Introduction to the course

Network Design and Planning (sq2016)

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Some of the material is by courtesy of Prof. Biswanath Mukherjee @ UCD
Email, phone, etc..

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- Phone: (530) 366-0076
- Office hours (kemper hall 2245):
  - Thursday 4.30p.m. - 6.00p.m.
  - Also possible to fix an appointment
- Website
  -> ECS289I (SQ16)
Schedule and Aim

• Course
  – Schedule: 27 hours in 6 weeks
    – 4.5 hrs per week
      » 3hrs on Tuesday (6pm to 9pm)
      » 1.5hrs on Thursday (6pm to 7.30pm)
  – We should be done by May 5th with lectures
  – May 12 written exam, May 19th project presentation

• Aim of the course:
  – The course is intended to provide students with a large-spectrum knowledge on mathematical and simulative tools used to design and plan communication networks
Topics

- **Introduction.** Telecom network overview and trend evolution, business models, traffic engineering vs network engineering vs network design, the telecom network hierarchy (core vs. metro vs. access network), overview of technologies and protocols. [1hr]


- **Simulation of a telecom network.** Definition of simulation, discrete event stochastic simulation, generation of pseudo-random numbers, analysis and validation of the results. [4.5hrs]


- **Capacity and Traffic Flow Assignment Problems in Communication Networks.** Delay analysis, the capacity assignment problem, the traffic flow assignment problem, the capacity and flow assignment problem. [4.5hrs]

- **Presentations from students.** [3hrs]

- **Final Exam.** [3hrs]
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</table>
Prerequisites and Material

• **Prerequisites**
  - Basics of networking (ECS 152)
  - Preferably, a basics of Operation Research and Queueing Theory
    - Integer Linear Programming, Branch and Bound

• **Bibliography**
  - Material distributed by the lecturer
Exam

• Basis for Grading
  – 1) Approx. 4 Homework Assignments (1/3)
  – 2) Project (1/3)
  – 3) Final Exam (1/3)
• Current Trends in Telecommunication Networks
• Some «quantitative» considerations on the ICT market
• Network evolution
• Definition of “Network Design” problems
• Current Trends in Telecommunication Networks
• Some «quantitative» considerations on the ICT market
• Network evolution
• Definition of “Network Design” problems
Before we start

- It’s a good time to be in networking
- Data/Telecom networks are no more the exclusive realm of network operators

The world now boasts an estimated 5.3 billion mobile subscriptions, of which 3.8 billion are in the developing world. And Internet users have surpassed the 3-billion mark.
Introduction

M. Tornatore: Communication Network Design

Note: * Estimate
Source: ITU World Telecommunication/ICT Indicators database

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014*

Developing (in millions)
Developed (in millions)
World (%)
Applications for residential users

- P2P files sharing

- IP-TV

- Video Sharing

Youtube™ is the most popular video portal that creates 10% of total Internet traffic and 20% of HTTP traffic. Others video portals are dailymotion.com™ and metacafe.com™
Applications for residential users (2) - IPTV

- Delivery of VoD and interactive IP-based services (e.g. video sharing)
  - A triple-play application
- Already offered by major service providers
- Great expectations on the growth in the number of subscribers
- Customers’ expectations for instant, always-on and personalized service

A new paradigm for the Web

- **Web 1.0**
  - Static html page
  - Separated Content management
  - Isolated information
- **Web 2.0**: a new paradigm where Internet is a service platform allowing a high interaction level with users who are also content providers
  - Blog, forum, chat, e-commerce, reputation feedbacks
  - Wikipedia, Youtube, Facebook, Myspace, Gmail

The mind-map pictured above (constructed by Markus Angermeier on November 11, 2005) sums up some of the themes of Web 2.0
The Cloud Computing Universe

Vertically-integrated services with proprietary Application Programming Interfaces

Who is driving Consumer world?

Who is driving Business world?

