Wireless Communications Systems

ENEL 529

(Fall 2014)

Instructor: Dr. A.O. Fapojuwo
Office: ICT 310
Phone: 403 - 220 - 8524
E-Mail: fapojuwo@ucalgary.ca

Lecture 1 Objectives

1) Introduction
   - Course Objectives
   - Prerequisites
   - Course Material
   - Course Outline
   - Roadmap

2) Topic 1: Overview of Terrestrial Wireless Communications Systems
   - What is a Wireless Communications System?
   - Evolution of Wireless Communications System
   - Classification & Examples of Wireless Communications Systems
   - Wireless Networking Challenges

Course Objectives

The objectives of *Wireless Communications Systems'* Course are to:

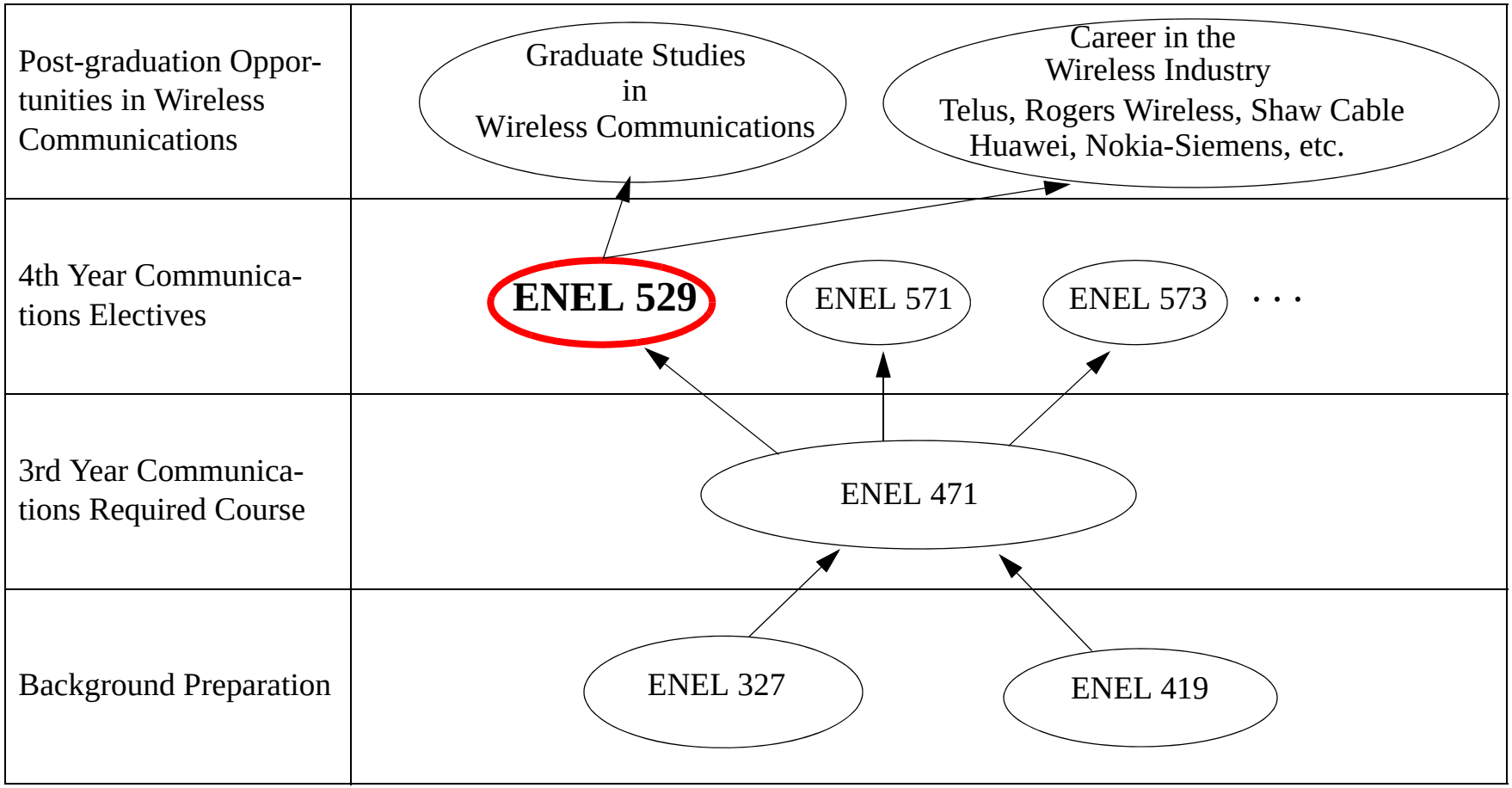
1) Provide students with

- fundamental concepts, theory and techniques used in the design, analysis and engineering of wireless communications systems

