ECE519B/496A Selected Topics

MIMO and UWB Communications

Part 1 Introduction and Review

Xiaodai Dong

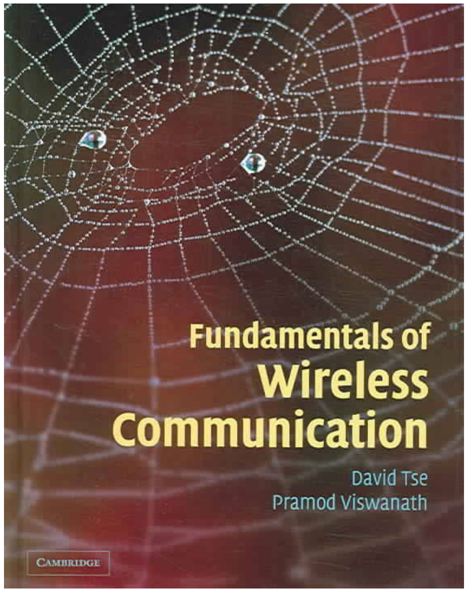
Course information

- Instructor: Xiaodai Dong
- Schedule:
  - Lectures: Mondays, Thursdays 11:30 am-12:50 pm
  - Location: ECS 128
- Office Hours:
  Thursdays 1:00 pm-2:00 pm or by email appointment
  EOW 439
- CourseSpaces for course materials

Optional Textbooks

Fundamentals of Wireless Communication

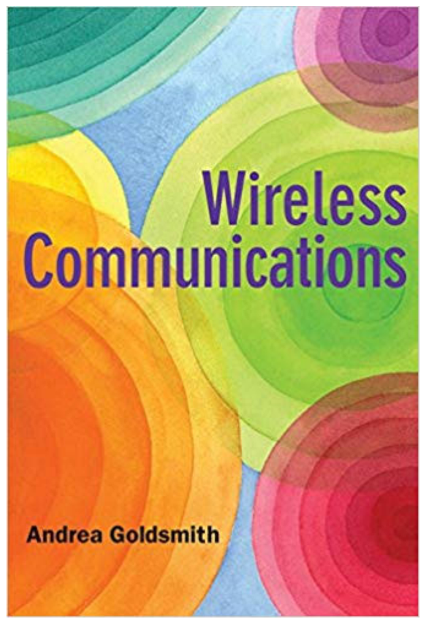
by D. Tse and P. Viswanath



Optional Textbooks

Wireless Communications

by A. Goldsmith



Marking Scheme

- Assignments: 15%
- Mid-term 30% Date: Feb. 28, 2019 in class
- Presentation 25%
- Project 30%

Instructor

- Professor at UVic (ECE)
- 2002-2004: Assistant professor at U of Alberta (ECE)
- 1999-2002: Wireless Division, Nortel Networks

- Office: EOW 439
- Email: xdong@ece.uvic.ca

- My research: Wireless communication and signal processing
  - www.ece.uvic.ca/~xdong
  - https://scholar.google.ca/citations?user=esI-KA0AAAAJ&hl=en&oi=ao

Course Objectives

- Introduce the fundamentals of wireless channels, orthogonal frequency division multiplex (OFDM), multiple input multiple output (MIMO), 4G mobile standards, narrowband internet of things (NB-IoT), and new technologies of 5G: massive MIMO, millimeter wave

Course Outlines

- Wireless propagation and channel modeling
- OFDM
- MIMO
- 4G LTE specifications
- Carrier aggregation
- LTE-U, LAA
- NB-IoT
- Millimeter wave (mmWave) channels
- Massive MIMO

Prerequisites

- ECE 350, 450
- Signals and systems
  - LTI systems
  - Convolution
  - Fourier series and Fourier transform
  - Sampling theorem
- Complex numbers
- Probability, random variables and stochastic process

Introduction

- Wireless industry is huge and the driving force to the internet of things (IoT).

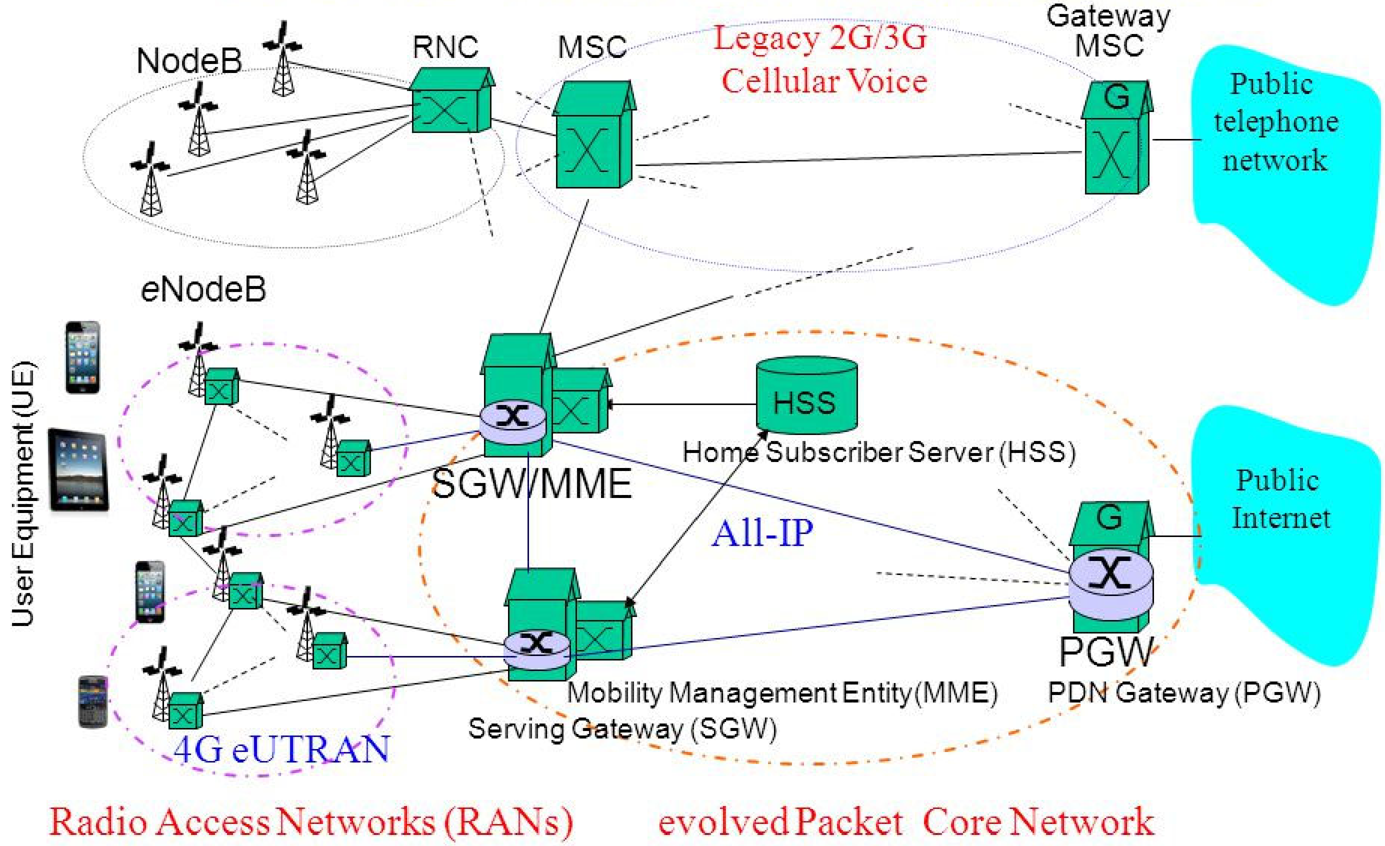
- There are various wireless technologies of different
  - data rates bits/s
  - system capacity sum rate or # of users supported
  - coverage distance
  - power/energy efficiency wattz (joules) per bit or per km
  - latency ms

No single solution fits all applications.

Popular Wireless Technologies

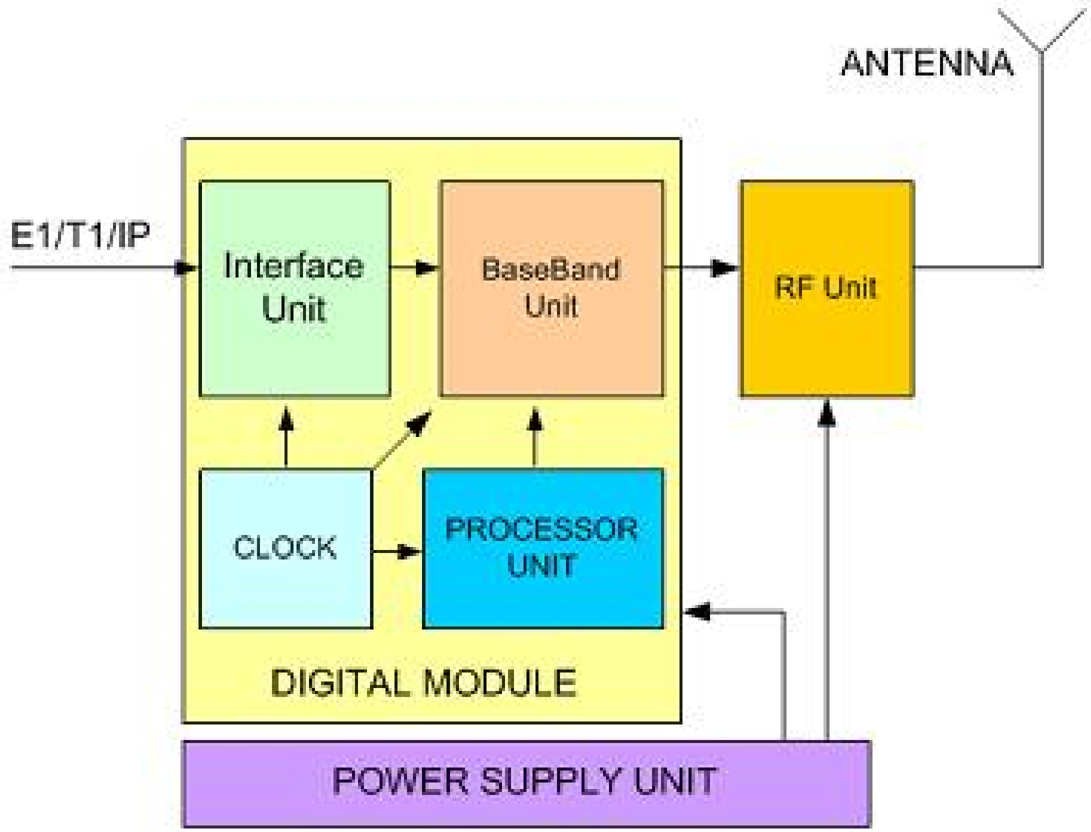
- **Cellular networks: 1G, 2G, 3G, 4G, upcoming 5G**
  - Organization: 3GPP
  - Licensed spectrum
  - Global/regional deployment, mobility support
  - NB-IOT
  - Star topology, D2D in the talks
- **Wi-Fi**
  - Organization: WiFi Alliance
  - Unlicensed ISM bands: 2.4 GHz, 5.8 GHz, 60 GHz
  - 20+ meters indoor, greater distance outdoor
  - 802.11a/b/g/n/ac/ax (2.4, 5 GHz), 802.11ad/ay (60 GHz)
  - 802.11ah Wi-Fi Halow (sub-1 GHz)
  - Star topology, peer to peer

