full-duplex bearer services up to 34 Mb/s and a maximum mobile speed of 50-60 km/h were demonstrated in the SAMBA tests. Extensive Field Trials were carried out in the city of Aveiro, Portugal, and in different environments [5].

Air Interface and Cell Coverage

The air interface should provide the necessary resources and functions for the transparent transfer of information with the required quality of service concerning information loss and error rates, as well as delay. Several implementation constraints have been taken into account when designing the physical transmission scheme for the Trial Platform, namely:

- Propagation constraints of the millimetre wavebands.
- Power amplification constraints.
- Adoption of single carrier modulation with equalisation.
- Omnidirectional MT antenna (low gain).

The system is based on a single carrier modulation technique, and a hybrid TDMA/FDMA scheme (Time/ Frequency Division Multiple Access). It uses the Frequency Division Duplexing (FDD) mode to allow simultaneous transmission and reception on up- and downlinks [21]. The adopted access/duplexing scheme supports a gross symbol rate of 32 MBd full duplex (64 Mbit/s). For the Trial Platform only two carriers are required per cell (for up- and downlinks). The two have a separation of 160 MHz to avoid the adjacent channel interference, they being respectively: 39.58 and 39.74 GHz for uplink, and 42.58 and 42.74 GHz for downlink, Table 1.

Air Interface Parameters	Characteristics
Transmitted power	Approximately 20 dBm (100 mW)
Carrier frequencies	Uplink: 39.58 and 39.74 GHz Downlink: 42.58 and 42.74 GHz
Multiple access technique	FDMA/TDMA
Duplexing	FDD
Modulation & symbol rate	OQPSK at 32 Mbaud
Diversity	Two branch space diversity with "quasi-MRC (maximum ratio combining)"
Equalisation	DFSE – type Viterbi, 8 symbols (250 ns delay window)
Forward Error Correction (FEC)	(130, 110) Reed-Solomon code, 8-bit symbols
Frame	80 time slots (1.7125 ms)
Time slot	Duration of 21.406 µs. See [5] for details on the burst fields.

Table 1. Air interface parameters.

Since the power amplifiers used in the Trial Platform are strongly non-linear, an OQPSK-type modulation (Offset Quadrature Phase Shift Keying) scheme was selected. OQPSK is known to be well-suited to radio applications where saturated power amplifiers are employed since it provides a constant envelope or, at least, a low envelope fluctuation, a compact spectrum and a high detection efficiency obtained with simple low-cost receivers. The structure of the air interface frame and burst is explained in [5].

The shape of the cell was designed to cover the most likely general type of scenarios such as streets, large squares and large indoor arenas. The selection of lens type antenna technology, Fig. 8, allows for the easy design of the cell shape and a fairly uniform power flux density in the cell coverage area [22].

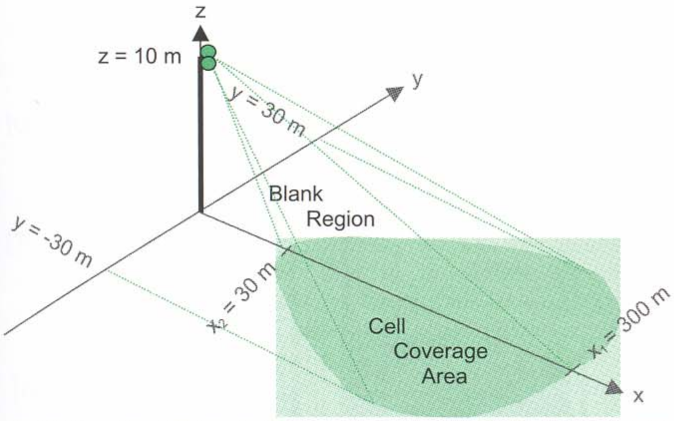

***Figure 8.** Lens antenna radiation patterns and BS cells coverage area*

Moreover, the delay spread is maintained at acceptable levels by shaping the radiation pattern to avoid the transmission of the power to zones of no interest and potentiating the appearance of strong multipath reflections and therefore having a direct impact in the equaliser complexity. Given these facts, it is evident that the configuration of the cell (size and location of BS) is of primary importance for the global system performance. The change of the BS antenna height and tilting angle can be used to modify the coverage area. This allows a simple mean of controlling the illumination of sidewalls near the edges to minimise the channel impairments [23].

