Three-Tier Shared Spectrum, Shared Infrastructure, and a Path to 5G

Preston Marshall

Written by a leading expert in the field, this unique book describes the technical requirements for three-tier shared spectrum, the key policy rationale, the opportunity it creates for shared infrastructure such as neutral host networks, and the likely impact for 5G.

Detail is provided on the inception of the concept and its implementation in the US Citizens Broadband Radio Service (CBRS), along with descriptions of standards for deployment, algorithms required for implementation, and the broader consequences for wireless network and service architectures.

The economic and innovation incentives offered by three-tier spectrum are described, along with potential outcomes such as widely deployed neutral host networks. There is also detailed technical analysis of the unique challenges introduced by three-tier spectrum, such as coexistence among non-cooperating networks.

Covering a wide range of spectrum bands, ITU international allocations, and rule structures that can be adapted for different spectrum-sharing regimes and nations, this is ideal for an international readership of communications engineers, policy-makers, regulators, and industry strategic planners.

Preston Marshall led the Google and Alphabet Inc. efforts to establish the technical, commercial, and regulatory ecosystem to make three-tier spectrum a success in the USA. He was a major participant in the USA PCAST study that was the basis of the three-tier concept. He chairs the Wireless Innovation Forum Spectrum Sharing Committee, and is founding vice chair of the CBRS Alliance. Previously he was Deputy Director of the Information Sciences Institute (ISI) at the University of Southern California (USC), Research Professor at USC's Electrical Engineering Department, and Program Manager for wireless, cognitive radio, and networking programs at the US Defense Advanced Research Projects Agency (DARPA).

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ISBN 978-1-107-19696-4

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University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India

79 Anson Road, #06-04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107196964
DOI: 10.1017/9781108165020

First published 2017

Printed in the United Kingdom by Clays, St Ives plc

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-19696-4 Hardback

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Acknowledgments

The development of the three-tier spectrum concept has created new opportunities for innovation, not just in spectrum management, but in the wireless service architectures, and wireless technologies themselves. Flexible, scalable, rapid, and low cost access to the spectrum offers the opportunity to create whole new industries that could not exist with more static spectrum models. Neither this book, nor this concept, could exist without the very significant efforts and initiative by a large number of individuals and groups.

First and foremost, I thank the two co-chairs of the President's Council of Advisors on Science and Technology (PCAST) study. Mark Gorenberg, was instrumental in facilitating the development of the principles, and in creating acceptance of this concept within the US executive offices. Eric Schmidt (Alphabet Inc., then Google Inc.) contributed the concept of micro-transactions to reduce transaction costs and create the dynamic market concept that underlies the three-tier concept. It would have been hard to imagine the Department of Defense (DoD) supporting highly flexible sharing of its spectrum prior to this study. Mark worked tirelessly not only to run this study, but to ensure that its recommendations would be supported and acted on by the US Government. Another significant contributor to this initiative was Milo Medin (then Google Inc., now Alphabet Inc.) who introduced many of the commercial and competitive considerations that were central to the recommendations. I also thank the staff of the White House Office of Science and Technology Policy (OSTP) for supporting the study recommendations, and turning them into action by the Administration.

The development of the concept, and its acceptance, would not have occurred without the extensive research performed by the Dynamic Spectrum Access (DSA) and Cognitive Radio (CR) communities. Although many of the more progressive concepts developed in these research areas have not yet been incorporated into the proposed three-tier frameworks, their effort did socialize and demonstrate the value of shared and dynamic spectrum, which was instrumental in its ultimate acceptance.

Additionally, although regulators are often considered to be an obstacle to innovation, the US Federal Communications Commission (FCC) was extremely aggressive in pursuing this opportunity, and in particular, John Leibowitz (Deputy Chief of the FCC Wireless Bureau and Special Advisor to the FCC Chairman for Spectrum Policy at the time) was instrumental in initiating the regulatory process, despite much opposition from those that did not see the vision.