4G LTE Network Architecture

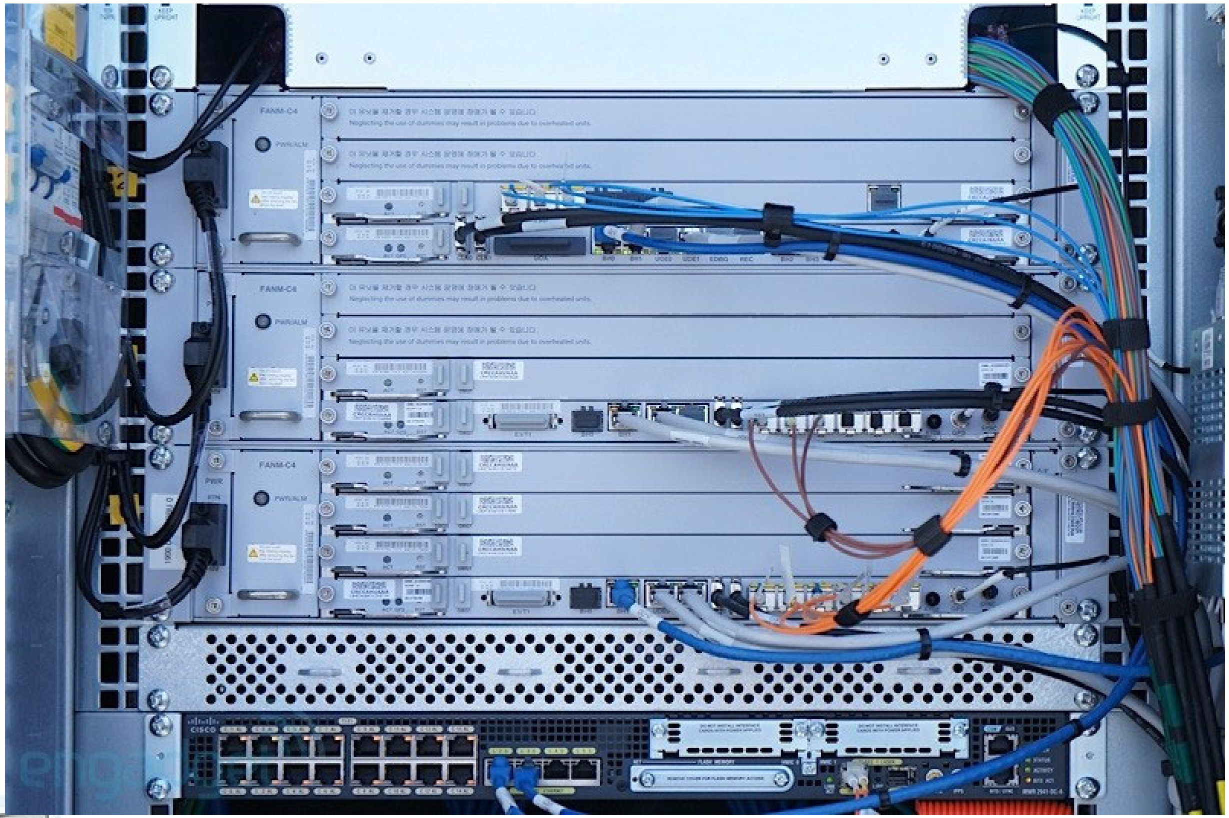


CSci5221: 3G/4G Cellular Network Architecture Overview

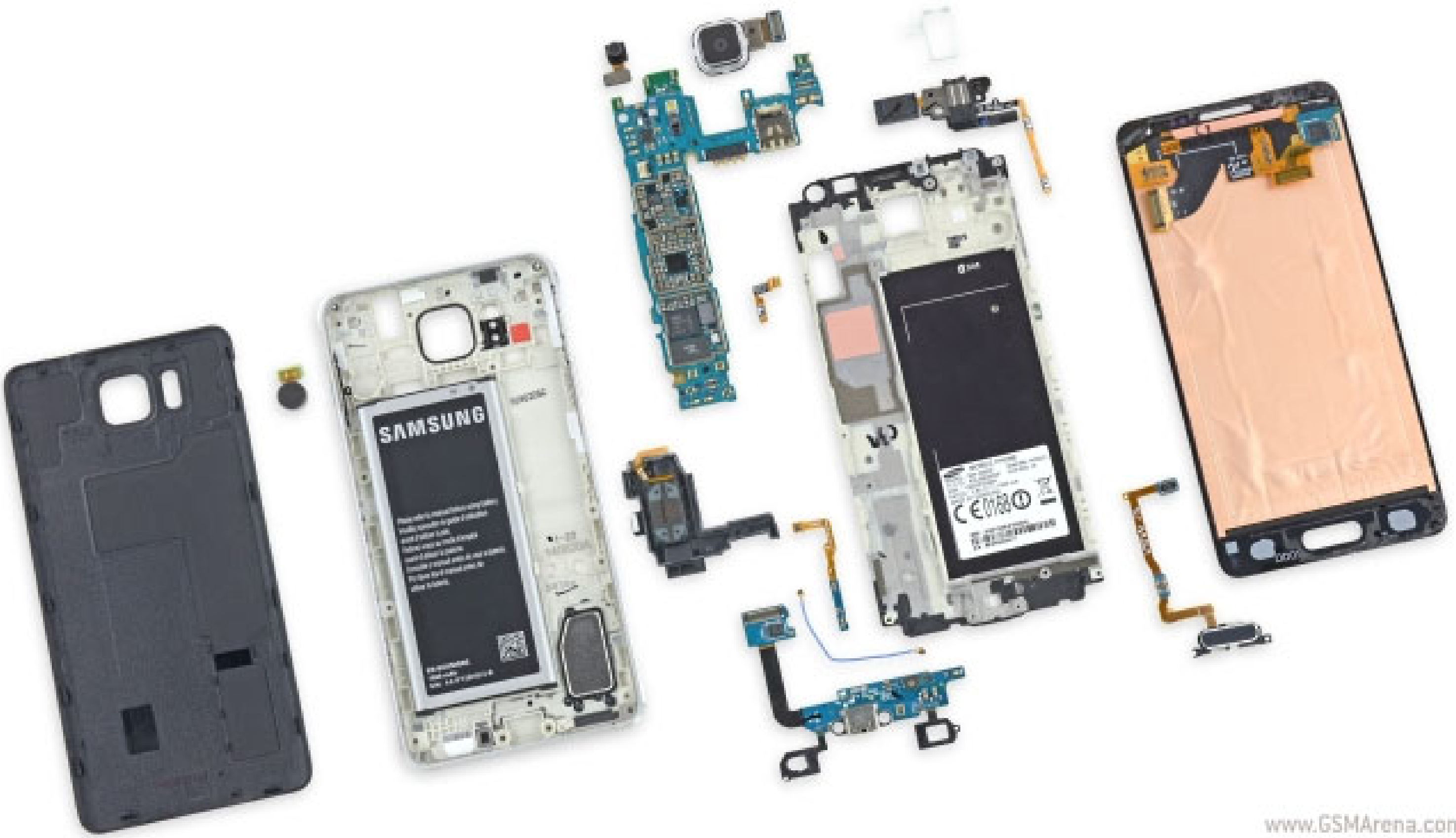
Base Transceiver Station (BTS)



BTS/ Cell site/ Cell tower



User Equipment



http://blog.gsmarena.com/take-peek-inside-galaxy-alpha-samsungs-first-metal-clad-smartphone/

Popular Wireless Technologies

- **Bluetooth/Bluetooth Low Energy**
  - Organization: Bluetooth Special Interest Group
  - Unlicensed ISM band: 2.4 GHz
  - Master/slave architecture, piconet (1 Master and up to 7 slaves)
  - 10-60-240 meters
  - Physical layer all the way to application profiles
  - 25, 50 Mbps

Popular Wireless Technologies

- **IEEE 802.15.4 + Zigbee**
  - Organization: IEEE and Zigbee Alliance
  - Unlicensed ISM bands: 2.4 GHz, 868 MHz (Europe, 915 MHz (USA, Australia)
  - 10-300 meters
  - IEEE 802.15.4: Low rate wireless personal area networks, physical layer and media access control layer
  - Zigbee: wireless mesh networks, network layer, applications layer, etc.
  - Low data rate, long battery life

