Computer Networks and the Internet

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Lecture 03

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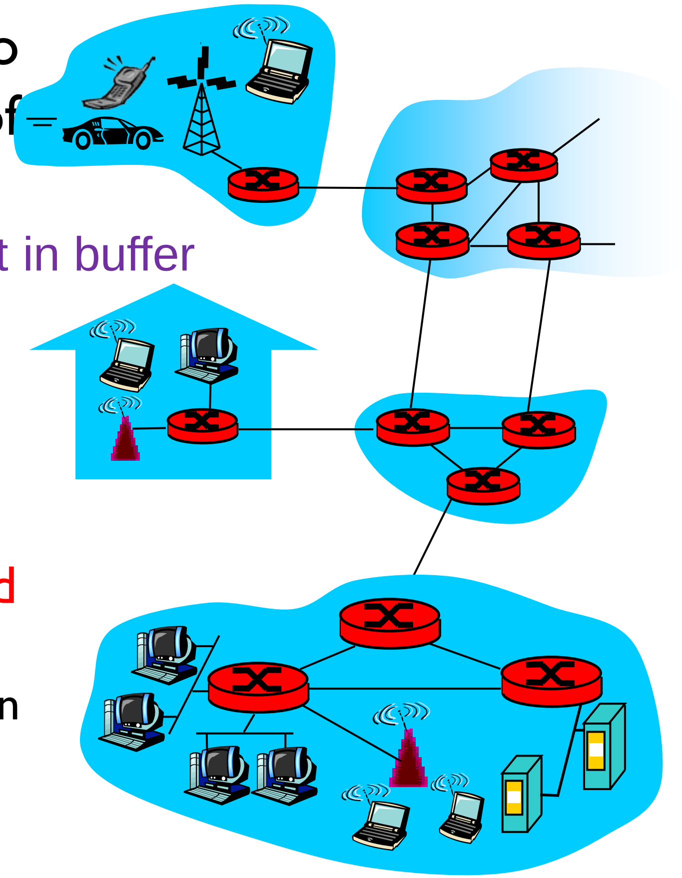
Complete Review Quiz 1 on Blackboard

Network Core: Circuit Switching

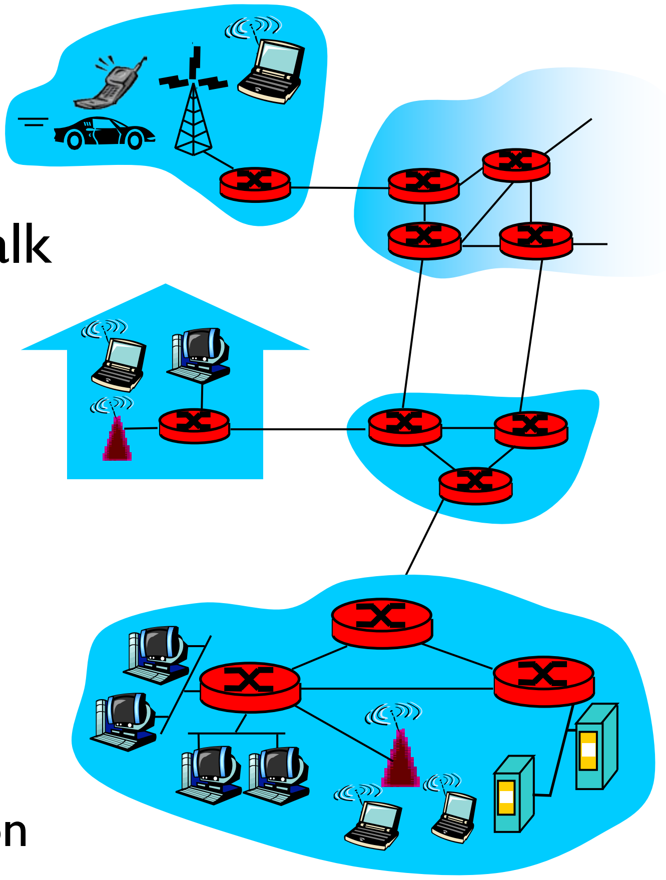
- Two fundamental approaches to moving data through a network of links and switches
- **packet-switched networks**
  - resource *not reserved*
  - use resources on demand
  - may wait for access to commu. link
- **circuit-switched networks**
  - resource for communication reserved
    - between two end systems
    - for duration of the communication session
- simple analogy,
  - restaurant requires reservation “=“ circuit-switched
  - restaurant requires no reservation “=“ packet-switched



Network Core: Circuit Switching

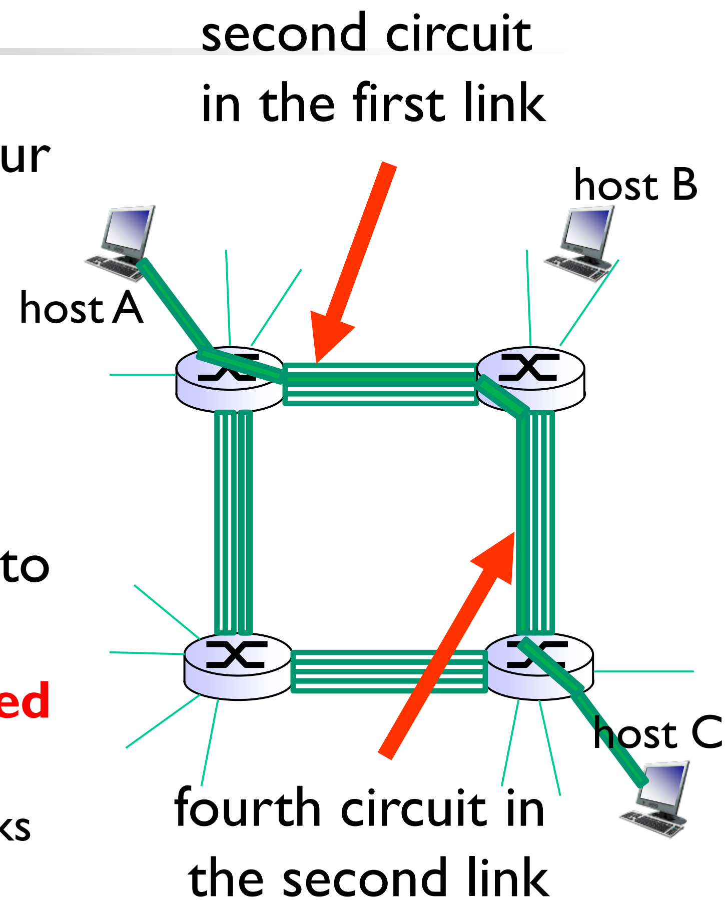
- traditional telephone networks
  - circuit-switched networks

