Speed/Performance

Frustrating!

- Very disappointing!

  Why am I getting only a few % of the advertised 3G (or 4G, LTE, 5G) speed?

- It is advertised that the 3G downlink speed for stationary users should be 7.2 Mbps.

- When you try to download an email attachment of 3 MB, it often takes as long as one and half minutes.

  – 3 MB equals 24 Mbits; therefore downloading the attachment shouldn't take longer than 4 sec!

- You get around 267 kbps, 3.7% of what you might expect.

- Who took away the 96%?

Things Are Confusing! (1/2)

- Specs are decisions within Standardization bodies, which may not be universally accepted.
- The terms 3G, 4G, and 5G can be confusing.
  - One track following the standardization body 3GPP (3rd Generation Partnership Project) called UMTS (Universal Mobile Telecommunications System) or WCDMA
  - Another track in 3GPP2 called CDMA2000 (Code Division Multiple Access).
- Each also has several versions in between 2G and 3G, often called 2.5G, such as EVDO (Evolution-Data Optimized), EDGE, etc.

Things Are Confusing! (2/2)

- For 4G, the main track is called Long Term Evolution (LTE), with variants such as LTE light and LTE advanced.
- Another competing track is called WiMAX.
- Some refer to evolved versions of 3G (e.g., HSPA+) (HSPA = High Speed Packet Access) as 4G too.
- 5G is the term for new mobile technologies. Definitions differ and confusion is common. The ITU IMT-2020 (ITU = International Telecommunication Union, IMT = International Mobile Telecommunications) standard provides for speeds up to 20 gigabits per second and has only been demonstrated with millimeter waves of 15 gigahertz and higher frequency.
- All these have created quite a bit of confusion in a consumer's mind as to what really is a 3G (or even 4G and 5G) technology.

Trends

- Many countries have moved toward LTE.
- They use a range of techniques to increase the spectral efficiency, defined as the number of bits per second that each Hz of bandwidth can support.
- These include methods like OFDM (Orthogonal Frequency Division Multiplexing) and MIMO (Multiple-Input and Multiple-Output), and Cell Splitting (splitting a large cell into smaller ones).
- But the "user observed throughput" in 4G, while much higher than that for 3G, still falls short of the advertised numbers we often hear in the neighborhood of 300 Mbps.
- Why is that? Will 5G make a difference?

Two Main Reasons

- There are two main reasons:
  - non-ideal network conditions
  - overheads.
- Many parts of the wireless network exhibit non-ideal conditions, including both the air-interface and the backhaul network.
- Furthermore, networks, just like our lives, are dominated by overheads, such as the overhead of network management in the form of control bits in packets or control sequences in protocols.

Speed Reduction

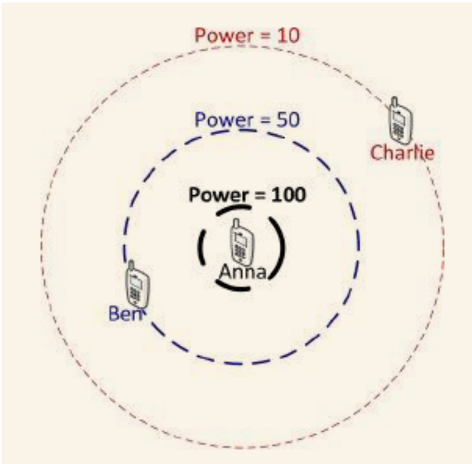
- Useful throughput is defined as the number of bits of actual application data received, divided by the time it takes to get the data through.
  - It is some form of average.
- This is what you “feel” you are getting in your service, but might not be what advertisements talk about or what speed tests measure.

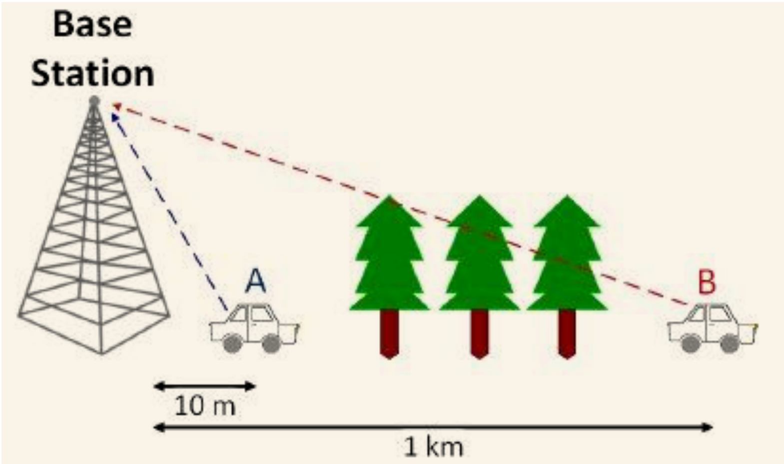
The Culprits

- Air-interface
- Backbone (or Backhaul) network
- Network (Communication) Protocols
- Simple Network Management Protocol
- Mathematical Modeling, Simulations, and Testing