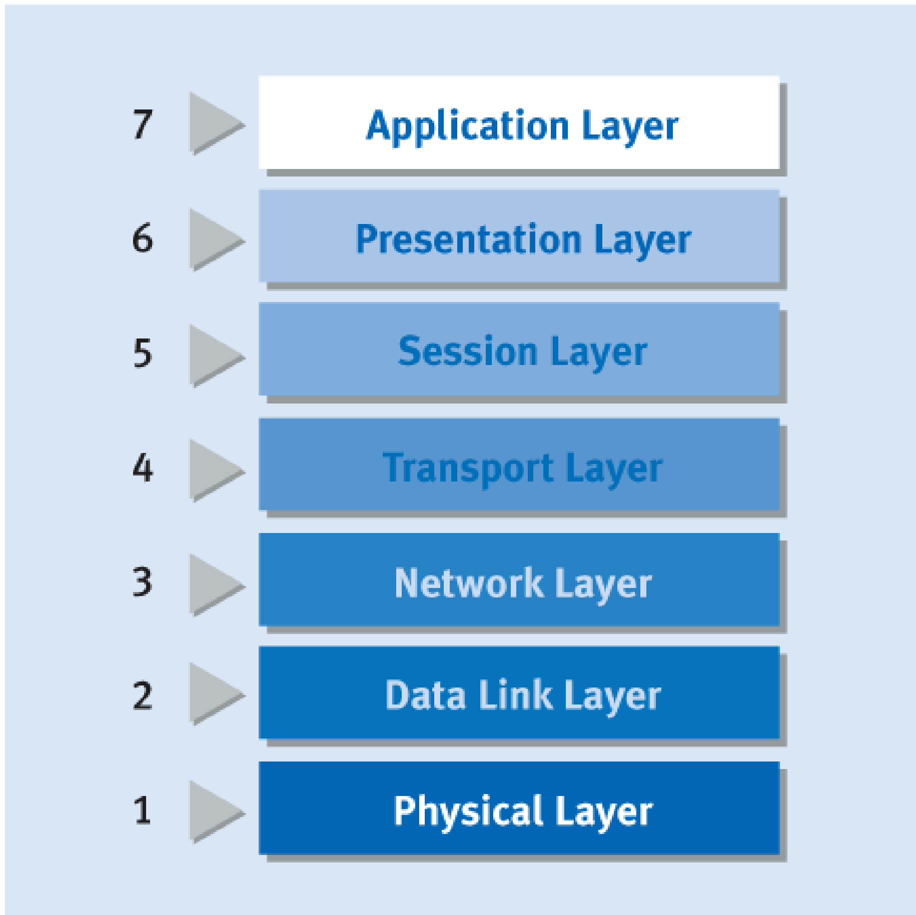
Popular Wireless Technologies

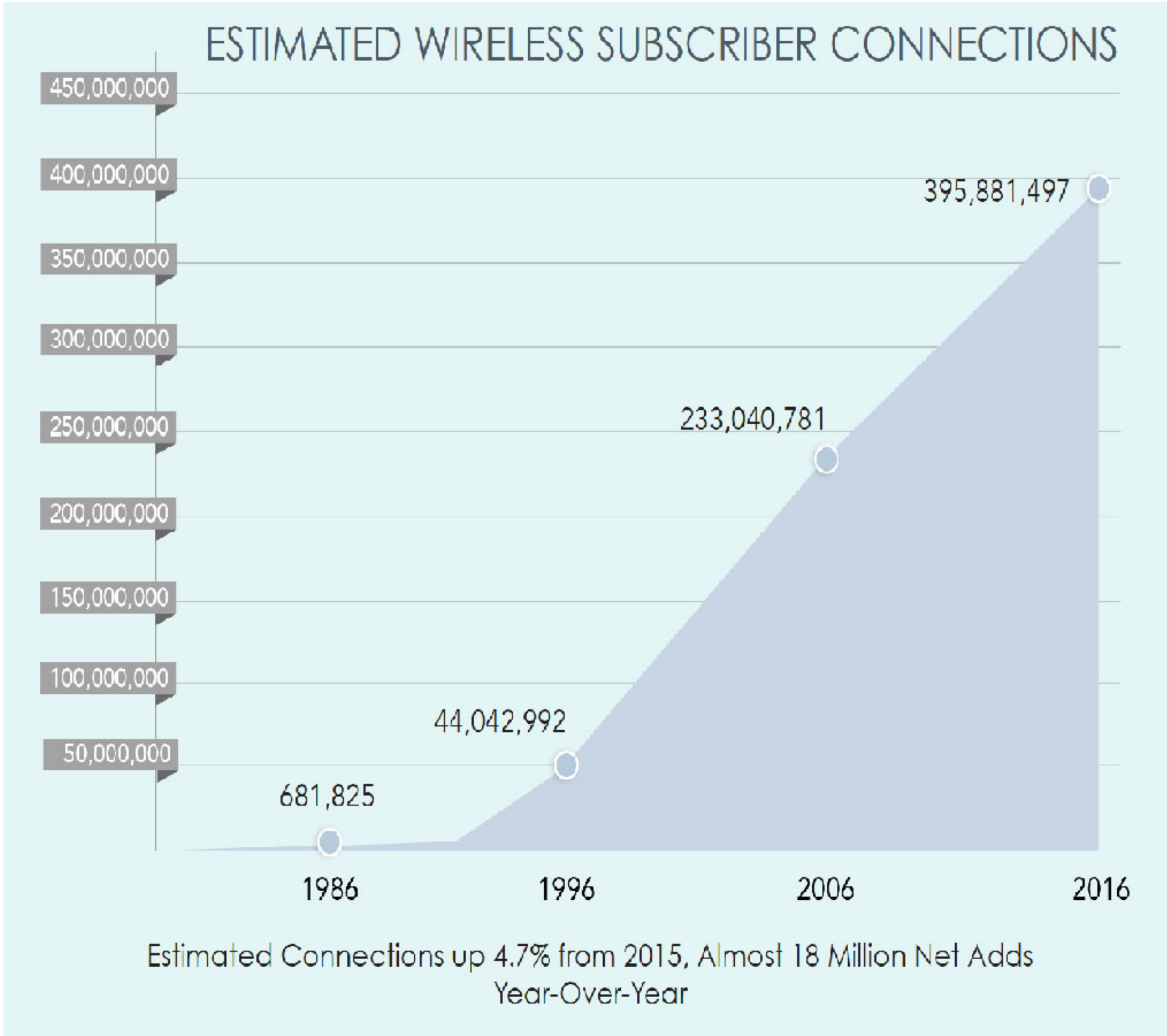
- **Low power wide area networks (LPWAN)**
  - Many IoT applications need low data rate, long battery life and long distance communications.
  - NB-IoT and LTE-M are the low power solutions from cellular industry.
  - Other proprietary technologies gaining tractions.
    - Sigfox: BPSK, ultra narrowband (200Hz)
    - LoRa: chirped modulation, spread spectrum
    - https://www.link-labs.com/blog/sigfox-vs-lora
    - https://www.postscapes.com/long-range-wireless-iot-protocol-lora/
    - A few km to 15-30 km (miles), star topology, same ISM band
    - Build the network