- what will happened if you want to talk to someone?
  - before sender sends information
    - must establishes the connection
    - switches maintain connection
      - connection is called **circuit**
  - When network establishes ***circuit***
    - *reserves* a constant trans. rate
      - in network's link
      - for the duration of connection
    - transfer at the *guaranteed* rate



Network Core: Circuit Switching

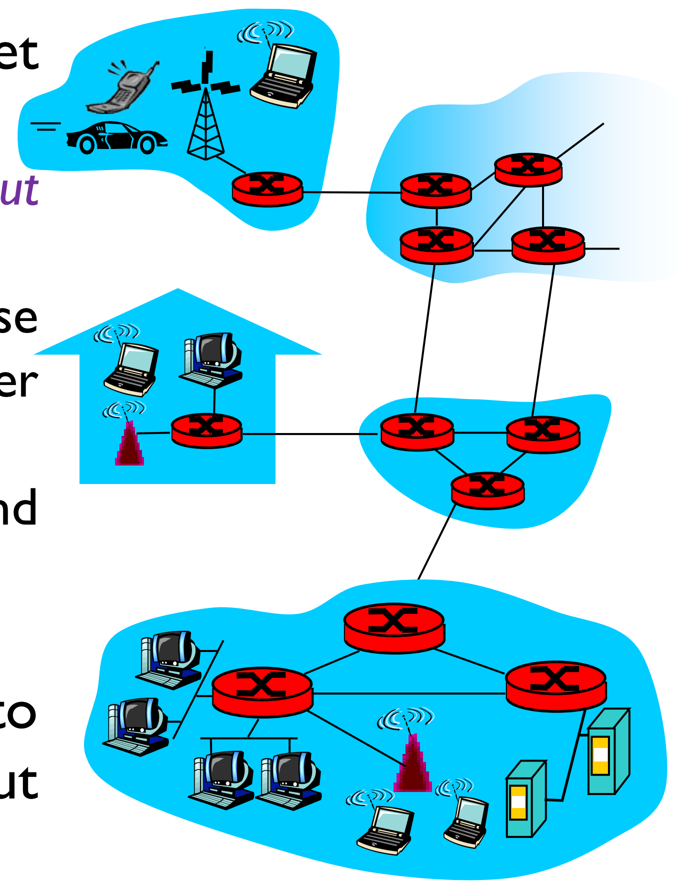
- four switches interconnected by four links
- each link has four circuits
  - support *four simultaneous connections*
- when two hosts (A & C) want to communicate
  - Network establishes a **dedicated end-to-end connection**
    - reserve one *circuit* on each of two links
- each connection gets one fourth of the link's total trans. capacity
  - e.g., link: 1Mbps, circuit: 250 kbps



Circuit-switched network

Network Core: Circuit Switching

- what happens when transmit a packet over a packet-switched network?
  - packet sent into the network *without reserving* any link resources
  - if one of links is *congested* because other packets are transmitting over the link at the same time
    - packet will wait in a buffer and suffer a delay

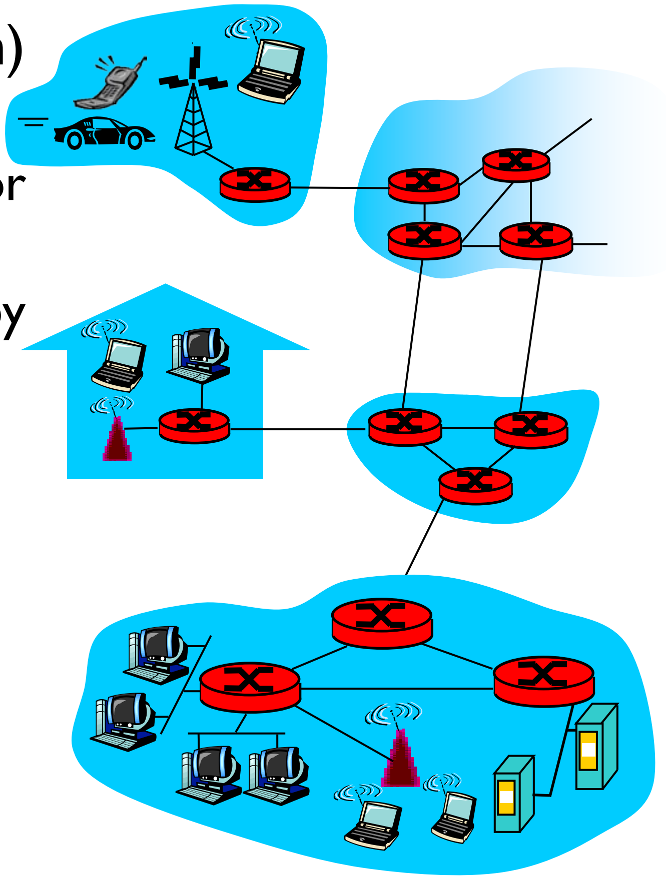


- the Internet makes its best effort to deliver packets in a timely manner, but no guarantees

Network Core: Circuit Switching

- network resources (e.g., bandwidth) divided into “pieces”
  - pieces allocated to calls (or communications)
  - resource piece is idle if not used by owning call (communications)
    - no sharing

- dividing link bandwidth into “pieces”
  - ***frequency division***
  - ***time division***