2) Enable students to

- conduct wireless system design studies through performance analysis.

Where does ENEL 529 fit in?



Prerequisites

1. Courses:

- Introduction to Communications Systems & Networks (ENEL 471)
- Probability & Random Variables (ENEL 419)

2. Specific Probability Topics for Review:

1. Probabilities
2. Distributions and Expectations of Random Variables
3. Joint Distributions of Random Variables
4. Conditional Expectations
5. Stochastic Processes - discrete & continuous time

Useful References:

1. Introduction to Probability Models by S.M. Ross
2. Introduction to Stochastic Processes by R.M. Goodman

3. Proficiency in MATLAB

Course Material

1. Required Text:

Introduction to Wireless Systems by P. M. Shankar, John Wiley & Sons.

2. Additional Reference:

- Wireless Communications - Principles & Practice by T. S. Rappaport, Prentice Hall.

3. ENEL 529 Lecture Notes by Dr. A.O. Fapojuwo

- Softcopy of Lecture Notes can be downloaded from ENEL529 D2L site, under *"Course Documents --> Lecture Notes"* folder
- Bring hardcopy to Class

Important Folders on ENEL 529 D2L Site

Course Outline ← Stores ENEL 529 Approved Course Outline

Course Documents ← Stores all the documents associated with ENEL 529, as listed below in separate folders

- Lecture Notes
- Labs
- Tutorials
- Assignments
- Quizzes
- Midterm Exam
- Final Exam

Course Outline

1. *Overview of Terrestrial Wireless Communications Systems* [Chapters 1 & 6 of Text]

2. *Propagation Characteristics of Wireless Channels* [Chapter 2]

3. *Modulation and Demodulation Techniques for Wireless Communications* [Chapter 3]

4. *Fading Mitigation Techniques in Wireless Systems* [Chapter 5]

5. *Cellular System Design and Performance* [Chapter 4]

6. *Multiple Access Techniques for Wireless Communications* [Chapter 6]

Roadmap

Week & Dates		Topics / Activities
1	Sep 8, 10 & 12	Overview of Terrestrial Wireless Communications Systems
2	Sep 15, 17 & 19	Propagation Characteristics of Wireless Channels
3	Sep 22, 24 & 26	Propagation Characteristics of Wireless Channels
4	Sep 29, Oct 1 & 3	Propagation Characteristics of Wireless Channels
5	Oct 6, 8 & 10	Prop. Characteristics of Channels & Modems for Wireless Communications
6	Oct 15 & 17	Modems for Wireless Communications
7	Oct 20, 22 & 24	Modems for Wireless Communications / Midterm Exam on Oct 24 (8:00 - 8:50 am)
8	Oct 27, 29 & 31	Fading Mitigation Techniques in Wireless Systems
9	Nov 3, 5 & 7	Fading Mitigation Techniques in Wireless Systems
10	Nov 12 & 14	Cellular System Design and Performance
11	Nov 17, 19 & 21	Cellular System Design and Performance
12	Nov 24, 26 & 28	Multiple Access Techniques for Wireless Communications
13	Dec 1, 3 & 5	Multiple Access Techniques for Wireless Communications

Time:

Lectures: 8:00 am - 8:50 am Mondays, Wednesdays & Fridays; *Labs:* 3:00 - 4:50 am Mondays;
Tutorials: 2:00 - 2:50 pm Mondays (*Note:* Tutorials begin on September 15)

Venues: *Lectures:* Room CHE 110; *Labs:* ICT 320; *Tutorials:* ST 059

Evaluation

STUDENTS:

Final Grade will be based on:

i) Assignments:	10% (3 assignments are planned)
ii) Labs:	10% (4 Labs are planned: Oct 6, 20 & 27, and Nov 3)
iii) Quizzes:	10% (2 quizzes are planned, closed book)
iv) Mid-term Exam:	20% (closed book, scheduled for Oct 24, 8:00 am - 8:50 am)
v) Final Exam:	50% (closed book, date to be set by the Registrar's office)

Note: It is not necessary to earn a passing grade on the Final Exam to pass ENEL 529 as a whole

INSTRUCTOR:

- Students to complete a Course Evaluation form at the end of Course
- Evaluation Criteria: i) Course Content, ii) Course delivery, iii) Suggestions for improvement

TA Assigned to ENEL 529

TA Roles:

- Grading of Assignments, Quizzes & Lab Reports
- Supervision of Labs

Name & Contact Information of TA:

Name	Office	Phone #	Email Address
Jonathan Kwan	ENA 119	403 - 210 - 9810	jkwan@ucalgary.ca

Instructor and TA Office Hours

Name	Office Hours
Dr. A.O. Fapojuwo	Wednesdays: 4:00 - 5:00 pm, or by appointment
Jonathan Kwan	Tuesdays: 1:00 - 2:00 pm, or by appointment

Topic 1: Overview of Terrestrial Wireless Communications Systems

Content:

- What is a Wireless Communications System?
- Evolution of Wireless Communications Systems
- Classification of Wireless Communications Systems
- Examples of Wireless Communications Systems
    - Wireless Wide Area Networks (WWANs)
    - Wireless Local Area Networks (WLANs)
- Wireless Networking Challenges

Topic 1 Learning Outcomes

At the end of this Topic, you will be able to:

- Define the basic features and characteristics of wireless communications systems
- Distinguish among the different types of wireless systems

What is a Wireless Communications System?

- an inter-connection of elements that provide anytime and anywhere personal communication services

"elements": infrastructure (network) elements (e.g., base station) and user devices (e.g., handset, iphone, etc.)

"anytime" implies that the system is always on (24 x 7) to provide the required services

"anywhere" implies that there is no wire (tether) connecting the user device to the infrastructure elements. That is, connection is radio based.

"personal communication services" include basic and supplementary services

Focus of ENEL 529

Communication quality and reliability problem: caused mainly by the

- hostile and fluctuating wireless (radio) propagation channel:
  - + Causes of bad channel: path loss, shadow and multipath fading (spatial- & time-varying)
  - + Effects of bad channel: low bandwidth (or data rate) and high latency

Treatment will be at the:

- physical layer level (OSI layer 1): MODulation & DEModulation (MODEM) techniques and radio channel
- system-level: radio transmitter + radio channel + radio receiver

(OSI: Open System Interconnection)

ENEL 529 addresses the Communication Quality and Reliability Problem in Wireless Systems

Why deploy Wireless Communications Systems?

- Convenience and flexibility:
  - wireless service is ubiquitous, available almost anywhere
  - wireless service can be deployed much faster than the traditional fixed service
- Cost-effective:
  - no cost of cable plant in the “last mile”
- Higher data rates obtainable with broadband wireless technology:
  - graphics, video & audio

Evolution of Wireless Communications Systems

Timeline / Criteria	1980's	1990's	2000 & beyond
System Generation	1st generation (1G) Cellular, 1G Paging systems	2nd Generation (2G) Cellular; WLANs	Evolved 2G (2.5G), 3G, 4G Cellular, WMANs, WLANs, WPANs
Focus	Radio	Handsets	End-to-End Networks
Cellular Standards	AMPS, NMT, TACS	IS95, GSM, PDC	CDMA2000, UMTS, LTE
MS size	bulky	small	very small
Modulation format	analog	digital	digital
Communication mode	full duplex	full duplex	full duplex
# of users supported	very small	large	very large
Data rate supported (Cellular)	low (< 9.6 kbps)	high (up to 14.4 kbps)	very high (up to 2 Mbps for 3G, up to 1 Gbps for 4G)
Communication quality	poor	good	very good
Services	VOICE	VOICE + data	voice + DATA + VIDEO
Subscription cost	very expensive	expensive	cheap