Competition fully open

Maurizio Dècina, “Future Networks and Services”, ICC 2011, Kyoto, June 6, 2011
The Internet of the future

- Mobile Broadband
- Cloud Computing
- Network Function Virtualization
- Software Defined Networking
- Internet of things
- Social Media
- Application Store
- eCommerce
- Tablet e Smartphone

What is 5G?
For now, just a set of requirements
5G PPP Vision and Requirements

Key requirements

- 1,000 X in mobile data volume per geographical area reaching a target ≥ 10 Tb/s/km²
- 1,000 X in number of connected devices reaching a density ≥ 1M terminals/km²
- 100 X in user data rate reaching a peak terminal data rate ≥ 10Gb/s
- Guaranteed user data rate >50Mb/s
- 1/10 X in energy consumption compared to 2010
- 1/5 X in end-to-end latency reaching 5 ms for e.g. tactile Internet and radio link latency reaching a target ≤ 1 ms for e.g. Vehicle to Vehicle communication
- 1/5 X in network management OPEX
- 1/1,000 X in service deployment time reaching a complete deployment in ≤ 90 minutes
- Mobility support at speed ≥ 500km/h for ground transportation

Accuracy of outdoor terminal location ≤ 1m

5G Enablers

- SDN
- NFV
- MEC
- CRAN
- ...

M. Tornatore: Communication Network Design
Software Defined Networking

Closed

Features
Control plane
Hardware

SDN Network Operating System

Agent
OS
Loader
Merchant Silicon

Control Apps
Config Apps
Mgmt Apps
Network Function Virtualization

- Networks are populated with a huge number of proprietary hardware equipment performing different network functions (*middleboxes*)
  - Finding places to accommodate them is becoming difficult
  - Hardware-based appliances rapidly reach the end of life

- **Network Functions Virtualisation (NFV)** tries to address the above mentioned issues
  - NFV leverages standard IT virtualization techniques to **consolidate** many network equipment types onto industry standard high volume servers, switches and storage
  - The off-the-shelf hardware can be located in **datacenters**, **network nodes**, **customer premises**
  - Network equipment is implemented as **virtual network function (VNF)** in **software**

[1] *Network Functions Virtualisation, An Introduction, Benefits, Enablers, Challenges & Call for Action, SDN and OpenFlow World Congress, Darmstadt-Germany, 2012*
Network Function Virtualization

Classical Network Appliance Approach

- Message Router
- CDN
- Session Border Controller
- WAN Acceleration
- DPI
- Firewall
- Carrier Grade NAT
- BRAS
- SGSN/GGSN
- PE Router

- Fragmented non-commodity hardware.
- Physical install per appliance per site.
- Hardware development large barrier to entry for new vendors, constraining innovation & competition.

Network Virtualisation Approach

Mobile Edge Computing (MEC)

- **Goal:** to provide IT and cloud-computing capabilities in close proximity to mobile users
- **MEC** means cloud servers running in the mobile edge
- **Scope:** mobile networks and services
- **Motivation:**
  - Ultra-low latency (very short RTT for user interactive apps)
  - High bandwidth
  - Direct access to real-time radio network information (cell-id, UE location, cell load, throughput guidance => location aware).
- **Intendend to perform tasks that could not be achieved with traditional network infrastructure**
- **New value chain with third party partners to develop applications and services**
MEC

Introduction

M. Tornatore: Communication Network Design
• Current Trends in Telecommunication Networks
• Some «quantitative» considerations on the ICT market
• Network evolution
• Definition of “Network Design” problems
Value chain in the ICT sector

Information and Communication Technology (ICT)

- Content providers
  - TV
  - Movies
  - Goods
  - News
  - Advertizing
- Data centers
- ‘Online providers’
- Network
- Telecom network
- Information Technology (IT)

- Telecommunication
- Terminals
- Users Home

Contents:
- Providers
  - TV
  - Movies
  - Goods
  - News
- Data centers
  - ‘Online providers’
- Network
  - Telecom network
- Information Technology (IT)
Overall Value of Italian ICT market (1)