Circuit Switching: FDM and TDM

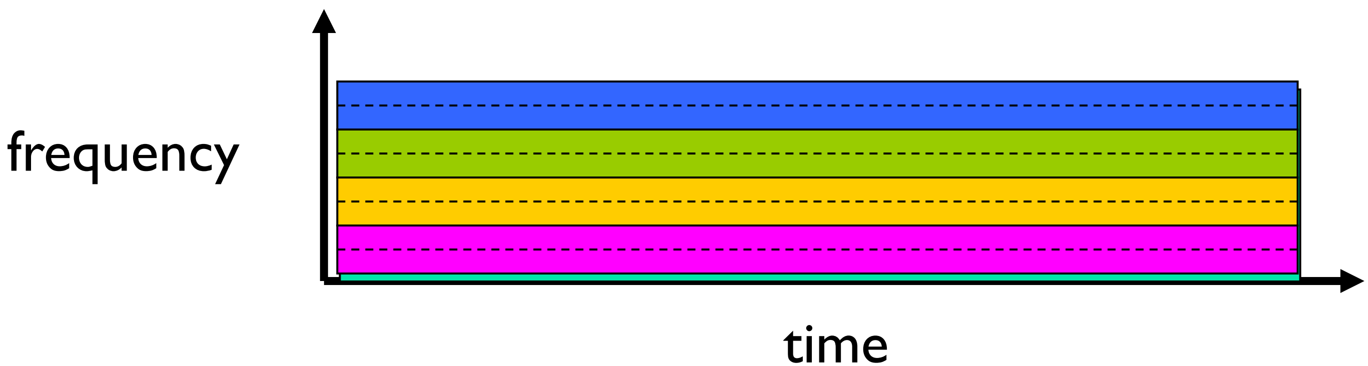
- circuit in a link is implemented with
  - **frequency-division multiplexing (FDM)**
    - the frequency spectrum of a link is divided up among the connections established across the link
    - the link dedicates a frequency band to each connection for the duration of connection
    - telephone networks: 4 kHz
    - FM radio: between 88 MHz and 108 MHz
  - **time-division multiplexing (TDM)**
    - time is divided into frames of fixed duration, and each frame is divided into a fixed number of time slots
    - when establishing a connection, dedicating one time slot in every frame to the connection
    - slots are dedicated for the sole use of that connection, to transmit the connection's data

Circuit Switching: FDM and TDM

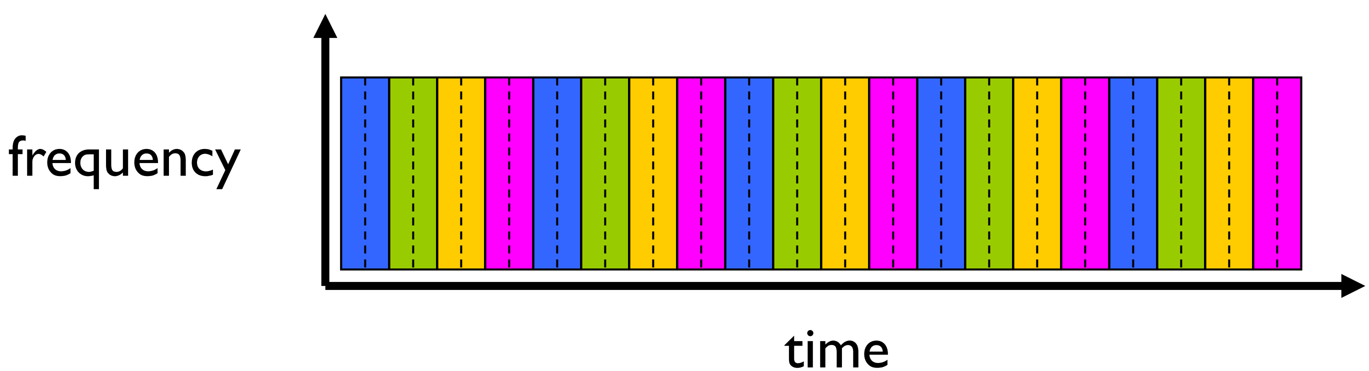
Example:

4 users

FDM



TDM



Circuit Switching: Argument

- circuit switching is wasteful because dedicated circuits are idle during **silent periods**
  - e.g.,
    - One person in a telephone call stops talking
      - resources can't be used by other ongoing connections
    - Radiologist remotely access a series of x-rays
      - setup connection
      - request an image
      - contemplate the image but, not using network resources
      - request a new image
- circuit switching requires extra effort to establish circuits and reserve end-to-end trans. capacity, complex signaling software to coordinate the operation of switches

Circuit Switching: Numerical Example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - all links are 1.536 Mbps
  - each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

  - Answer:
    - each circuit has a trans. rate of 1.536 Mbps / 24 = 64 kbps
    - trans. file: 640,000 bits / 64 kbps = 10 seconds
    - total time: 10 seconds + 500 msec = 10.5 seconds

Packet Switching Vs. Circuit Switching

- Critics of packet switching
  - not suitable for real-time switching, e.g., telephone call, video conference calls
    - variable and unpredictable end-to-end delays

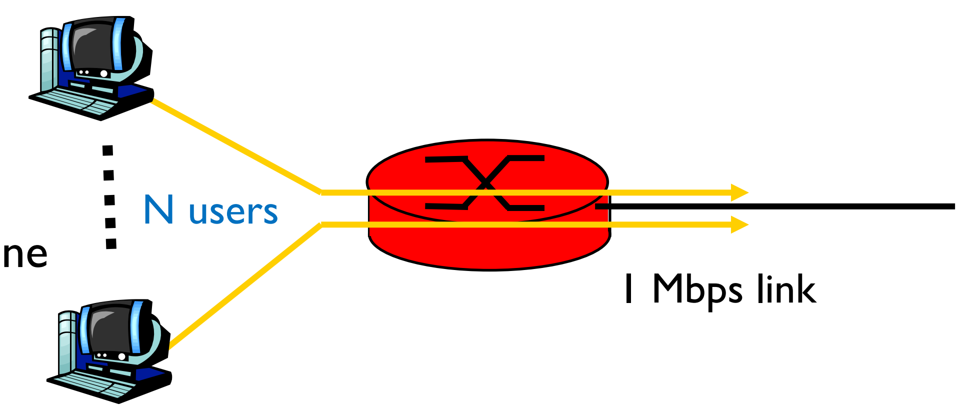
- Proponents of packet switching
  - better sharing of trans. capacity
  - simpler, more efficient, and less costly

- Generally, packet switching is more efficient. Why???