AMPS: Advanced Mobile Phone System
TACS: Total Access Communication System
IS95: Interim Standard 95
GSM: Global System for Mobile Communications
PDC: Personal Digital Cellular
WMANs: Wireless Metropolitan Area Networks

CDMA2000: Code Division Multiple Access 2000
UMTS: Universal Mobile Telecommunications System
WLANs: Wireless Local Area Networks
WPANs: Wireless Personal Area Networks
NMT: Nordic Mobile Telephony
LTE: Long Term Evolution

Classification of Terrestrial Wireless Communications Systems

1st Basis of Classification: Geographical extent of Service Area

Wireless Domain	Geographical Extent	Practical Implication
WWAN	- Wide area coverage (outdoors & indoors) - Cell Type: macrocell (10 - 30 km radius) microcell (500 m radius)	- High transmission power by BS and MS - Small # of BS's to cover a given service area
WMAN	- Metropolitan coverage (outdoors & indoors) - Cell Type: macrocell (1 - 3 km radius) microcell (500 m radius)	- High transmission power by BS and MS - Small # of BS's to cover a given service area
WLAN	- Local coverage (indoors & outdoors) - Cell Type: microcell (100 m radius)	- Low transmission power by BS and MS - Large # of BS's to cover a given service area
WPAN	- Personal area coverage (indoors) - Cell Type: minicell / picocell / femtocell (1 m or 10 m radius)	- Peer-to-peer communication between devices - Complicated device design due to new functionality: neighbor discovery, routing, etc.

WWAN: Wireless Wide Area Network; WMAN: Wireless Metropolitan Area Network

WLAN: Wireless Local Area Network; WPAN: Wireless Personal Area Network

Classification of Terrestrial Wireless Communications Systems

2nd Basis of Classification: Fixed vs. Mobile wireless communication system

1. Fixed wireless communication system: user devices are at fixed locations

2. Mobile wireless communication system: user devices can move about

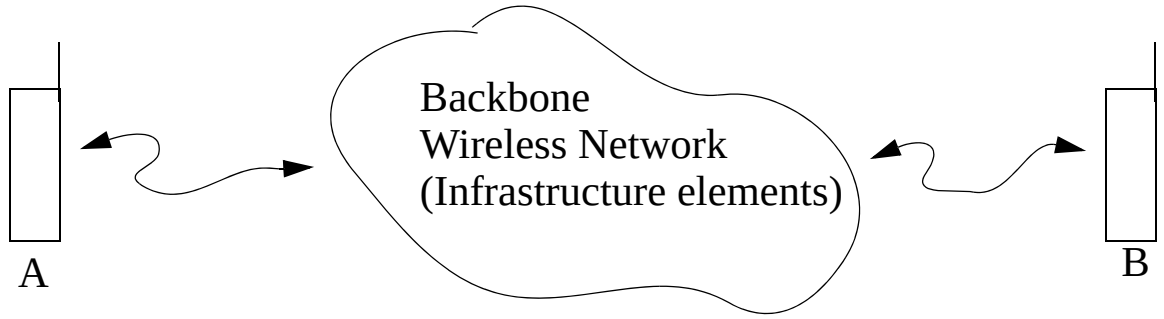
    Degrees of mobility: pedestrian, vehicular and high speed

Classification of Terrestrial Wireless Communications Systems

3rd Basis of Classification: infrastructure vs. infrastructureless

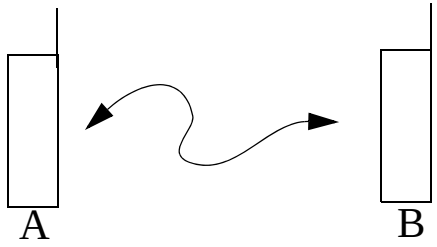
1. Infrastructure -based wireless network architecture:

   - there exists a backbone network between communicating wireless devices



2. Infrastructureless wireless network architecture:

   - peer-to-peer (direct) communication between communicating wireless devices

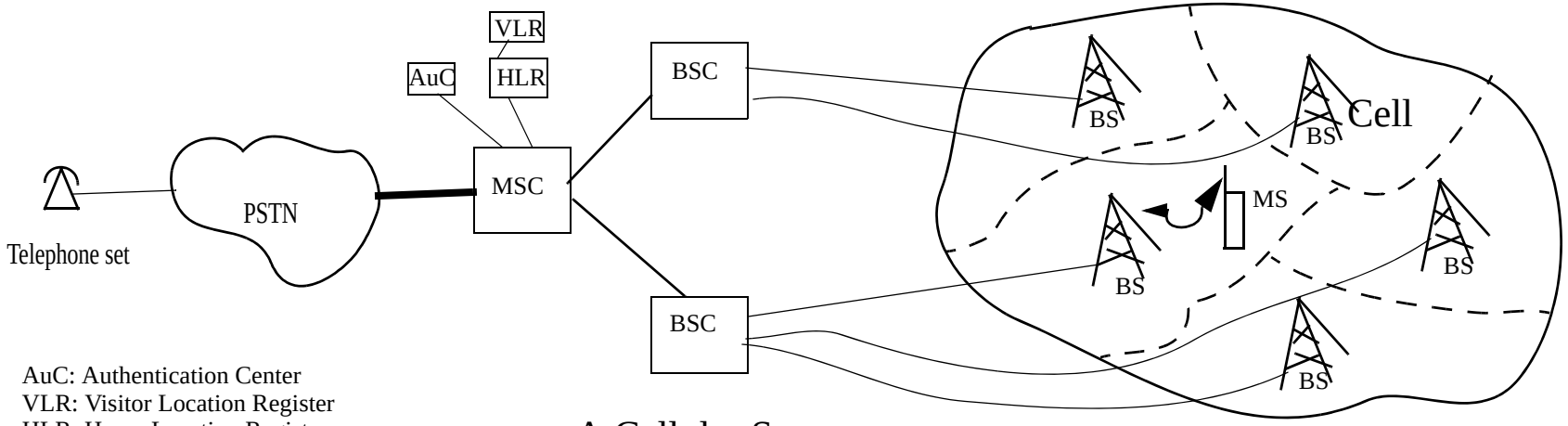


Examples of Terrestrial Wireless Communications Systems

1. Cellular Telephone System (belongs to WWAN, mobile, infrastructured class)
2. Wi-Fi (belongs to WLAN, mobile or fixed, infrastructured or infrastructureless class)

Cellular Telephone (Mobile Communications) System

- communications system for connecting a mobile station (MS) to a base station. Other network elements include the base station contoller (BSC) and the mobile switching center (MSC)
- supports voice, data and video traffic (video traffic support in 3G & 4G))
- full duplex system: simultaneous two-way communications
- service (coverage) area of a cellular telephone system is over a wide area partitioned into cells
- wide-area coverage imposes high infrastructure (e.g., large # of base stations) requirements
- Base station requires high Tx powers (on the order of tens of watts)



A Cellular System

Elements of a Cellular System

1. Mobile Station (MS): wireless device carried by the subscriber

2. Propagation Channel: radio (wireless) channel

3. Base Station (BS): a fixed station that communicates with mobile stations within its cell

4. Base Station Controller (BSC): a fixed element that controls a number of base stations

5. Mobile Switching Center (MSC): performs routing (switching) of wireless calls

6. Visitor Location Register (VLR): maintains information about subscribers currently present in the VLR area (or MSC area)

