MEETING MOBILE DEMAND WITH A COMBINATION OF SPECTRUM ALTERNATIVES

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The laws of physics have not changed: Higher frequencies still require smaller antennas, while lower frequencies penetrate objects more easily. But technology to harness the potential of radio waves continues to improve, enabling us to both use frequencies not practical or possible in the past, and to employ ever wider radio channels that enable higher performance. The implications are far-reaching, likely to significantly change how we construct future networks. Spectrum policy decisions should be cognizant of such developments — if focused too sharply on today's technologies and their limitations, they could undermine optimal future spectrum deployment. In particular, some of the current premiums placed on low-frequency bands are unwarranted.

Two technology arenas illustrate progress in spectrum utilization: WiFi and cellular. Both employ the best available radio methods to achieve high throughput rates, low latency, high spectral efficiency, and high capacity. Driven by escalating mobile broadband demand, both are undergoing constant innovation. Of the two, WiFi tends to adopt new techniques sooner, partly because deployments are more localized, and partly because WiFi involves far less costly infrastructure. Both WiFi and cellular currently use the same core principles: orthogonal frequency division multiplexing, smart antennas, dynamic modulation and coding, and beam steering.

The biggest challenge for both technologies is that in the 5-GHz-and-below frequencies traditionally used for mobile computing, spectrum is largely accounted for. Clearing large new amounts of dedicated spectrum is becoming extremely difficult, and hence the impetus for spectrum sharing, as well as for means to extract greater capacity from existing spectrum, whether by smaller cells or spectrally more efficient technologies. But wireless technologies are reaching theoretical limits of spectral efficiency. And while small cells will boost capacity significantly, interconnecting and managing them is complex. The mobile broadband industry is therefore pursuing all available options, including higher frequencies where more spectrum is far less congested.

Radio history is replete with examples of the march to higher frequencies. Television's ultra high frequency (UHF) band (470–794 MHz) was a "high" frequency in the 1950s; today it is considered a "low" frequency. Similarly, WiFi has progressed from 900 MHz to 2.4 GHz to 5 GHz bands.

A new band of great interest is the millimeter wave (mmW) band (ranging from 30 to 300 GHz), so called because wavelengths range from 10 mm at 30 GHz to 1 mm at 300 GHz. At these frequencies, wider swaths of spectrum not only boost capacity, but enable much wider radio channels, resulting in an order of magnitude increase in throughput.

Multiple organizations have specified operation in mmW frequencies. Most significant is IEEE's recently completed standard, IEEE 802.11ad, "Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band," [1] which adapts 802.11 to operate in unlicensed frequencies at 60 GHz. Other specifications include IEEE 802.15.3c-2009 for wireless personal area networks and ECMA-387 ("High Rate 60 GHz PHY, MAC and PALs").

Significant engineering horsepower is required to address the problems posed by high frequencies: higher free space path loss, and higher losses through materials and human bodies. At 60 GHz, oxygen absorbs radio energy, making longer-range transmissions difficult.

Using new technology, circuits can not only harness these high frequencies, but can implement beam steering that directionally concentrates radio energy to improve range and penetration. Higher-order multiple-input multiple-output (MIMO) antennas are also easier to implement because they are small thanks to the small wavelengths. Engineers are contemplating massive MIMO systems that incorporate tens if not hundreds of antennas, compared to the simple 2 × 2 systems used in most Long Term Evolution (LTE) deployments today.

Numbers illustrate the benefits of high frequencies. At 2.4 GHz, WiFi only has access to 80 MHz of spectrum (slightly more in other parts of the world), a larger 500 MHz at 5 GHz, but a massive 7 GHz at 60 GHz (57–64 GHz in the United States, with the same or similar allocations in other parts of the world). In the United States, other mmW bands include 71–76 GHz and 81–86 GHz for license-light operation per FCC Part 101 regulations, and 92–95 GHz for unlicensed indoor applications per FCC Part 15.257 regulations.