Packet Switching Vs. Circuit Switching

Packet switching allows more users to use network!

- 1 Mbps link
- suppose one user generates one thousand 1000-bit packet out of 10 users
  - 9 users remain quiet
- *TDM circuit-switching:*
  - e.g., 10 time slots per frame
  - the active user can only use its one time slot per frame
  - support 10 simultaneous users
- *packet switching:*
  - The active users can continuously send its packet at the full link rate of 1 Mbps



Packet Switching Vs. Circuit Switching (cont.)

Is packet switching a "slam dunk winner?"

- great for burst data
  - resource sharing
  - simpler, no call setup

- excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control

- Q: how to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem

Internet Structure: Network of Networks

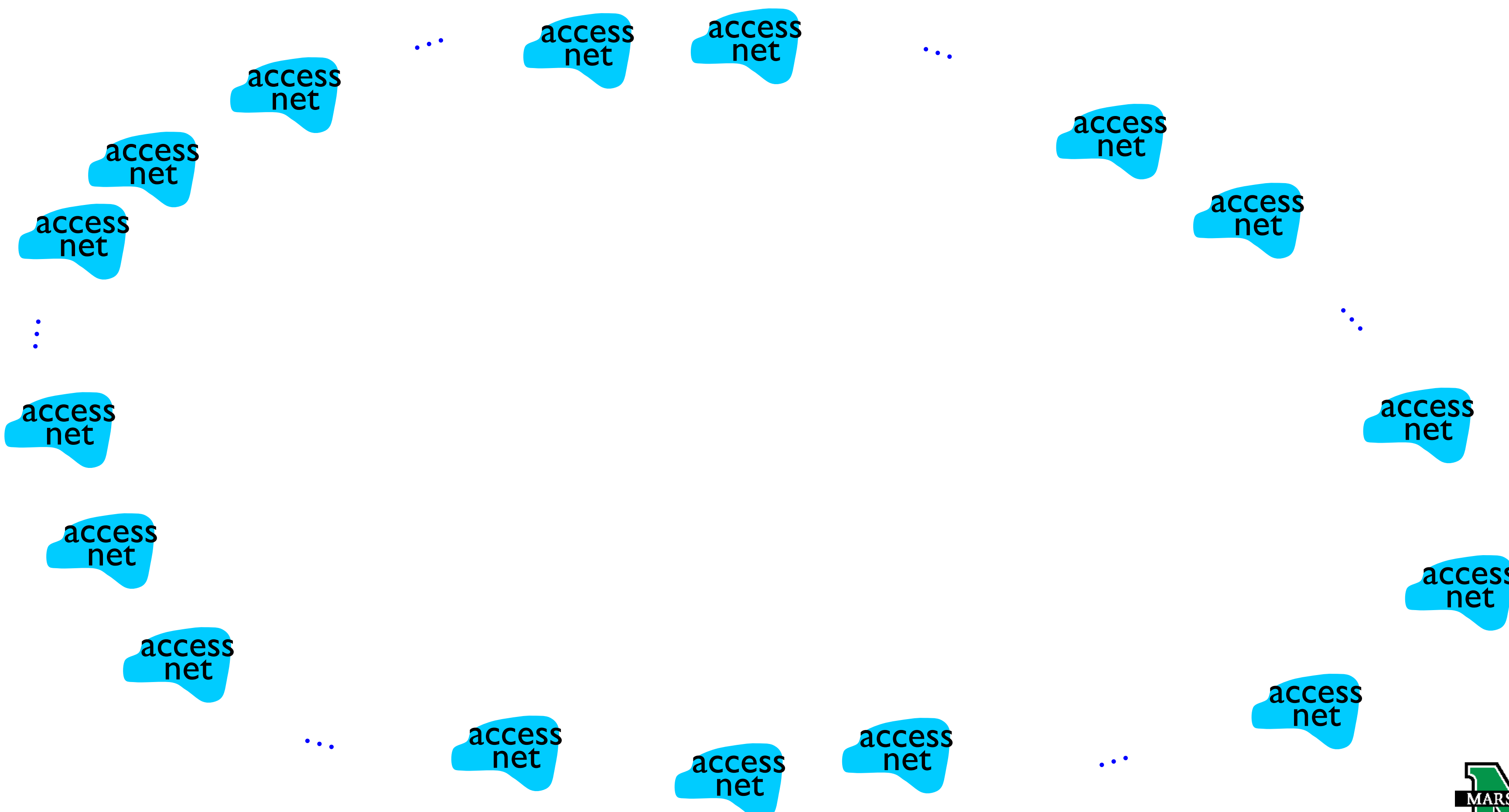
- End systems connect to the Internet via an access ISPs (Internet Service Providers)
  - wired or wireless connectivity
    - DSL, cable, FTTH, Wi-Fi, and cellular
  - residential, company, and university ISPs

- Access ISPs in turn must be interconnected
  - so that any two hosts can send packets to each other

- Resulting **network of networks** is very complex
  - evolution was driven by economics and national policies

