

Wireless Network Pricing

Chapter 2: Wireless Communications Basics

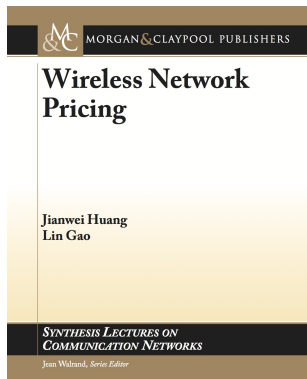
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The Book



- E-Book **freely** downloadable from NCEL website: <http://ncel.ie.cuhk.edu.hk/content/wireless-network-pricing>
- Physical book available for purchase from Morgan & Claypool (<http://goo.gl/JFGLai>) and Amazon (<http://goo.gl/JQKaEq>)

Chapter 2: Wireless Communications Basics

Focus of This Chapter

- **Key Focus:** Provide a brief introduction to **wireless communications and networking technologies** to help readers understand the applications in this book.
- Discussions in this chapter are based on the materials in
 - ▶ “**Wireless communications: principles and practice**” by T. S. Rappaport et al. (1996)
 - ▶ “**Wireless communications**” by A. Goldsmith (2005)
 - ▶ “**Fundamentals of wireless communication**” by D. Tse and P. Viswanath (2005)
 - ▶ “**Wireless Communications & Networking**” by V. Garg (2010.)

Section 2.1: Radio Propagation

Radio Propagation

- **Radio propagation** refers to the transmission of **radio waves** from one point to another.
- Radio propagation behaviors:
 - ▶ **Line-of-sight (LOS) Propagation**: Direct propagation of radio waves between two points that are visible to each other;
 - ▶ **Reflection**: Physical effect arise when a radio wave hits the interface between two dissimilar media, so that all or part of the wave returns into the medium from which it originated.
 - ▶ **Diffraction**: Propagation of radio waves that bending around corners or sharp edges.
 - ▶ **Scattering**: Physical effect of radio waves when hitting irregular objects (e.g., walls with rough surfaces).
 - ▶ Others: **refraction, absorption, polarization**, etc.

Radio Propagation Characterization

- It is **impossible** to perfectly characterize the propagation of a radio wave, due to the rapid fluctuation of radio propagation.
- In general, radio propagation can be **roughly** characterized in the large-scale and small-scale.
 - ▶ **Large-scale propagation**: Characterize the **mean attenuation** of radio waves over large travel distances;
 - ▶ **Small-scale propagation**: Characterize the **fast fluctuations** of radio waves over very short travel distances (e.g., a few wavelengths) or short time durations (e.g., a few milliseconds).
- **Key features** of radio propagation
 - ▶ Distance-based Path Loss (Large-scale)
 - ▶ Slow Log-normal Shadowing (Large-scale)
 - ▶ Fast Multi-path Fading (Small-scale)
- **Channel modeling** → characterize the features of radio propagation

Channel Modeling

- When radio wave propagates,
 - ▶ → its power density diminishes gradually;
 - ▶ → it is polluted by the undesired noise signal – **interference**.
- Given the **transmitted signal** x , after propagation through a **channel** h , we have the following **received signal** y :

$$y = h \cdot x + \epsilon$$

- ▶ ϵ is the noise, usually formulated as a random variable following the normal distribution (called **Gaussian Noise**).
- The purpose of **channel modeling** is to accurately characterize the features of channel h , i.e., **path loss, shadowing, multi-path**.

Channel Modeling – Path Loss

- **Path Loss** is a fundamental characteristic of radio wave propagation in order to predict the average received power (**Large-scale model**)
- Path loss follows the **Friis transmission formula**:

$$|h| = \frac{P_r}{P_t} = A \cdot \frac{\lambda^2}{d^2}$$

- ▶ λ is the wavelength, d is the transmission distance,
 - ▶ A is a constant (independent of propagation) related to antenna gains, antenna losses, filter losses, etc.
- Path loss (in dB) purely based on **distance**:

$$\bar{P}L = -10 \log(|h|) = 20 \log(d) - 20 \log(\lambda) - 10 \log(A)$$

- ▶ Low frequency (large wavelength λ) \rightarrow Low propagation loss \rightarrow Long range transmission;