Fig. 8 shows the dimensions of the coverage area based on the signal strength. Dielectric type lens antennas with a sec2(q) radiation pattern were selected for the BS to compensate for the free space attenuation [24]. The MT antenna is omnidirectional to provide unrestricted mobility.

Field Trial Measurements

The main objective of the field trials was to evaluate the performance of the Trial platform in real scenarios at the 40 GHz band [5], considered to be as representative as possible of those in which MBS will operate, in order to anticipate the behaviour of the future MBS cellular segment. This was performed in a variety of outdoor and indoor scenarios. Moreover, to facilitate the measurement procedures the MT was installed on a trolley or in a van, for indoor and outdoor operation, respectively. Velocities up to 60 km/h were reached.

The aspects that can be evaluated range from the used baseband and RF technology, radio channel propagation behaviour, and air interface structure flexibility, up to the higher layer protocols. In each scenario, the MT moved along different paths, collecting enough measurements data to characterise the cell coverage in terms of power level and the system performance throughout the cell, namely BER (Bit Error Rate) at the output of the equaliser and before forward error correction, and the received signal power. These signals were collected by the BSC separately, with each data stream coming down from the corresponding BST. All measurement details concerning the conditions and configuration setup such as weather, BST location, antenna height, antenna orientation, MT path, scenario description, etc., were also registered for follow-up analysis.

A typical urban street in a residential area with a width of 36 m was selected for the outdoor measurements, Fig. 9. The outdoor measurements were performed with the MT antenna on the top of a van with the antenna fixed to 2.5 m. The BS was located near the central part of the street shown in Fig. 9, at different heights and pointing towards the end of the street, i.e., parallel to the buildings that exist on both sides. For the particular results presented here, the height of the BS was at 11.3 m. Results were obtained for several paths.

Fig. 10, on the left, depicts the received power in both channels (Ch. 1 and Ch. 2), and the combination of both channels using the MRC (maximum ratio combining) technique as a function of the distance between the BS and MT measured along the x-axis at a constant speed of 10 km/h. The MRC power level is also depicted together with the BER, calculated as an average value per frame, on the right. As shown in Fig. 4, the cell has a blank zone nearby the BS up to the 30 m distance. Beyond this point and up to the 50 m, the signal suffers variations caused by the BS and MT antennas radiation pattern fluctuations (see Fig. 5 of [15]). The average received power level dynamic range on the first 150 m is rather low due to the shaped radiation pattern of the BS antenna, and the small-scale fading depth increases significantly for distances above 100 m as the MT moves away from the BS with a visible improvement when diversity is employed.

Analysing the signal level variations along the path we can verify that during the first part (up to approximately 100 m) the variations are fast and of small amplitude, in contrast with the second part, where they are slower and deeper. This behaviour can be explained by the fact that in the first part the LoS component dominates, imposing the average level of the signal.

For the second part, the two rays model is a good approximation since, in this case, there is a clear dominant effect of the direct and ground reflected rays, although other multipath components are superimposed creating the low-level signal fluctuation.

***Figure 9**. Outdoor scenario*

In Fig. 10 two deep fades are shown. After the first deep shadow fade due to an obstacle (e.g. small truck) the BER recovers quite well because the power level is significantly high (the system noise floor is about -92 dBm). However, after the second deep fade, the system was not able to recover. The Figure also shows that the BER rises with the increase of the small-scale fading depth, and also with the decrease of the average power level. However, even when the average power level is high enough (distances below 100 m), the BER sometimes is slightly above 10-3 due to the fact that in this zone the channel time dispersion tends to be higher.