I personally thank the many people at Alphabet and Google, and the participants in the Wireless Innovation Forum (WinnForum) Spectrum Sharing Committee (SSC) for their many contributions and further refinement, development, and implementation of these concepts. Also, I thank the Information Sciences Institute (ISI) at the University of Southern California (USC) Viterbi School of Engineering for support during my involvement in development of the PCAST report. It has been an extreme pleasure to follow this work from its early inception in academia and the Defense Advanced Research Projects Agency (DARPA), through to its deployment in real world wireless systems serving users.

Preface

The United States of America (USA) is embarking on the development and application of a new model for the management of spectrum. This model has evolved through more than a decade of academic, policy, and economic concept development and analysis. It has now been embraced by sufficient major participants in the wireless ecosystem to achieve the critical mass to succeed. Although this model is focused on spectrum management, it has significant implications on the broader questions of wireless architecture, the structure of wireless service models, and even the nature of the wireless industry itself.

As the title suggests, this book is about the intersection of spectrum and innovation. There is a fundamental linkage between the flexible availability of spectrum, and the ability of entrepreneurs and innovators to create and deploy new technology, business models, and services. Therefore, we consider spectrum policy from the perspective that it should effectively provide spectrum to the services that require it, and at the same time, ensure that the operation of the spectrum mechanism does not fossilize the industries and services it supports. Spectrum policy that focuses primarily on the technical protection of incumbents will inevitably end up primarily protecting the business and technical models of those same incumbents.

While many topics in spectrum management and wireless have a rich literature, the rapid growth of the three-tier concept has not yet created an extensive base of either rationale or descriptive material. I believe there was a need to create a single work that is inclusive of the ideas that had been developed, and the actions that had been taken in the concept's short history. Second, the available documentation, mostly consisting of government regulations, reports, and legal filings, is deficient in establishing the rationale for many aspects of, and objections to, three-tier spectrum, and do not address the link between this regime and the creation of innovation-friendly spectrum policies. From an implementation perspective, there was no source of context describing what the real-world implementations of these concepts were, and could be.

Today, the community is focused on a very small set of use cases; one country, one primary incumbent, and a limited set of bands. A general framework that can be applied internationally, with many incumbent user classes, and many bands, is necessary for a scalable introduction of the concept worldwide. Lastly, although the subject is spectrum management policy, it is important to look beyond the lower layers, and consider the impact of three-tier spectrum policies that create a band accessible by a much wider

range of participants and technical models. There are many opportunities for different network and service architectures that are enabled by this flexibility in spectrum usage.

The opportunity to share spectrum through bands that are common to operators and non-operators has led to the consideration of large-scale neutral host networks that leverage shared infrastructure to provide localized capacity to multiple wireless operators. In the three-tier framework, carrier accessible deployments can be performed by a wide range of organizations, such as venue owners and enterprises that are able to perform these deployments at a lower cost through integration with their own information technology, power and management infrastructures, and where the costs would be shared among them, and the carriers using the offload service. Shared, or common, spectrum, is an enabler for these neutral host deployments, and at least one industry organization, the CBRS Alliance in the USA, is aggressively pursuing the technical standards for the integration of private capacity into carrier networks.

In this book, we will first examine the traditional methods of allocating spectrum to users and services. These mechanisms have been highly effective, enabling a vast ecosystem of wireless services and sensing to be deployed, and it is certainly the baseline from which all other concepts must evolve. This book will then examine more flexible ideas of spectrum management that have emerged, driven by the need to enable innovation, as well as the need to more flexibly utilize spectrum.

This discussion will start with the concepts developed in two successive US policy efforts, the initial PCAST report, and the subsequent US regulations that established the three-tier Citizens Broadband Radio Service (CBRS) band. These are not the complete models of three-tier spectrum, but they are valuable points of departure. The technical constraints are common for all the world, while regulatory law, economics, policy, and of course, politics will vary nation by nation and region by region; and all of these impact three-tier spectrum. That said, the US efforts are a valuable point of departure, and their development and implementation are highly instructive about the challenges all nations will face in developing appropriate three-tier policies.

