Massive Notes 1.13

Key Points : Acquiring Channel State Information; TDD vs. FDD; Channel Parameterizations

1. Acquiring Channel State Information

1. The channel response, $\mathbf{h}_{jk}^{j}$, are utilized by BS j to process the UL and DL signals. In practice, $\mathbf{h}_{jk}^{j}$ are not that easy to be known. More precisely, the channels responses are typically **only constant for a few milliseconds** and **over a bandwidth of a few hundred kHz**.

2. The current set of channels response realizations is called the **channel state** and the knowledge that the BSs have of them is referred to as the **Channel State Information (CSI)**.

3. **Full statistical CSI** regarding the distributions of random variables is assumed to be available anywhere in the network. However, **instantaneous CSI regarding the current channel realizations** need to be acquired at the same pace as the channels change.

4. The main method for CSI acquisition is **Pilot Signaling**, where a predefined pilot signal is transmitted from an antenna. As illustrated in figure 1, any other antenna in the network can **simultaneously receive** the transmission and compare it with the known pilot signal to estimate the channel from the transmitting antenna.

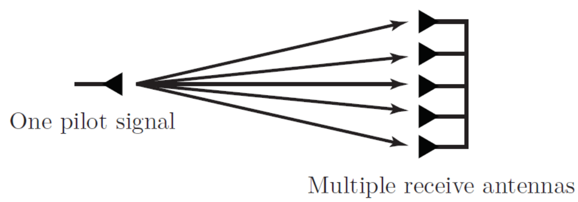

Figure 1. When an antenna is transmitting a pilot signal, any number of receive antennas can simultaneously receive the pilot signal and use it to estimate their respective channels to the transmitter.

5. If we need to estimate the channel response from two transmitting antennas, two **orthogonal** pilot signals are generally required to **separate** the signals from the two antennas.

6. We want to **minimize the overhead** caused by pilot signaling. In SDMA, the overheads for channel acquisition in UL and DL are very different. In UL, there are K single-antenna UEs per cell and thus K pilot signals are required to estimate the channels in the UL.

7. In DL, there are M antennas at the BS and the M pilot signals are required to estimate the channels. Since we often define an antenna-UE ratio $M/K \geq 4$ is the preferable operating regime in SDMA, the overhead from sending DL pilots is typically **much larger** than that from UL pilots.

2. TDD vs. FDD

8. The UL and DL can be separated in either **time (TDD)** or **frequency (FDD)**; see figure 2.

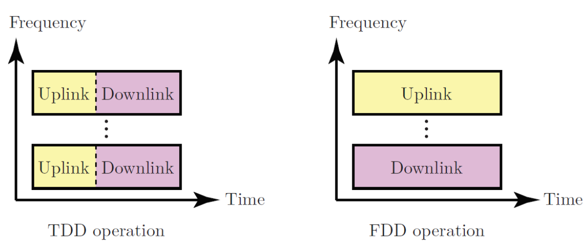

Figure 2. Each solid box represents a time-frequency block where the channel responses are constant and need to be estimated.

9. If the UL and DL are separated in time, using a time-division-duplex (TDD) protocol, then the channel responses are **Reciprocal** (this means that the channel response is the same in both directions and can be estimated at the BS using only K UL pilots. In fact, the physical propagation channels are reciprocal, but the transceiver chains are not full reciprocal. We now suppose there are all reciprocal.)

10. The BS in cell j needs to know the complete channel response $\mathbf{h}_{jk}^{j}$ to its kth UE, while the corresponding UE only needs to know the **effective scalar channel** $g_{jk} = (\mathbf{h}_{jk}^{j})^{\mathrm{H}}\mathbf{w}_{jk}$ that is obtained after precoding.

11. Since the value of g_{jk} is constant as long as the channels are constant, it can be estimated **blindly** from the DL payload data signals, **irrespective of the channel distribution**. For example, the BS can use its CSI to **adjust the phase of $\mathbf{w}_{jk}$** so that the phase of g_{jk} becomes (nearly) **deterministic**, thereby mainly **the magnitude** $|g_{jk}|$ needs to be estimated.

12. If the UL and DL are instead separated in frequency, using a frequency-division duplex (FDD) protocol, then **the UL and DL channels are always different and we cannot rely on reciprocity**. Hence, we need to send pilots in **both UL and DL**.

13. In addition, the estimates of the DL channel responses **need to be fed back to the BS**, to enable DL precoding computation. The feedback overhead is **approximately the same as that of sending** $\max(M, K)$ **additional UL pilot signals**.

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15. Since the required channel acquisition overhead is K in TDD and $\frac{M+K+\max(M,K)}{2}$ in FDD, SDMA should use TDD to obtain the reciprocity between UL and DL. When $M \approx K$, the FDD overhead is around 50% larger. When $M \gg K$, it is much larger and is the preferable operating regime for SDMA.

16. Note that it is the channel acquisition needed for DL precoding that **differs** between TDD and FDD, while the UL works essentially **the same**.

3. Channel Parameterizations

17. In some propagation scenarios, the set of possible M-dimensional channel responses can be **parameterized** using much less than M parameters. Consider in the LoS case the channel responses is

$$\mathbf{h}_{jk}^{0} = \sqrt{\beta_j^0}\left[1, e^{2\pi \mathrm{j} d_{\mathrm{H}} \sin(\varphi_{jk}^0)}, \ldots, e^{2\pi \mathrm{j} d_{\mathrm{H}} (M-1) \sin(\varphi_{jk}^0)}\right]^{\mathrm{T}} \tag{1}$$

and it mainly depends on the angle φ_{jk}^0 between the BS and the UE. Instead of transmitting M DL pilots, we can in the LoS case select a set of equally spaced angles between 0 and π and send precoded DL pilot signals only in these directions. If the number of such angles is much smaller than M, then this method can enable FDD operation with reduced pilot overhead and can still give good estimation quality.

17. There are several drawbacks with building a system that strictly relies on channel parameterizations. 1) One is that even if some UE channels can be parameterized efficiently, there might not exist a single low-dimensional parameterization model that applies to all channels. 2) Another drawback is that practical channels are not bound to follow a particular channel model.

18. TDD operation is generally preferred because we want to design a network that can operate efficiently in any kind of propagation environment, **with any array geometry**, and **without inter-antenna phase-calibration**. However, TDD also has its own specific challenges: 1) the SNR is slightly lower than in FDD since **the power amplifier is only turned on part of the time**; 2) the transmitter and receiver hardware of an antenna must be **calibrated** to maintain channel reciprocity. (END)