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

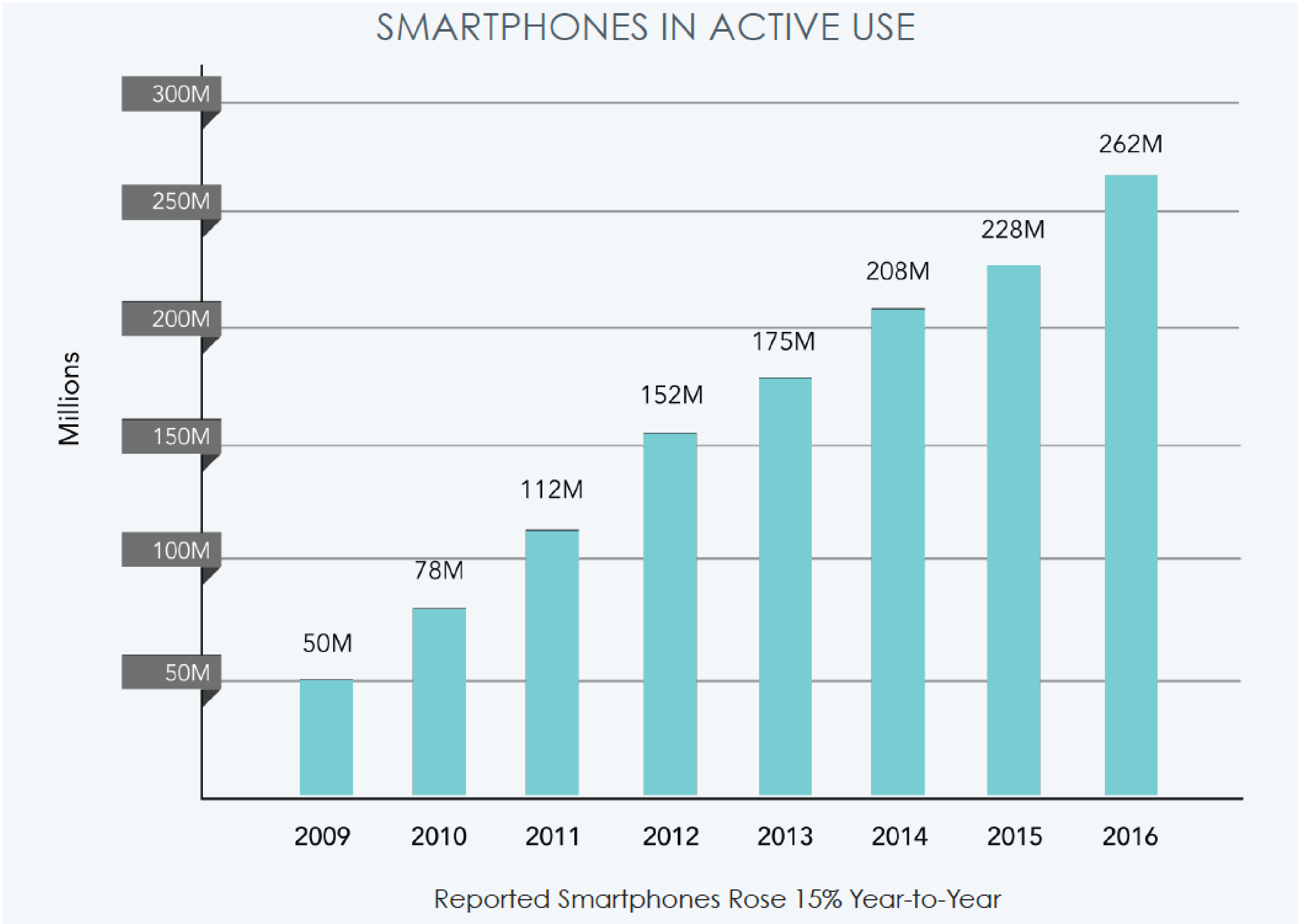
Source: LoRa Alliance

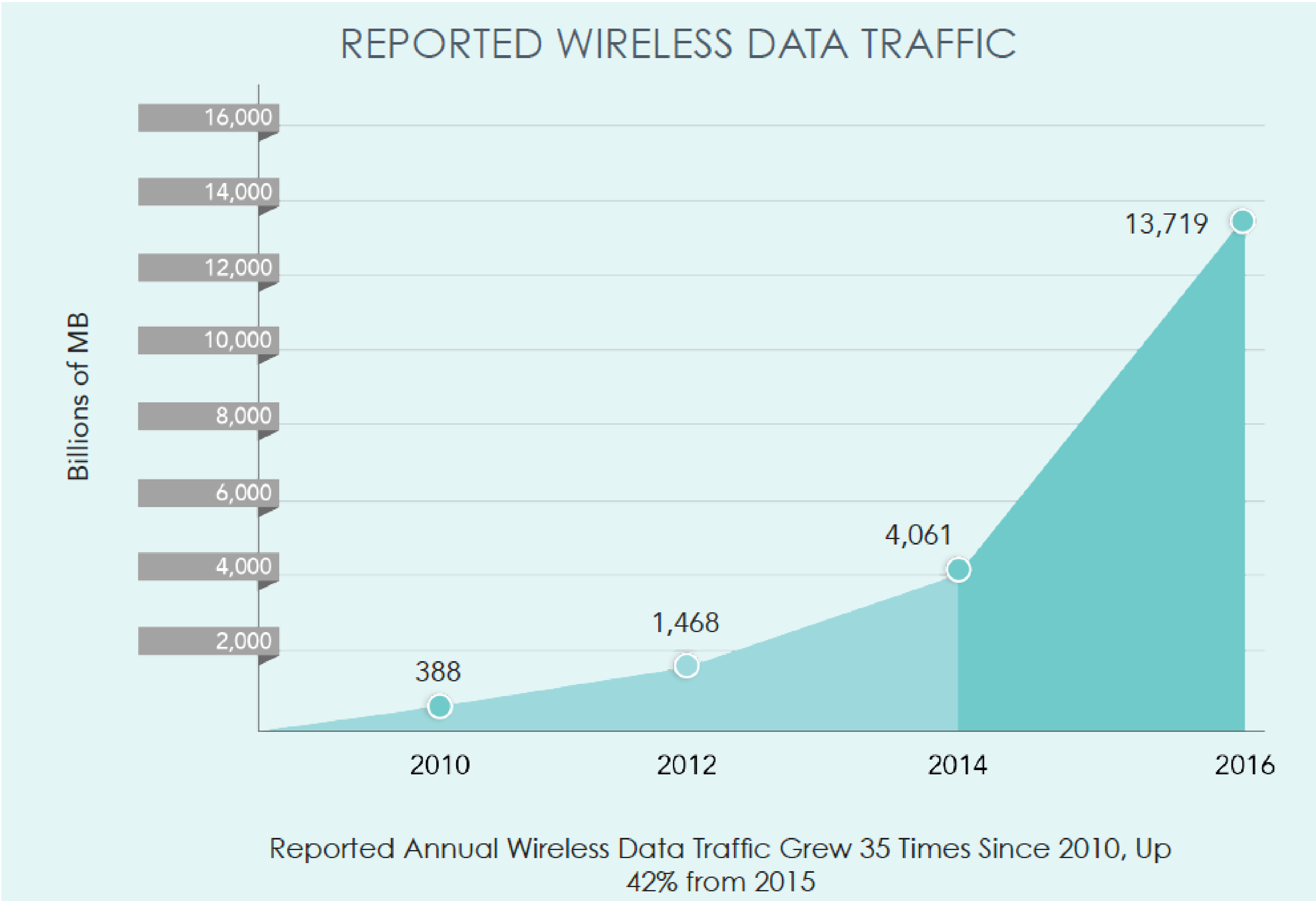
OSI reference model for computer/communication networks

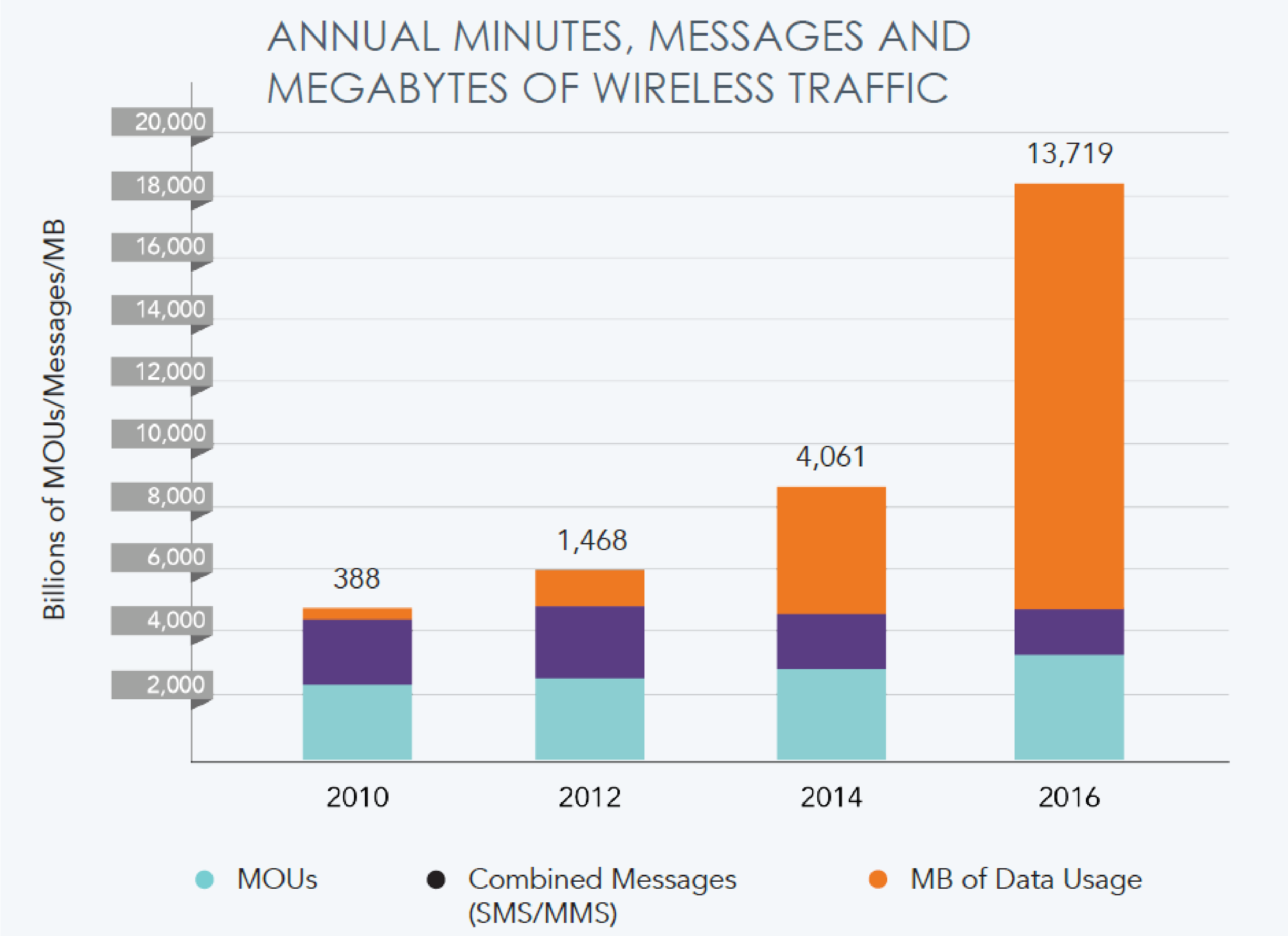



ESTIMATED WIRELESS SUBSCRIBER CONNECTIONS
450,000,000
400,000,000
350,000,000
300,000,000
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
395,881,497
233,040,781
44,042,992
681,825
1986
1996
2006
2016
Estimated Connections up 4.7% from 2015, Almost 18 Million Net Adds Year-Over-Year

