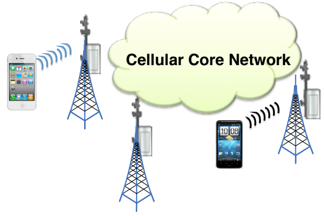


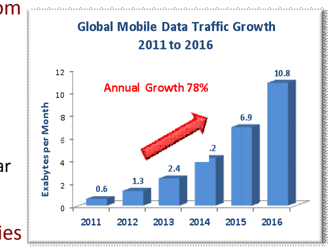
Cellular Networks

COS 461: Computer Networks
Spring 2013

Guest Lecture by Li Erran Li, Bell Labs
4/10/2013 W 10-10:50am
http://www.cs.princeton.edu/courses/archive/spring13/cos461/

Mobile Data Tsunami Challenges Current Cellular Technologies

- Global growth 18 times from 2011 to 2016
- AT&T network:
  - Over the past five years, wireless data traffic has grown 20,000%
  - At least doubling every year since 2007
- Existing cellular technologies are inadequate
  - Fundamental redesign of cellular networks is needed



Source: CISCO Visual Networking Index (VNI) Global Mobil Data Traffic Forecast 2011 to 2016

Outline

Goal of this lecture: understand the basics of current cellular networks

- •Physical Layer
- •Access Procedure
  - Why no carrier sensing
- •Connection Setup
- •Mobility Management
- •Power Management and Mobile Apps
- •Differences between 3G and LTE
- •What is Next
- •Conclusion

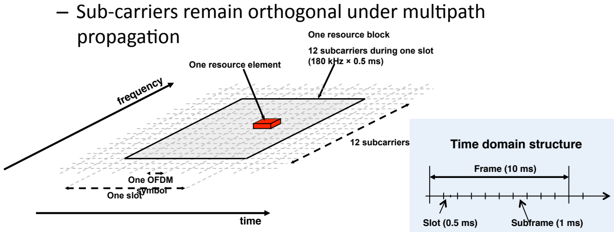
Physical Layer: UMTS

Code Division Multiple Access (CDMA)

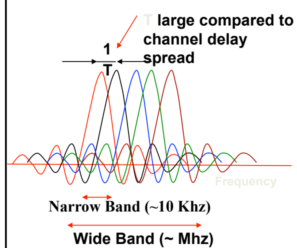
- Use of orthogonal codes to separate different transmissions
- Each symbol or bit is transmitted as a larger number of bits using the user specific code – Spreading
- Spread spectrum technology
  - The bandwidth occupied by the signal is much larger than the information transmission rate
  - Example: 9.6 Kbps voice is transmitted over 1.25 MHz of bandwidth, a bandwidth expansion of ~100

Physical Layer: LTE

- The key improvement in LTE radio is the use of OFDM
- Orthogonal Frequency Division Multiplexing
  - 2D frame: frequency and time
  - Narrowband channels: equal fading in a channel
    - Allows simpler signal processing implementations
  - Sub-carriers remain orthogonal under multipath propagation



Physical Layer: LTE (Cont'd)

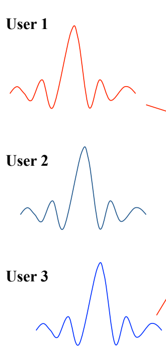


Sub-carriers remain orthogonal under multipath propagation

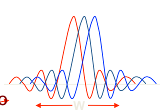
Orthogonal Frequency Division Multiple Access (OFDM)

- Closely spaced sub-carriers without guard band
- Each sub-carrier undergoes (narrow band) flat fading
  - Simplified receiver processing
- Frequency or multi-user diversity through coding or scheduling across sub-carriers
- Dynamic power allocation across sub-carriers allows for interference mitigation across cells
- Orthogonal multiple access

Physical Layer: LTE (Reverse link OFDM)



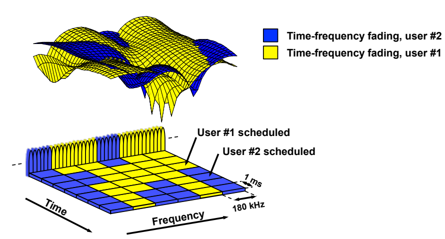
- Users are carrier synchronized to base station
- Differential delay between users' signals at the base need to be small compared to symbol duration