7. Home Location Register (HLR): stores information about each subscriber that belongs to the home network

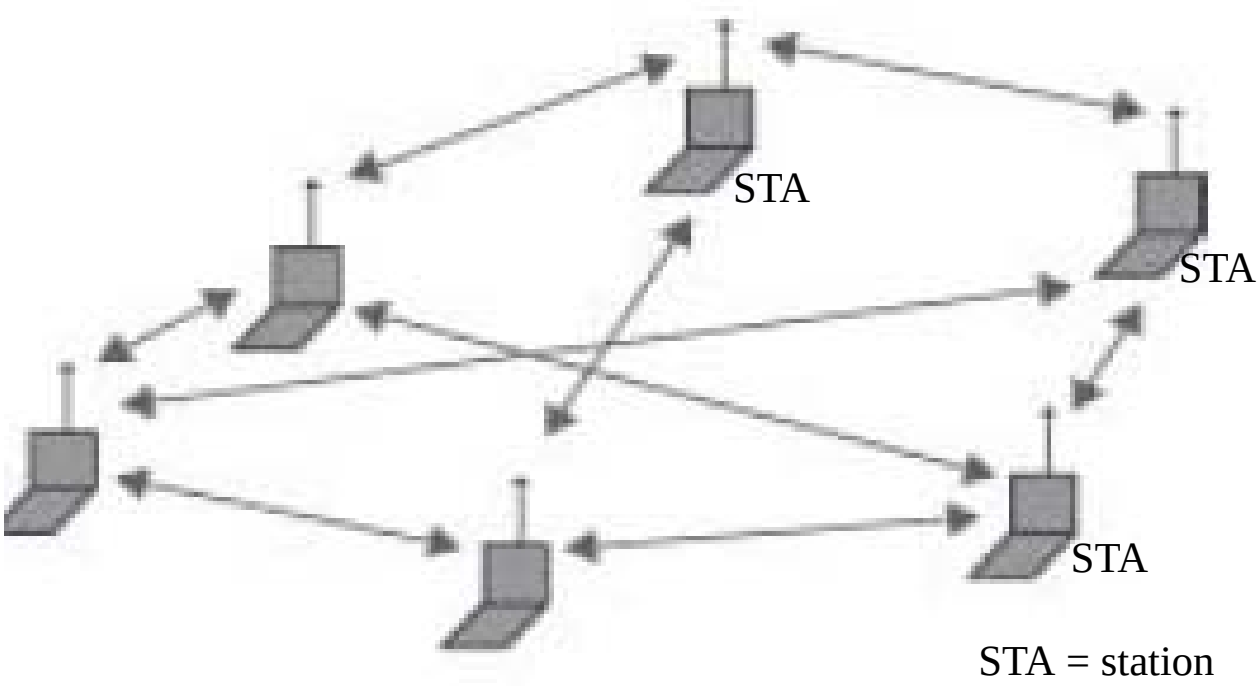
8. Authentication Center (AuC): performs authentication functionality, stores the encryption keys

802.11 based WLANs (Wi-Fi)

- **Main Features:**
  - High Data rates (better than WWAN)
  - License free (unlike WWAN) ==> No subscription fee!
  - Cheap and simple to deploy (much cheaper than WWAN)
  - Short range communications (< 100 meters)
- **Standards:**
  1) IEEE802.11b & g: 2.4 GHz, 11 Mbps & 54 Mbps (peak)
  2) IEEE802.11a: 5 GHz, 54 Mbps (peak)
  3) IEEE802.11n: 2.4 GHz and 5 GHz, ~100 Mbps (peak)
  4) IEEE802.11ac: 5 GHz, ~500 Mbps (peak)
- **Tradename:** Wi-Fi = Wireless Fidelity

  There are 2 interpretations of Wi-Fi:
  1) Synonym for 802.11 WLAN
  2) Wi-Fi Alliance: industry group promoting interoperability of 802.11 products
- **Applications:** Private (e.g., homes, offices) and public (e.g., airports, University campuses, etc.)