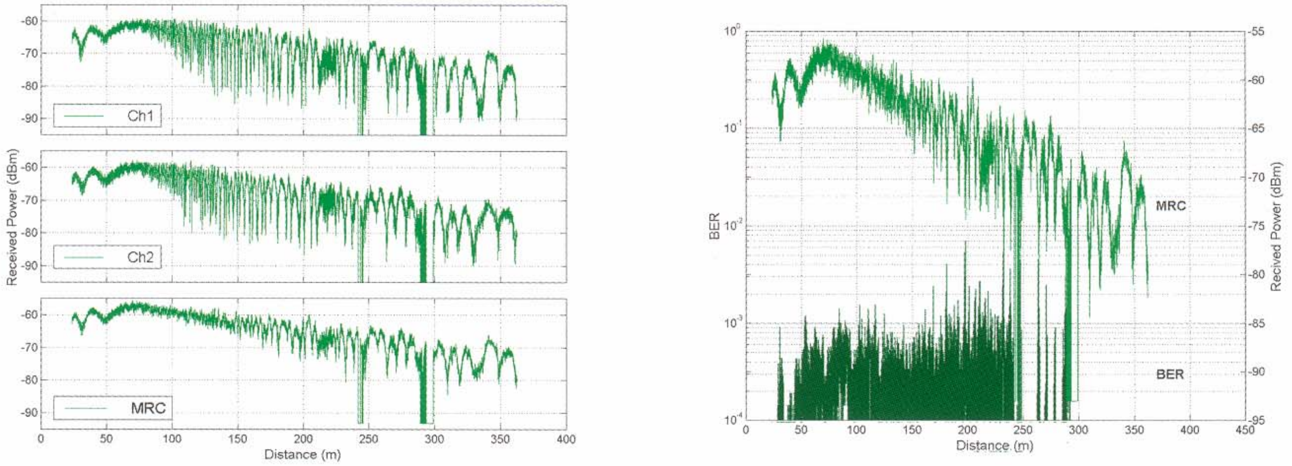

***Figure 10**. Received power and BER as a function of distance in a street.*

From radio interface measurement results performed in this outdoor canyon type street, and one indoor sports pavilion, it can be concluded that the average power level is approximately uniform for distances up to 150 m, as long as there is no antenna tilting, especially in the BS antenna, due to the lens antenna shaped radiation pattern. The wide cell size length was proved to be on the range of about 300 metres. However, for distances beyond 150 m, there was no compensation for the free space losses by the BS antenna. The Rician propagation models proved to fit well to the selected MBS outdoor scenario. Diversity has definitively contributed to the improvement of the received signal quality mainly under high fading depth. Analysing the BER figures it can be concluded that the selected equaliser is good enough, in general, for operating on the selected environments.

The system has proved to work with speeds up to 60 km/h but the maximum value was not reached due to safety reasons. Analysing the characteristics of the received signals when the speed changes, no significant impact on the average power level was detected although the LCR (Level Crossing Rate) and AFD (Average Fade Distortion) presented different, but expected, behaviours.

Conclusions

Given the large demand foreseen for mobile multimedia services and applications, MBS will certainly be necessary in the future, supporting high data rate applications, and to support very high traffic densities per square kilometre at low cost. R&D activities were presented, focusing on activities undertaken at the European level. The MBS concept was introduced to provide an overview of expected MBS features.

Aspects of cellular planning were discussed from the point view of cell coverage and large-scale frequency reuse, and a comparison between the 40 and 60 GHz bands was performed, by considering a simple model for the average received power, and analysing the carrier-to-interference ratio in different conditions. The characterisation of services and applications, deployment scenarios, and aspects of mobility have a strong impact on multi-service traffic which, in turn, in conjunction with the cell coverage and frequency reuse, yield inputs to a cost-revenue function that allows for MBS optimisation.

The main characteristics of the developed ACTS-SAMBA Trial Platform operating at the 40 GHz band were identified, covering system design and mitigation techniques, the shape and dimensions of the cells, and the main air interface characteristics. Different system configurations were trailed to investigate the effect of the antennas tilting both BS and MT. The results reflect the characteristics of the antennas radiation patterns. The two-ray propagation model was found to represent the behaviour of the radio channel for distances far from the BS. The main results obtained in the SAMBA project have shown that enough cell coverage area can be provided in the millimetrewave bands for MBS, although LoS may be required.

The utilization of a single-carrier modulation technique has proven to be a possibility to consider for the provision of a high transmission bit rate over the air interface. The equalization scheme proposed was able to handle the multipath delay spread in the environments selected for the tests. The handover of a 34 Mb/s full duplex radio link between two cells was also demonstrated. More recent measurements at the 60 GHz band can be found in [25].

