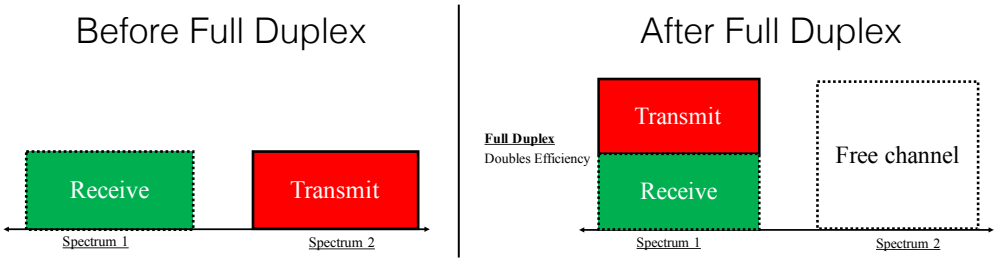
Dinesh Bharadia - Personal Statement

> "It is generally not possible for radios to receive and transmit on the same frequency band because of the interference that results." Wireless Communication, Andrea Goldsmith, 2005 [1].

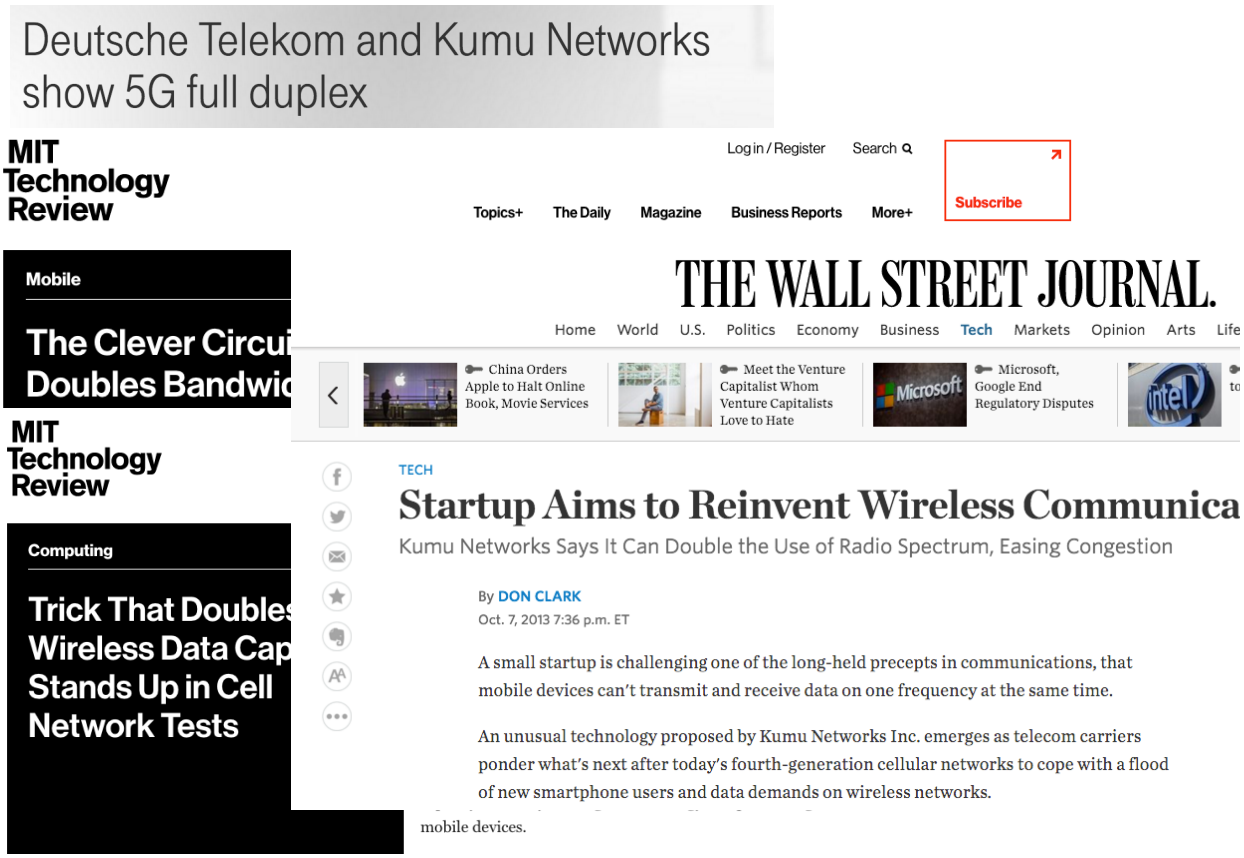
This quote from a popular wireless communications textbook captures a long held assumption in wireless communications that radios cannot transmit and receive at the same time and the same frequency. A simple equivalent analogy is one cannot shout and listen to whispers at the same time; the same applies to wireless radios.