Channel Modeling – Shadowing

- **Shadowing** characterizes the **deviation** of the actual received power about the average received power (**Large-scale model**)
 - ▶ It usually occurs when a large obstruction (such as a hill or large building) obscures the main propagation path between the transmitter and the receiver.
 - ▶ In general, such a power deviation due to the shadowing effect can be formulated as a **zero-mean normally (Gaussian) distributed** random variable X_σ (in dB) with a standard deviation σ .
- Path loss (in dB) with **shadowing effect**:

$$PL = \bar{PL} + X_\sigma = -10 \log(|h|) = 20 \log(d) - 20 \log(\lambda) - 10 \log(A) + X_\sigma$$

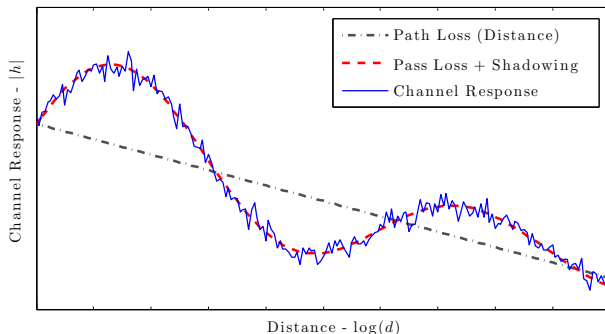
- ▶ The same distance d may lead to different pass losses due to the shadowing effect.

Channel Modeling – Multi-Path

- **Multi-path** is the propagation phenomenon that results in radio waves reaching the receiver by multiple paths (**Small-scale model**)
 - ▶ Different propagation paths may have **different amplitudes and phases**;
 - ★ Combination of signals in these paths may result in increased or decreased received power at the receiver.
 - ▶ Even a very slight change in the propagation path may result in a **significant difference in phases** of the receiving signals.
 - ★ Thus, the multi-path propagation will lead to the **fast fluctuation** of receiving radio wave.
 - ▶ Different propagation paths may have **different propagation time**;
 - ★ Thus, the multi-path propagation will introduce a delay spread into the receiving radio wave (called **inter-symbol interference, ISI**).

Channel Modeling

- Illustration of **Pass Loss**, **Shadowing**, and **Multi-Path**
 - ▶ **Gray dot-dashed**: distance-based path loss (without shadowing);
 - ▶ **Red dashed**: path loss with log-normal shadowing;
 - ▶ **Blue solid**: real channel response with the path loss, shadowing, and multi-path propagation.



Section 2.2: Wireless Multiple Access Technologies

Multiple Access Technology

- **Multiple access technology** allows multiple users to share the limited wireless communication resources.
- Multiple access technologies are usually based on the **multiplexing**:
 - ▶ Frequency Division Multiple Access (FDMA)
 - ▶ Orthogonal Frequency Division Multiple access (OFDMA)
 - ▶ Time Division Multiple Access (TDMA)
 - ▶ Code Division Multiple Access (CDMA)
 - ▶ Random Access Technologies
 - ★ E.g., Carrier Sense Multiple Access (CSMA)

FDMA and OFDMA

- The frequency division multiple access (FDMA) is based on the **frequency division multiplex** technology, which provides **separated** frequency bands to different mobile users.
 - ▶ That is, it allows several users to transmit at the same time by **using separated frequency bands**.
 - ▶ Typical FDMA systems include the second-generation (2G) cellular communication systems such as Global System for Mobile Communications (GSM), where each phone call is assigned to a specific uplink channel and a specific downlink channel.

FDMA and OFDMA

- The orthogonal frequency division multiple access (OFDMA) is an advanced form of FDMA, where different frequency bands are **not fully separated** but **partially overlapped**.
 - ▶ The spectrum efficiency can be greatly improved by allowing the **partially overlapping of frequency bands**;
 - ▶ Although different frequency bands are partially overlapped, they are **logically orthogonal**.
 - ▶ OFDMA has been used in the fourth-generation (4G) cellular communication systems and wireless local area networks (WLAN) based on the latest versions of 802.11 standards.

