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A New Stochastic Spatio-Temporal Propagation Model (SSTPM) for Mobile Communications with Antenna Arrays

Robert J. Piechocki, Student Member, IEEE, Joe P. McGeehan, and George V. Tsoulos, Member, IEEE

Abstract—In order to evaluate the performance of third-generation mobile communication systems, radio channel models are required. The models should be capable of handling nonstationary scenarios with dynamic evolution of multipaths. In this context and due to the introduction of advanced antenna systems to exploit the spatial domain, a further expansion is needed in order to include the nonstationary characteristics of the channel. In an attempt to solve these problems, this paper presents a new stochastic spatio-temporal propagation model. The model is a combination of the geometrically-based single reflection and the Gaussian wide-sense stationary uncorrelated scattering models, and is further enhanced in order to be able to handle nonstationary scenarios. The probability density functions of the number of the multipath components, the scatterers’ lifetime, and the angle of arrival are calculated to support these features. The input parameters of the model are based on results from measurement campaigns published in the open literature.

Index Terms—Antenna arrays, radio channel model, wireless communications.

I. INTRODUCTION

The propagation models that have been developed to date to simulate the radio channel have evolved according to the needs of the mobile communication industry. As a result, propagation models for first-generation analog systems considered the power and Doppler characteristics of the radio signal. Second-generation systems utilize wideband digital modulation and this required an extension in order to include the temporal characteristics of the radio channel. Hence, models for second-generation systems provide Doppler characteristics along with power delay profiles. It is almost certain, mainly due to strict frequency efficiency requirements, that emerging third-generation systems will have to exploit more efficiently the spatial domain. Consequently, there is currently a demand for new models that will provide the required spatial and temporal information necessary for studying such systems.

Spatio-temporal models can be generally classified into two groups: deterministic and stochastic. With deterministic models the channel-impulse response (CIR) is obtained by tracing the reflected, diffracted, and scattered rays, with the help of databases that provide information about the size and location of physical structures in addition to the electromagnetic properties of their materials [1]–[4]. Deterministic models have the advantage of providing the ability to generate accurate site specific and easily reproducible information. Stochastic models on the other hand describe characteristics of the radio channel by means of joint probability density functions (pdfs). Statistical parameters employed in such models are usually estimated from extensive measurement campaigns or inferred from geometrical assumptions. Stochastic models usually need less information than deterministic models, and they produce more general results given that many repetitions are performed.

This paper is structured as follows. Section II presents the proposed radio channel model and describes the employed parameters. It also derives expressions and discusses issues such as the Doppler spreading, the angle of arrival, the number of multipath components, and the multipath components’ lifetime. Section III discusses the range of values for the parameters employed by the model in order to achieve more accurate modeling of different radio channel types. This information is based on results from extensive measurement campaigns, published in the open literature. Typical results generated by the model are presented in Section IV, and finally Section V presents a number of conclusions drawn from this paper.

II. DESCRIPTION OF THE MODEL

A. General Description

The model is a combination of two statistical channel models, the geometrically-based single reflection (GBSR) [5]–[7] and Gaussian wide-sense stationary uncorrelated scattering (GWSSUS) [8] channel models, and is extended to include temporal variations. Since it is geometrically based, the signal statistics depend on the position of the base station (BS), the mobile station (MS), the geometrical distribution of the scatterers, and the velocity of the mobile. In order to simplify the derivation of expressions for the radio channel characteristics, two important assumptions are made within the GBSR channel model. Firstly, that the signal undergoes only one reflection as it travels from the MS to the BS, and secondly, that all the scatterers are confined within a scattering disc. With a GWSSUS model the scatterers are grouped into \(N\) clusters under the assumption that there is insignificant time
dispersion in each of these clusters. The steering vector $s$ due to multipaths from the $i$th cluster can be expressed in this case as the sum of all the contributions ($L$) from the scatterers within the $i$th cluster [8]