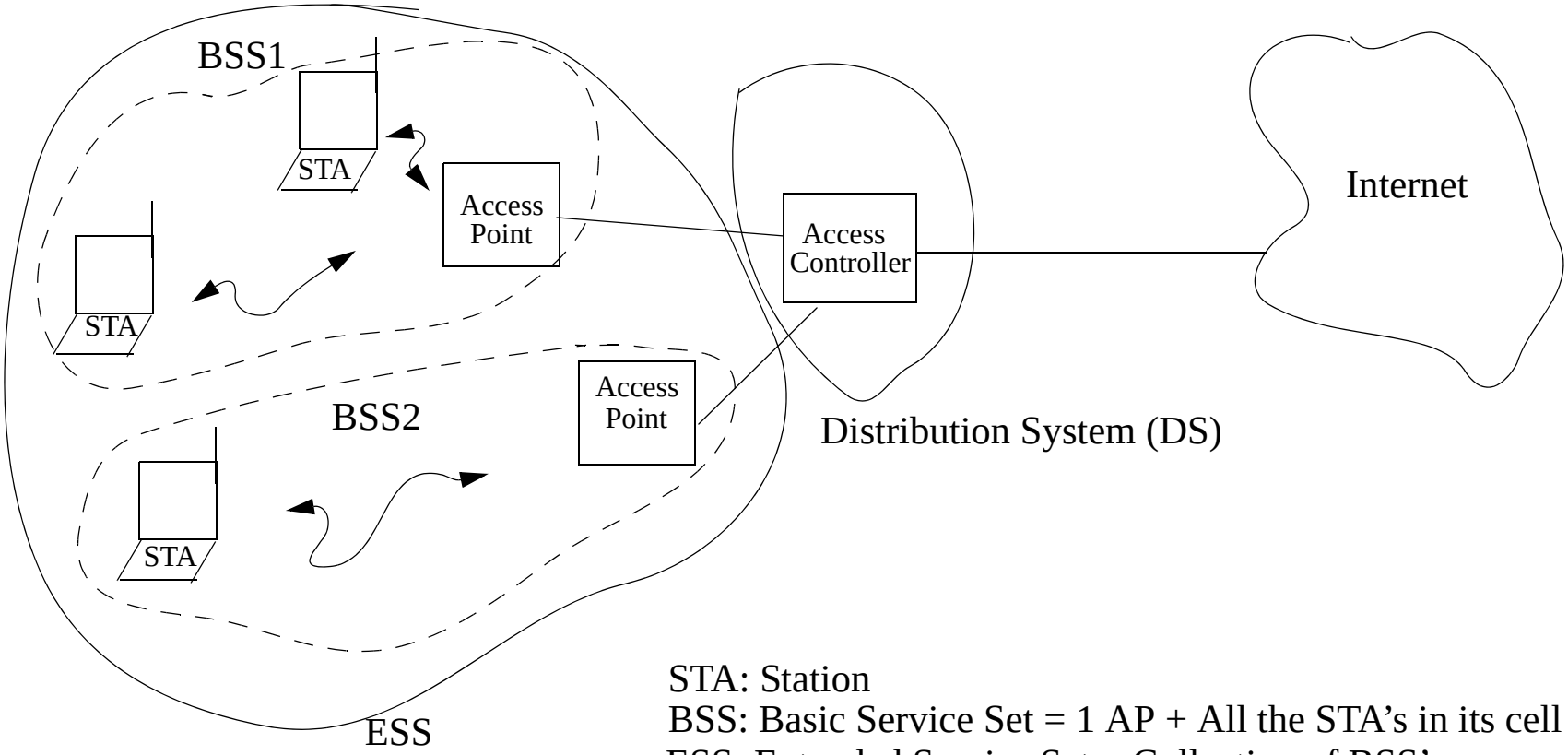
WLAN Architecture: Peer-to-Peer (ad-hoc Mode)



STA = station

- Created spontaneously by a group of stations (nodes)
- The group of nodes forms an independent basic service set (IBSS)
- Communication between stations is via one or multiple hops
- Practical Example: Wi-Fi Direct