- Efficient use of spectrum by multiple users
- Sub-carriers transmitted by different users are orthogonal at the receiver
  - No intra-cell interference
- CDMA uplink is non-orthogonal since synchronization requirement is ~ 1/W and so difficult to achieve

LTE Scheduling: Downlink

- Assign each Resource Block to one of the terminals
  - LTE – channel-dependent scheduling in time *and* frequency domain
  - HSPA – scheduling in time-domain only



LTE Scheduling: Uplink

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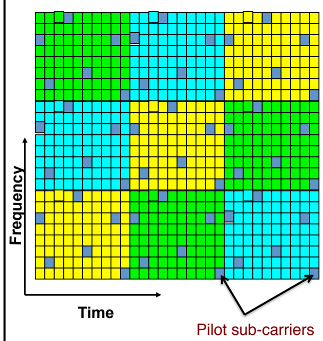

Each color represents a user
Each user is assigned a frequency-time tile which consists of pilot sub-carriers and data sub-carriers
Block hopping of each user's tile for frequency diversity

Typical pilot ratio: 4.8 % (1/21) for LTE for 1 Tx antenna and 9.5% for 2 Tx antennas

Physical Layer LTE vs WiFi

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- Speed: LTE is designed to operate with a maximum mobile speed of 350km
  - Shorter channel coherence time, more frequent pilot transmissions
- Coverage: several kilometers
  - Larger delay spread, more guard time overhead

Access Procedure

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- Cell Search
  - Base station broadcasts synchronization signals and cell system information (similar to WiFi)
  - UE obtains physical layer information
    - UE acquires frequency and synchronizes to a cell
    - Determine the start of the downlink frame
    - Determine the cell identity
- Random access to establish a radio link

Random Access

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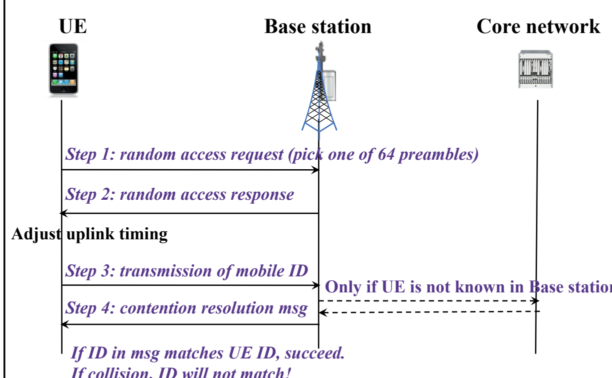

Random Access (Cont'd)

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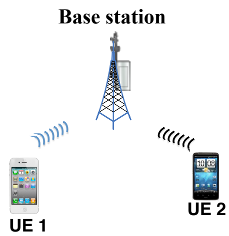
Why not carrier sensing like WiFi?

•Base station coverage is much larger than WiFi AP

- **UEs most likely cannot hear each other**

•How come base station can hear UEs' transmissions?

- **Base station receivers are much more sensitive and expensive**



LTE Architecture

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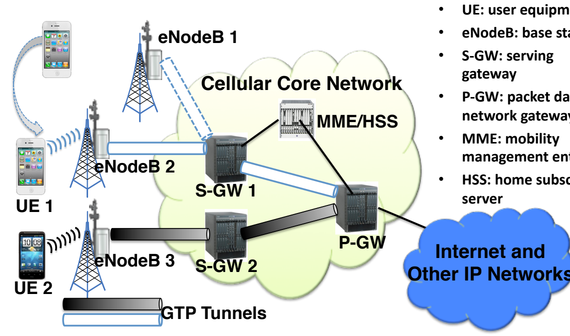

- **UE: user equipment**
- **eNodeB: base station**
- **S-GW: serving gateway**
- **P-GW: packet data network gateway**
- **MME: mobility management entity**
- **HSS: home subscriber server**