$$s_i = \sum_{k=1}^{L} \alpha_{i,k} \exp(-j\xi_{i,k}) a(\varphi_k, f). \tag{1}$$

For the $i$th cluster, $\alpha_{i,k}$ represents the amplitude and $\xi_{i,k}$ the phase of the multipath resulting from the $i$th scatterer and $a(\varphi_k, f)$ is the vector of the complex responses of the receive antenna elements for the direction $\varphi_k$ and at frequency $f$. In general, the steering vector $s$ depends also on the elevation angle, but for the sake of simplicity, (1) assumes azimuth dependency only. By the central limit theorem it can be shown that the steering vectors $s_i$ are complex Gaussian distributed random variables. It is assumed that the locations of the $N$ clusters remain unchanged over several data bursts.

The GWSSUS channel does not impose any conditions on the spatial distribution of the received power, and hence, it requires additional information if it is to be used in space–time analysis. Contrary to the GWSSUS model, the GBSR model provides space–time characteristics. The scatterers in this case are assumed to be isotropic reradiating elements with random complex scattering coefficients, (yet in practice it is rather difficult to assign realistic scattering coefficients [9]). Nevertheless, GBSR channel models do not provide information about the temporal evolution of the generated CIR, e.g., there is no relationship between consecutive snapshots. Hence, the only way to employ these models is to assume that consecutive CIRs are uncorrelated, which is a rather unrealistic assumption.

In order to relax the problems associated with both channel models, it is proposed in this paper to combine them by replacing the single scattering elements in the GBSR model with subclusters containing scattering elements that satisfy the GWSSUS channel assumptions (see Fig. 1). To further enhance the flexibility of the model, time variations associated with the movement of the mobile are also considered.

Given that the transmitting source (mobile) is in the far field of the BS antenna, then the received signal at the BS is a superposition of plane waves. In the model’s basic case, the signal reaches the BS after it has been reflected from the scatterers in the vicinity of the mobile. As mentioned above, each scatterer now constitutes a subcluster, which includes a number of scatterers. The subclusters satisfy narrow-band assumptions, i.e., the delay and angle spread are very small when compared with the time and space resolution of the employed system. For simplicity, the subclusters are also referred to as scatterers in the remainder of the paper, unless otherwise stated.

Clearly, a basic problem for this kind of model is to define the shape and size of a cluster. A straightforward solution is to use a circular shape with a given radius $R$ [10]. When site specific information (databases) is not available, one can assume a uniform distribution of scatterers with a given area density (number of scatterers per square kilometer). The area density of the scatterers will obviously depend on the different types of environment, as discussed in detail later in the paper.

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Fig. 2 shows the principle for the extension of the combined GBSR-GWSSUS model to include temporal variations. The mobile is located at the centre of the circular scattering area (the cluster), and as it moves, so too does the cluster. The scatterers remain at fixed locations and although they are uniformly placed over a larger area (e.g., the whole cell), the active scatterers only include those covered by the cluster. When the mobile moves, a number of new scatterers contribute to the received signal (move into the cluster) and at the same time, some scatterers move out of the cluster, or their multipath contributions fall below some predetermined power window. For the algorithm employed here, there is no fixed number of scatterers for a simulation run. The number of multipath components fluctuates with time (or distance covered by the MS)—as depicted in Fig. 3. The number of
Fig. 4. The geometry of the model.

The model assumes a constant velocity for the mobile motion. This is sufficient to introduce nonstationarity into the channel model. The instantaneous Doppler spectra also change on a snapshot by snapshot basis. This is caused by the angular change between the scatterers, the mobile, and the direction of the mobile motion.

### B. Geometrical Relations

Fig. 4 illustrates the geometry of the model. All scatterers \( S_k \), the MS \( M \), and the BS \( B \) are placed in the same plane at locations \( S_k = (x_{S_k}, y_{S_k}) \), \( M = (x_M, y_M) \), \( B = (x_B, y_B) \). The distance between the \( k \)th scatterer and the mobile is given by \( l_{MS} = ||M - S_k|| \). The value of \( l_{MB} \) and \( l_{BS} \) can be calculated in a similar manner.

