Preface

Decades of exponential improvements in integrated circuit manufacturing and design have been spurred by (and given rise to, in a virtuous circle) relentless reduction in the cost per transistor, as well as many other interesting consequences. The cost reduction keeps following a well-proven learning curve, which includes Moore's law as a corollary, and will continue in spite of the end of this law. According to the Bell's law, such technology trend has led to inexorable shrinking of electronic systems, which are now approaching the sub-centimeter scale and below. At the same time, the Koomey's and Gene's laws promise the reduction in the energy consumption by another two orders of magnitude. Those trends promise the possibility of integrated electronic systems that are very inexpensive, small, and extremely low power. In other words, we will increasingly see systems that are pervasive in space and long-lived in time. At the same time, Metcalfe's law (or Sarnoff's law for the least optimistic) traces the fast-growing value of connectivity, thanks to the rapidly increasing number of connected users, and, more in general, connected objects.

At the same time, several megatrends are demanding more pervasive and continuous sensing, as well as sensemaking and transfer of physical data. Accelerated urbanization and increasing worldwide population requires sustainable usage and sharing of resources, as well as more livable and smarter environments at all scales (from home to city). Pervasive sensing and sensemaking are also being required by assistive and proactive technologies (e.g., robotics, decision support) that increasingly relieve humans from routine tasks, repetitive labor, and recently data-driven decision-making. The sharing economy is demanding the ability to spatially track, to physically monitor and manage objects, to encourage responsible usage, and to charge users by the actual usage. Well-being and other human factors are being modeled and monitored to create healthy environments where humans can be happy and productive. Geosocialization and participatory sensing are progressively involving objects other than individuals or as support to human activities. Three-dimensional remote physical interaction with reality provides sensory feedback, thus demanding ubiquitous sensing to enable this ability on a wider scale and on a finer granularity.

The push and the pull effect of the above technological trends and applications is converging on and creating a virtuous circle that we now call the “Internet of Things” (IoT). The IoT can evidently create a huge value and bring unprecedented benefits to the society. To set this on a trend perspective, we can extrapolate Hick’s law to artificial intelligence and cloud computing: more physical data will enable us to take more automated decisions with an effort that is only logarithmic in the space of decision choice. The IoT is ultimately a powerful enabler to share on a larger scale, make technology more human centric and real time, and decouple socioeconomic progress from intensive use of resources. And, interestingly, IoT silicon technology becomes so small that the user is immersed in it (there is no more “user experience,” in a sense), with interesting implications in terms of market and perceived value.

In spite of the daily IoT-related claims in the chip design community, the tiny sensing nodes of the IoT at its edge (the “IoT nodes”) are still in their technological infancy. Several challenges need to be tackled, such as energy efficiency and related lifetime, cost, security, and interoperability, among others. Such challenges need to be tackled in a holistic manner, developing both an understanding of the different parts of IoT nodes and an insight into the big picture and the strong linkage to applications and related requirements.

To the best of our knowledge, this is the first book on integrated circuit and system design for the Internet of Things. This book develops in both the “vertical” and the “horizontal” dimension. Vertically, it provides a comprehensive view on the challenges and the solutions to successfully design chips for IoT nodes as systems (from circuits to packages), a broad analysis of how chip design needs to evolve to meet those challenges, and a fresh perspective grounded on historical and recent trends. Horizontally, the book covers in one place the very diverse domain-specific expertise of the subareas involved in the design of IoT nodes, which was previously scattered across a large number of talks, journals, and conferences.

This book provides a design-centric perspective, providing an understanding of what the IoT really means from a design point of view. Typical specifications of commercial IoT nodes are discussed, and constraints imposed by IoT applications are translated into design constraints that chip designers are used to deal with. Design guidelines to meet them are systematically discussed in every chapter.

This book started in the form of talks at various venues, such as VLSI Symposium, HotChips, and ISCAS, where I had very interesting conversations with several other speakers. Those talks were motivated by the lack of a cohesive and detailed source of accessible knowledge on the design of IoT nodes. The idea to write this book came exactly from those conversations, which later continued throughout the interaction with chapter authors. They really made this book possible, providing their deep insights and invaluable expertise. I deeply thank all outstanding researchers and designers who contributed to the chapters of this book, sharing their expertise in an accessible and concise manner for the benefit of our community.

This book is structured as follows. Chapter 1 describes the big picture in view of technological trends, an overview of the challenges ahead and the possibilities that research has recently opened, and some link to the economics of the IoT and social megatrends. Chapter 2 provides a system-level perspective of IoT nodes. Then, Chaps. 3–7 cover the design of digital subsystems of IoT nodes, from architectures to circuits, and memories in CMOS and other emerging technologies. Chapter 8 is about hardware-level security techniques, whereas Chap. 9 focuses on System-on-Chip design methodologies. Power management and energy harvesting are covered in Chaps. 10 and 11. Analog interfaces and analog–digital converters are discussed in Chaps. 12 and 13. Short-range radios are discussed in Chap. 14. Batteries as further essential component of IoT nodes are the focus of Chap. 15. Packaging is the topic of Chap. 16. Finally, Chaps. 17 and 18 describe two system integration examples, exemplifying the design techniques introduced in the previous chapters. As a common thread, all chapters include a final section on perspectives and trends, which provides a glance into the future, and a good starting point for further research and advances.

There are many ways to use this book. In particular, it can serve as a reference to practicing engineers working in the broad area of integrated circuit/system design of IoT nodes, in view of the wide and detailed coverage of state-of-the-art solutions for IoT and the fresh perspective on the future of such technologies. The book is also very well suited for undergraduate, graduate, and postgraduate students, thanks to the rigorous and lean coverage of topics and selected references.

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