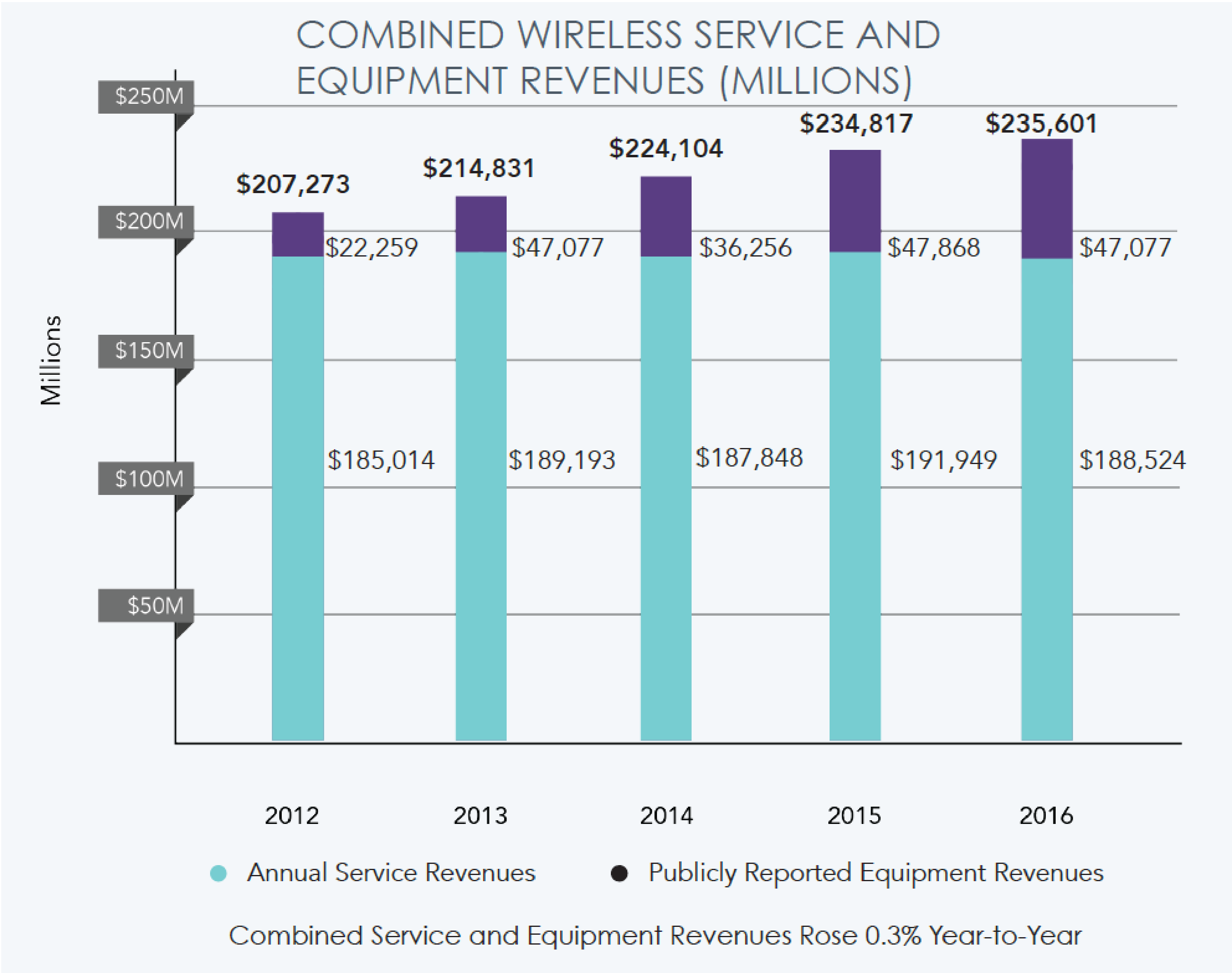
Source: CTIA

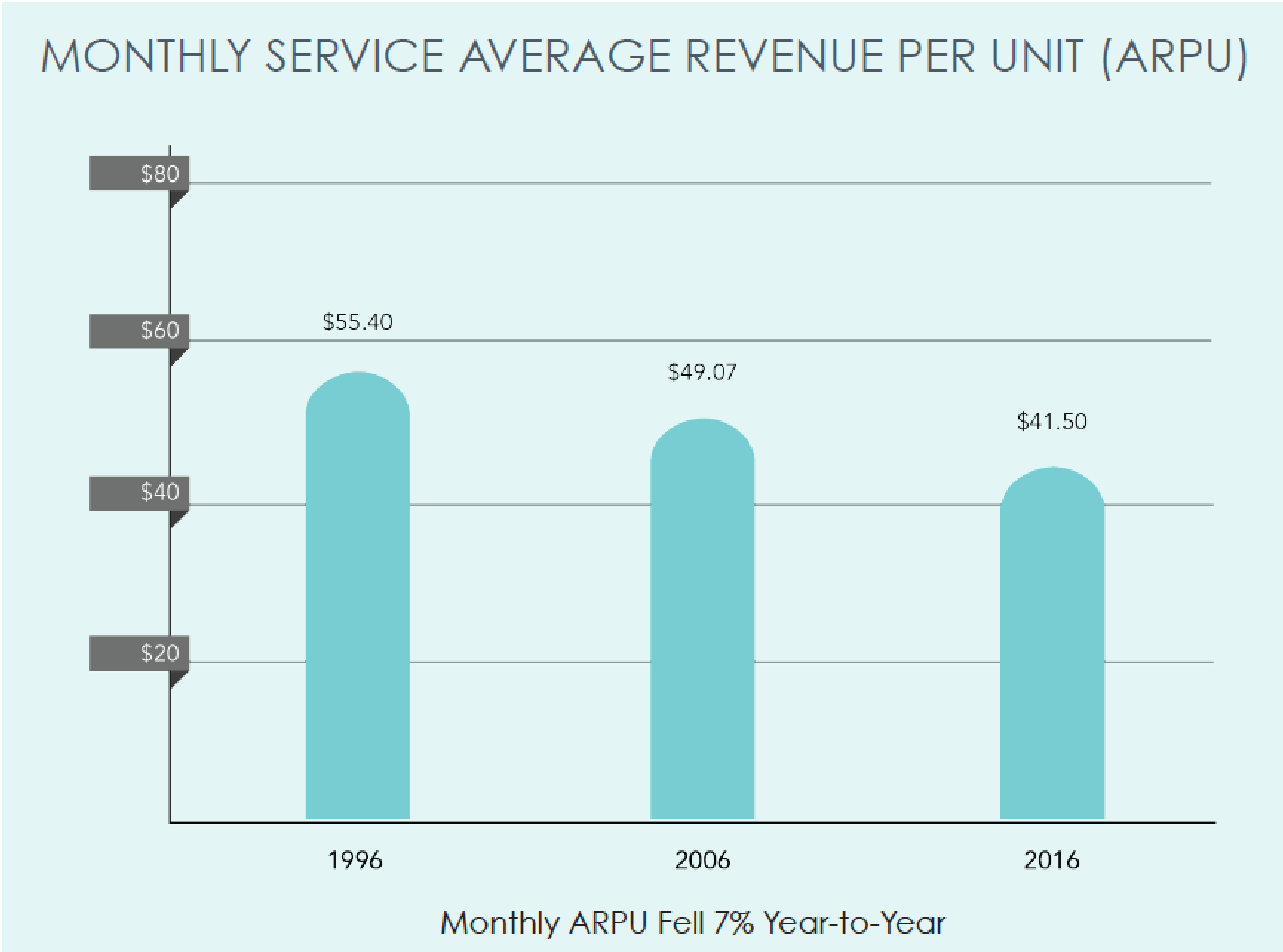

SMARTPHONES IN ACTIVE USE
Millions
300M
250M
200M
150M
100M
50M
50M
78M
112M
152M
175M
208M
228M
262M
2009
2010
2011
2012
2013
2014
2015
2016
Reported Smartphones Rose 15% Year-to-Year


REPORTED WIRELESS DATA TRAFFIC
Billions of MB
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
388
1,468
4,061
13,719
2010
2012
2014
2016
Reported Annual Wireless Data Traffic Grew 35 Times Since 2010, Up 42% from 2015