Connection Setup

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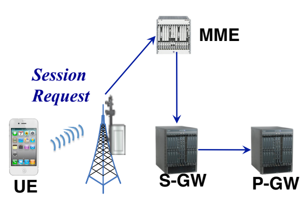
- Session Requests
  - UE to base station
  - Base station to MME
    - MME obtains subscriber info from HSS, selects S-GW and P-GW
  - S-GW sends to P-GW
    - P-GW obtains policy from PCRF



Connection Setup (Cont'd)

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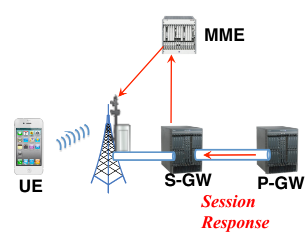
- Session Response
  - Establishes GPRS Tunnels (GTP) between S-GW and P-GW, between S-GW and UE
  - Base station allocates radio resources to UE



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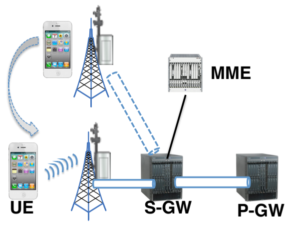
Mobility Management

Handoff

- Handoff without change of S-GW
  - No change at P-GW
- Handoff with change of S-GW or MME
- Inter-technology handoff (LTE to 3G)



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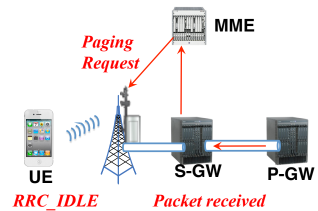
Mobility Management (Cont'd)

Paging

- If S-GW receives a packet to a UE in IDLE state, inform MME
- MME pages UE through base station



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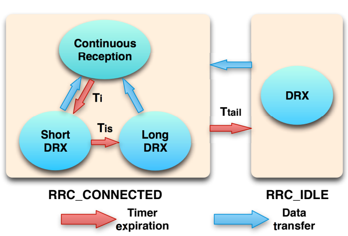
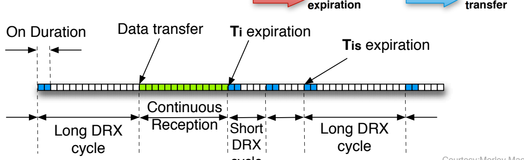
Power Management: LTE

- UE runs radio resource control (RRC) state machine
- Two states: IDLE, CONNECTED
- Discontinuous reception (DRX): monitor one subframe per DRX cylce; receiver sleeps in other subframes





Courtesy:Morley Mao

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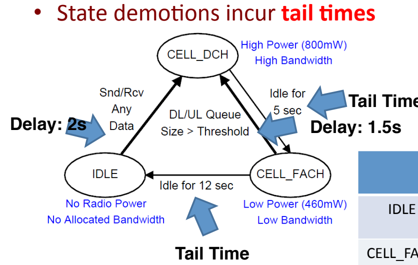
Power Management: UMTS

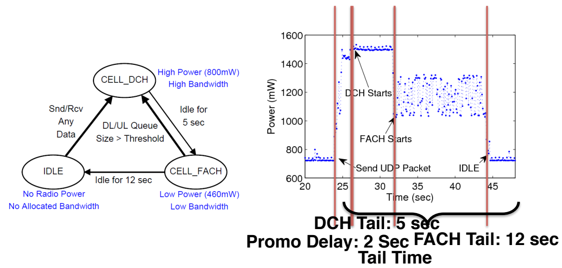
- State promotions have **promotion delay**
- State demotions incur **tail times**



	Channel	Radio Power
IDLE	Not allocated	Almost zero
CELL_FACH	Shared, Low Speed	Low
CELL_DCH	Dedicated, High Speed	High

Courtesy: Feng Qian

Example in Detail: RRC State Machine for a Large Commercial 3G Network



DCH: High Power State (high throughput and power consumption)
FACH: Low Power State (low throughput and power consumption)
IDLE: No radio resource allocated

Courtesy: Feng Qian

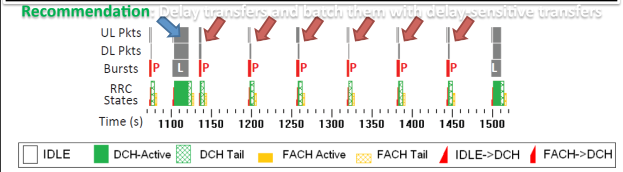
Example in Detail: Pandora Music

Pandora profiling results (Trace len: 1.45 hours)

