TSUNAMI II Active Calibration System

C.M. Simmonds and M.A. Beach

Centre for Communications Research,
University of Bristol, Merchant Venturers Building, Woodland Road, Bristol BS8 1UB.
Tel:+44 (0) 117 927 9023, Fax:+44 (0) 117 954 5206,
E-Mail:Chris.Simmonds@bristol.ac.uk

Abstract: *The TSUNAMI II project is an investigation into the use of adaptive antenna technology for use in future generation mobile communications systems. The aims of the project are to study the complexity versus increase in system capacity and coverage extension over the existing, non-adaptive networks. It is expected that TSUNAMI II will produce results indicating a significant capacity increase over the existing, non-adaptive GSM network, through the use of spatial diversity. However, the adaptive system relies on the accurate transfer of signal phase and amplitude from the baseband beamformer to the antenna array patches. From previous investigations [2] it is known that environmental effects (e.g. changes in temperature) can alter the electrical characteristics of both the active and passive components in the transmission and reception paths, thus disrupting the beam patterns and hence degrading the beamformer performance. The active calibration system is designed to null these effects through periodic measurement of the signal distortions and allow sympathetic adjustment to the required beamformer parameters at the base station.*

Introduction

The unprecedented growth of personal communications popularity [1] requires future generation mobile systems to provide greater spectral efficiency and system capacity improvements far beyond those catered for by present-day communications networks. As such, adaptive antennas have been identified as a key enabling technology in this area.

In the initial stages of network deployment, adaptive antennas can be used to extend the range of each cell. Hence, a smaller number of basestations would be required to achieve a given radio coverage. As the network matures, adaptive antenna techniques can increase the capacity of the system using techniques such as Space Division Multiple Access (SDMA) [2] in TDMA/FDMA systems, or interference cancellation through Spatial Filtering Interference Reduction (SFIR).

Adaptive antennas, along with the concepts of software radio technology, could produce network infrastructures capable of re-configurability in response to short term system demand. Alternatively they could provide long term portability of the network, as the trends in user requirements and air interface standards evolve [3]. This, in itself, will have an enormous impact on the economics of network infrastructure deployment and operation.

The TSUNAMI II Project

The TSUNAMI II (Technology in Smart antennas for UNiversal Advanced Mobile Infrastructure - Part 2) project has been set-up under the EU ACTS research programme and is the extension of the ACTS TSUNAMI I project.

The project is an investigation into the use of adaptive antenna systems for use in third generation networks. As such, its key aims are to demonstrate the capacity increase and coverage extension [4] that can be gained through the use of spatial diversity in an Adaptive Antenna Base Station Subsystem (AA-BSS) used in a mixed cell environment. Other aspects of the project study the cost efficiency and system complexity increase as a result of of employing adaptive antennas in a third generation network infrastructure.

The adaptive antenna system operates via filtering in the spatial domain, through modification of the transmitted or received antenna array signals with respect to time, frequency and spatial response. This is accomplished by means of amplitude and phase weightings across the array and an internal feedback method [2].

These antenna array weightings can be derived through analogue technology at Radio Frequency (RF) or Intermediate Frequency (IF), or Digital circuit technology at Base-band (DB). The TSUNAMI II system utilises a DB beam forming method which avoids many of the short-comings and inflexibility of the other two techniques, when used in a UMTS adaptive antenna context [5][6].

The use of beam forming algorithms allows a narrow beam pattern to be produced from the adaptive array such that the main beam can be steered towards or *track* the desired user. In addition, spatial nulls can be introduced into the beam pattern towards any sources of interference or unwanted users occupying the same channel bandwidth, effectively cancelling out the effects of their presence.

Requirements on Adaptive Antenna Array systems

Previous investigations, through TSUNAMI I [7], have shown that DB beam forming systems rely on the accuracy of the phase and magnitude weightings applied across the array elements to form the required beam pattern.

