Class Project: Channel Modeling a Mobile Repeater

Due Date: 22 April 2004 (Thursday)

1 Introduction

You have been hired as a consultant by NTT DoCoMo to evaluate a new radio concept for use in the *Shinkansen* – the Japanese bullet train that runs the length of the main island of Honshu. Many of DoCoMo's cellular phone customers in Japan travel by Shinkansen and expect excellent cellular coverage and service while the train is in motion. Being able to supply near-constant service to people in a moving train would give DoCoMo a marketing advantage over its chief rival, J-phone. You have been asked to use your vast knowledge of electromagnetics to model the radio channel seen by the speeding train.

2 Concept System

The Shinkansen provides a harsh radio propagation environment for cellular phones. Because most of the train operates on an elevated track, it is exposed to many radio waves from all the cellular towers in a town or city. Reliable operation in this high-interference environment requires a sophisticated receiver structure. Further complicating things is the presence of small-scale fading due to multipath waves that all originate from the serving base station. Since the Shinkansen travels at top speeds of 260 kph, the received signal power will fluctuate wildly over just a few hundred milliseconds. Thus, a mobile phone operating directly with a base station will have an unreliable link.

To solve this problem, DoCoMo has proposed installing small repeater radios in every train. The transmit and receive antennas for this unit are fixed atop the lead car, as shown in Figure 1. This transceiver would maintain communications with one or more base stations near the train at all times, performing all of the high-speed hand-offs during travel. This unit would be connected to low-powered antennas in each car. Here it could communicate with the passengers' cellular phones, relaying the data to the outdoor base stations and, thereafter, the public switched telephone network (PSTN).

It is here that the engineers at DoCoMo have run into a problem. They are unsure what the radio signal will look like at the terminals of the two antennas. The engineers plan to place two monopole antennas on opposite sides of the lead train, separated by 2 meters. At the receiver, they will employ *selection diversity* to choose which of the signals from the two antennas are the strongest. First and foremost, the engineers need to know how fast they must sample power at each antenna to make seamless signal switches.

3 Channel Modeling

First you must model your multipath channel with the appropriate set of received plane waves. For this, you must assume from-the-horizon propagation and use an *azimuth spectrum* to capture the typical distribution of plane wave amplitudes. You may assume time-harmonic plane waves with a frequency of 1900 MHz. You find that the *Laplacian distribution* makes for a nice model of azimuth

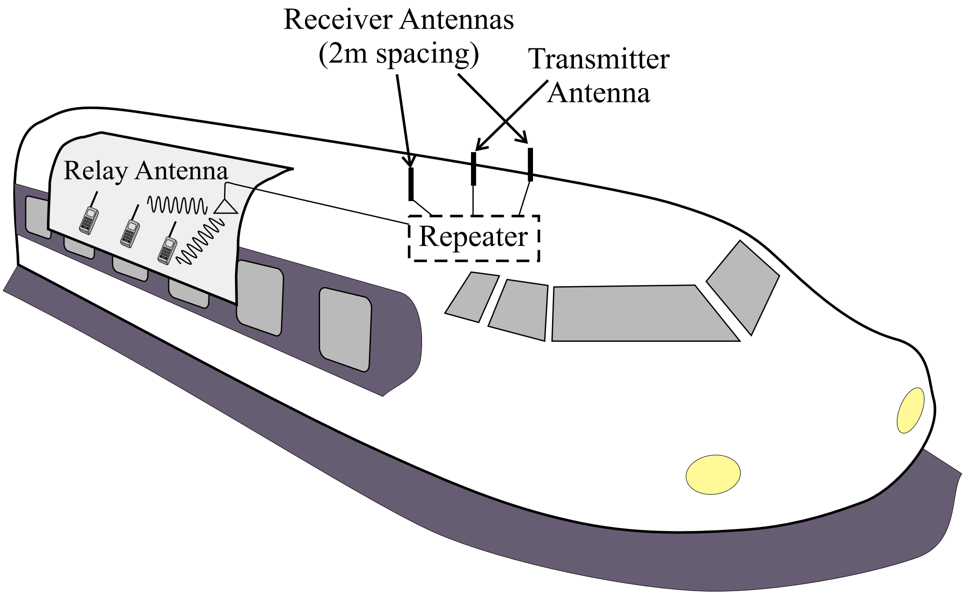

Figure 1: Diagram of the bullet train repeater with diversity antennas.

spectrum in this band:

$$p(\theta) = A \exp\left(-\left|\frac{\theta - \theta_0}{\theta_1}\right|\right)$$

The constant A is arbitrary (it will only change the average received power, not the shape of the distribution or the statistics of the fading.) The value θ_0 is the azimuth direction of peak arrival and, in general, points in the direction of the base station transmitter. The value θ_1 is related to the thickness of the distribution.

The bullet train travels through two types of terrain. One type of terrain is open rural areas with relatively little multipath. In this environment, θ_1 is equal to 3°. When the bullet train arrives in a high-urban or mountainous region, θ_1 is equal to 120°.

Since the position of the train with respect to the base station angle can vary, you will need to analyze two cases for each type of radio environment. The first case is the one where the train is moving directly towards the base station. The second case is the one where the train is moving transverse to the base station. These cases are illustrated in Figure 2.

