Classical and Wi-Fi Doppler Spectra – Comparison and Applicability

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1. Overview

This white paper introduces and compares the classical (Jakes) and Wi-Fi (Bell) spectra and provides some much-needed guidance on the Doppler Spectrum to be used for mobile Wi-Fi devices.

2. Fading

One inescapable phenomenon of the mobile radio channel is multipath, which is the scattering of Electromagnetic (EM) waves from objects that lie between a radio transmitter and receiver. The objects can be buildings, hills, automobiles, office walls, furniture, etc., and even people. When the waves reflect off the scatterers, they arrive at the radio receiver at slightly different times, due to the different travel distances. This causes the signal to undergo constructive and destructive interference, much like the water waves shown in Figure 1.

Wherever the wave crests or troughs line up, there is constructive interference; when a crest and trough line up together, there is destructive interference. This fundamental phenomenon drives all mobile radio propagation effects.

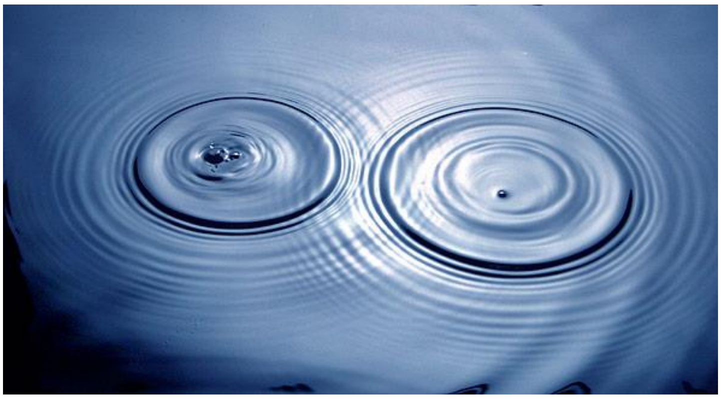

Figure 1: Example for Constructive and Destructive Interference with Water Ripples

The interference pattern of the signal received from a base station does not move if the reflectors don't move. So, when a mobile device is moving, it moves through this interference pattern and experiences fluctuations in the received signal. The rate at which this fading happens depends on the speed of the mobile and the wavelength of the waves. The faster the mobile moves, the faster the fading. The higher the carrier frequency, the shorter the waves and the faster the fading experienced by the moving mobile.

Fading can also occur when both the transmitter and receiver are stationary. This would happen if the scatterers happened to be moving instead of the radios, and produces fading with characteristics much different than with a moving endpoint.

Radio engineers characterize the properties of the fading by what is known as a Doppler spectrum. The form of the Doppler spectrum depends on propagation conditions. Three Doppler spectra of interest to this paper are shown in Figure 2.

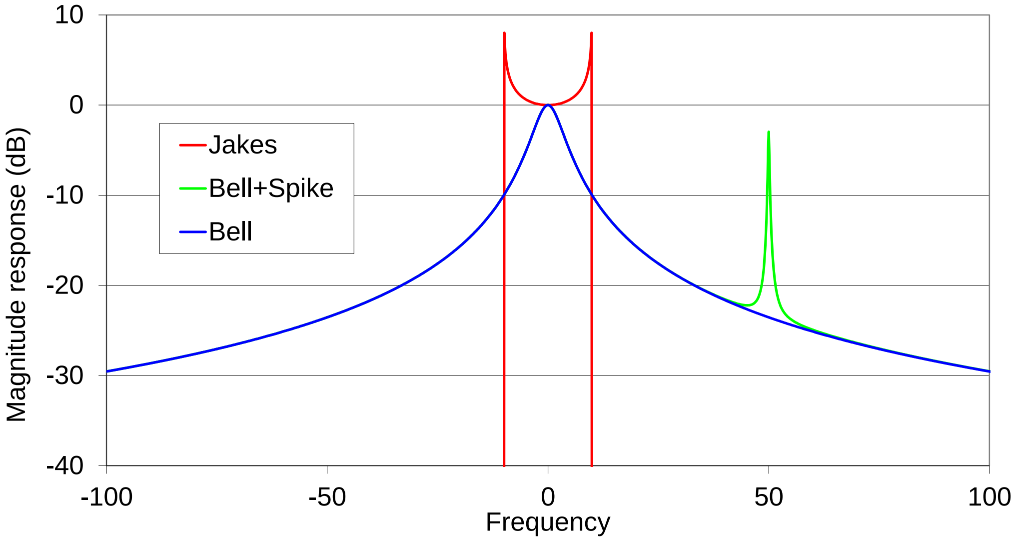

Figure 2: Doppler Spectra

3. Classical Mobile Doppler Spectrum – "The Jakes Model"

For mobile devices, the key word is mobility; these are used in a wide range of mobile situations, such as in automobiles and trains and by pedestrians. The main difference in each of these situations is the speed of motion.