Time variant distortions occur in the transceiver chain due small environmental changes such as: temperature, electrical and mechanical variations and even changes in the channel centre frequency and channel gain. These distortions will effectively alter the transfer function of each adaptive antenna path. The study in [7] found that temperature variations over a range of 14°C to 27°C, resulted in mean distortions of 1.76dB magnitude and 180° phase error across the array and hence rendered the beam forming algorithms of little use at these times.

However, most of these fixed mismatches between channels can, theoretically, be removed using a simple calibration technique. Although temperatures are not expected to change over such a wide range during a short time period, it is with a view to the long-term stability of the system that the active calibration scheme is being developed. In an operational network, it would not be practical to off-line the system and perform a manual calibration (the calibration approach adopted in TSUNAMI I). Instead, an active, and ideally *transparent*, calibration process would be a more viable approach.

Active Calibration System

The TSUNAMI II calibration system is set to provide an automatic and *transparent* calibration process, providing 30dB spatial isolation between the wanted signal and each interferer in the same channel for both the uplink and downlink directions.. Intuitively, this spatial filtering can only be achieved if the individual paths of that adaptive antenna array have nominally identical transfer functions.

The TSUNAMI II calibration system can be split into two parts: the uplink or receiver (Figure 1) and the downlink or transmitter side (Figure 2). The receive system calibration uses the AA-BSS to calculate the calibration coefficients using an RF tone injection into the receive array, whilst the transmit calibration system uses the *live* transmitted data from the transmit array.

For calibration purposes, each antenna can be regarded as an adaptive array, consisting of 8 branches.