The angle of arrival of the \( k \)th multipath component is

\[
\tan(\varphi_k) = \frac{y_{S_k} - y_B}{x_B - x_{S_k}}.
\]

The path length and the time of arrival of the ray resulting from the \( k \)th scatterer are given by

\[
l_k = ||M - S_k|| + ||B - S_k|| = l_{MS_k} + l_{BS_k}
\]

\[
ToA_k = \frac{l_k}{c}
\]

where \( c \) represents the speed of light. The \( k \)th multipath due to the \( k \)th scatterer can be expressed as

\[
Y_k = \left( \frac{1}{l_k} \right)^{n/2} \exp \left( -2\pi l_k \right) \cdot s_k
\]

where \( n \) is the pathloss exponent, \( \lambda \) is the wavelength, and \( s_k \) is the steering vector given by (1).

The instantaneous Doppler shift of each multipath component can be calculated from

\[
f_{\text{Doppler}} = \left[ -\frac{1}{\Lambda} \frac{dl_k}{dt} \right].
\]

Based on (6), the discrete Doppler spectrum (assuming CW transmission) centred at \( f_c = 0 \) Hz is

\[
S_{\text{Doppler}}(f) = \sum_{k=1}^{N} Y_k \delta \left( f - \left( \frac{V}{\lambda} \frac{-\Delta l_k}{\Delta t} \right) \right)
\]

where \( \delta(\cdot) \) is the Dirac function, \( \Delta l \) the distance covered by the MS within a single time step \( \Delta t \) at constant velocity \( V \), and \( \Delta l_k \) is a corresponding change of length of the \( k \)th path.

The angular spread of the channel can be described by the pdf of the angle of arrival, which was calculated for such a model in [11] and shown to be

\[
f_{\varphi_k}(\varphi_k) = \begin{cases} 
\frac{2}{\pi} \cos(\varphi_k) \sqrt{\cos^2(\varphi_k) + F^2 - 1}, & \text{for } -\varphi_{k,\text{max}} < \varphi_k < \varphi_{k,\text{max}} \\
0, & \text{elsewhere}
\end{cases}
\]

where \( F = R/l_{BM} \), i.e., the cluster radius over the distance between the MS and the BS. The formula given in (8) is a special case of the elliptical case derived in [11]. The elliptical cluster model is more flexible as a static GBSR model. However, in order to avoid the additional complexity associated with the elliptical cluster, only the circular scattering cluster is adopted here. For the proposed dynamic mode, the elliptical scattering cluster would also need to support the direction of the ellipse’s semiaxes versus the direction of motion.

### C. Multipath Components’ Lifetime

As the mobile travels, some scatterers move out of the chosen disc of scatterers while others move in and as a result new multipath rays contribute to the received signal (“multipath generation”). Furthermore, multipath rays exist for a period of time \( t_d \) and then disappear (“multipath recombination”). Clearly, the duration \( t_d \) is a random variable described by some pdf and it also depends upon the velocity \( V \) of the mobile and the scattering disc radius \( R \).

The pdf of the scatterers’ lifetime is given by (15) and is depicted in Fig. 5 (a proof is provided in Appendix B). It can be seen from (15) and Fig. 5 that the pdf of the time duration approaches infinity for \( t_d = 2R/V \), i.e., when the diameter of the scattering cluster aligns with a trace of a scatterer. Nevertheless, this is not a problem, since the pdf is continuous and the probability of such an event is zero.

### D. Simulation Procedure

Typically, simulating the mobile radio channel with statistical models involves generating the required parameters (e.g., angle of arrival, time of arrival, amplitude, phase), according to provided joint pdf functions. This procedure is feasible with time-invariant GBSR models [5]. However, the proposed model also provides the Doppler shift and time evolution of the parameters. As a result the accuracy and complexity of the model is increased. The simulation procedure can no longer be based on
The area density of the scatterers is not explicitly stated in the provided references, it can be easily obtained from the information provided for the number of scatterers in a given disc with known area.