Air-interface: Physical Characteristics

- Propagation channel degradation:
  - path loss (the signal strength drops as the distance of propagation increases),

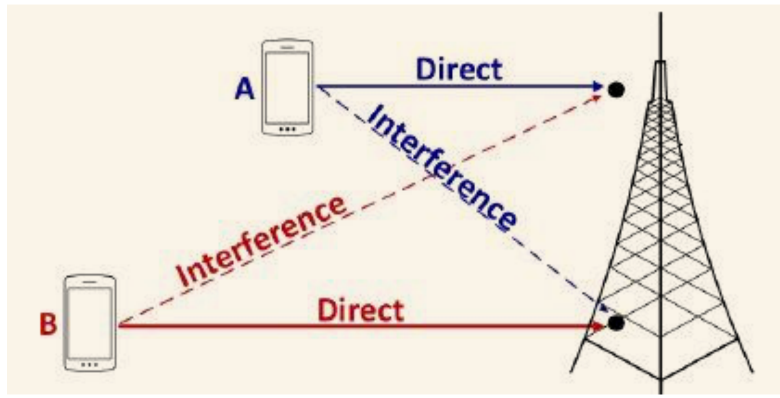




  - shadowing (obstruction by objects), and
  - multipath fading (each signal bounces off of many objects and is collected at the re- ceiver from multiple paths)

Air-interface: Interference

- There are many users, and they interfere with each other.

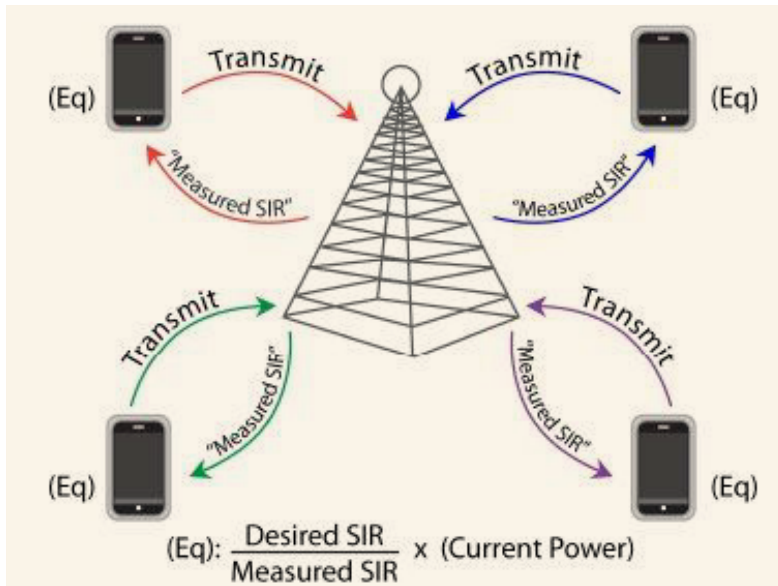


- Received SIR (Signal to Interference Ratio) might be so low that modulation needs to be toned down and transmission rate reduced so that the receiver can accurately decode.

- Typical instance of the problem in CDMA networks is the near far problem: Even power control cannot completely resolve this problem.

