Opportunities in Communication

John M. Cioffi

Hitachi Professor Emeritus of Engineering
Communication uses and applications
Basic Communication (digital)

- Communication is fundamental to all we do (information is the natural resource)
  - Up there with water, electricity, food, ...
  - Sender chooses a message to send (can be from large set)
  - Channel will distort this message (maybe a lot or maybe only slightly)
  - Receiver attempts to decide what the message was (mathematically “detection”)

- Talking, texting, sending/viewing video, searching on internet, facial recognition, radar, lidar, ....
Traditional Internet Service Provider Comm Channels

**Messages**
- Internet
- Email
- Text
- Video, audio
- Sensor/camera images

**Channels**
- Fiber, copper
- Wireless
- Many or single
- Mesh

**OSI Model**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
<th>Example Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application Layer</td>
<td>network process to application, HTTP, FTP, SSH</td>
</tr>
<tr>
<td>6</td>
<td>Presentation Layer</td>
<td>data representation &amp; encryption, XML, JSON</td>
</tr>
<tr>
<td>5</td>
<td>Session Layer</td>
<td>interhost communication, Mostly theoretical</td>
</tr>
<tr>
<td>4</td>
<td>Transport Layer</td>
<td>end-to-end connections &amp; reliability, TCP, UDP</td>
</tr>
<tr>
<td>3</td>
<td>Network Layer</td>
<td>path determination &amp; logical addressing, IP Addresses</td>
</tr>
<tr>
<td>2</td>
<td>Data Link Layer</td>
<td>physical addressing, MAC Addresses</td>
</tr>
<tr>
<td>1</td>
<td>Physical Layer</td>
<td>介质 signal &amp; transmission, Ethernet, Bluetooth, Wireless</td>
</tr>
</tbody>
</table>

**OSI = ?**

**Open Systems Interconnect**

How much money spent on connection Subscriptions by consumers globally?

$1.3T
Any one spot a problem?

- Delayed signal could be 180 degrees out of phase at some frequencies
  - What happens then?
- Solution: Exploit the dimensions
  - use/leverage other frequencies that reinforce (frequency dimensions)
  - Look only in one direction (spatial dimensions)

This could be a reflection
Also (building, mountain, etc)
Not so traditional – Search Engine

Yes, a search engine is also receiver/detector – decides which pages to display ("page rank")
- Searches among many possible messages

The channel output is the typed phrase
- That channel-output phrase for this user has a message (page or group of pages) detected for it

Dimensions are the words, phrases, context, etc (along with some history and user knowledge or "cookies")

The ultimate receiver is the woman herself – she decides to click on one of the displayed pages
- "iterative decoding" – the system may refine the decision with additional passes (more dimensions added)
Self-Driving Cars

- Messages to be estimated
  - Relative position
    - Chan out = Lidar reflection
    - delay = distance = position
  - Route
    - Channel out = destination
  - Location: current, anticipated
    - Chan out = GPS coordinates, recent locations
    - Message is the position
  - Driver ID
    - Chan out – facial image, finger prints (cameras in or out)
  - Time
    - Chan out = electronic ref, GPS, base station signal
  - Info to/from other vehicles
    - Chan out = Wi-Fi, Bluetooth, other

- So self-driving cars have many communication channels and receivers
  - Multi-dimensional in many ways
Drones/Satelites and Communication

- Messages
  - Emails/web pages
  - Tests/chats
  - images
  - Video
  - Audio

- Channel
  - air
  - Moving fast
  - attenuates
  - noise

Dimensions are in time, possibly space (multiple antennas)
3D Cameras (images and videos)

- Messages =
  - Sporting event
  - Traffic conditions
  - Security/intruders
  - People/faces

- CHANNEL OUTPUTS
  - Visible spectrum
    - Obstacles (opaque) affect this
  - Multiple paths
  - 2D arrays of pixels
    - Multiple places

Who is in the photo?
Manufacturing/Factories

- **Messages**
  - Status of “widget”
  - Test results
  - Position of machines
  - Position of “widget”
  - faults

- **Channel**
  - Wired and/or wireless
  - Interference from others
  - Sensor and other low-power limitations
Health Care

• Messages
  ➢ Diagnostics
    Sensors around the body
    Sensors in the body

  ▪ Channel .. could be
    ➢ Half-way around world
    ➢ From internal organ to cellphone
    ➢ Unusual propagation
    ➢ Very high frequencies within body
      ➢ Or very low frequencies (pills with radios)
Agriculture – Feed the world better

- **Message**
  - Plant status
  - Animal status
  - Water, fertilizer levels
  - Machine position

- **Channel**
  - wireless
  - To drone, satellite, local AP
Smart Cities and/or Smart Homes

- Messages – appliance status, typical internet messages,
- Channel – wireless and wires, many paths
Despite all our communication algorithms/knowledge
Self-Driving Auto Rage coming? 😞
Patient Rage even worse?

Security as service, privacy as service?
- What happens if these have outage?
Basic Communication
3 Basic Problems to Solve

- **CHANNEL IDENTIFICATION** – what kind of limits does it have, does it vary, vary with what?

- **CODING** - What is a good (best) set \( X \) for a given channel?

- **DETECTION** – What is a good (best) receiver for deciding \( X \)?

The same 3 problems occur in Machine Learning
Simple Additive White Gaussian Noise Channel

Detection Problem First

- Pick closest point
- For AWGN
- Maximum Likelihood
  - Uniform input distn

Pick closest point is maybe obvious, But also mathematically optimum
The Intersymbol Interference (ISI) Channel

- The ISI channel with additive white Gaussian Noise (AWGN)

\[ n(t) \]

\[ X_k \rightarrow p(t) \rightarrow + \rightarrow y(t) \]

Every T seconds, a symbol is transmitted – the channel “stretches” them and causes “intersymbol interference (ISI)”

- Most detection designed for no band limitations, but how about this bandlimited ISI Channel?