1Although the area density of the scatterers is not explicitly stated in the provided references, it can be easily obtained from the information provided for the number of scatterers in a given disc with known area.
TABLE I
SUMMARY OF PARAMETERS USED WITH THE SSTPM MODEL TO SIMULATE DIFFERENT OPERATIONAL ENVIRONMENTS

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrocold Urban</strong></td>
<td>scatters density area: ( 70 &lt; \sigma &lt; 600 ) [scat/km(^2)]</td>
</tr>
<tr>
<td>Total mean number of scatterers</td>
<td>( N_{sc} = 20 )</td>
</tr>
<tr>
<td>Mean number of local scatterers</td>
<td>( N = 20 )</td>
</tr>
<tr>
<td>Radius of local scatterers</td>
<td>( 100 \text{ m} \leq R \leq 300\text{ m} )</td>
</tr>
<tr>
<td>Cell range</td>
<td>( 3000 \lambda \leq CR \leq \text{maximum system radius} )</td>
</tr>
<tr>
<td><strong>Macrocold Bad Urban</strong></td>
<td>scatters density area: ( 70 &lt; \sigma &lt; 600 ) [scat/km(^2)]</td>
</tr>
<tr>
<td>Total mean number of scatterers</td>
<td>( N_{sc} = 30 )</td>
</tr>
<tr>
<td>Additional scattering clutter</td>
<td>1 clutter</td>
</tr>
<tr>
<td>Number ( N_r ) of scatterers in the additional clutter</td>
<td>( N_r = N/2 )</td>
</tr>
<tr>
<td>Radius of additional clutter</td>
<td>( R_r = R/2 )</td>
</tr>
<tr>
<td>Distribution of the additional clutter</td>
<td>uniform within cell range</td>
</tr>
<tr>
<td>Further parameters</td>
<td>as for “Macrocold Urban” type</td>
</tr>
<tr>
<td><strong>Macrocold Sub-urban</strong></td>
<td>scatters density area: ( 10 &lt; \sigma &lt; 35 ) [scat/km(^2)]</td>
</tr>
<tr>
<td>Total mean number of scatterers</td>
<td>( N_{sc} = 10 )</td>
</tr>
<tr>
<td>Mean number ( N ) of local scatterers</td>
<td>( N = 8 )</td>
</tr>
<tr>
<td>Radius of local scattering cluster</td>
<td>( 300 \text{ m} \leq R \leq 500\text{ m} )</td>
</tr>
<tr>
<td>Number ( N_r ) of additional distinct remote scatterers</td>
<td>uniform between ( 0 \leq N_r \leq 4 )</td>
</tr>
<tr>
<td>Distribution of the additional distinct remote scatterers</td>
<td>uniform within cell range</td>
</tr>
<tr>
<td>Power in LoS component</td>
<td>( K_{R_{LoS}} = 0 - 20 \text{ dB} )</td>
</tr>
<tr>
<td>Further parameters</td>
<td>as for “Macrocold Urban” type</td>
</tr>
<tr>
<td><strong>Macrocold Rural</strong></td>
<td>scatters density area: ( 3 &lt; \sigma &lt; 7 ) [scat/km(^2)]</td>
</tr>
<tr>
<td>Total mean number of scatterers</td>
<td>( N_{sc} = 6 )</td>
</tr>
<tr>
<td>Mean number ( N ) of local scatterers</td>
<td>( N = 4 )</td>
</tr>
<tr>
<td>Radius of local Scatters</td>
<td>( 500 \text{ m} \leq R \leq 800\text{ m} )</td>
</tr>
<tr>
<td>Number ( N_r ) of additional distinct remote scatterers</td>
<td>uniform between ( 0 \leq N_r \leq 4 )</td>
</tr>
<tr>
<td>Distribution of the additional distinct remote scatterers</td>
<td>uniform within cell range</td>
</tr>
<tr>
<td>Power in LoS component</td>
<td>( K_{R_{LoS}} = 0 - 40 \text{ dB} )</td>
</tr>
<tr>
<td>Further parameters</td>
<td>as for “Macrocold Urban” type</td>
</tr>
<tr>
<td><strong>Microcell Urban</strong></td>
<td>scatters density area: ( 7000 &lt; \sigma &lt; 60000 ) [scat/km(^2)]</td>
</tr>
<tr>
<td>Total mean number of scatterers</td>
<td>( N_{sc} = 20 )</td>
</tr>
<tr>
<td>Mean number ( N ) of local scatterers</td>
<td>( N = 18 )</td>
</tr>
<tr>
<td>Radius of local Scatters</td>
<td>( 10 \text{ m} \leq R \leq 30\text{ m} )</td>
</tr>
<tr>
<td>Cell range</td>
<td>( 30\text{ m} \leq CR \leq 500\text{ m} )</td>
</tr>
<tr>
<td>Number ( N_{BS} ) of local to BS scatterers</td>
<td>uniform between ( 0 \leq N_{BS} \leq 4 )</td>
</tr>
<tr>
<td>Distribution of local to BS scatterers</td>
<td>range – uniform between ( [0 \text{ 10m}] ) angle – uniform in cell sector width</td>
</tr>
<tr>
<td>Power in LoS component</td>
<td>( K_{R_{LoS}} = 0 - 20 \text{ dB} )</td>
</tr>
<tr>
<td><strong>Common parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Reflection coefficient ( \rho ) for scatterers in the sub-clusters</td>
<td>uniform phase between ( [0 2\pi] ) uniform amplitude between ( [0 1] )</td>
</tr>
<tr>
<td>Number of scatterers in the sub-clutter</td>
<td>( L = 8 )</td>
</tr>
<tr>
<td>Radius of the sub-clutter</td>
<td>( R_s = 10\lambda )</td>
</tr>
</tbody>
</table>