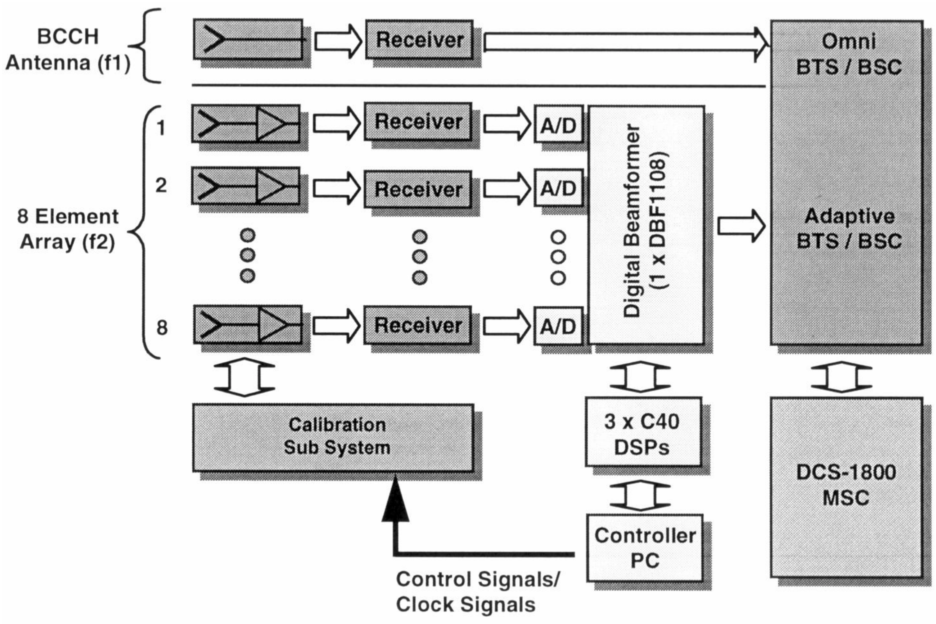

Figure 1.: TSUNAMI II Uplink Overview

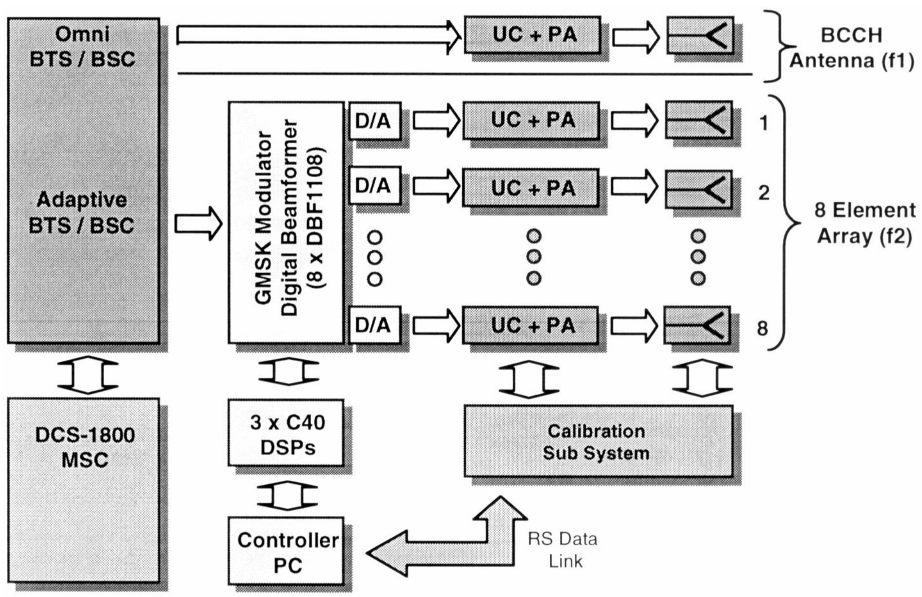

Figure 2.: TSUNAMI II Downlink Overview

Receiver Calibration System

The functionality of the TSUNAMI II BSS receiver allows the receive calibration process to be performed during vacant timeslots within the DCS1800 frame structure (Figure 3).

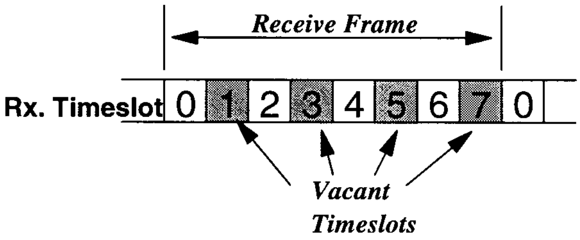

Figure 3.: Receiver Vacant Timeslot Structure

Figure 4 shows an outline of the receive calibration system. A Carrier Wave (CW) signal is injected simultaneously into each of the receiver antenna array elements via directional couplers, during the appropriate timeslots. Injected signal strengths can be varied over a 60dB range, in 2 to 3dB steps, using digital attenuator units. These units are controlled from the main AA-BSS system during the calibration process. Errors in the expected received signal phase and amplitude are measured by the main AA-BSS after the downconversion process to digital baseband. The beam former weights can then be adjusted accordingly to regain the optimum beam pattern.

Control of the receiver calibration process is via request signals from the main AA-BSS system. These requests enable the calibration sequence and increase the degree of attenuation according to the calibration measurement requirements. Timing signals are taken directly from the AA-BSS Frame Clock and Timeslot Clock to maintain the timing integrity of the system.

