

# Massive Notes 1.1

**Key Words : Cellular Network; Area Throughput**

## 1. Cellular Network

1. The **Cellular Network** consists of a set of base stations (**BSs**) and a set of user equipments (**UEs**).
2. The downlink (**DL**) refers to signals sent from the **BSs** to their respective **UEs**.
3. The uplink (**UL**) refers to transmissions from the **UEs** to their respective **BSs**.

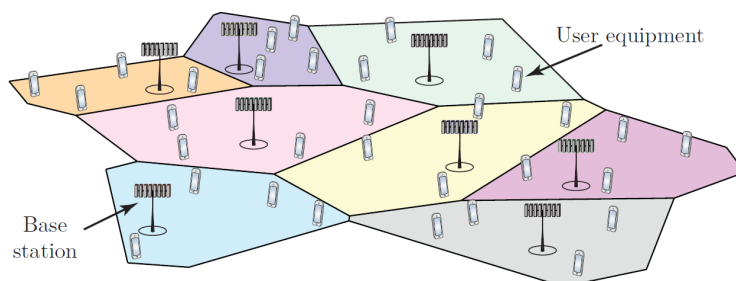


Figure 1: A Basic Cellular Network

4. There are two main tiers that form a **Heterogeneous Network**, namely, **Coverage Tier** and **Hotspot Tier**

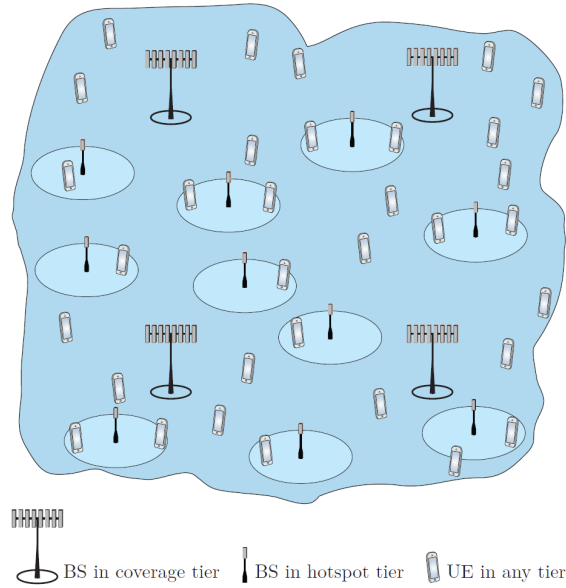


Figure 2: Coverage and Hotspot Tiers

5. It is important to note that in practice, coverage and hotspot tiers use **different spectrum** to avoid **inter-tier coordination**, say, 2.1GHz in coverage tier and 5GHz in hotspot tier.
6. The **Area Throughput** is a good performance metric cellular networks, and it can be modeled as follows

$$\text{Area Throughput}[\text{bit/s/km}^2] = \mathbf{B}[\text{Hz}] \cdot \mathbf{D}[\text{cells/km}^2] \cdot \mathbf{SE}[\text{bit/s/Hz/cell}] \quad (1)$$

where  $\mathbf{B}$  is the bandwidth,  $\mathbf{D}$  is the average cell density, and  $\mathbf{SE}$  is the amount of information that can be transferred per second over one Hz of bandwidth. In (1), the  $\mathbf{SE}$  refers to  $\mathbf{SE}$  per cell.

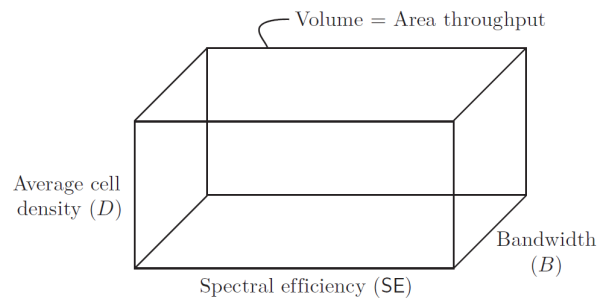


Figure 3: The area throughput can be computed according to (1) as the volume of a rectangular box where the bandwidth, average cell density, and SE are the length of each side.

7. In some cases, we can consider these three components as independent as a first-order approximation to gain basic insights. Therefore, there are three main ways to improve the area throughput of cellular networks, namely

**Allocate more bandwidth**

**Densify the network by deploying more BSs**

**Improve the SE per cell**

## 2. How to Improve Area Throughput?

8. The first way to increase area throughput is **increase the bandwidth  $B$** , but it is physically impractical since 1) the frequency spectrum is a global resource that is shared among many services, and 2) it entails using much higher frequency bands than in the past, which physically limits the range and service reliability. It is noteworthy that **mmWave** bands (30 - 300GHz) can be used in the hotspot tier rather than in the coverage tier since the mmWave signal is easily blocked by objects and human bodies thus it cannot offer robust coverage.

9. The second method is **densify the cellular network  $D$** . But the problem is, normally, the BSs are deployed at elevated locations to avoid being shadowed by large objects and buildings. Therefore, we don't have that much locations to deploy more BSs in the coverage tier. Although 1) deploying additional hotspots, 2) reusing the spectrum from the coverage tier and 3) using mmWave are more viable solutions, these techniques are associated with high deployment costs, inter-cell interference issues, and are not suitable for mobile UEs.

10. **Improving SE** is a realistic way to boost area throughput. It is particularly important for BSs in the coverage tier since using mmWave bands or network densification are all useless in this tier. So how to increase SE?

11. Increasing the SE corresponds to using the BSs and bandwidth that are already in place more efficiently by virtue of 1) new modulation and 2) multiplexing techniques. It is worth noting that we mainly focus on the coverage tier since 1) it provide ubiquitous coverage, 2) support mobility, and 3) simultaneously deliver a uniform service quality within each cell. However, we can use densification and mmWave directly on the hotspot tier. So we don't concentrate on hotspot tier.