Invalidation of this assumption has important implications; on one front it would increase the efficiency of the spectrum by 100%, which would help resolve the spectrum crunch and provide better data rates on our wireless devices [2]. On other end, it also enables a whole host of new applications, from extremely low-power Internet of Things connectivity [3] to full duplex relays [4] to motion tracking [5] to activity recognition.



My research at Stanford broke this long-held assumption in wireless communications. By building a working prototype, I was able to invalidate this fundamental assumption, which had been an open research problem in the field for 150 years. We built radios that can transmit and receive at the same time and on the same frequency called *In-Band Full Duplex Radios*. For a radio to realize in-band full duplex, it needs to receive the signal from the other radio while it is transmitting on the same frequency. The major challenge in doing so, is the interference of the self-transmitted signal. To make matters worse, this self-transmitted signal is typically 100 billion times stronger than the incoming signal from the other radio. As such, to remove this self-interference, one requires to estimate the transmitted signal, as seen at the receiver to an accuracy better than 1 in 100 billion. Our prototype is the first of its kind to be able to enable In-band Full Duplex Radio in real time; which achieves the theoretical doubling of the spectral efficiency [6, 7].

The ability to double the efficiency of spectrum received tremendous interest from industry, academia, technology news and the venture capitalist. MIT Technology Review [8, 9, 10] covered this invention as, "A clever circuit that doubles bandwidth" with citing the crucial paper as [7]. I co-authored several key patents on this technology at Stanford University, which received significant interest from entire wireless industry (AT&T, Verizon, Qualcomm, Ericsson, Nokia, Motorola Mobility, Broadcom, Intel etc.). These patents and technology form the foundation of a startup Kumu Networks, which is able to raise funding of $45 million [11] from the leading venture capital firms. I spent the better part of two years at Kumu Networks building this technology as a commercial product. I lead the technology (both architecture and algorithm design) for in-band full duplex radios. I co-authored 13 important patents at Kumu Networks for developing this technology as a product [12]. In the short span of time, we completed successful field trials of a commercial full duplex product with major Tier 1 network providers – Deutsche Telekom [13] and SK Telecom [14]. Several news and media outlets covered Kumu Networks successful field trials. Wall Street Journal covered Kumu Networks as, "Startup Aims to Reinvent Wireless Communication" [15], MIT Technology Review covered it as, "Trick That Doubles Wireless Data Capacity Stands Up in Cell Network



Collage of News Article Covering Full Duplex

Tests." [16] and others [17, 18, 9, 19, 20]. This technology disrupts existing wireless standards and thus is currently considered by wireless standards to incorporate. Both 5G Cellular and 802.11 Wi-Fi standards committee have made positive recommendation to incorporate this technology.

We have just scratched surface of the applications possible with this technology. We have used the technique of self-interference cancellation that enables full-duplex radios to build a variety of applications: motion tracking system using wireless signals (WiFi) [5], extremely low-power connectivity for Internet of Thing using reflections [3], full-duplex relay which can extend both range and coverage [4]. It has the potential to be used for important future applications such as building novel wireless imaging that can enable: driverless cars in bad weather scenarios, blind people to navigate indoors etc. Realizing these systems forms my current work.

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