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Expanding mobile wireless capacity: The challenges presented by technology and economics ☆, ☆☆

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ABSTRACT

As demand for mobile broadband services continues to explode, mobile wireless networks must expand greatly their capacities. This paper describes and quantifies the economic and technical challenges associated with *deepening* wireless networks to meet this growing demand. Methods of capacity expansion divide into three general categories: the deployment of more radio spectrum; more intensive geographic reuse of spectrum; and increasing the throughput capacity of each MHz of spectrum within a given geographic area. The paper describes these several basic methods to deepen mobile wireless capacity. It goes on to measure the contribution of each of these methods to historical capacity growth within U.S. networks. The paper then describes the capabilities of 4G LTE wireless technology, and further innovations off of it, to further improve network capacity. These capacity expansion capabilities of LTE-Advanced along with traditional spectrum reuse are quantified and compared to forecasts of future demand to evaluate the ability of U.S. networks to match future demand. Without significantly increasing current spectrum allocations by 560 MHz over the 2014–2022 period, the presented model suggests that U.S. wireless capacity expansion will be inadequate to accommodate expected demand growth. This conclusion is in contrast to claims that the U.S. faces no spectrum shortage.

1. Overview

Demand for mobile wireless services continues to explode. Cisco's latest *Visual Networking Index* (*VNI*) reports that "global mobile data traffic grew 70% in 2012," driven by average connection speeds that more than doubled from 248 kbps to 526 kbps (Cisco, 2013, p. 1). Further, Cisco estimates that by 2017, global mobile data traffic will exceed its 2012 level by a factor of 12.6. While in many parts of the world, significant portions of expansion in mobile wireless network capacity will continue to be due to expansions in the geographic coverage of wireless data networks, in developed countries such as the

☆☆ The analyses and data presented in this paper are intended to portray the U.S. mobile wireless industry on a national average basis. They may not be representative of any particular U.S. geographic region or mobile operator, including AT&T. No proprietary AT&T data were used in performing these analyses. The conclusions developed in this paper are those of the author, alone, and should not be construed as representing any official position of AT&T. I am indebted to my colleagues at AT&T and Peter Rysavy for valuable assistance in preparing this paper. Very useful suggestions were also received from two anonymous reviewers. All remaining errors are my own. An earlier version of this paper was presented at the 19th Biennial Conference of the International Telecommunications Society in Bangkok on November 20, 2012.

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U.S., advanced mobile broadband networks already cover 98.5% of potential subscribers (FCC, 2011, ¶ 46). Thus, the network expansions necessary to accommodate demand growth in developed countries will focus most greatly on *deepening* network capacities. Technically and economically, this presents a different set of challenges from simply expanding coverage scope – a topic that has been addressed extensively in universal service research.[1]

The purpose of this paper is to describe and quantify the challenges particularly associated with wireless network deepening. This includes an analysis of the technical issues concerning what techniques for capacity deepening are feasible, and also consideration of the costs of these techniques to determine the economic capability of these techniques to keep up with growing demand. While certain parties have suggested that improvements in technology to increase throughput capacity per megahertz (MHz) of spectrum and increased geographic reuse of spectrum will be adequate to address wireless demand growth in the U.S. over the next five to ten years, this analysis finds otherwise.[2] Although methods to improve throughput capacity per MHz or increase spectrum reuse may be technologically feasible, and are expected to be used intensively by wireless providers, by themselves they are likely to be inadequate or to become uneconomic absent significant increases in mobile wireless pricing. Thus, even under the conservative modeling assumptions of this paper, substantial quantities of additional spectrum (on the order of 560 MHz) will need to be deployed for mobile wireless use if currently forecasted demand is to be satisfied over the next decade without significant service quality degradation or rationing from price increases.

This finding is consistent with the conclusions developed by several other studies in the literature that have examined the ability of current or expected spectrum assignments and technologies to accommodate forecasted demand.[3] The analysis presented in this study will differ from these prior efforts both by improving on the accuracy of their analyses and by projecting certain enhancements in the ability of evolving wireless technologies to carry more mobile traffic.

This paper begins by describing the basic techniques that may be used to expand mobile wireless capacity. These include increasing raw amounts of available radio spectrum, increasing the absolute carrying capacity of each MHz of spectrum, reducing the bandwidth required to carry popular applications, and increasing the utilization of each MHz of spectrum or unit of infrastructure through cell-splitting, sharing or multiple use. In Section 3, this history of technological evolution is contrasted with both the growth in available mobile wireless spectrum and the growth in mobile wireless demand. The paper goes on to catalog the possible forward-going capabilities and economics of several of the most well-known potential Fourth Generation (4G) Long Term Evolution (LTE) wireless technology innovations, including innovations whose effects remain highly speculative. By comparing the joint capacity expansion capabilities of these new and old techniques with demand growth estimates, it is possible to evaluate their ability to accommodate demand growth and to reduce upwards pressure on current wireless pricing. In the end, the analysis demonstrates that by themselves, these methods will be inadequate to accommodate fully expected demand growth at today's prices. Thus, increased assignment of radio spectrum to mobile wireless will be essential. This is in contrast to suggestions from certain parties that spectrum scarcity should not be a terribly significant concern for government policymakers.

2. Mobile wireless capacity expansion techniques

Methods for expanding mobile network capacity divide into three general categories: the deployment of more radio spectrum; more intensive geographic reuse of spectrum; and increasing the throughput capacity of each MHz of spectrum within a given geographic area.

The carrying capacity of a mobile wireless system is the total amount of data or voice traffic that the system is able to transfer to and from customers.[4] Wireless data are carried by modulating or distorting radio waves. The quantity of waves (or amount of spectrum) a wireless system is allowed to modulate each second is called its bandwidth, and is measured in hertz (Hz). Everything else equal, a signal with a higher bandwidth (i.e., more Hz) can carry more data per second than a signal of lower bandwidth (i.e., less Hz).

The total amount of data that a network may transfer over a given period of time relates closely to the rate at which it transfers data bytes. All things equal, a faster network will transfer more bytes than a slower network. Rates of data transfer are measured in terms of bits per second (bps).[5] Note, however, that in addition to raw transmission speed, the total amount of data transfer will be higher on a network that operates as a higher usage/fill factor (i.e., transfers data during more seconds of the measurement period). This can be achieved if a network has traffic offered more uniformly to it over the measurement period – either because the network serves multiple users whose patterns for offering traffic to the network

[1] See, for example, Williams et al. (2011).

[2] See Bazinet and Rollins (2011), Bode (2012), Burstein (2011), Chen (2012a,b) and Reardon (2010) for arguments suggesting that the U.S. faces no serious shortage of mobile wireless spectrum.

[3] See FCC (2010b), Feldman et al. (2011), Lawson (2012), Rysavy (2011) and Rysavy Research (2010, 2011a,c) for analyses suggesting that mobile wireless spectrum will become critically scarce.

[4] In general, the capacity of the total network will be limited by the capacity of its last-mile radio access network (RAN). Although congestion on fixed backhaul links may possibly occur, increased availability of fiber backhaul facilities should allow backhaul bottlenecks to be engineered away.

[5] By convention, data transfer rates are typically measured in terms of bits (b), and data quantities in terms of bytes (B). Because there are eight bits in a byte, a transfer rate of 8 bps corresponds to transferring one byte per second (1 Bps).