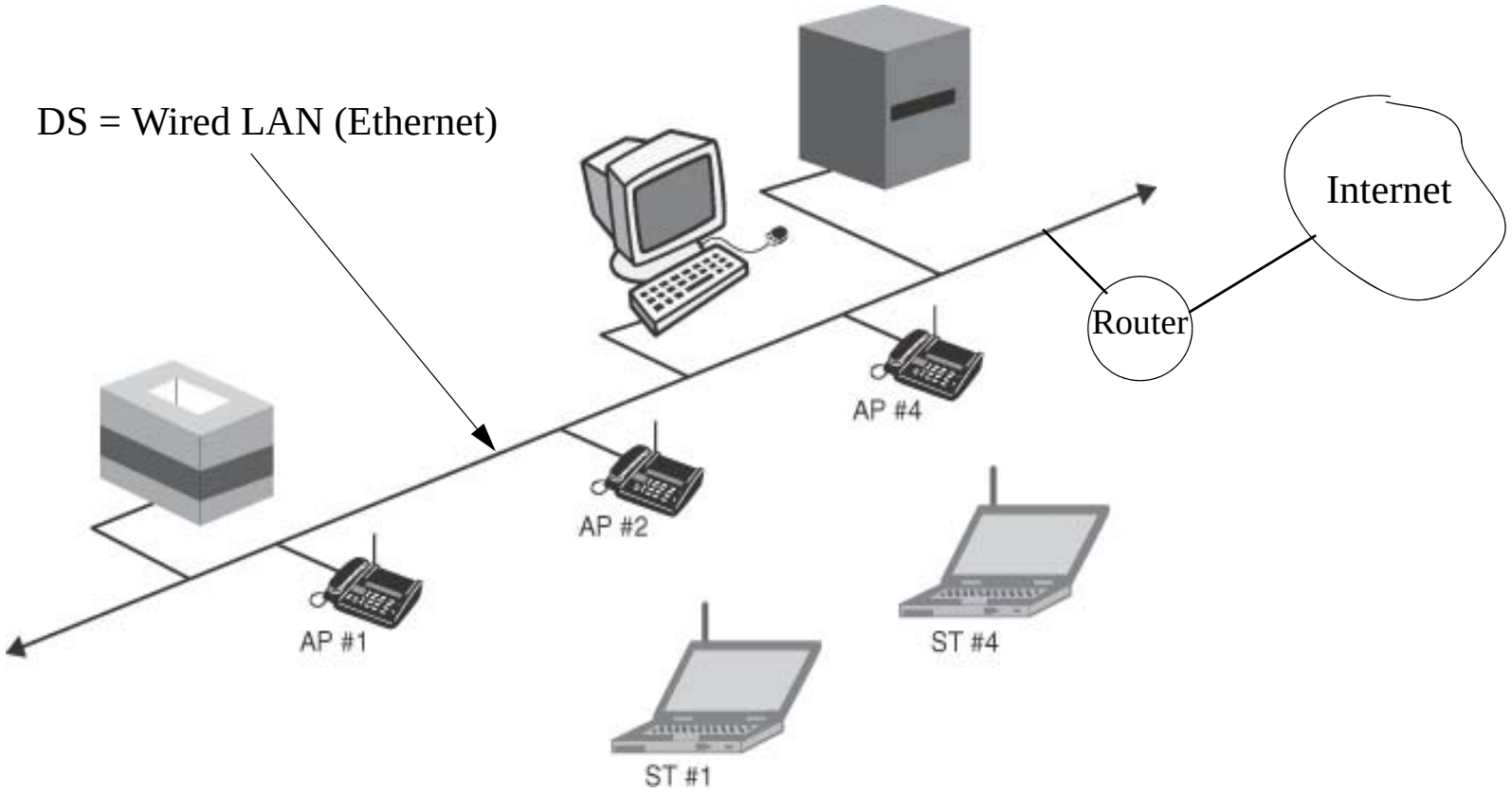
WLAN Architecture: Infrastructured Mode



STA: Station
BSS: Basic Service Set = 1 AP + All the STA's in its cell
ESS: Extended Service Set = Collection of BSS's

- Consists of infrastructure elements (e.g., access points, access controller) and stations
- Communication between 2 stations is via the Access Point (AP)

WLAN Infrastructured Mode: Distribution System (DS)



Wireless Networking Challenges

1) Limitations of wireless devices:
   - limited CPU, memory & battery life
   - limited user interface: small size keyboards & small size screen
   - Challenge: design of highly capable wireless devices that are cheap and easy to use, yet portable

2) Hostile and random radio (wireless) medium: unpredictable, unreliable & unstable
   - error-prone due to path loss, slow (shadow) and fast fading (spatial- & time-varying)
   - low bandwidth (data rate) and high latency
   - Challenge: how to mitigate the problems of the radio channel and radio frequency interference

3) High (and sometimes unrealistic) expectations of mobile users
   - ease of use of wireless devices & network services (and cheap too!!!)
   - hard guarantee on quality of service (QoS) during communication session
   - Challenge: achieve and maintain high QoS in the wireless environment with hard guarantee

4) Security: authentication & privacy of communication mechanisms are not fool-proof
   - Challenge: design of fool-proof and highly efficient authentication and encryption algorithms