TDMA

- The time division multiple access (TDMA) channel access scheme is based on the **time division multiplex** technology, which provides different time slots to different mobile users in a cyclically repetitive frame structure.
 - ▶ That is, the whole time period is divided into multiple time slots, each for a particular mobile user.
 - ▶ TDMA has been used in the the second-generation (2G) cellular communication systems such as GSM. More precisely, GSM cellular systems are based on the combination of TDMA and FDMA.

CDMA

- The code division multiple access (CDMA) scheme is based on the **spread spectrum technology**, which allows several mobile users to send information simultaneously over a single frequency channel using different **spreading codes**.
 - ▶ That is, each information bit (of a mobile user) is spread to a long code sequence of several pulses (called **chips**). Such a code sequence is usually referred to as the **spreading code**.
 - ▶ The separation of the signals of multiple users is made by **correlating** the received signal with the locally generated spreading code of the desired user.
 - ▶ CDMA has been used in the third-generation (3G) cellular communication systems.

Random Access Scheme

- In the previous channel access schemes, each mobile user accesses the transmission medium under the **full control of a controller**.
 - ▶ For example, in CDMA, each user spreads its data by using the spread code assigned by the controller; in TDMA or FDMA, each user occupies the time slot or frequency band assigned by the controller.
- In the **random access scheme**, however, each user has the right to access the medium **without being controlled by any controller**.
 - ▶ If more than one user tries to access the same medium at the same time, there is an access conflict (called a **collision**), and the signals will be either destroyed or polluted.
 - ▶ To avoid collision → **Carrier Sense Multiple Access (CSMA)**
 - ★ Follow the principle “sense before transmit” or “listen before talk”. That is, mobile users check the existence of other users’ signal before transmitting on a shared transmission medium.

Section 2.3: Wireless Networks

Wireless Network Classifications

- Classification based on **transmission range or coverage area**:
 - ▶ Wireless personal area network (e.g., IEEE 802.15 Bluetooth)
 - ▶ Wireless local area network (e.g., IEEE 802.11WiFi)
 - ▶ Wireless metropolitan area network (e.g., IEEE 802.16WiMAX)
 - ▶ Wireless wide area network (e.g., IEEE 802.20 MobileFi, and 3GPP)
 - ▶ Wireless regional area network (e.g., IEEE 802.22)
- Classification based on **access and networking technologies**:
 - ▶ Wireless cellular network
 - ▶ Wireless ad-hoc network
 - ▶ Wireless sensor network
 - ▶ Wireless mesh network
 - ▶ Cognitive radio network

Wireless Cellular Network

- In a wireless cellular network, a **wide area** is divided into regular shaped zones called **cells**, and each cell is associated with a fixed transceiver called **base station** located in the center of the cell.
 - ▶ Mobile users communicate with each other via connecting to base stations.
 - ▶ Each cell serves those mobile cellular users within its coverage area via the corresponding base station.
 - ▶ Since mobile cellular users can move between cells, thus **handoff and mobility management** are very important in a cellular network.
 - ▶ To avoid the interference from signals from other cells, the adjacent neighboring cells are usually operated on different frequency bands, whereas the far apart cells can operate on the same frequency band (called **frequency reuse**).

Wireless LAN Network

- A wireless local area network (WLAN), usually based on IEEE 802.11 standard (WiFi), is used to provide high-speed radio service in a local **small area** (e.g., $\leq 200\text{m}$).
- The most common architecture of WLAN is based on an infrastructure-based controller called **access point**.
 - ▶ Mobile users communicate with each other or access the wider Internet via connecting to access points.
- Another common architecture of WLAN is the so-called **ad-hoc mode**, where mobile users transmit data to other user directly.

Wireless Ad-hoc Network

- A wireless ad-hoc network is a type of **decentralized** wireless network, usually based on the IEEE 802.11 standard.
- It does not rely on the pre-existing infrastructures such as base stations and access points, but enables the **direct connections and communications** among different mobile users.
 - ▶ Due to the limited transmission range, a source user may need to communicate to a destination user in a **multi-hop** fashion.
 - ▶ Due to the fast changing of network topology, mobile devices need to **self-organize** to establish network connectivity.