Backbone: Multiple Links

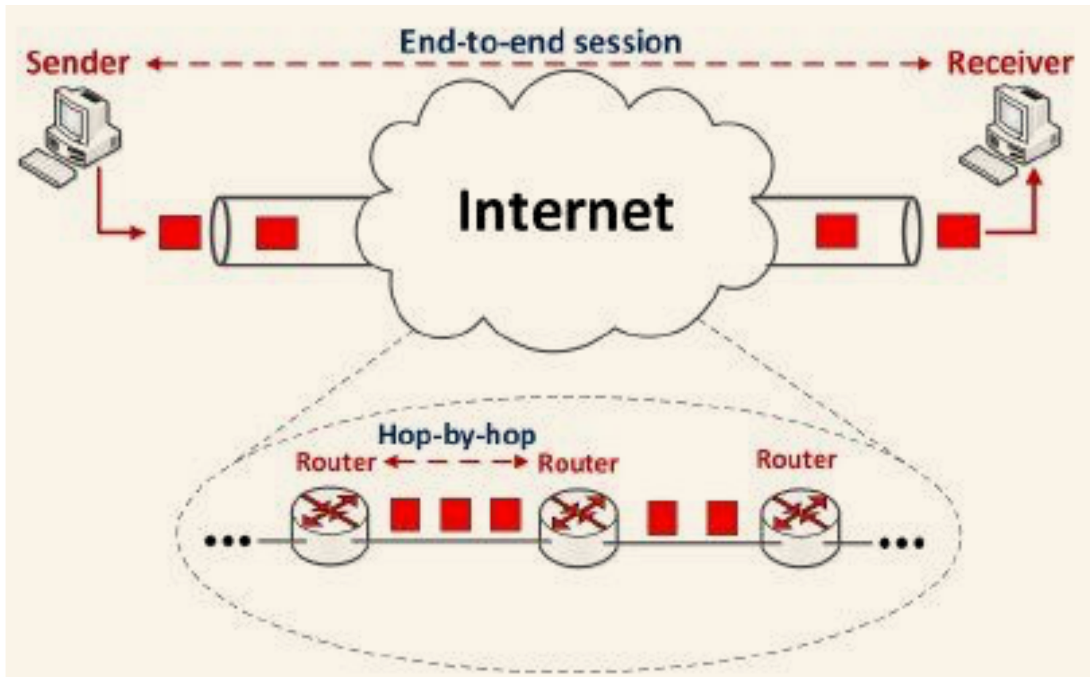
- There can be more than ten links traversed from the base station to the actual destination on the other side of a wireless session of, say, YouTube streaming.



- Links: Users' traffic competes with the traffic of other users on the links behind the air-interface in the cellular network.

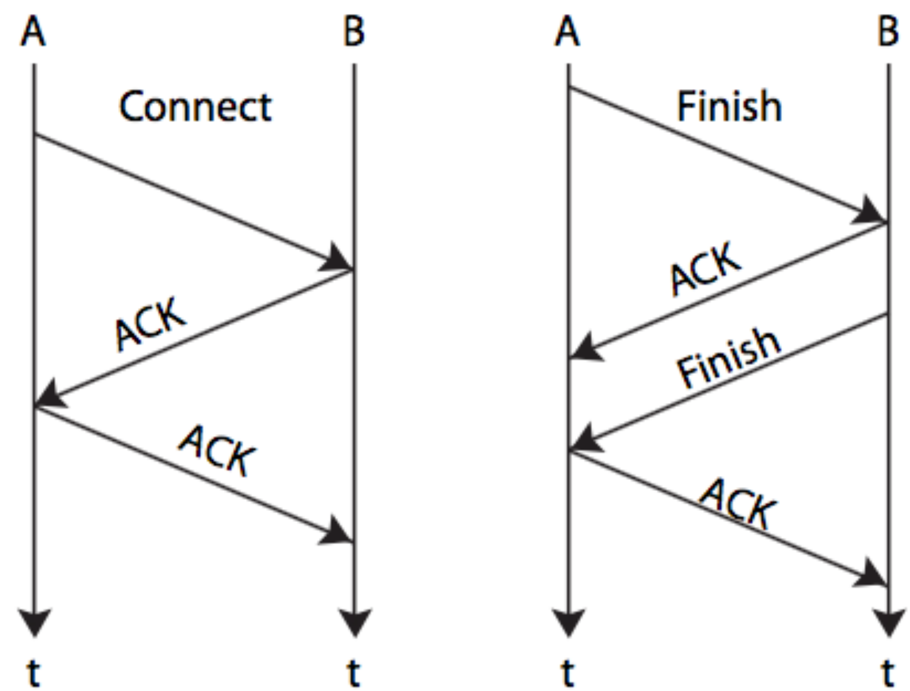
Backbone: Multiple Links

- Nodes: These links are connected through nodes of various kinds: gateways, switches, routers, servers, etc.