A continuous azimuth spectrum can be simulated using a discrete number of plane waves. The total electric field in the z-direction due to N multipath waves[1] is given by

$$\tilde{E}_z(x, y) = \sum_{n=1}^{N} \sqrt{p(\theta_n)} \exp(j[2\pi U_n - \frac{2\pi}{\lambda}\hat{\mathrm{k}}_n \cdot (x\hat{\mathrm{x}} + y\hat{\mathrm{y}})]) \tag{1}$$

where θ_n is the angle-of-arrival for the nth plane wave such that:

$$\hat{\mathrm{k}}_n = -\cos\theta_n \hat{\mathrm{x}} - \sin\theta_n \hat{\mathrm{y}}$$

The term U_n is a random variable that is uniformly distributed between 0 and 1[2]. This term models the random, unknown phases on each multipath wave.

[1] To get a really nice simulation, you should probably set N to at least 100.

[2] This type of random variable is easy to generate in mathematical packages. The Matlab command `rand` is one example

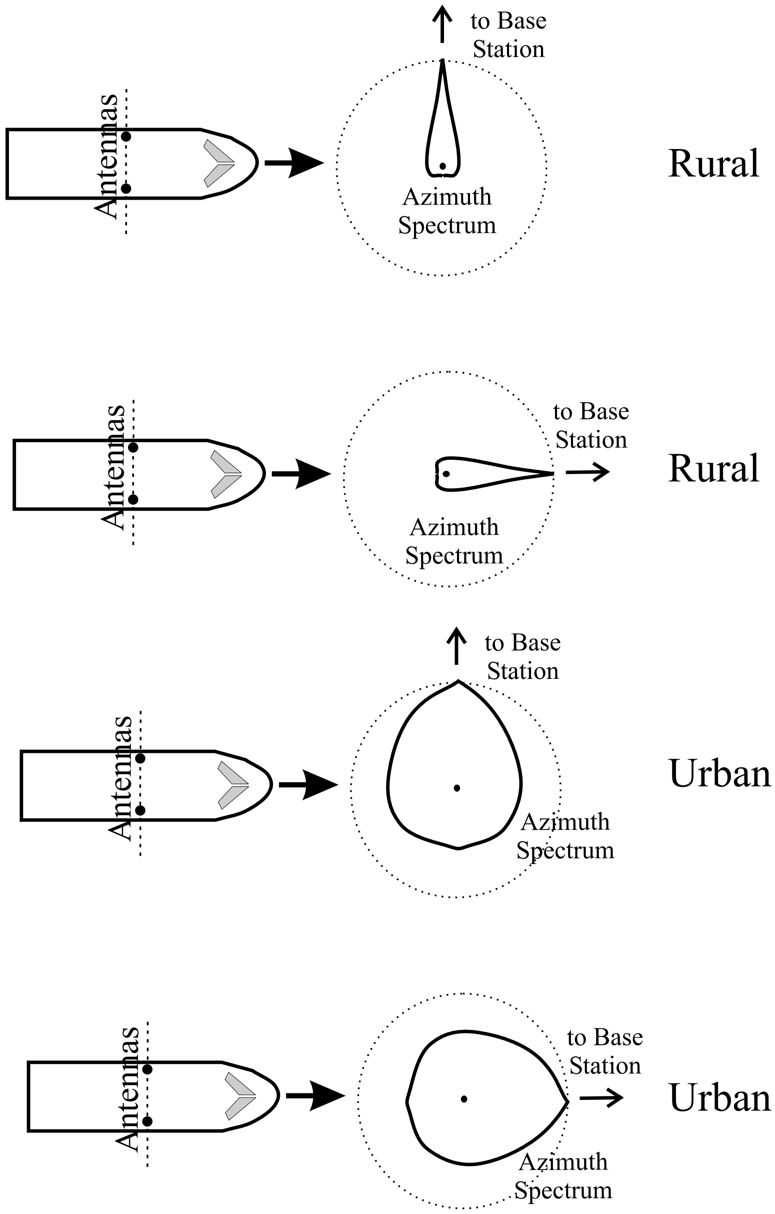

Figure 2: The four cases of multipath wave interference that you must analyze.

Note that the total *envelope*, $R(\vec{r})$, of the received signal is given by

$$R(\vec{r}) = |\tilde{E}_z(\vec{r})|$$

and that *power* is proportional to the squared envelope.

4 Deliverables

You must prepare a technical report detailing the results of your study. The report should be in html-format with all files submitted in-class on a CD or through e-mail[3]. The report must include:

- Sample plots of the threshold selection diversity output superimposed upon the individual received powers of the two monopole antennas. One set of plots for each permutation of channel model and orientation. Each plot should show 100ms of data.
- Analytical calculations of level crossing rates and fade durations for top-speed travel by the bullet train.
- Recommendations for how fast the selection diversity algorithm must measure power.

Your report will be graded on the following:

- Completeness
- **Technical Writing**
- Technical Correctness
- Professional Content
- Research (cite all references)
- Conciseness

Your project reports will be graded harshly, but I will offer +5% bonus points to superlative reports in the following categories:

- Best Technical Writing
- Best Demonstration of Technical Understanding
- Most Professional Content
- Most Artistic
- Creative Use of Web Presentation

Late projects will not be accepted. I may enshrine (with the author's permission, of course) one or two exceptional reports on the web for all time.

[3]e-mail submissions must be ZIPped and are only recommended for files less than 1 MB