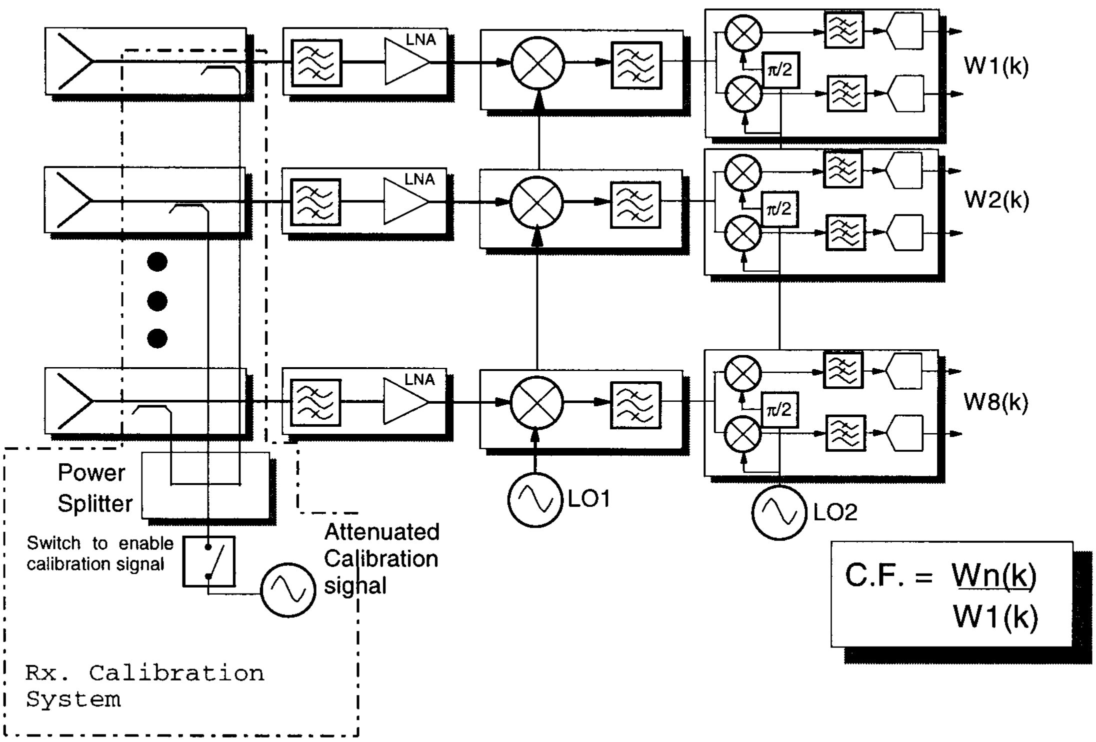

Figure 4.: Receiver Calibration Outline.

Transmitter Calibration System

Calibration of the transmitter system is not possible through the use of CW signal injection as used in the receive calibration system. This approach would result in RF tone transmission across the entire network and hence invalidate the transparent nature of the calibration scheme. Alternatively, a feedback system utilising the *live* transmitted data has been implemented. Figure 5. shows the outline of this system.