Protocols: Semantics

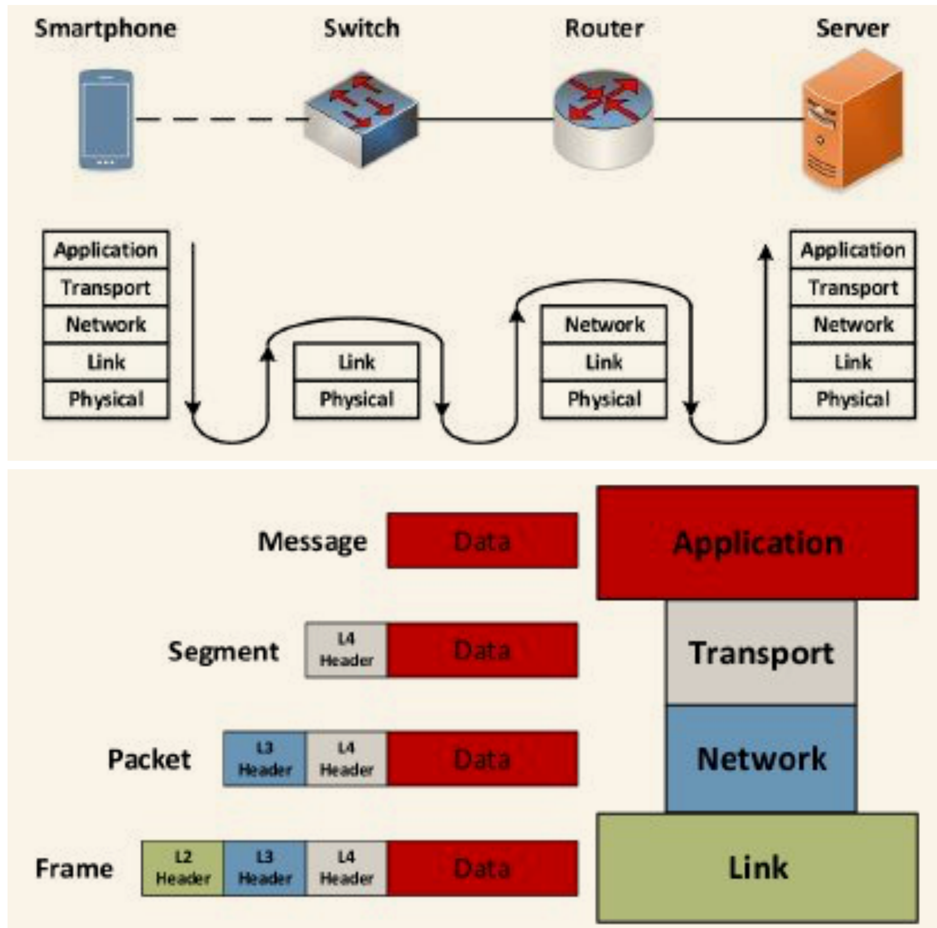
- Protocol semantics: Many functionalities require sequences of message passing.



- Are the protocols adequate?

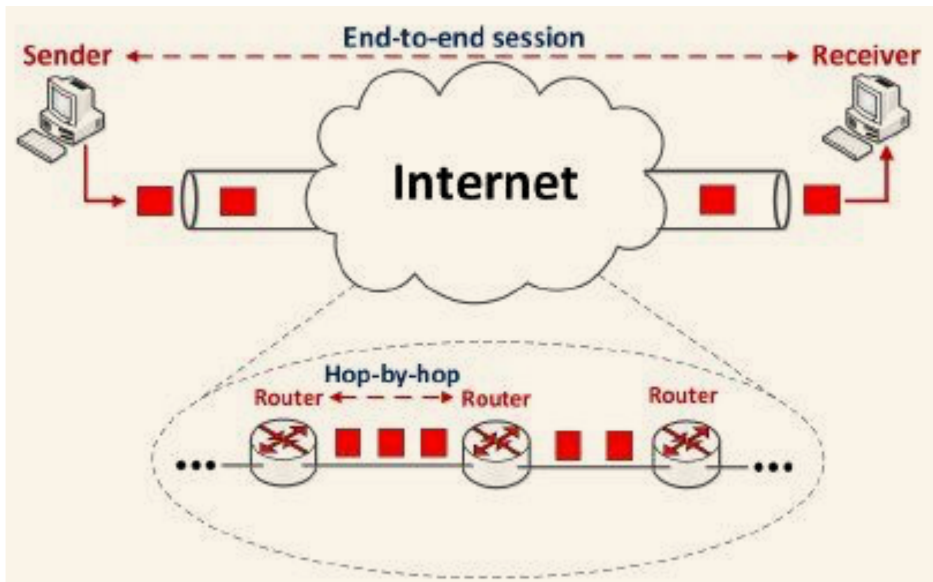
Protocols: Packetization

- Each layer adds a header to carry control information: address, protocol version number, quality of service, error check, etc.