Values in Millions of Euro

<table>
<thead>
<tr>
<th>Year</th>
<th>IT</th>
<th>TLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>19,496</td>
<td>43,115</td>
</tr>
<tr>
<td>2006</td>
<td>19,804</td>
<td>44,040</td>
</tr>
<tr>
<td>2007</td>
<td>20,190</td>
<td>44,200</td>
</tr>
</tbody>
</table>

Source: AITech - Assinform / NetConsulting

Unfortunately we went from growth to contraction

- Telecom is largely predominant
Mobile is still the “cash-cow”

Source: Assinform / NetConsulting (September 2011)
The value chain in Internet

- 62% revenues from online services, 17% from connectivity
- 62% revenues from business users, 38% from consumers
- 80% business revenues from online services

Source: AT Kearney, 2010. (Year 2008 data)
Just to have an idea

- USA 2012 GDP (similar to national debt): 16000 billions
- Telco industry is worth 12% of it!!
• Current Trends in Telecommunication Networks
• Status of the ICT market in Italy
• Network evolution
• Definition of “Network Design” problems
Network evolution: convergence

1890
- Telephone Net.

1950
- Television Net.
  - TV
  - Set-Top-Box
  - Trasmettitore

1970
- Data Network
  - PC
  - Client

1980
- Internet
  - PC
  - WS
  - Gateway
  - Router
  - LAN
  - WAN
  - Server
  - TCP/IP
  - cavo
  - software
Telecom Network Overview

Long haul
- 100s-1000s km
- Mesh
  - Mainly WDM networks (OTN)

Metro (interoffice)
- 10s of km
- Rings
  - Sonet/SDH, GE, RPR

Access
- a few km
- Hubbed rings, PONs
  - Dial-up modems, xDSL, T1/E1

Users
Telecom Network Hierarchy
Internet Growth

Internet Domain Survey Host Count

July 2012 - Total Host Count 1,048,766,623

Internet Domain Survey Host Count

Source: Internet Systems Consortium (www.isc.org)
Traffic Growth

[S.K. Korotky, OFC 2012]

- RHK - NA
- McKinsey - NA
- MINTS - Global
- ATLAS – Global
- Cisco Forecast – Global
- Regression

**Annual Growth Rate (%)**

**Year**

- 1995
- 2000
- 2005
- 2010
- 2015
- 2020
- 2025

**Data Network Traffic**

- 100 Tb/s
- 10 Tb/s
- 100 Gb/s
- 10 Gb/s

**2 dB/year (58%/year)**

**US Data Network Traffic**

- 60%
- 10 log_{10}(1.6) dB
- 2 dB
The content “big bang”

- More than 15 billions of Web pages by the end of 2002 – 281 by the end of 2008!!
- Annual Growth ~100%
- More than all data contained in any digital or physical support in the rest of the world:
  - Paper – Film – Optical – Magnetic Storage

Source: UC Berkeley

Source: Sims University of California at Berkeley, November 2003
Big Data

- Big data is data that exceeds the processing capacity of conventional database systems.
- New effective «ICT approaches» are needed to tame the volume, velocity, and variability of big data.
- The challenges include capture, curation, storage, search, sharing, access, analysis, and visualization.
Optical Networks & BigData (1)

It all started with Lambda grids, consisting of:

- high capacity pipes connecting the grid sites;
- storage and computing resources (supercomputers, clusters)

Lambda-Grid Implementations (for large-scale scientific applications):

- National LambdaRail
- DOE UltraScience Net
- Canarie CA*Net
- European Geant (Phosphorous)
- CHEETAH testbed
Energy scalability of the Internet

- Energy consumption of the net grows with average access rate
- Let us assume 33% of world population is connected to the Internet

<table>
<thead>
<tr>
<th>Access rate</th>
<th>1 Mbit/s</th>
<th>10 Mbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption</td>
<td>100 GW</td>
<td>1 TW</td>
</tr>
<tr>
<td>% of world’s 2007 electricity supply</td>
<td>5%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Most of the energy consumption will come from high capacity router switch situated in the core

Baliga et al., COIN/ACOFT, June, 2007
• Current Trends in Telecommunication Networks
• Status of the ICT market in Italy
• Network evolution
• Definition of “Network Design” problems
What’s network design?