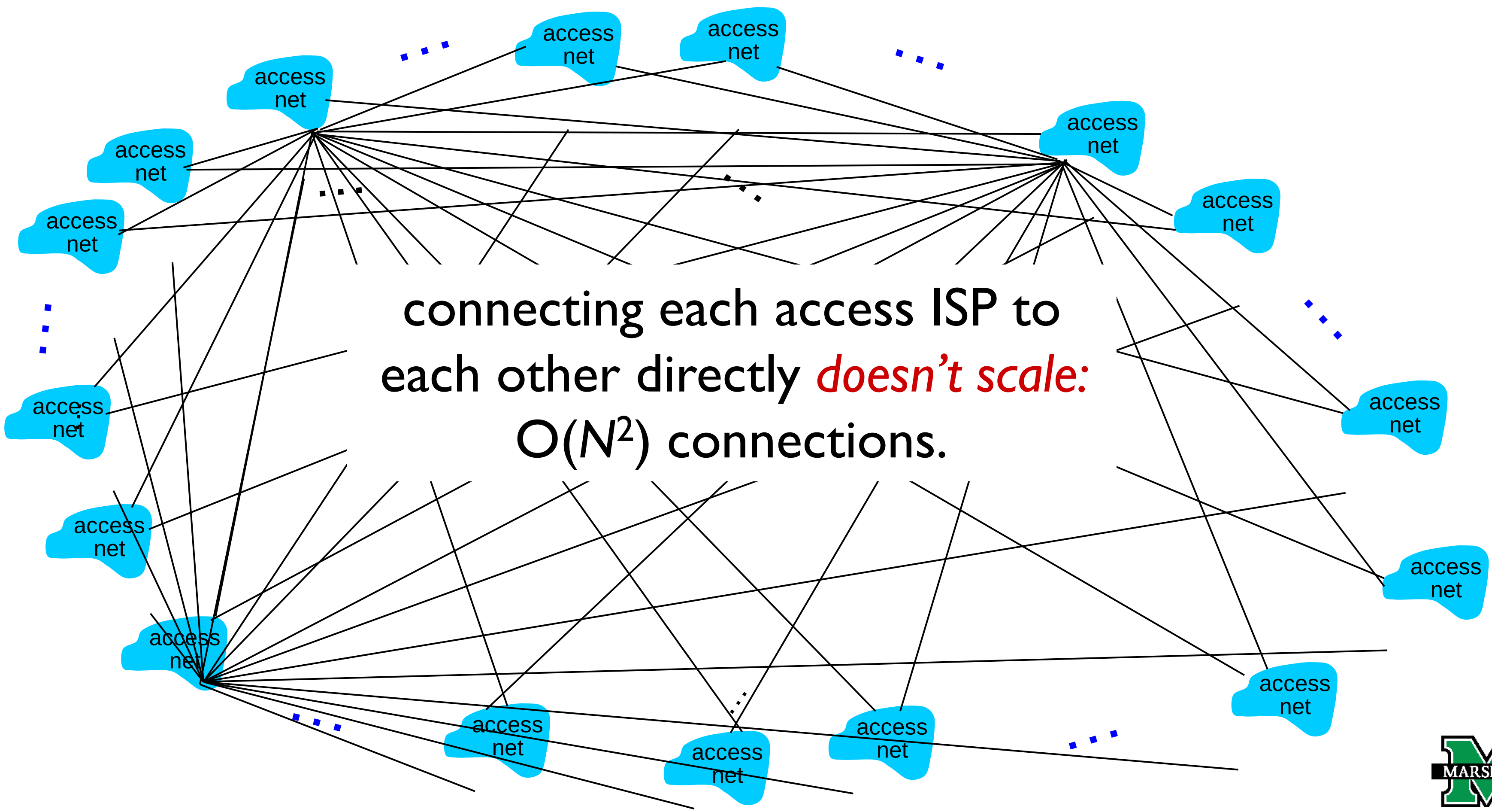
Internet Structure: Network of Networks (cont.)

Question: given *millions* of access ISPs, how to connect them together?



Internet Structure: Network of Networks (cont.)

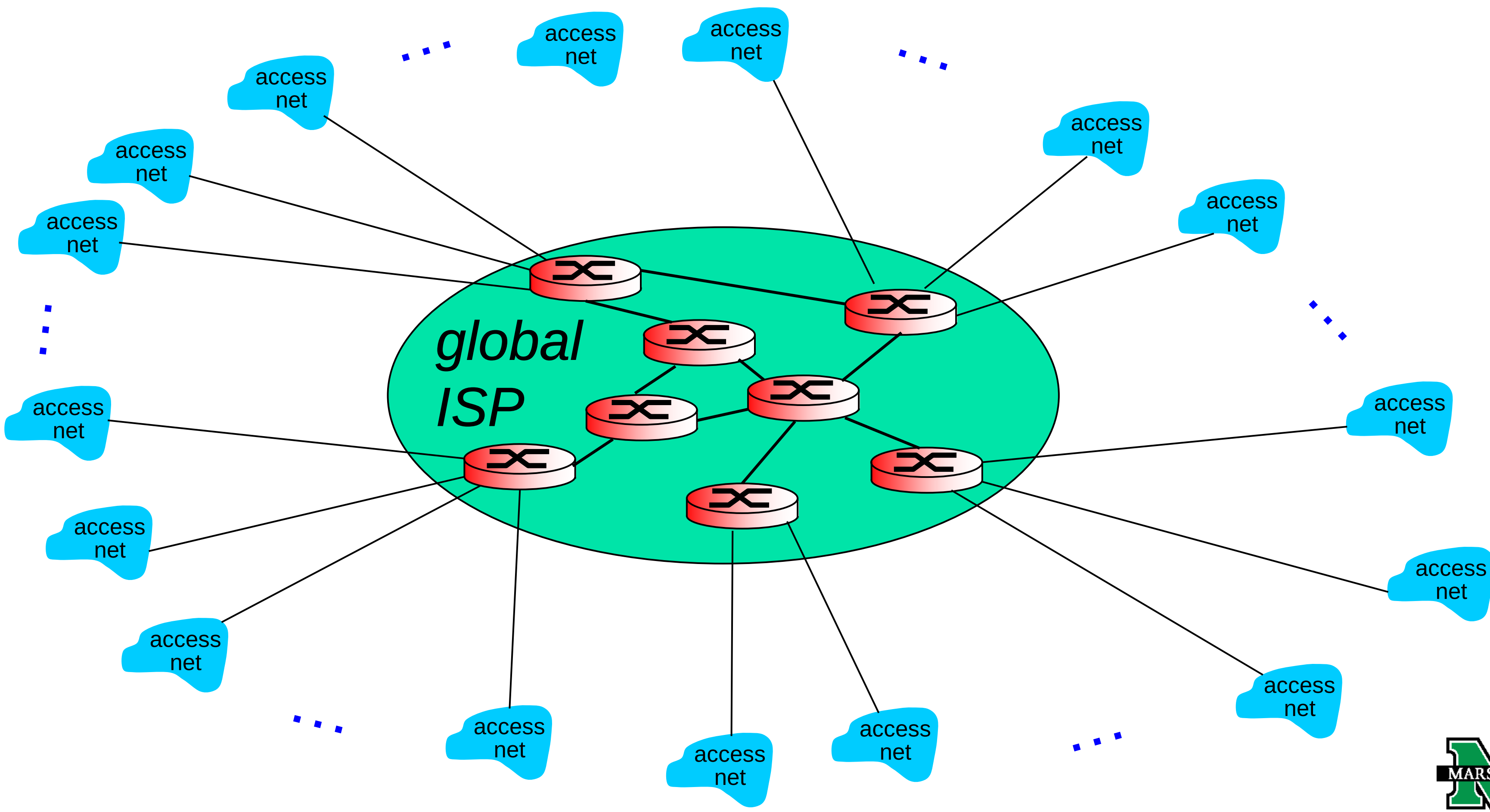
Option: *connect each access ISP to every other access ISP?*