Protocols: Control Plane Signaling

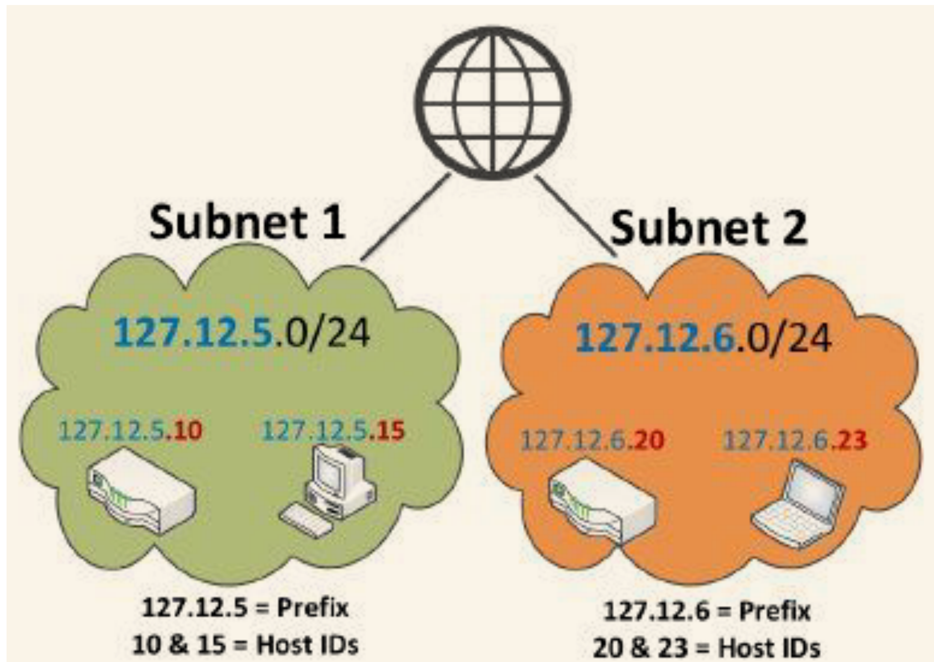
- Actual data traffic flows on data channels (a logical concept, rather than physical channels), while control signals travel on control channels. Control signals may have to travel half of the world even when the source and destination nodes are right next to each other.



  – E.g., the actual traffic of people and cargo is carried by airplanes flying between airports following particular routes.