MBS research activities are continuing at various levels, and in various locations. This will help in the definition and specification of beyond 4G mobile communication systems, noting that one of the main characteristics will be the availability of large transmission bandwidths and capacity per unit area and high mobility in a full converged scenario. The trend towards pervasive device interconnection highlights the need for network addresses space, which may justify the adoption of IPv6 technology in the near future.

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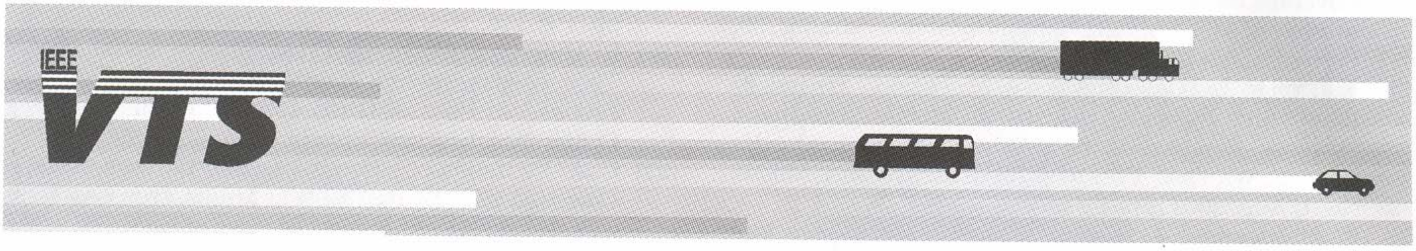

Automotive Electronics—What Makes it So Special?

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Automotive electronics consists of advanced sensors, control units, and "mechatronic" actuators forming increasingly complex, networked vehicle systems. The article shows typical requirements for automotive electronic systems and their components. While quantities are typically lower than in mainstream (consumer/telecommunication/computer) electronics applications, requirements regarding safety (flawless design), reliability and durability, operating conditions and temperature cycles, as well as long-term supply capability are much higher. As a consequence, automotive electronics is typically using well-proven technologies derived from mainstream electronics with some time delay regarding their introduction. In addition, automotive specific technologies have been developed for highly integrated control units and "mechatronic" actuators. Some recent examples are given. The paper closes with a vision regarding further developments and trends in Automotive Electronics.

Introduction

In recent years, modern vehicles are showing an increasing number of electronic systems and functions. The driving forces behind this development are the ever growing needs for more safety, less emissions and energy consumption, more driver information and driver assistance, and last but not least more driving fun and comfort.

The history of modern automotive electronics started in the 50's to 60's of the last century with the introduction of semiconductor transistors in car radios and power diodes in alternators. Since the 80's, the integration of electronic systems like engine management or brake control systems has come into focus. The era of today is characterized by the vehicle-wide networking of all electronic vehicle systems, thus allowing for new additional functions. As a next wave, we expect an increasing networking between the vehicle and its environment. All those trends are enabled by electronics and communication technologies supporting increasing digitalization, integration and networking of electronic devices.

Towards the Intelligent Vehicle—Challenges and Requirements

In our vision, the "intelligent" vehicle of the future will consist of three mayor architectural elements:

- "intelligent" sensors
- powerful electronic control units
- "mechatronic" actuators

Thus, all vehicle functions will be controlled using networked electronic sensors, control units, and "mechatronic" actuators.

As a consequence, automotive electronics is expected to continue its growth - by about 6% p.a. regarding the overall systems value, or even 10% p.a. regarding the specific semiconductor content.

However, this growth will only continue if we cope with some severe challenges:

- How to handle the increasing complexity of networked automotive systems in the development phase?
- How to keep vehicles – despite their increasing electronics content – affordable for the consumer?
- How to assure extended lifetime reliability and availability of the vehicles despite the underlying, very complex electronic systems?
- How to cope with the necessity to supply the aftermarket with affordable electronic components

Naturally, there is not one single answer to those challenges, but a plurality of solutions is required to fulfill the requirements.

The Importance of Architectures, Interfaces and Standards

In this paper, we highlight primarily the perspective of automotive electronics hardware. Obviously, other aspects of automotive electronic systems are as well of great importance for the overall performance and will certainly affect hardware. Some of those aspects are listed here:

Systems Architecture: the further development of automotive electronics will be strongly influenced by underlying