As the mobile device moves, it receives radio waves from many reflectors in its immediate environment. The mobile may be moving toward some of these reflectors, in which case, a positive Doppler shift is produced in the received signal. For all the reflectors it is moving away from, a negative Doppler shift is produced. This is depicted in Figure 33 below. The largest positive Doppler shift is experienced by signals received from the direction of the green arrow, and the largest negative Doppler shift is experienced by signals in the opposite direction. Signals received from reflectors perpendicular to the motion experience little or no Doppler shift.

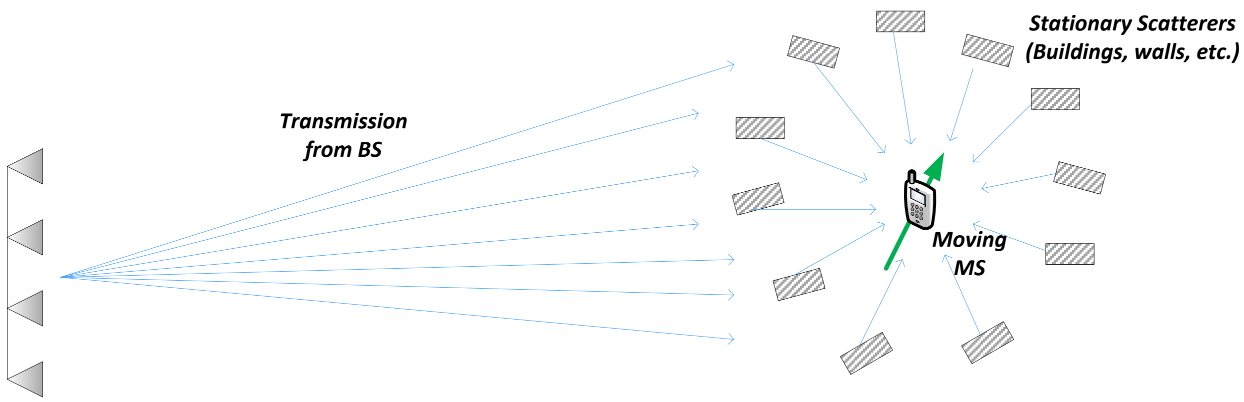

Figure 3: Scattering Environment for a mobile device

The radio signals are received as a sum at the mobile device receiver, and because of the many Doppler shifts, the signal has a spectrum of Doppler shifts imposed on it. Early work on mobile communications [1] determined that this so-called Doppler spectrum has the shape of the red curve depicted in Figure 2, labeled "Jakes" after the author of the reference. Since then, this model has been enhanced several times to handle the increasingly complex modeling needs of mobile radio technology [2]-[8], most notably, the cross-correlation properties required for

MIMO channel modeling. Through all this, the shape of the Doppler spectrum and the amplitude distribution of the fading has remained the same.

4. TGn/Wi-Fi Doppler Spectrum – "The Bell Spectrum"

In 2002, the IEEE Working Group for Wireless LANs (802.11) started its High Throughput Study Group, looking to standardize a new physical layer. This became Task Group n, and within it was developed an evaluation methodology for selecting the new standard. The evaluation methodology included a set of MIMO channel models; these became known as the TGn or Wi-Fi models [9].

TGn recognized that propagation conditions were different in the wireless LAN environment compared to the mobile radio environment. Most notably, TGn assumed that in the WLAN environment, both radio nodes were stationary.

This has a big impact on Doppler spectrum. If there is no motion at all in the environment, there is no fading. The Doppler spectrum would simply be an impulse at zero frequency. In reality, there are people or other objects moving in the environment, which act as reflectors and impart a Doppler shift on the waves reflected from them. Assuming a uniform distribution of moving objects, this leads to the "bell-shaped", or simply "Bell" Doppler spectrum.

The Bell spectrum is depicted with the blue curve in Figure 2. Aside from [9], there is no other discussion of this Doppler model.

As we have seen, the Doppler shift is proportional to speed of motion, hence Wi-Fi Doppler is typically very low – 3 to 6 Hz. Given the propagation scenario, it's hard to imagine a situation with lots of rapidly moving scatterers (people), so Bell-shaped Doppler with a much larger spread is unrealistic.