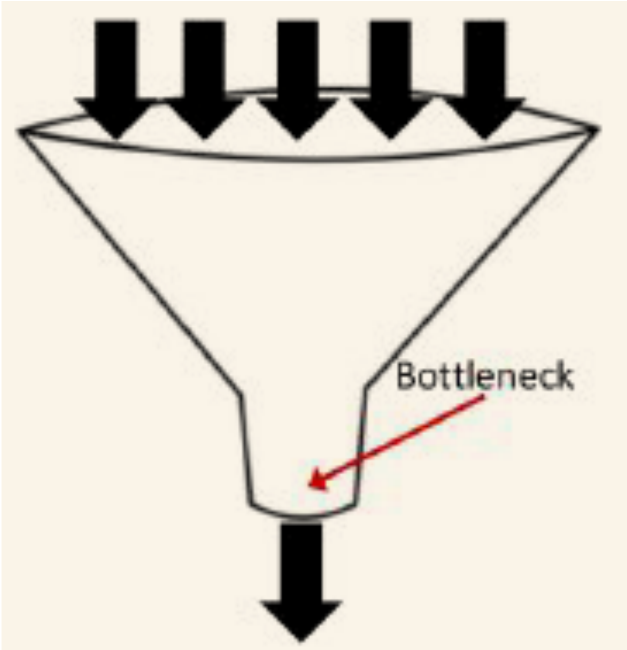
Protocols: Addressing

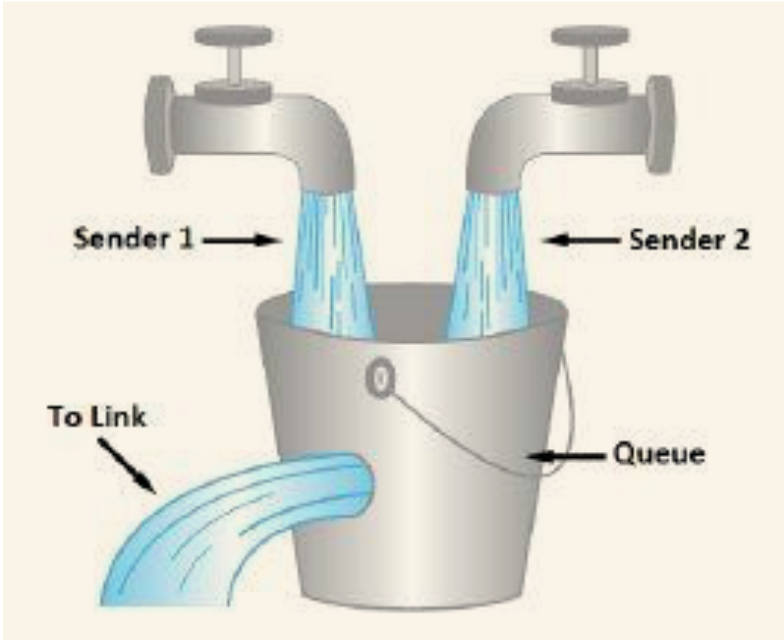
- Data cannot be routed and will be lost unless proper addressing schemes are used.



Bottlenecks

- All these issues create bottlenecks.





- Unless flow is managed bottlenecks can form.

Paradigms Help!

- Traffic scenarios tend to offer great analogies to communication networkss.

Simple Network Management Protocol (SNMP)

- Performance:
  Monitor, collect, and analyze performance metrics.
- Configuration:
  of the control knobs in different protocols.
- Charging:
  Charge each network usage in time-dependent pricing.
- Fault-management:
  Monitor to see whether any link or node is down, and then contain, repair, and root-cause diagnose the fault.
- Security:
  authentication, integrity, and confidentiality

Speed? What Speed?

- Improving Technologies in 802.11

Standard	Year	Frequency (GHz)	Maximum Speed (Mbps)
-	1997	2.4	2
b	1999	2.4	11
a	1999	5	54
g	2003	2.4	54
n	2009	2.4 & 5	100

What is the Speed of my Network?

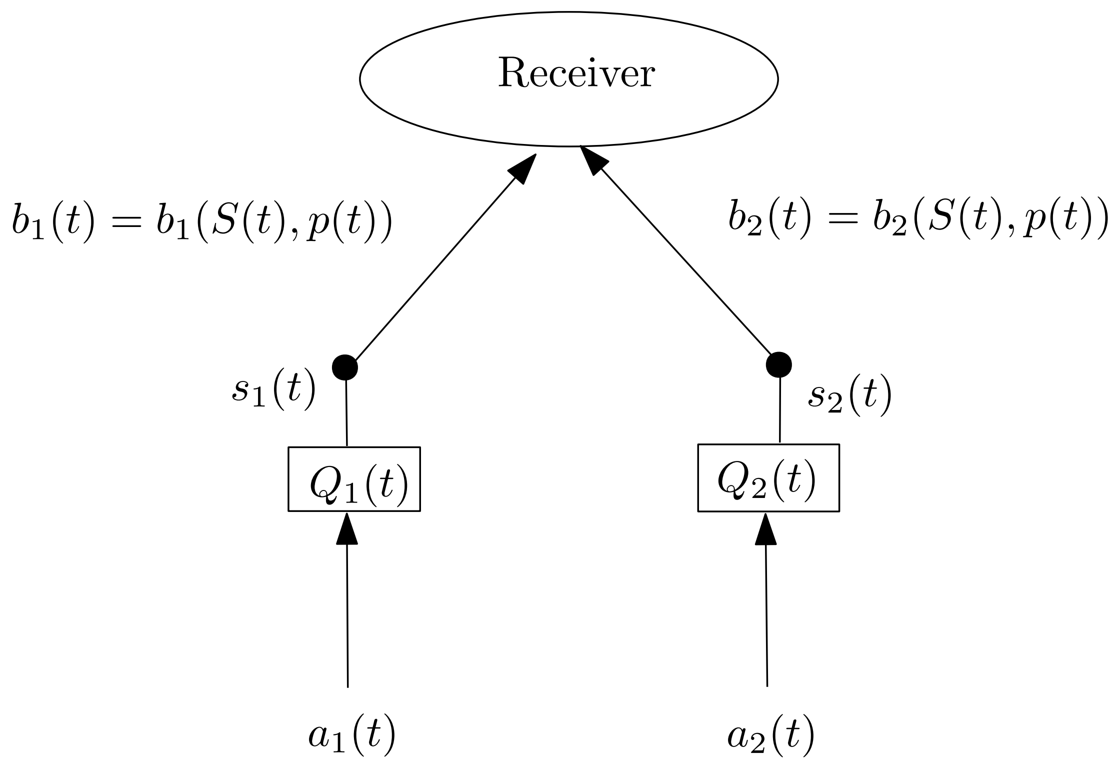
- The speed of your wireless (or wireline) Internet connection is not one number, but many numbers depending on the answers to the following four questions,
  - Which layer? MAC layer: Medium access control, RLC layer: Radio link control, and PDCP layer: Packet data convergence protocol.
  - Where is it measured? Depending on the locations of the two end points.
  - When is it measured? Traffic intensity during different hours of the day.
  - What application? Different traffic runs different sets of protocols and user utility and expectation.