connecting each access ISP to each other directly *doesn't scale:* O(N^2) connections.

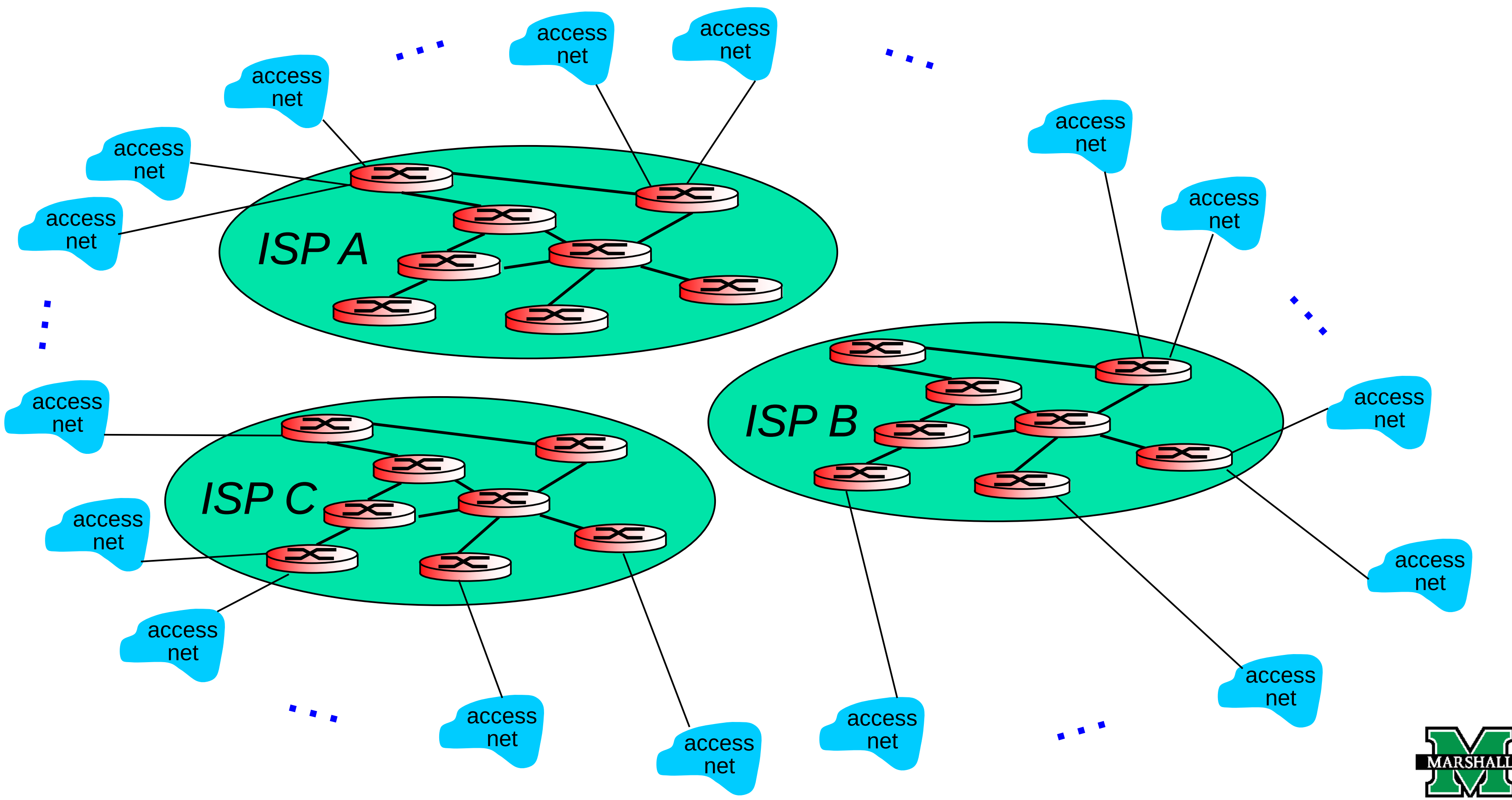
Internet Structure: Network of Networks (cont.)

Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



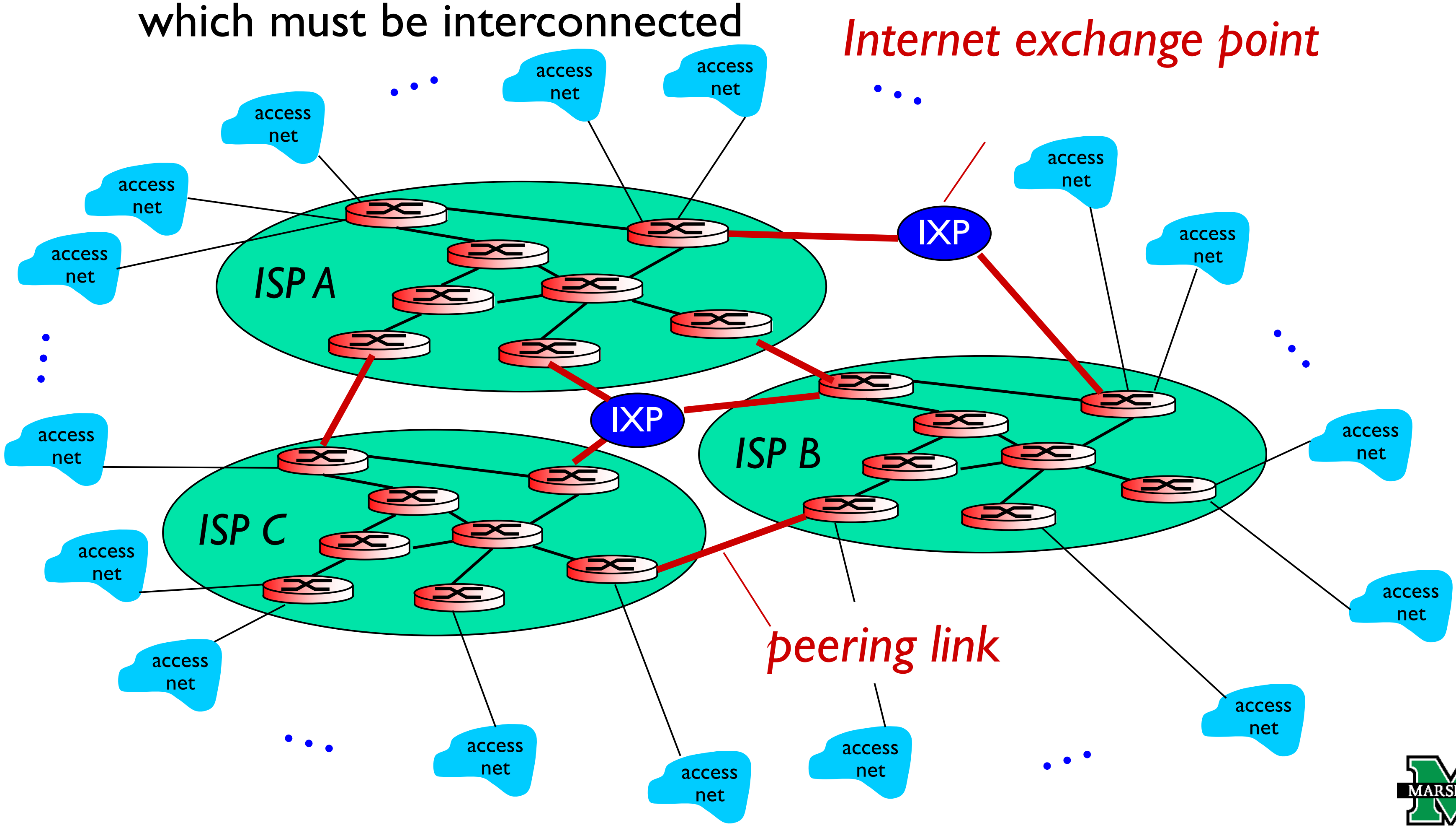
Internet Structure: Network of Networks (cont.)

But if one global ISP is viable business, there will be competitors ….



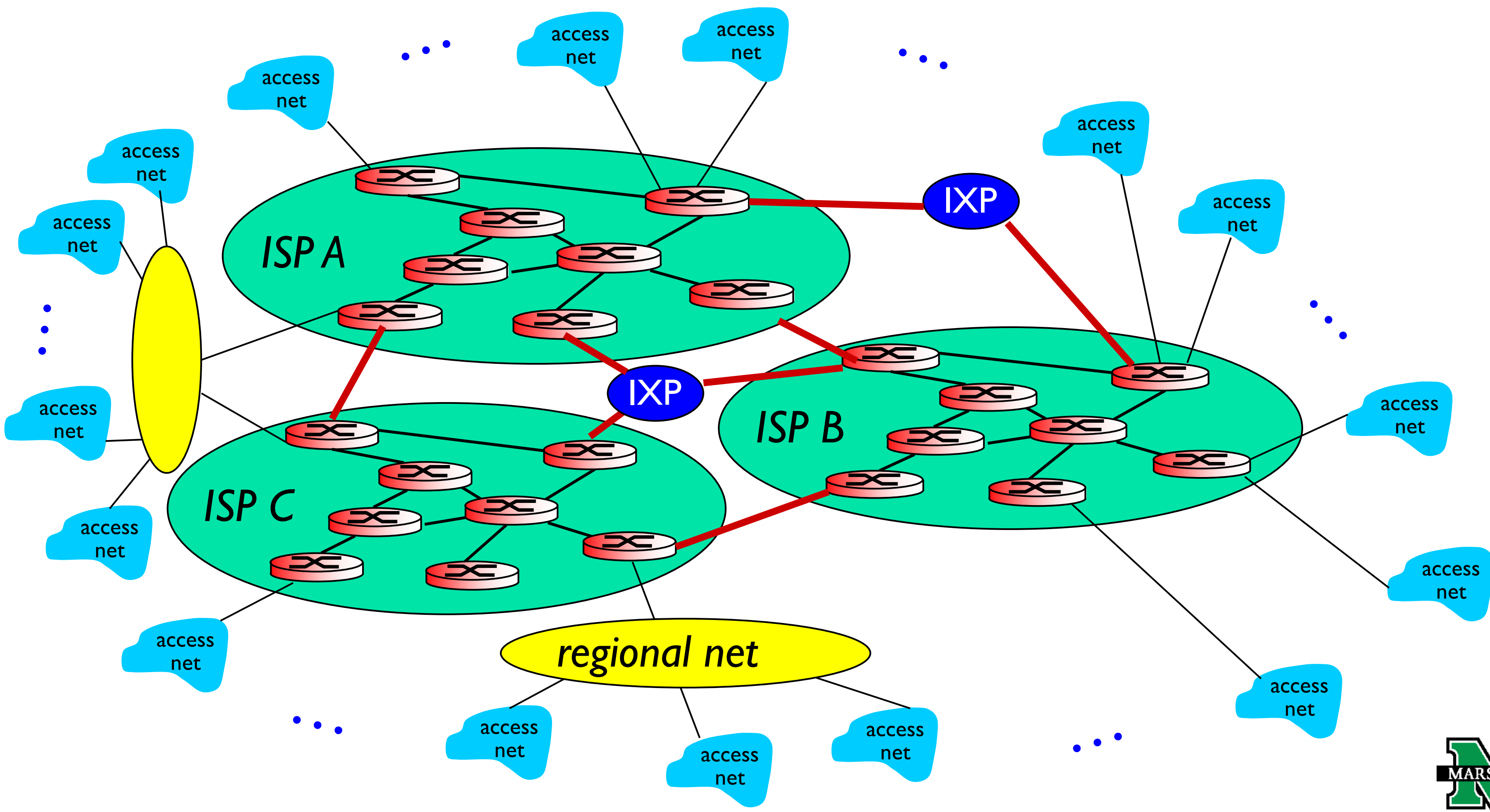
Internet Structure: Network of Networks (cont.)