- Equalization??

Channel sums message with .9 x message delayed T sec

“Enhances” the noise
Multiple carriers/dimensions in frequency

- How do we learn and adjust
  - Dynamically
- Some of very first AI methods in com (from Stanford)

Use “bit-swapping” AI/ML Method – SU patent #3 in Engineering (#7 overall)
2 x 2 Antenna System (MIMO)

- There is crosstalk between dimensions (kind of like ISI, just different dimensions)
  - Can actually double the data rate if right signal processing used (and antennas are not too close)

\[ y = P x + n \]
\[
\begin{bmatrix}
1 & 0 \\
-0.8 & 1
\end{bmatrix}
\sim R_{nn} = E[n \cdot n^T]
\]
\[ \sigma^2 = 0.1 \]
Multiple directions in Space

Best Energy will also be water-fill over
The singular vectors of the channel

Essentially matrix form of machine learning
From earlier
MU-MIMO (multi-user) involves more learning/factoring

Virtually all communication problems can be cast into the
Same theory of finding the critical modes of channel
An Example from the field
A Network State Machine

- Net may be in a state
- GYR
  - More detail
- Relates to more traditional models
• Strong correlation between WiFi problems and Complaint Rate
• 48% of APs have WiFi issues
• Customers identified as having poor Wi-Fi performance are 5 times more likely to complain

Selling more mesh points to ISP often increases instability percentage
Root Causes of Wi-Fi QoE Degradation – 2.4GHz

- Interference
- Coverage
- Noise

- Top Three Wi-Fi Problem Drivers
  - Correlated with the main User QoE
Coverage (noise) & signal strength

Crosstalk

who controls phy
Cocktail Party Effect (crosstalk)

- **Solution:** All speak politely at low volume (lower power)
  - All send more information (more power and/or higher data rate)
- This can be learned and optimized
- **EG:** Wi-Fi Box/Chips blasting at 1-10 Gbps!
  - Or worse yet – install repeaters/mesh and have them all blast
  - Or use MU-MIMO when 3 people are collinear (BAD)
Chip X’s “Auto-Channel” vs ML Cloud Optimization

<table>
<thead>
<tr>
<th>Throughput</th>
<th>Pre-Optimization Population %</th>
<th>Post-Optimization Population %</th>
<th>%Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 3M</td>
<td>12.3%</td>
<td>4.7%</td>
<td>61.5%</td>
</tr>
<tr>
<td>≤ 5M</td>
<td>20.9%</td>
<td>11.4%</td>
<td>45.5%</td>
</tr>
<tr>
<td>≤ 10 M</td>
<td>42.8%</td>
<td>28.6%</td>
<td>33.3%</td>
</tr>
</tbody>
</table>

62% reduction in Wi-Fi below 3Mbps
45% reduction in Wi-Fi below 5Mbps
**Optimization, QoE, and Stability**

based on several hundred million daily internet users

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### Consumer Survey

- **Did your overall performance improve with management?**
  - Yes: 40%
  - No: 53%
  - Neutral / Not sure: 7%

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### Machine-Learned Stability

- **United Kindom**
- **France**
- **USA**
- **Canada**
- **Hungary**
- **Germany**
- **Romania**
- **Czech Republic**

**Stability improvement**

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**Unmanaged Internet connections**

- Globally ~20% of unmanaged fixed connections are unstable each month!

**Dynamic (optimized) Managed Connections**

- Often see the above numbers drop by ½ or more
- From experience both in electronic measures and consumer feedback
QoE Time Trend learned (300k IPTV customers)

- Note the dynamic learning and adjusting ongoing
Data Wars Game

- Uses FM loading on several cross-talking links/connections
  - Signal from other user is treated as Gaussian noise

If Link 2 could use lower energy, then Link 1 sees less noise \( \Rightarrow \) Link 1 loads to higher data rate

But Link 2 might want Link 1 to save energy so it can transmit faster

Who wins – sometimes called “the prisoner’s dilemma” in game theory
Example for 25 users all sharing same spatial channel

- 25 users all sharing same spectrum
  - Near-end ("echo") as well – grows with $f^{1.5}$ and far-end ("xtalk") attenuates with same transfer but has additional $f^2$ coupling.
  - Each effects the other 24 users
  - All are of same distance between xmit/rcvr

- Speeds roughly double
Spectra after convergence

- The echo-crosstalk is strong – see “FDM” effect between down and up

- It was all learned by water-filling
  - No clever designer
  - No FCC / regulator

- Called “cognitive radio” by some

- Not best, but pretty good!

- Can work with different topology, rates, etc

- How’s that for Machine Learning, eh?
Virtualization – Software Defined Network
Converged Virtual 5G networks (fixed & wireless lines)

Virtual Network Operators Need “functions” (VNFs)

Infrastructure Provider Software-Defined-Network (SDN)

- Single infrastructure shared by multiple operators
X-Haul – basically allows for just ADC/DAC at antennas

• Increasingly everything in software
  ➢ For most/all connections

5GPP X-Haul Group
The Opportunity

• 4B people using internet → hopefully all
  ➢ They all need, and increasingly depend seriously, on the connection

• It affects all applications
  ➢ The new hot ones of today
  ➢ The old voice, video
  ➢ The ones we don’t know yet

• These networks and problems will always be there
  ➢ And need help, design, improvement from EE’s – like those in this class!
Thank you

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