The wider allocations also enable much wider radio channels, which translates directly to higher throughput rates. Recent WiFi standards such as IEEE 802.11n and 802.11ac already emphasize wider channels: up to 80 MHz operation in 802.11n and 160 MHz in 802.11ac. Similarly, LTE-Advanced specifications define aggregation of up to five 20 MHz radio channels. In mmW frequencies, however, channels can be some 10 times wider. For example, IEEE 802.11ad uses 2.16 GHz channel spacing to deliver 7 Gb/s of peak throughput in a simple antenna configuration, 28 Gb/s using 4 × 4 MIMO.

Similarly, recent 5G research efforts are examining the mmW bands and contemplating 1–4 GHz wide radio channels, far wider than LTE's maximum width radio channel, or even the maximum 100 MHz possible through carrier aggregation in LTE-Advanced. No 5G standards exist yet, but various organizations are forming, including Europe's METIS 2020 [2] research effort and the 5G Public-Private Partnership (5G PPP), also in Europe, which will fund research and development.

Just as technology pushes upper bounds, technology also creates new options at lower frequencies. For example, IEEE 802.11ah [3], "Amendment — Sub 1 GHz License-Exempt Operation," is based on 802.11 a/g, but will operate in sub-gigahertz spectrum to provide lower throughputs of 100 kb/s across 1 km distances to serve machine-to-machine (M2M) applications such as smart meters.

White space technology is another emerging low-frequency area in which unlicensed networks can use vacant TV channels (UHF and VHF) for communication. IEEE has two applicable standards: IEEE 802.11af [4], "Amendment 5: TV White Spaces Operation," which is still in development, and IEEE 802.22-2011 [5], "Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and Procedures for Operation in the TV Bands." It is unclear whether white space networks can provide a high-capacity alternative to today's mobile broadband technologies, but they could be particularly effective in emerging economies, such as Africa and India, and other regions lacking broadband infrastructure.

These TV bands are also important for cellular networks as the FCC begins auction proceedings on the 600 MHz band that will reallocate up to 120 MHz of spectrum from television broadcasters to the mobile industry [6]. Signals at these lower frequencies propagate well, requiring fewer cell towers for a coverage area. White space advocates also hope for unlicensed spectrum allocations from the incentive auctions.

Unlike the mmW bands, which require new radio technology, the 600 MHz band will use existing LTE technology. In rural deployments, larger cells can cover areas with fewer base stations because of lighter network loading, but in cities, capacity drives deployment and mandates cells with much smaller coverage. Since resulting propagation distances are much smaller, operators can use either low or high frequencies, and the lower frequencies do not represent any significant advantage, and even a disadvantage as technology progresses.

The disadvantage is antenna size. Modern radio technologies have reached the Shannon bound, which governs the bits per second per Hertz of spectral efficiency available relative to noise. One effective avenue to boost spectral efficiency is MIMO. Multiple antennas can be practically realized more readily at multi-gigahertz frequencies than at 600 MHz. At mmWave frequencies, antennas will be so small that they can be implemented directly on integrated circuits [7].

Mobile broadband networks of the future will use multiple frequencies. Underlays at lower frequencies will provide coverage (e.g., LTE under 3 GHz), while small cells will augment capacity. Initially, these small cells will operate sub 3GHz, but over time they will take advantage first of the forthcoming 3.5 GHz small-cell band (100 MHz available) [8], then, in the next decade, mmW bands where they will exploit many gigahertz of new capacity. The resulting networks, likely available in the next decade, will have capacity and throughput rates at least 10 times higher than today. Users will be able to enjoy applications such as super HD mobile video as well as applications not yet invented.

The advantages of low-band spectrum are overstated. Mobile broadband network deployments will increasingly be driven by capacity concerns, and most traffic will travel at ever higher frequencies.

REFERENCES

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BIOGRAPHY

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