in Section III. It is assumed that a narrow-band signal is transmitted at a frequency \( f = 1.8 \text{ GHz} \) and that the BS antenna is a linear array consisting of omnidirectional elements.

A typical Rayleigh (for channels without LOS) fading envelope at a frequency \( f \), as seen by one antenna element at the BS, is depicted in Fig. 6. The received signal is spread across the full Doppler range \( (-f_{Dopmax} < f < +f_{Dopmax}) \) and is independent of the scattering cluster size, hence the number of fades per second is the same for all channel types. It can be seen from the same figure that the number of fades per second of the modulus of the steering vectors is lower. This occurs because of the minor angle spreading in the subclusters. The number of fades per second of the steering vectors depends upon the distance to the MS. The closer the subcluster is to the mobile, the larger the number of fades of the steering vector. Fig. 7 shows results generated by the SSTPM model for a macrocellular bad urban scenario. It can be seen from the figures that apart from the multipaths due to scatterers local to the mobile, there are multipaths due to distant scatterers as well as multipaths reflected on the additional cluster. All of them are distinguished both in space and time [Figs. 7(a) and (b)]. Fig. 7(c) depicts the discrete Doppler spectrum given by (7), and Fig. 7(d) shows a plot of the correlation coefficient between the real parts of the received complex envelope as a function of the interelement distance.
Fig. 6. Typical fading of the superposition of all multipaths: solid line; two typical fluctuations of the steering vectors’ modulus: two dashed lines.