Burst type	Payloads	Energy		DCH	
		LB	UB	LB	UB
LARGE_BURST	96.4%	35.6%	35.9%	42.4%	42.5%
APP_PERIOD	0.2%	45.9%	46.7%	40.4%	40.9%
APP	3.2%	12.8%	13.4%	12.4%	12.8%
TCP_CONTROL	0.0%	1.2%	1.6%	1.1%	1.5%
TCP_LOSS_RECOVER	0.2%	0.2%	0.6%	0.3%	0.7%
NON_TARGET	0.0%	1.8%	1.8%	1.7%	1.7%
Total	23.6 MB	846 J		895 sec	

Problem: High resource overhead of periodic audience measurements (every 1 min)

Recommendation: Delay transfers and batch them with delay-sensitive transfers



Courtesy: Feng Qian

Why Power Consumptions of RRC States so different?

- IDLE: procedures based on reception rather than transmission
  - Reception of System Information messages
  - Cell selection registration (requires RRC connection establishment)
  - Reception of paging messages with a DRX cycle (may trigger RRC connection establishment)
  - Location and routing area updates (requires RRC connection establishment)

UMTS RRC State Machine (Cont'd)

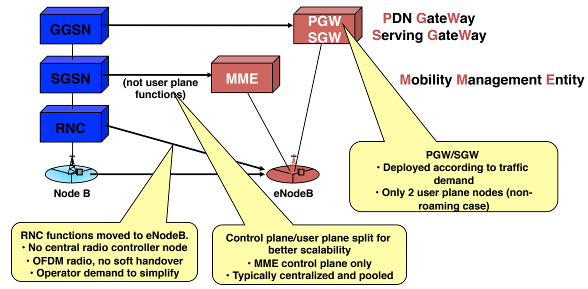
- CELL_FACH: need to continuously receive (search for UE identity in messages on FACH), data can be sent by RNC any time
  - Can transfer small data
  - UE and network resource required low
  - Cell re-selections when a UE moves
  - Inter-system and inter-frequency handoff possible
  - Can receive paging messages without a DRX cycle

UMTS RRC State Machine (Cont'd)

- CELL_DCH: need to continuously receive, and sent whenever there is data
  - Possible to transfer large quantities of uplink and downlink data
  - UE and network resource requirement is relatively high
  - Soft handover possible for dedicated channels and Inter-system and inter-frequency handover possible
  - Paging messages without a DRX cycle are used for paging purposes

LTE vs UMTS (3G): Architecture

- **Functional changes compared to the current UMTS Architecture**



LTE vs UMTS (3G): Physical Layer

- UMTS has CELL_FACH
  - Uplink un-synchronized
    - Base station separates random access transmissions and scheduled transmissions using CDMA codes
- LTE does not have CELL_FACH
  - Uplink needs synchronization
    - Random access transmissions will interfere with scheduled transmissions

What Is Next?

What Is Next?

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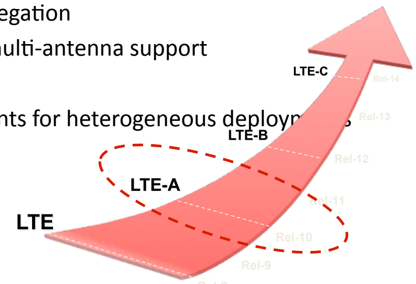
- LTE Evolution
- Dynamic Spectrum Sharing
- Base Station with Large Number of Antennas
- Software Defined Cellular Networks

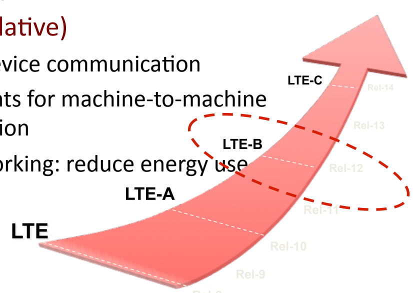
LTE Evolution

- LTE-A – meeting and exceeding IMT-Advanced requirements
  - Carrier aggregation
  - Enhanced multi-antenna support
  - Relaying
  - Enhancements for heterogeneous deployments