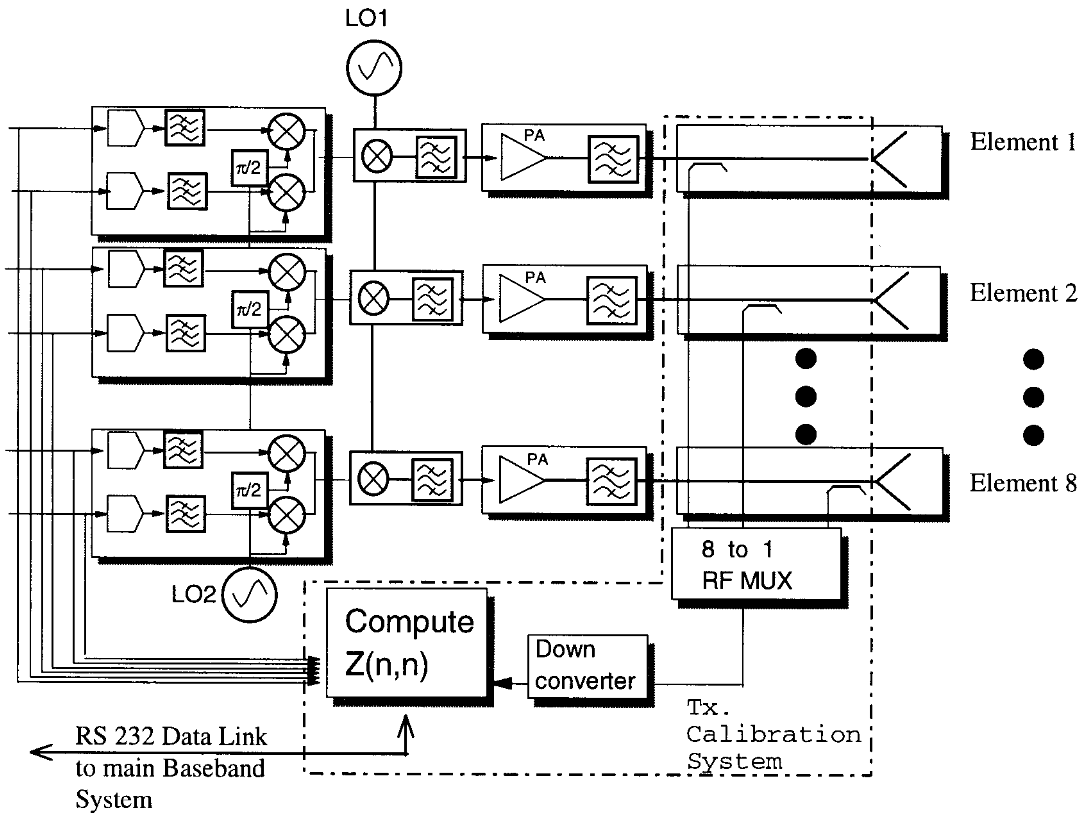

Figure 5.: Transmit Calibration System

Transmitter Calibration Overview

The transmit calibration process takes place during the even timeslots of the transmitted frame structure, except Timeslot No. 0 which is used for the Broadcast Control CHannel (BCCH). Each branch of the antenna array is sampled in turn, using the masthead injection couplers and switched combiner network. In addition, a complimentary signal sample is obtained from the baseband digital beam former output for the appropriate branch, at the time of data transmission. This digital signal comprises 8-samples per bit for each I and Q data symbol.

The RF transmitted signals, sampled at the masthead, are fed down to the calibration system via a 75 metre, low loss cable and downconverted to baseband in quadrature, using local oscillator signals obtained directly from the TSUNAMI AA-BSS. These quadrature signals are sampled using a dual 8-bit A/D converter, also at 8 samples per transmitted data bit and stored in a buffer (FIFO) until required for processing. The sample clock used is taken directly from the main TSUNAMI II system, to maintain signal phase accuracy.

The stored data from both digital and RF sources are processed to calculate a relative error or *Correction Factor* for each array path. These Correction Factors can be applied to the appropriate beam former output weights, at digital baseband, to compensate for the present distortions in the transmitter chain.

Currently, the system operates on a continuous calibration basis. Storing the *last valid calibration Correction Factor* calculated. This value is only used to update the main AA-BSS system on request, through the RS-232 link.

Beam Former Weight Correction Factor Calculation

Digital Signal Processing (DSP) of the stored data is performed using a TMS320C50 processor. With reference to Figure 6, $F_i(t)$, $G_i(t)$ and $H_i(t)$, represent the forward path transmitted data, analogue sampled path transmitted data and the baseband digitally sampled data respectively, where *i* represents the transmission path or array element number (1..8).