Fig. 7. Typical results generated by the model for a macrocellular bad urban scenario in the uplink (power normalized to the weakest ray): (a) power-delay profile; (b) power-angle (azimuth) profile; (c) Doppler profile; (d) correlation between antenna elements.
V. CONCLUSIONS

The SSTPM proposed in this paper alleviates problems encountered in known statistical channel models. A hybrid approach that combines two classes of radio channel models, the GBSR and the GWSSUS, has been proposed in order to simultaneously exploit the advantages and minimize the disadvantages of both classes of models. An extension to the proposed hybrid model includes the generation of consecutive snapshots based on the method of a moving scattering cluster. This extension introduces temporal characteristics to consecutive CIRs and hence makes them correlated. This is more representative of reality than the previous uncorrelated assumption made by the GBSR and GWSSUS models. This also allows for direct calculation of the correlation functions, since complex envelopes are available. A further extension in the proposed model allows the number of multipaths to be varied as the MS moves. The number of multipaths follows a random process with Poisson distributed values. The pdf of the “scatterers’ lifetime” has been calculated and shown to depend upon the size of the scattering cluster and the MS velocity. The Doppler spreading and the pdf of the angle of arrival were also provided. To further increase the model’s ability to provide realistic channel information, parameters for five different types of environments, ranging from microcellular urban to macrocellular rural, are incorporated into the model. The values of these parameters provide environment-specific characteristics and are based on results published in the open literature from extensive measurement campaigns.

APPENDIX A

PDF OF A NUMBER OF SCATTERERS

Let the scattering cluster area be denoted by $A$ and some larger area by $\Omega$, with $A \subset \Omega$ ($\Omega$ might be the cell). If the scatter area density $\sigma$ is uniform across $\Omega$, the probability for one scatterer to be inside $A$ is $p = A/\Omega$. If $n$ is the number of scatterers in $\Omega$, then the average number of scatterers in $A$ is $N = p \cdot n = A \cdot \sigma$. The probability for exactly $k$ scatterers to be in $A$ is given by a binomial law

$$P(k) = \binom{n}{k} p^k (1-p)^{n-k} \approx \frac{1}{K^k} N^k \left( 1 - \frac{N}{n} \right)^{n-k}$$

where $n(n-1)\ldots(n-k+1) \approx n^k$. For a very large number of scatterers, the limit of the binomial coefficient is

$$P(k) = \lim_{n \to \infty} \frac{1}{K^k} N^k \left( 1 - \frac{N}{n} \right)^{n-k} = \frac{N^k}{K^k} e^{-N} = \frac{(\sigma A)^k}{K^k} e^{-\sigma A}$$

Hence, the probability distribution function of the number of scatterers in the scattering cluster with area $A$ is given by the Poisson distribution.

APPENDIX B

PDF OF MULTIPATH COMPONENTS’ LIFETIME

In the case of a uniform distribution of scatterers, the traces $y$ of all the scatterers contributing to the received signal cross the disc diameter at a distance $x$ from the centre of the disc. The variable $x$ has a uniform distribution since the marginal distribution across a line containing the diameter is uniform, hence

$$f_x(x) = \frac{1}{2R^2}, \quad -R \leq x \leq R.$$  (11)

The transformation between variables $x$ and $y$ is given by a simple relationship: $y = g(x) = 2\sqrt{R^2 - x^2}$. Now it is possible to find the pdf $f_y(y)$ from (11) and the function $g(x)$. These types of problems are solved by [12]

$$f_y(y) = \sum_{i=1}^{m} f_x(w_i(y)) |J_i|$$

where $J = dx/dy = w'(y)$ is the Jacobian of the transformation, and $x = w_i(y)$ is the reciprocal of the function $g(x)$. If $y < 0$, then the equation $y = g(x)$ has no real solutions and thus $f_y(y) = 0$. However, for $y \geq 0$, two solutions exist: $w_1(y) = \sqrt{R^2 - (y/2)^2} = -w_2(y)$. The Jacobians are

$$\frac{dx_1}{dy} = \frac{dx_2}{dy} = \frac{-y}{4\sqrt{R^2 - (y/2)^2}}.$$  (13)

Hence the desired pdf is

$$f_y(y) = \frac{y}{4\sqrt{R^2 - (y/2)^2}} [f_x(w_1(y)) + f_x(w_2(y))].$$  (14)

