# Statement of Research Goals

## Andrew C. M. Austin

The past thirty years have seen rapid growth in the popularity of wireless communications. In particular, technological innovations and investment in infrastructure helped drive the cellular boom and the more recent growth in wireless local area networks. These advances have made low-cost, untethered communications a ubiquitous part of the modern world, and the benefits brought to society overall are unquestionable. However, the increasing uptake of wireless communications—particularly for emerging technologies, such as wireless sensor networks, the 'internet of things', smart grids, autonomous robots, and body-centric communications—places increased demand on the limited radio spectrum resources. Spectral reuse leads to interference, which lowers the capacity and performance of a wireless network, often below acceptable levels. The saturation of suitable radio spectrum has become one of the most significant technological and engineering challenges that must be overcome to realise the full potential of wireless communications.

My research thus focuses on:

- designing and implementing physical-layer technologies for future wireless systems that more efficiently utilise the radio spectrum; and
- developing accurate and reliable models to predict the wireless channel for urban and indoor environments, so that spectrum allocations can be optimised to maximise system performance before deployment.

My other research interests are in the area of computational electromagnetics, with a particular emphasis on developing numerical methods to efficiently characterise the impact of uncertainties. In the following sections I will briefly outline some of my contributions to these topics and the research challenges that remain.

## Full-Duplex Wireless Systems

Practically all wireless systems in use today operate in half-duplex mode: to transfer information in both directions two communicating transceivers either take turns to use the radio channel, or divide it into two disjoint frequency bands. In *full-duplex* mode, both transceivers simultaneously receive and transmit in the same frequency band. An immediate advantage of full-duplex operation is the effective *doubling* of the spectral efficiency, which is of considerable interest for cognitive radio, co-operative communications, relay networks and 5th Generation (5G) wireless systems. Furthermore full-duplex links would greatly simplify resource allocation and spectrum management, reducing the overhead for ad-hoc and self-organising systems, such as wireless sensor networks. One of the main challenges to realising full-duplex systems is the presence of strong self-interference, i.e., the signal power from the transceiver's own transmitter is many orders of magnitude larger than the desired signal from the other transceiver. In theory, as the transmitted signal is 'known' within the transceiver, the resulting self-interference can be 'subtracted' off completely, leaving only the desired signal.

Only with recent advances in digital systems design, analog and digital signal processing techniques and reconfigurable radio frequency hardware have implementations of full-duplex systems been reported. While state-of-the-art full-duplex systems can achieve up to 80 dB self-interference suppression, all the reported implementations have been for narrowband systems operating with very low power. Scaling these results to practical transmit powers and bandwidths remains an active area of research. In particular, due to hardware limitations, increasing the transmit power introduces significant non-linearities in the self-interference signal, which are challenging to characterise and suppress. Similarly, increasing the bandwidth makes the system more susceptible to timing jitter and phase noise, reducing the amount of self-interference that can be removed. A major focus of this research will be development and hardware implementation of novel analog and digital self-interference cancellation schemes to specifically target non-linear signal components.

## Wireless Channel Modelling

Radio wave propagation is the integral part of any wireless technology, and understanding the characteristics of the radio channel is essential in the development, implementation and successful deployment of a wireless system. Currently, models based on experimental measurements are widely used. The network specifications of future 5G wireless systems, particularly the large number of users that must be supported at high data-rates, along with improved coverage and reliability, will require more detailed and refined models to accurately predict the wireless channel. A major focus of my research is thus the development of models to predict the radio propagation channel in areas of high population density, such as multi-storey buildings and urban environments, and in electromagnetically challenging environments, such as subway tunnels and between on-body wireless sensors.

The lack of available spectrum in the frequency bands currently used for wireless communications, e.g., 300 MHz–10 GHz, has led to considerable interest in developing systems to operate at much higher frequency bands, e.g., 30 GHz–300 GHz (also known as mm-Wave). In this frequency range, most of the spectrum has not yet been allocated and significantly higher data-rates and more users and devices can be supported. Operating in the mm-Wave bands presents considerable technical challenges—not least in the design of systems and the digital hardware required to process the high data-rate signals—but perhaps most importantly, the physics of the radio channel are significantly different, and propagation models developed for lower frequencies are inapplicable. There have been few reported models to characterise realistic mm-Wave propagation channels, and these have largely focused on simplified environments. I intend to build on my previous background in wireless channel characterisation to develop appropriate measurement- and simulation-based models for mm-Wave propagation within buildings and other environments where these systems may be deployed.

## Modelling Uncertainty in Computational Electromagnetics

Computational electromagnetics (EM) has become an indispensable part of the design and analysis process for antennas, microwave and photonic circuits and many other electromagnetic structures and devices. However, as numerical methods become more refined, the old computer adage ‘garbage in, garbage out’ becomes an increasingly large problem. For example, in the most widely used computational EM techniques—such as the finite-difference time-domain method, finite element method and method of moments—the input parameters (e.g., the problem geometry and the corresponding material properties) *must* be carefully set to yield the correct results. In many practical EM problems these input parameters are often not known completely and must be treated as uncertain. These uncertainties are either inherent in the problem—e.g., temperature fluctuations, random media and surface roughness—or are introduced by the manufacturing processes, e.g., fabrication tolerances during milling or etching. Uncertainties in the input parameters will induce randomness in the outputs (e.g., radiation patterns and device or circuit responses) and due to various complicated interactions these can be difficult to predict. It is vital to quantify the expected variations in the outputs/response to estimate the sensitivity of the design and to set realistic design margins.

While none of the widely used computational EM techniques account for uncertain inputs directly, combining these with parametric sweeps or the Monte-Carlo method can work well for small problems; but for many problems requiring long simulation times, repeated iteration is not a suitable solution. Accordingly, this research program will investigate other more recently proposed methods to efficiently quantify uncertainty in computational EM. A particular aim is the application of the *polynomial chaos method* (PCM) to computational EM techniques. The PCM approximates quantities in a stochastic process as the finite summation of orthogonal basis polynomials in the random input parameter space, and typically converges orders-of-magnitude faster than the Monte Carlo method, providing estimates for the statistics and sensitivities from a *single* simulation run. However, the PCM often requires a reformulation of the numerical method to which it is applied, which will be the major focus of this research. Another avenue of investigation will be the use of polynomial chaos expansions in optimisation algorithms for antenna and microwave circuit designs.