• Network design
  – Put the bandwidth where the traffic is forecasted to be

• Traffic engineering
  – Put the traffic where the bandwidth is

• Network engineering
  – Put the bandwidth where the traffic is

  – Traffic typologies
    • Static, dynamic, scheduled, incremental...
Business model & Design perspective

- Network operator
  - Level 3, PG&E (?)
- Service provider
  - Netflix, Google (HyperGiant?)
- Network operator AND service provider
  - AT&T, Verizon
- Bandwidth broker
  - Many service provider, many network operators and a bandwidth broker which manages negotiation between them
    - 60 Hudson in New York, AMPATH in Miami, Palo Alto Internet Exchange (PAIX) in Palo Alto, Startap in Chicago
Hyper Giants

Figure 1. Internet evolution [1]: a) 1995-2007; b) 2009.

Table 1. ATLAS top 10 public Internet bandwidth generating domains [1].
Different planning problems, different metrics

• Network design
  – Optimization Metric: cost, energy, capacity
    • Note on cost: CAPEX vs OPEX!

• Traffic engineering
  – Blocking probability
    • Connection vs. Bandwidth Blocking Probability

• Network engineering
  – Upgrade time, upgrade cost, blocking, penalty, exhaustion probability, etc....
From Static to Dynamic Traffic (1)

- Traditional planning: Static Traffic

<table>
<thead>
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<th>2</th>
<th>3</th>
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</table>
But traffic varies…

Scheduled Traffic
- Duration is known
- Starting time is also given

at instant $t_0$ we have a complete knowledge of future connections
TABLE I
EXAMPLE OF THREE SCHEDULED LIGHTPATH DEMANDS (SLDs)

<table>
<thead>
<tr>
<th>No.</th>
<th>s</th>
<th>d</th>
<th>n</th>
<th>α</th>
<th>ω</th>
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<td>17:00</td>
<td>19:30</td>
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</table>

Fig. 2. Two alternative routing solutions for the SLDs of Table I.
Dynamic Traffic
- Starting time of connections is not known in advance
- Two options:
  - Duration Aware knowledge of connection duration can be used to improve network utilization
  - Duration Unaware

At instant $t_0$ we don’t have knowledge of future connections,
Incremental Traffic: once connections are routed, they stay in the network.
Analytical models and tools

- Static traffic:
  - Integer Linear Programming
  - Heuristic Optimization
- Dynamic Traffic
  - Simulation
  - Markov chains (analytical approach)
- Incremental
  - Exhaustion, multi-period planning
Challenge: cross-layer network planning

Applications

Network Architect

Physical Layer

("Customer" needs)

Differentiated Services:
Bandwidth: OC-192, OC-48, ..., STS-1, VT1.5, ...

Failure-Recovery Delay: The "50-ms myth!"

Network Economics: Pricing, SLA, ...

(Design, TE, ...)

+ routing protocols to combat optical channel impairments
+ breakthroughs needed in device technologies?
- optical RAM, ultra-wideband amp, "tunable" AWG, ...

(optical/wireless channel) -- materials, devices, subsystems
Central Europe Fiber Routes
Asia-Pacific Fiber Routes

ASIA-PACIFIC TERRESTRIAL AND UNDERSEA FIBEROPTIC ROUTES PLANNED AND IN PLACE
South Korea Fiber Routes
Global (Undersea) Fiber Routes
Before Starting: Switching

• Function performed by switching elements
  – To associate an exit to an entry for each informative unit (UI)
    • Nb: P2p vs p2mp

• Specifically, 2 sub-functions
  – Routing
    • Decisional function (choose the exit)
    • Need routing algorithms
  – Forwarding
    • Implemental/executive function

• Two main paradigms/approaches
  – Circuit Switching
  – Packet Switching
Packet Switching

A

X

Y

Z

B

Spazio

Propagazione

Trasmissione

Elaborazione

Attesa

Ritardo end-to-end

L/f₀

L₀/f₀

Lₚ/f₀

Lₚ₀/f₀

Tempo
Circuit Switching
Backup slides