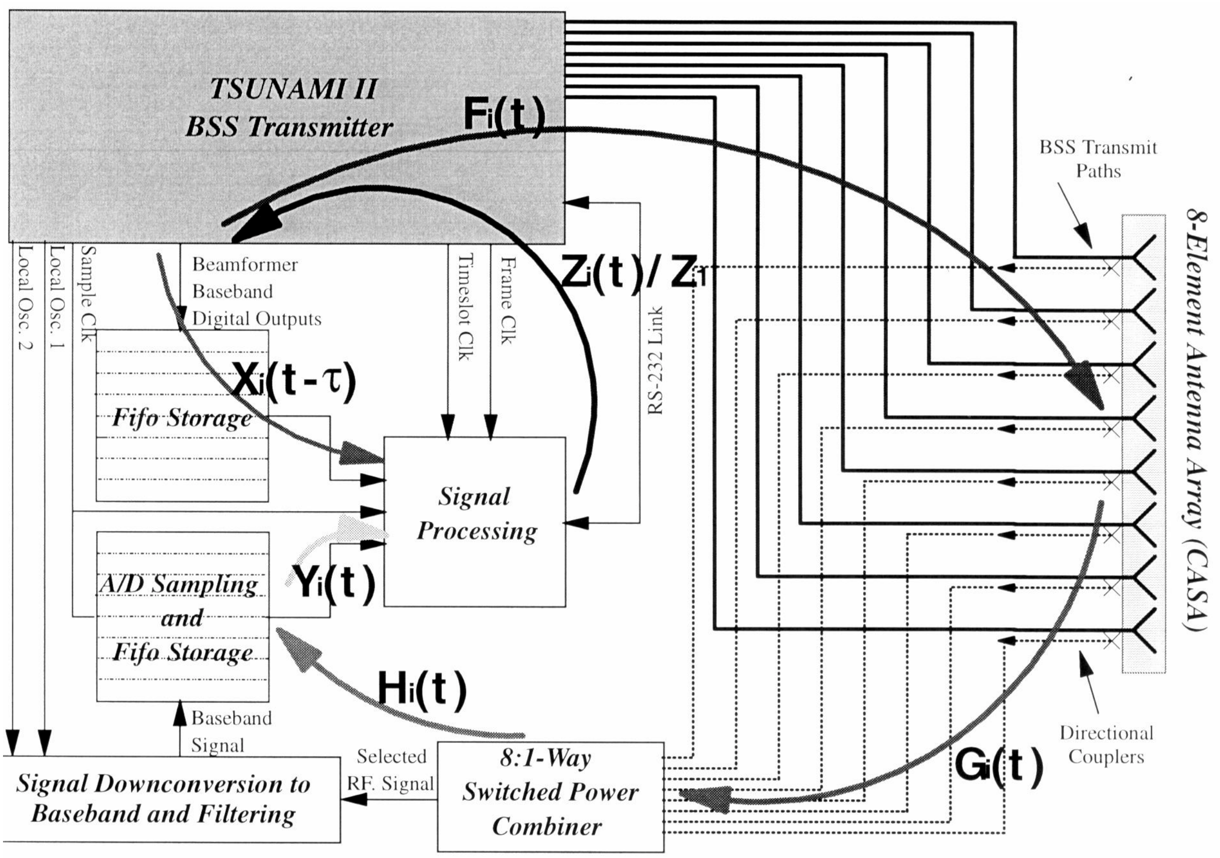

Figure 6.: Transmitter Calibration Outline.

$X_i(t\text{-}\tau)$ represents the baseband digital output in quadrature (8-bit I and 8-bit Q data) of the beam forming network in the AA-BSS, where τ represents the time delay between the data becoming available at this output, to the time taken to sample the transmitted data from the RF analogue path. $Y_i(t)$ is the transfer function from the FIFO storage of the transmitted data signal to the DSP.

Using the above definitions of the transmitter calibration loop and taking into account the time alignment of the sampled signals, the transfer function of the calibration system $Z_i(t)$, for an adaptive antenna element *i* at time *t*, can be expressed as:

$$Z_i(t) = \frac{Y_i(t)}{X_i(t)} = \frac{Y_i(t)X_i(t)^*}{|X_i(t)|^2} \qquad (1)$$

where:

$X_i(t)^*$ - denotes the complex conjugate of $X_i(t)$.

$|X_i(t)|^2$ - represents the square of the modulus of $X_i(t)$.

From analysis of the calibration loop, this may also be expressed as:

$$Z_i(t) = F_i(t)G_i(t)H_i(t) \qquad (2)$$

Some assumptions can now be made about the calibration loop:

Assumption 1. The electrical characteristics of the calibration paths from the injection couplers to the switched power combiner ($G_i(t)$) can be accounted for and are invariant over the measurement sample periods, i.e. These parts of the system can be characterised at the start of field trial and are not expected to change value, relative to the variations in the forward/uplink path of the system.

Assumption 2. Assumption 1. applies for all the common signal paths ($H_i(t)$).

Assumption 3. The local oscillators run continuously and do not introduce any phase offsets/clock skew into the calibration system.

Assumption 4. The sampled data can be time-aligned with the baseband digital beam former weights.

Assumption 5. The calibration process removes the modulation scheme.

Following these assumptions, Equation 2 now becomes:

$$Z_i(t) = F_i GH = Z_i \quad (3)$$

Hence, the relative Correction Factor over the calibration measurement period, referenced to element 1 of the array, can be expressed as:

$$CorrectionFactor = \frac{Z_i}{Z_1} = \frac{F_i}{F_1} \quad (4)$$

Equation 1 and Equation 4 now show that the calibration technique, under the assumptions stated, will yield the appropriate Correction Factor to be applied to the beam former weights to adjust for forward path electrical variations and hence for reliable operation of the AA-BSS at this time.