Wireless Sensor Network

- A wireless sensor network (WSN) consists of a set of spatially distributed **autonomous sensors**.
 - ▶ Sensors are usually designed to **monitor or detect** physical or environmental conditions (e.g., temperature, sound, and pressure);
 - ▶ Sensors may also need to cooperatively **deliver** their measured data to a sink node.
 - ▶ An important feature of wireless sensor networks is the **energy constraint**, due to the limited capacity of energy storage (e.g., battery) on the sensors.

Wireless Mesh Network

- A wireless mesh network (WMN) is a communications network made up of radio nodes organized in a **mesh topology**.
- It often consists of two kinds of different nodes: **mesh clients** and **mesh routers**.
 - ▶ **Mesh clients** are often laptops, cell phones and other wireless devices, who transmit/receive data to/from other clients or the wider Internet;
 - ▶ **Mesh routers** are often stationary nodes such as base stations or access points, who forward a mesh client's traffic to/from other clients or the gateways which connect to the Internet.

Cognitive Radio Network

- Cognitive radio network is a novel network architecture based on advanced wireless technologies such as **cognitive radio** and **dynamic spectrum access**.
 - ▶ **Cognitive radio** is an adaptive, intelligent radio technology that can intelligently detect available frequency bands in a wide frequency range.
 - ▶ **Dynamic spectrum access** allows unlicensed devices to access to the frequency bands (licensed to other licensees) in an **opportunistic manner**, whenever such a secondary access does not generate harmful interference to the licensees.
- A real example: **TV white space network**
 - ▶ Unlicensed devices detect and access idle (licensed) TV frequency bands via querying a certified **geo-location database** .

Section 2.4: Radio Resource Management

Radio Resource Management

- Radio resource management (RRM) is a fundamental issue of wireless network management, and provides the system level control of **interference** and **efficiency**.
- RRM usually involves **strategies and algorithms** for controlling
 - ▶ transmit power
 - ▶ channel allocation
 - ▶ data rates
 - ▶ handover criteria
 - ▶ modulation scheme
 - ▶ error coding scheme
 - ▶ etc.

Power Control

- Power control is the **intelligent selection of transmit power** so as to achieve a good system performance (e.g., low mutual interference, high network capacity, and wide geographic coverage area).
 - ▶ Power control is very important for **reducing the mutual interference among users** in a CDMA system, where multiple users send information simultaneously over a single frequency channel (hence interfere with each other).
 - ▶ Power control is also important for **reducing the mutual interference among base stations** in a FDMA-based cellular system, where non-adjacent base stations may use the same frequency band due to frequency reuse.

Channel Allocation

- Channel allocation refers to the **intelligent allocation of frequency bands or channels** to base stations, access points, and mobile devices, so as to achieve high spectrum efficiency and low co-channel interference.
 - ▶ **Fixed channel allocation (FCA)** in cellular networks: Each cell is given a pre-determined set of channels.
 - ▶ **Dynamic channel allocation (DCA)** in cellular networks: Cells request channels dynamically based on their real-time traffic loads.
 - ▶ **Subcarrier allocation** in OFDMA systems: Assign different subcarriers to different users to achieve high efficiency (**multiuser diversity**).

Admission Control





- Admission control is important for **reducing transmission collisions** in wireless communication systems with limited resources but many potential users.
- Admission control can also be used to **differentiate QoS requirements** of different mobile users.
 - ▶ For example, **voice traffic** (with a strict QoS requirement) may be admitted with a higher priority than **data traffic** (with a loose QoS requirement) when the network is congested.

Section 2.5: Chapter Summary

Key Concepts

- Radio Propagation
- Wireless Multiple Access Technologies
- Wireless Networks
- Radio Resource Management

References

-  T. S. Rappaport et al., *Wireless communications: principles and practice*. Prentice Hall, 1996, vol. 2.
-  A. Goldsmith, *Wireless communications*. Cambridge university press, 2005.
-  D. Tse and P. Viswanath, *Fundamentals of wireless communication*. Cambridge university press, 2005.
-  V. Garg, *Wireless Communications & Networking*. Morgan Kaufmann, 2010.

Extended Reading

<http://ncel.ie.cuhk.edu.hk/content/wireless-network-pricing>