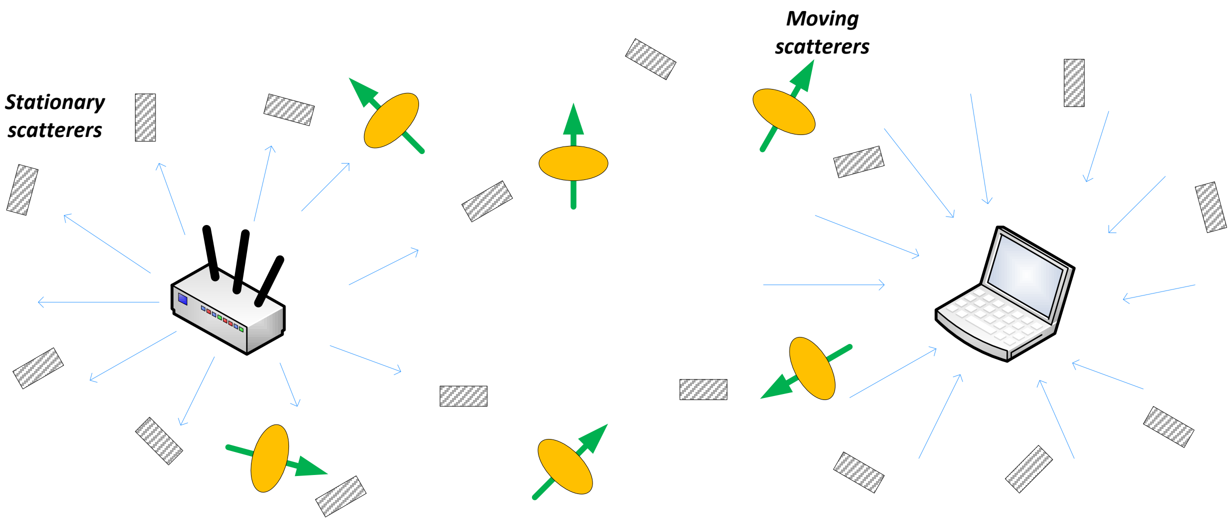

Figure 4: Scattering Environment for Wireless LAN

5. "Bell + Spike" Doppler Spectrum

Channel Model F of the Wi-Fi models gives one of the taps a "Bell + Spike" Doppler spectrum. This particular model emulates conditions one might find in a very large space, and TGn wanted to provide some effect of a moving vehicle within the model. The "spike" portion of the Doppler spectrum provides this effect. It intends to model a vehicle moving at 40 km/hr (25 mph), and appears as a sharp impulse offset approximately 85 Hz from zero (green curve in Figure 2).

6. Applicability of Jakes Doppler Spectrum in Wi-Fi Situations

As should now be understood, the classical Jakes spectrum was developed to model fading in mobile situations, such as mobile phones, while the Wi-Fi Bell spectrum was developed for stationary situations, such as laptops or PCs. Today's smart phones are Wi-Fi devices, but are assumed to be capable of operating in mobile situations. Therefore, one must question the applicability of the Wi-Fi Bell spectrum to the smart phone use case.

Certainly, the Wi-Fi feature of a smart phone is used mainly within buildings, such as pomes, offices or malls, and is carried by a person. The velocities expected are thus no faster than pedestrian speeds. The Jakes Doppler spectrum is already specified for testing LTE devices at this speed, using the "Extended Pedestrain A" model [10]. This model could be appropriate for Wi-Fi testing as well, since the RMS delay spread of 43 ns is consistent with the expectations of a Wi-Fi-device.

On the other hand, the Wi-Fi models offer five different power-delay profiles, with RMS delay spread ranging from 15 to 150 ns, and a range of MIMO conditions. Lacking further standards-based enhancement of the Wi-Fi models, it seems reasonable to use the classical Jakes spectrum with the Wi-Fi power-delay profiles and MIMO correlation. At the very least, Wi-Fi handsets would be exercised under more strenuous conditions, compared to the Wi-Fi standard model, and hence be better prepared to meet the real would challenges to which Wi-Fi devices are now subject.

7. Summary

In this white paper, we learnt about the Jakes spectrum, the Bell spectrum, the Bell + Spike spectrum and the fluorescent lighting effect. We also learnt about the applicability of these in defferent situations.

Given that smartphones are Wi-Fi devices in a mobile environment, a realistic model is a Wi-Fi power delay profile and MIMO correlation with Jakes spectrum. This model is more representative of the conditions under which the devices will be used and will yield test results that are closer to the actual performance in the field.

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