Mathematics, Simulations, and Testing

- Mathematics plays an important role.
  - There is a need for adequate mathemarical models that address the problems.
  - There is a plethora of such models, but not all models are the same.
- Simulations are needed to confirm the mathematical analysis.
- Testing of the models required in real world environments.

Mathematical modelling and analysis (1/2)

- Consider a 2-user wireless uplink that operates in slotted time $t \in \{0, 1, 2, \ldots\}$.



- Every time slot new data randomly arrives to each user for transmission to a common receiver.

Mathematical modelling and analysis (2/2)

- $(a_1(t), a_2(t))$ is the vector of new arrivals on slot t, in bits.
- Data is stored in queues $Q_1(t)$ and $Q_2(t)$ to await transmission.
- Receiver coordinates network decisions every slot.
- Channel conditions $S(t) = (S_1(t), S_2(t))$ on slot t may change from slot to slot between users and the receiver.
- Every slot t, the network controller observes the current $S(t)$ and chooses a power allocation vector $p(t) = (p_1(t), p_2(t))$ within some set P of possible power allocations.
- This decision, together with the current $S(t)$, determines the transmission rate vector $(b_1(t), b_2(t))$ for slot t, where $b_k(t)$ represents the transmission rate (in bits/slot) from user $k \in \{1, 2\}$ to the receiver on slot t.

Exercises[a]

1. The cellular backbone consists of some links (e.g., microwave links, free-space optical links, satellite links) that connect the air-interface with the rest of the end-to-end path, and then the cellular core network, and, finally, the public IP network. Discuss how can all these factors reduce the useful throughput.

2. The Internet is complex (in number of tasks it has to manage) and big (in number of users). Discuss how hierarchical assignment plays an important role in end- to-end sessions: a YouTube streaming session from Google servers to your iPhone may traverse a wireless air-interface, a few links in the cellular core network, and then a sequence of even more links across possibly multiple ISPs in the public Internet.

3. Consider the two-queue system in the slides on mathematical

[a] Not to hand in!

modelling and analysis.

(a) Assume the arrival rate at $a_i(t)$ is $10i$ bits per sec, for $i = 1, 2$. What is the arrival rate per sec at the receiver?

(b) Assume the arrival rate at $a_i(t)$ is $10i$ bits per sec, for $i = 1, 2$. However, the second server $s_2(t)$ is faulty and loses 10% of its bits in processing. What is the arrival rate per sec at the receiver?

(c) Assume the arrival rate at $a_i(t)$ is $10i$ bits per sec, for $i = 1, 2$. Server 1 pays a cost of 2 units per bit transmitted while server 2 pays 3 units per bit transmitted/ What is the payment per bit at the receiver?

4. Consider the two-queue system in the slides on mathematical modelling and analysis. For each $i = 1, 2$ at each time slot a packet arrives at node i with probability p_i. What is the total expected number of arrivals at the receiver after n time slots?

Reference

- M Chiang. Networked Life: 20 Questions and Answers, Princeton University Press, 2012.