To understand these challenges fully, a description of the USA's CBRS regime is provided in order to examine specific technical approaches and implementations that would enable three-tier regimes to be established in bands occupied by a much wider range of protected incumbents or mid-tier users. Lastly, in keeping with the desire for innovation, this book will examine the impact of three-tier spectrum on the ability of innovators to deploy their ideas in a scalable and effective manner. The growth of Internet services and applications was fostered because it could thrive in an incremental, scalable, funding regime, such as practiced by the venture capital community. We will consider how spectrum policy can enable wireless services to avail themselves of the same evolution path.

At the same time we consider these new objectives of a spectrum regime, we need to consider the changing needs for spectrum. Whereas the traditional wireless deployment was for Wide Area Network (WAN) base stations to provide reliable coverage, the need for spectrum is increasingly focused on small cells, serving dense populations in nomadic usage. It is not clear that the deployment model for this capacity is monolithic carrier owned, operated and deployed devices. Instead neutral host hybrid networks

might evolve more in the model of Wireless Fidelity (Wi-Fi) deployment than operator deployments, but still integrated into operator network services. If this evolves, this model requires a very different method of spectrum management.

At its core, three-tier spectrum sharing addresses the following two, apparently conflicting, objectives:

1. How do we provide a spectrum regime that can support the intensive capital investment and deployments that are essential to high capacity modern wireless; and
2. Still provide a regime in which all spectrum can be utilized for some useful purpose (*Use it or share it principle*)?

An example of this objective is a management framework in which one spectrum usage pattern might emerge in Times Square, New York and Piccadilly Circus, London; another distinct one in a suburb fifty miles from a major city center; and yet a third, completely different one, far away in agricultural fields, where the major application would be low density, soil condition instrumentation. Local demand in each of these locales would drive the spectrum allocation and usage, not the regulators.

This is the fundamental challenge of three-tier spectrum; to create not the optimal spectrum regime, but create a framework that can adapt itself to meet the local demand, market conditions, economics, and system needs. It is not an argument between licensed and unlicensed, or exclusive and non-exclusive spectrum access. Instead, it is a hybrid that is inclusive of all of these models, and adapts locally to demand, rather than be dictated by "one size fits all" regulation.

The concept of three-tier spectrum management is very much in its infancy. The development of three-tier spectrum sharing is a logical consequence of a series of developments in wireless networking, and the concomitant requirement to provide these networks with the needed spectrum. If this book was written three years ago, the concept would have been, at best, a proposal from an unknown study group. Several years ago, it was only a regulatory action in the USA, almost universally opposed by the entire commercial wireless industry. Even a year ago, it was an interesting US initiative, but not of worldwide significance. Today, it is fully embraced by major players in the wireless ecosystem.

Early consideration in the USA has certainly demonstrated that both traditional and non-traditional users have shown significant interest in using the first three-tier spectrum band. Among other benefits, it appears to solve some of the intractable problems in economically deploying indoor cellular coverage sufficient to meet the escalating demand. It is reasonable to assume that, as additional spectrum is made available through this mechanism, it will be used effectively, if differently, in each local situation.

Some of the concepts that underlay three-tier spectrum were described in a previous book by the author.[1] This previous work explored the unique challenges of dense and scalable capacity networks. The concept of treating the impact of emissions footprint and receiver protection symmetrically was the basis for the quantitative model of the

[1] P. Marshall (2012), *Scalability, Density, and Decision Making in Cognitive Wireless Networks*, Cambridge University Press.

spectrum that was provided in the PCAST report spectrum utilization model, and was the basis for several of the recommendations. This concept considers spectrum usage as the capacity that was denied to the other users of the spectrum, regardless of whether it was the impact of the emission causing interference to other users, or limitations on the use of the band, due to receiver performance. The effective spectrum usage was considered to be the "opportunity cost" lost to other spectrum users. Readers of this previous book should recognize many of its more theoretical principles applied to practice in three-tier spectrum management.

One final note. Three-tier spectrum is very much a work in progress. Trials in the USA have just started; tailoring of existing technology standards is now only at its infancy; and no systems have yet been developed that are native to, and fully leverage, the unique opportunities provided by three-tier spectrum. And it has not yet expanded beyond the USA. There are still many waves of innovation to come.

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