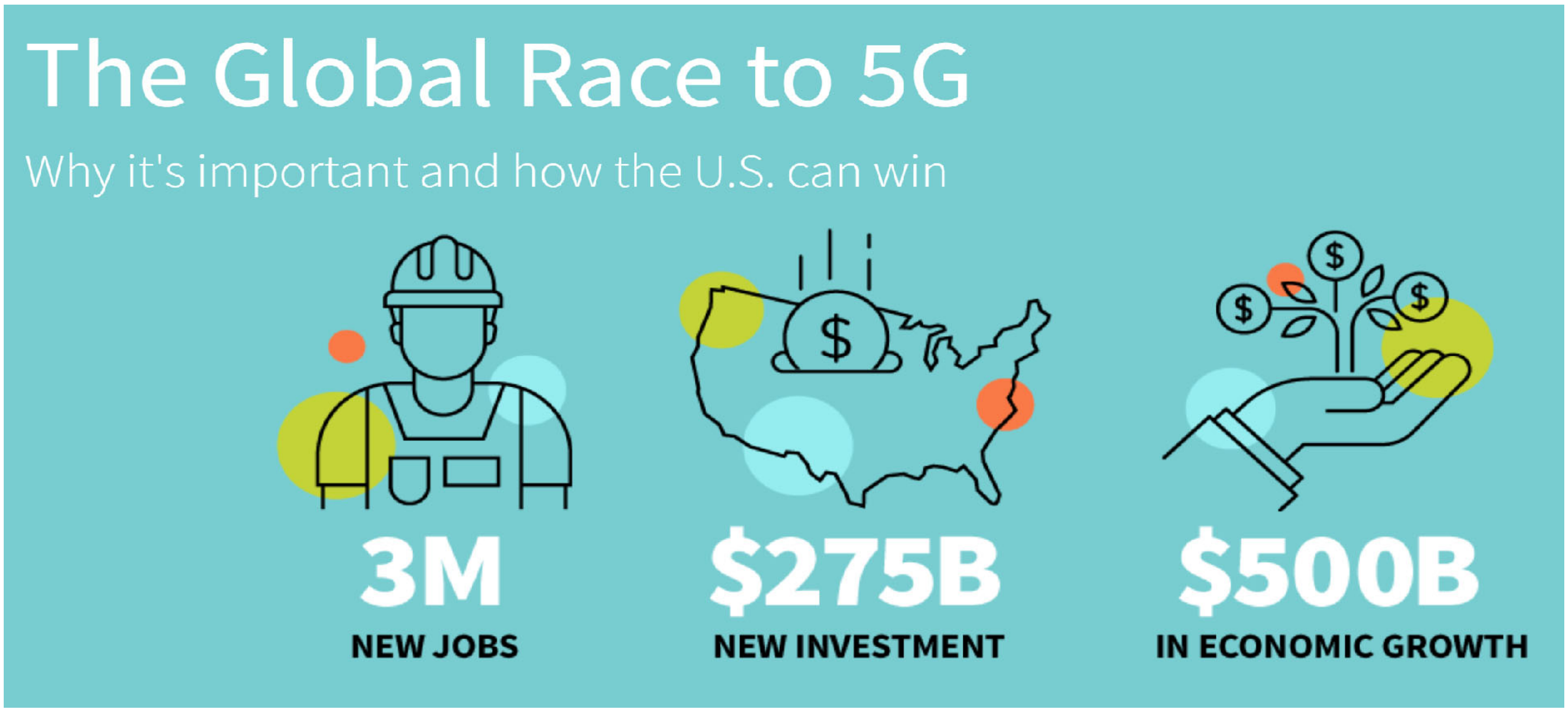


The Mix of Minutes, Messages and MBs Changes – Data Dominates


COMBINED WIRELESS SERVICE AND EQUIPMENT REVENUES (MILLIONS)
Millions
$250M
$200M
$150M
$100M
$50M
$207,273
$214,831
$224,104
$234,817
$235,601
$22,259
$47,077
$36,256
$47,868
$47,077
$185,014
$189,193
$187,848
$191,949
$188,524
2012
2013
2014
2015
2016
Annual Service Revenues
Publicly Reported Equipment Revenues
Combined Service and Equipment Revenues Rose 0.3% Year-to-Year


MONTHLY SERVICE AVERAGE REVENUE PER UNIT (ARPU)
$80
$60
$40
$20
$55.40
$49.07
$41.50
1996
2006
2016
Monthly ARPU Fell 7% Year-to-Year

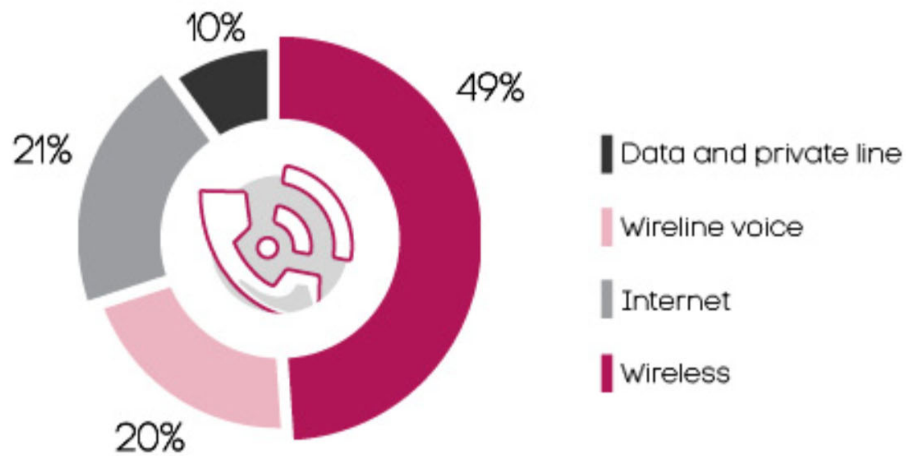
CTIA


The Global Race to 5G
Why it's important and how the U.S. can win
3M
NEW JOBS
$275B
NEW INVESTMENT
$500B
IN ECONOMIC GROWTH

CRTC.ca

Telecommunications revenues in 2015

$47.8 billion



Revenues	Capital Expenditures	Revenue Share	EBITDA Margin
$47.8 B	**$13.3 B**	**84%**	**39.8%**
Increase of 4.1% over 2014	Decrease of 8.9% over 2014	Of the top 5 companies	