From (11) it can be seen that $f_x(w_1(y)) = f_x(w_2(y)) = 1/(2R)$, and also since $y = Vt$, then the pdf of the time duration $t$ for any given radius $R$ and the mobile velocity $V$ can be calculated as

$$f_t(t) = \begin{cases} \frac{tV}{4R\sqrt{R^2 - (\frac{tV}{2})^2}}, & 0 \leq t \leq 2\frac{R}{V} \\ 0, & \text{otherwise.} \end{cases}$$  (15)

The mean of the multipath components’ lifetime can be simply expressed as

$$E[t] = \int_{-\infty}^{\infty} t f_t(t) dt = \frac{\pi R}{2V}.$$  (16)

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His research interests include the areas of statistical signal processing for communications and radio channel modeling for wireless systems. He is currently involved in design and optimization of the smart antenna systems for WCDMA.

Joe P. McGeehan received the B.Eng. and Ph.D. degrees in electrical and electronic engineering from the University of Liverpool, Liverpool, U.K., in 1967 and 1971, respectively.

He held the position of Senior Scientist at the Allan Clark Research Centre, The Plessey Company Ltd. Here, he was responsible for the research and development of two- and three-terminal GaAs devices and their application to radar, telecommunications, and ultra-fast logic (> 5 Gb/s). In September 1972, he joined the academic staff of the School of Electrical Engineering, University of Bath, where he began research into mobile communications in 1974. At Bath, he pioneered research into what he later termed linear modulation for the spectrum efficient transmission of speech and data (64 kbs in a 5-kHz channel), ray-tracing for propagation prediction in micro, macro, and large cells, automatic gain control, and frequency tracking systems for operation in the fading environment. In 1981, he developed, with his group, what is considered to be the first basic form of what he termed the “software radio,” a linear modulation radio based on TTIIB using the Intel 2920 digital signal processor.

On appointment to the Chair of Communications Engineering at the University of Bristol in 1985, he successfully developed, with colleagues, techniques for linearizing both narrow-band and broad-band power amplifiers. He continued research into linear modulation techniques and systems, ray-tracing, and initiated research into the use of adaptive beam-forming techniques in cellular and AWA systems. He also established in 1987 and is Director of the Centre for Communications Research at Bristol, which now has some 140 researchers in the fields of wireless communications, optical communications, computational electromagnetics, networks and protocols, and video and image processing. Many aspects of his research have formed the basis of international standards or equipments for the cellular, PCS, or private mobile radio markets. He is currently Managing Director of Toshiba Research Europe Ltd.; Telecommunications Research Laboratory, and Dean of Engineering at the University of Bristol.

Dr. McGeehan is a Fellow of the Royal Academy of Engineering and a Fellow of the Institute of Electrical Engineers. He has served on numerous international committees and standards bodies and was advisor to the UK’s first DTI/MOD “Defence Spectrum Review Committee” in the late 70s. He was the joint recipient of the IEEE Transactions Neal Shepherd Memorial Award (for work on SMART Antennas) and the IEE Proceedings Mountbatten Premium (for work on satellite tracking and frequency control systems).

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While at the Centre for Communications Research of the University of Bristol, he was actively involved in all three pioneering European collaborative research projects on adaptive antennas (RACE TSUNAMI I, ACTS TSUNAMI II, and SUNBEAM). In 1998, he became a Research Fellow at the University of Bristol, where his work focused on the area of smart antenna techniques for third-generation mobile communications. He has authored more than 50 international publications and more than 20 technical reports on adaptive antenna related topics. He is member of the organizing committee of the European action COST 260 on smart antennas, expert member of the COST action 259, the Technical Chamber of Greece. He joined the Wireless Technology Practice of the PA Consulting Group, Cambridge, U.K., in 1999. His current interests include design, optimization, implementation, and planning of “intelligent” wireless and broad-band future-generation communication systems.