LTE Evolution

- LTE-B
  - Work starting fall 2012
- Topics (speculative)
  - Device-to-device communication
  - Enhancements for machine-to-machine communication
  - Green networking: reduce energy use
  - And more…



Base Station with Large Number of Antennas

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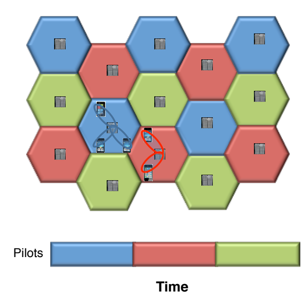
- M base station antennas service K terminals, M>>K
- Reduced energy (Joules/bit) plus increased spectral efficiency (bits/sec/Hz)
- All complexity is with the service-antennas
- No cooperation among cells



Base Station with Large Number of Antennas (Cont'd)

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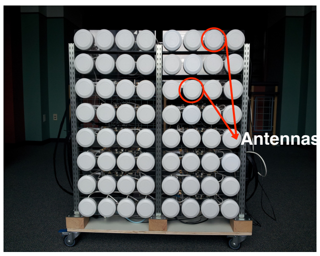
- Prototype front view



Base Station with Large Number of Antennas (Cont'd)

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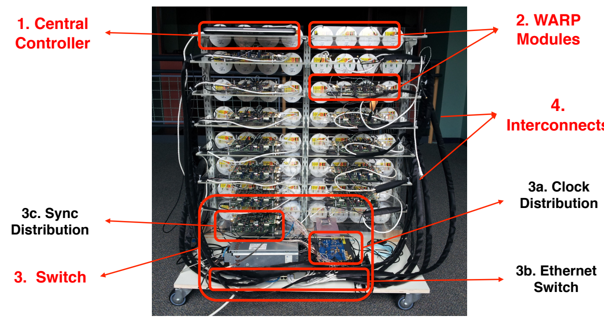
- Prototype back view



A Clean-Slate Design: Software-Defined Cellular Networks

CellSDN Architecture

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- CellSDN provides scalable, fine-grain real time control with extensions:
  - Controller: *fine-grain* policies on subscriber attributes
  - Switch software: local control agents to improve control plane *scalability*
  - Base stations: remote control and virtualization to enable flexible *real time* radio resource management

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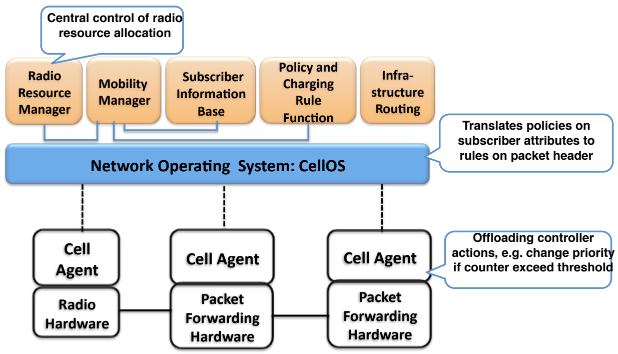
CellSDN Architecture (Cont'd)



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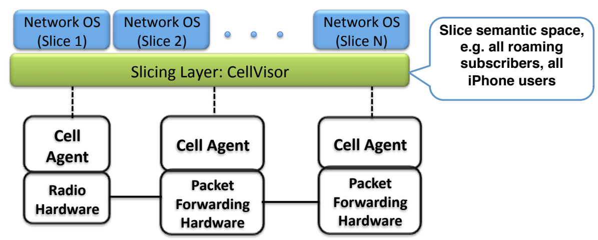
CellSDN Virtualization



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Conclusions

- LTE promises hundreds of Mbps and 10s msec latency
- Mobile apps need to be cellular friendly, e.g. avoid periodic small packets, use push notification services
- Roaming and inter-technology handoff not covered
- Challenges
  - P-GW central point of control, bad for content distribution, and scalable policy enforcement
  - Mobile video will be more than half of the traffic
  - Needs lots of spectrum (spectrum crunch)