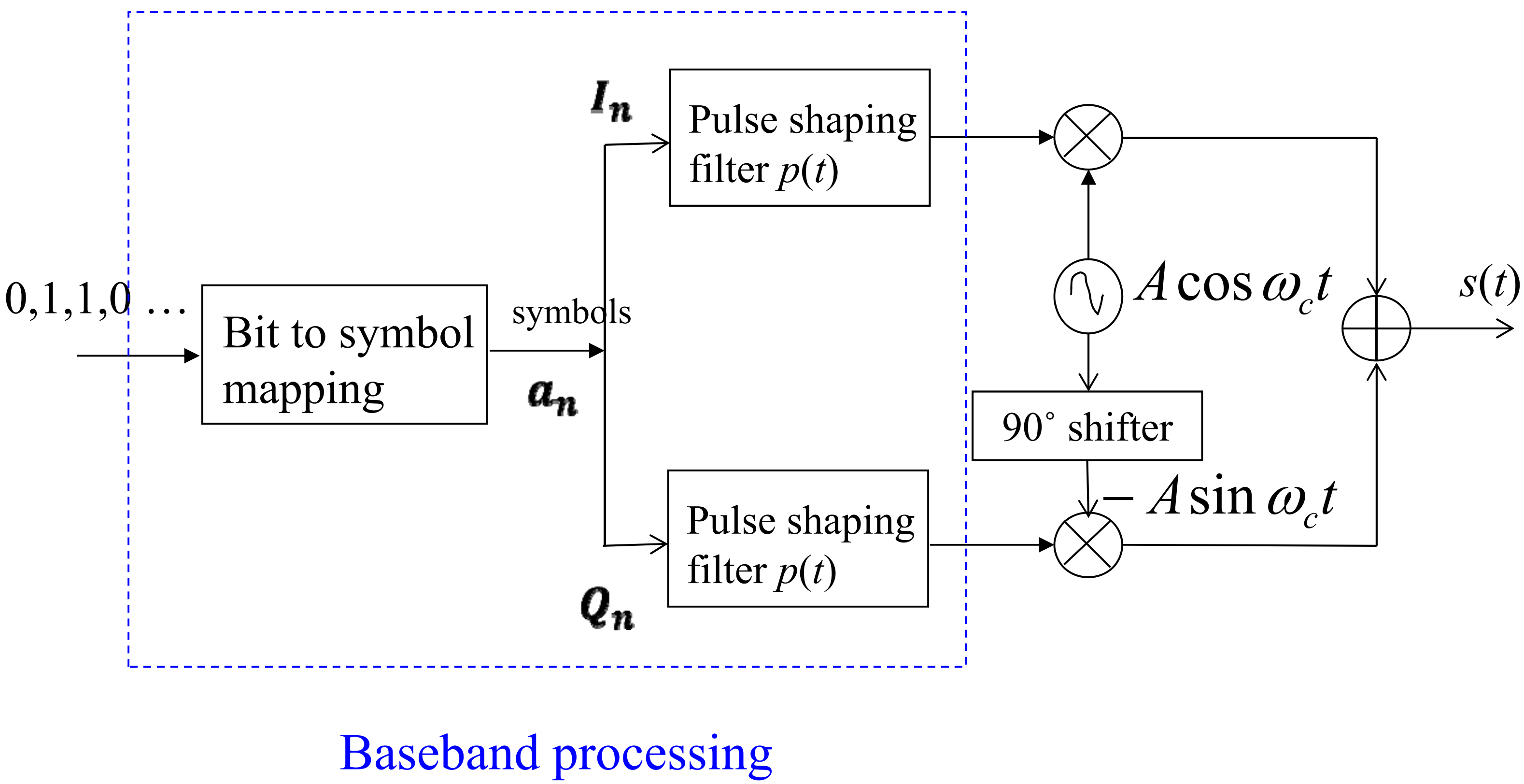
Signal and channel model

- The received signal is usually modeled as

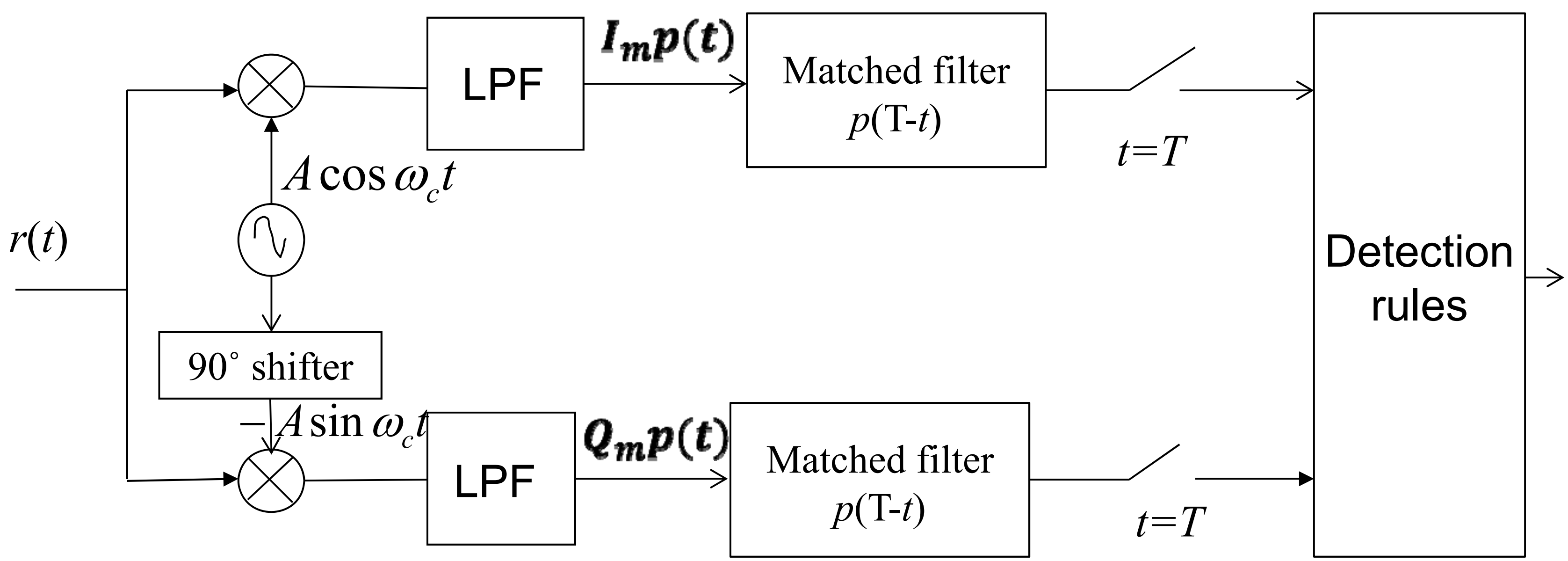
$$y(t) = h(t) * s(t) + n(t)$$

  where h(t) is the linear channel.
- In the previous chapters, we only considered
  - $h(t) = \delta(t)$ → AWGN channel
  - $s(t)$ has finite duration of T for each symbol
- We consider bandlimited channel $h(t)$ and bandlimited signal $s(t)$, because practical systems are all bandlimited.

I-Q transmitter for bandpass signals

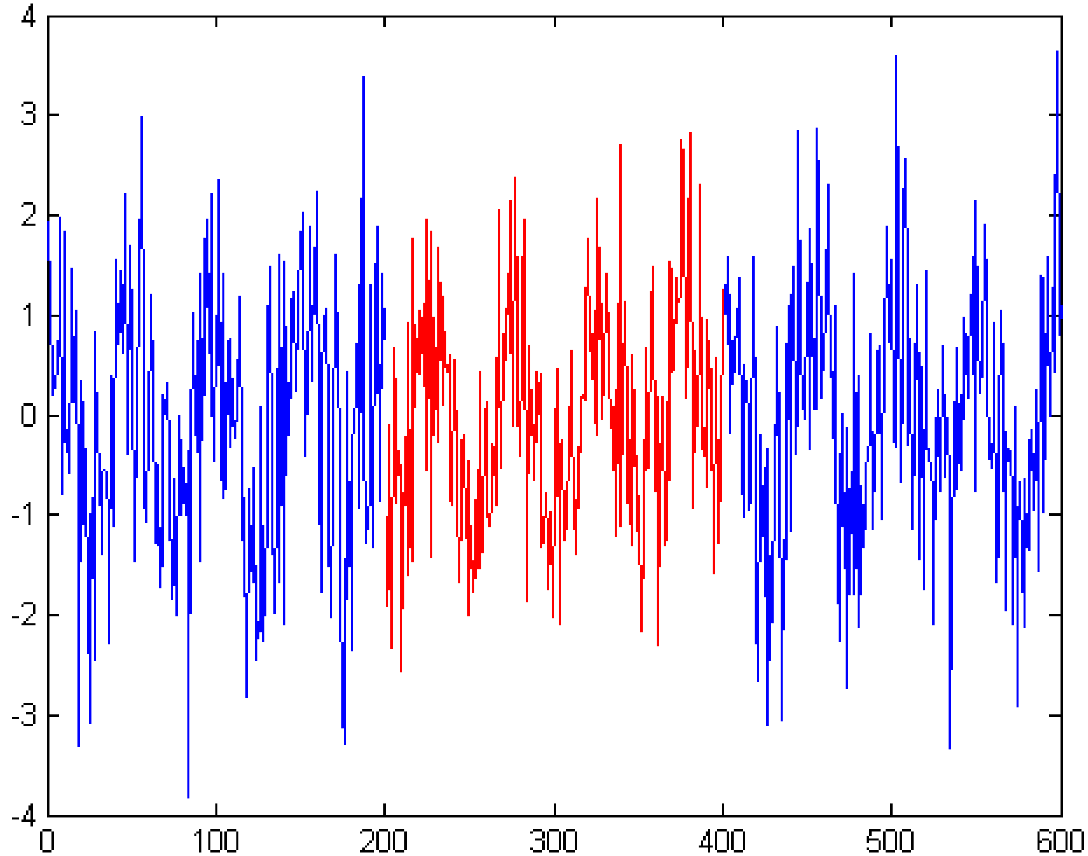


I-Q receiver for 2-D bandpass signals

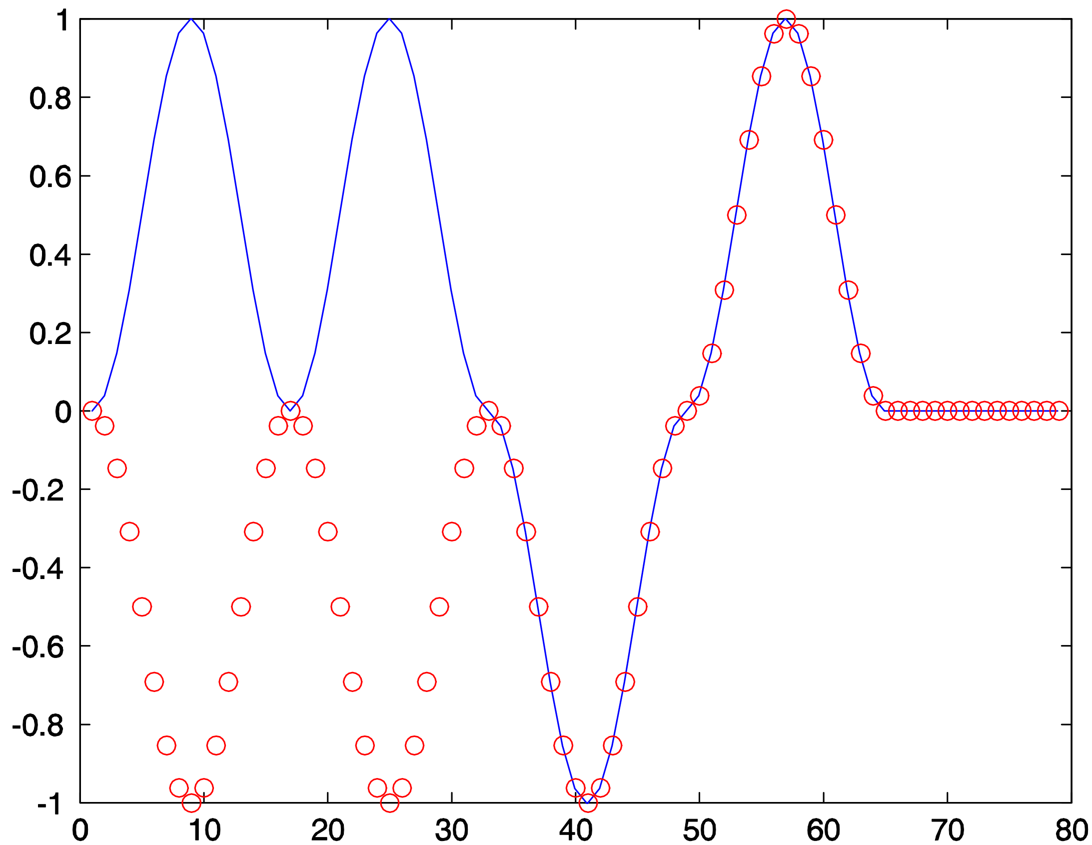


Receiver

- How to detect the transmitted information from the noise corrupted received signal?