TSUNAMI II Field Trials

The TSUNAMI II field trials are due to take place in late August of this year, at the Orange testbed in Bristol. At present, the calibration system operates on a continuous process, updating the AA-BSS with *last valid calibration Correction Factors* when prompted by the main TSUNAMI II system.

Investigations are to made during the equipment integration phase and main trials to validate the performance and need for an active calibration system. In addition, it is hoped that these studies will indicate the rate at which signal distortions drift over time for AA-BSSs of this type and hence, indicate the minimum calibration update rate required for a fully operational BSS.

Economic and social impact of Adaptive Antenna Technology [3]

One of the early activities of the TSUNAMI (II) project has quantified the expected improvements offered by adaptive antennas in terms of cost reduction and benefit analysis:

Applied to macrocellular systems, the analysis is consistent with reductions in BSS costs of 19.7% at the same time supporting a capacity increase of a factor of 6.5 (assuming 4:1 SDMA gain available).

⇒ Applied to Microcells SDMA as a technique offer potential solutions in urban centres of larger cities through facilitating support of traffic densities in excess of $500E/km^2$.

⇒ For a mobile network operator, the potential savings in macrocellular systems coupled with the flexibility for delivering high traffic densities in microcellular systems are financially highly attractive.

These dramatic cost reductions and traffic densities will greatly reduce the operator BSS infrastructure costs, which will inevitably lead to a better UMTS service for the end customer.

Growth rates in the region of 15 to 25% are currently being experienced in the mobile market. The total size of the market is projected to grow from around 33 million users in 1995 to over 100 million users in 2000. Two key market segments that will determine the future evolution of mobile are cellular (e.g. GSM and UMTS) and cordless (e.g. DECT). The projected market shares for these two categories are 25% and 62% respectively, but software radio techniques offer the opportunity to develop a network infrastructure which supports both sectors.

Acknowledgements

The Tsunami II project, is set-up under the EU ACTS research programme. The Tsunami II consortium consists of: Aalborg University (Denmark), Bosch (Germany), CASA (Spain) CNET (France), ERA Technology Ltd.(UK), Motorola (UK), Orange (UK), University of Bristol (UK), University of Catalonia (Spain) and Wireless Systems International Ltd. (UK). The authors are grateful for the support of the EU and the contributions of their partners in this project.

References

[1] G. Twyver, February 1995, "Wireless Access Technology : An Engine of Growth," Global Communications Congress and Exhibition, Vancouver, B.C., Canada, pp. 399-403, INTER COMM 95.

[2] G.V. Tsoulos, J. McGeehan and M.A. Beach, "Space Division Multiple Access (SDMA) Field Trials - Part I", IEE Proceedings, Radar, Sonar and Navigation, Special Issue: Array Processing Techniques, February 1998.

[3] R. Arnott and S. Ponnekanti, 20th September, 1997, "SUNBEAM - Smart UNiversal BEAMforming", ACTS 3rd Call proposal, AC417 Software Radio Technologies, Ref. No. 30221.

[4] G.V. Tsoulos, G.E. Athanasiadou, M.A. Beach, S.C. Swales, "Adaptive Antennas for Microcellular and Mixed Cell Environments with DS-CDMA", Accepted for publication to the Wireless Personal Communications Journal, Special Issue on CDMA, Kluwer Academic Publishers.

[5] H. Steyskal, Sept. 1988, "Digital Beam forming", *Proc. 18th EMC,* pp. 49-57, Sweden.

[6] *RACE TSUNAMI Deliverable R2108/ERA/WP5.1/DS/I/022/b1*, "Baseline Technology", March 1994.

[7] G.V. Tsoulos, J. McGeehan and M.A. Beach, "Space Division Multiple Access (SDMA) Field Trials - Part II", IEE Proceedings, Radar, Sonar and Navigation, Special Issue: Array Processing Techniques, February 1998.