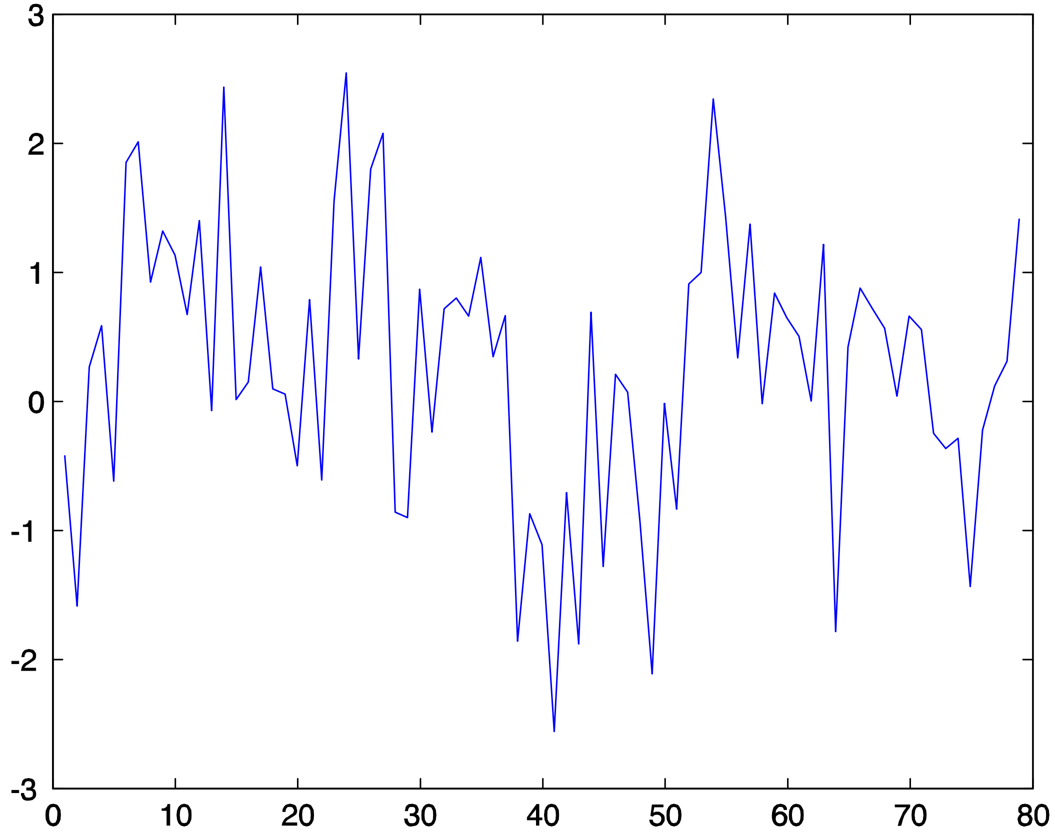
BPSK example



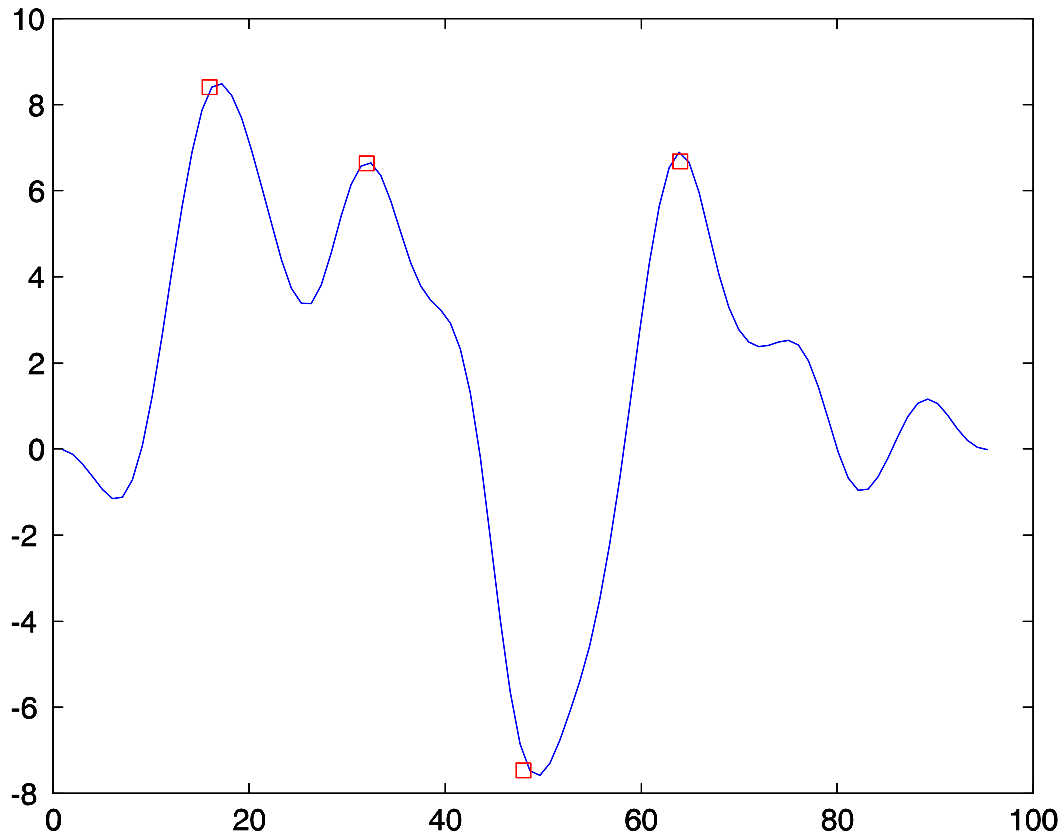
Blue: I
Red: Q (if QPSK)

Received noisy signal

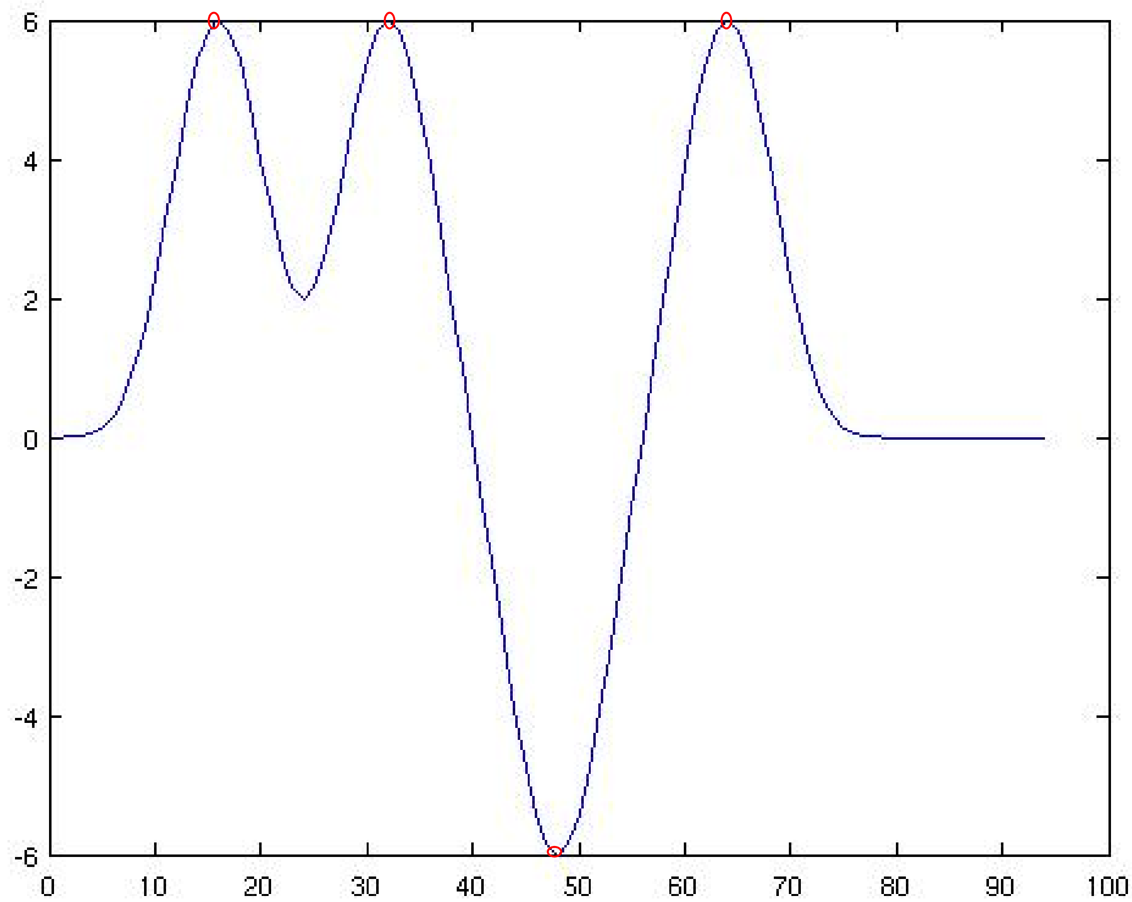
SNR = 5 dB



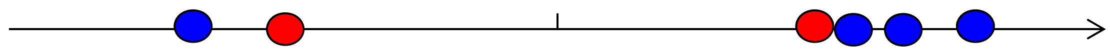
After matched filter and sampling



After MF noiseless signal



Geometric view



Equivalent channel

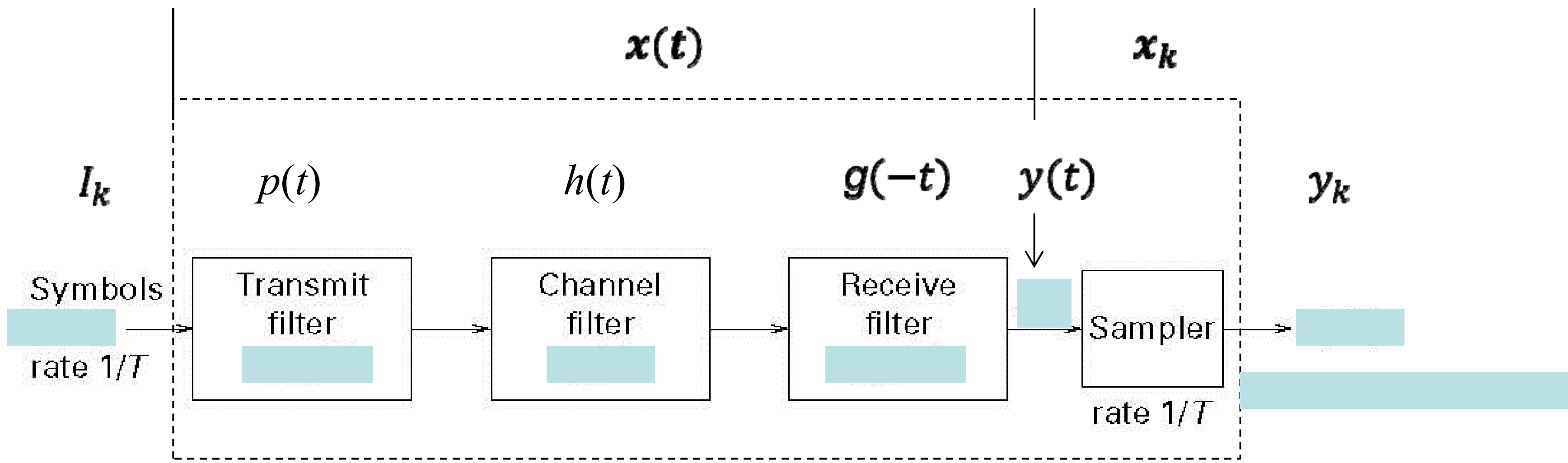


Figure 2.18 Set-up for applying Nyquist criterion.

When is $y_k = I_k$ *?*

LTE Video

- https://www.youtube.com/watch?v=2nsEAw_SirQ&index=2&list=PLE6yE0jB6BTMJXIXw4PS1kOqqZ9ty7eoG