But if one global ISP is viable business, there will be competitors …. which must be interconnected



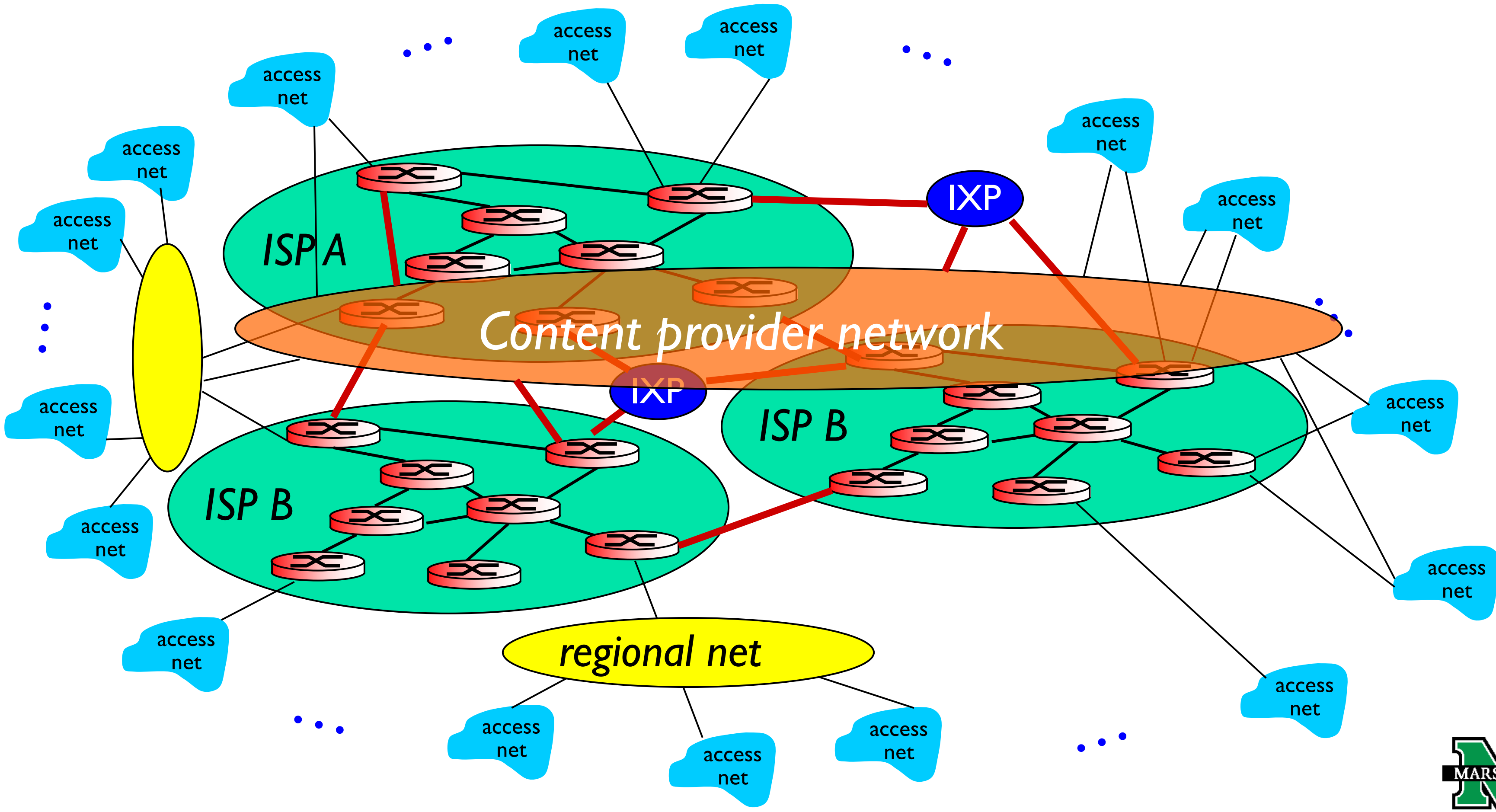
Internet Structure: Network of Networks (cont.)

… and regional networks may arise to connect access nets to ISPS

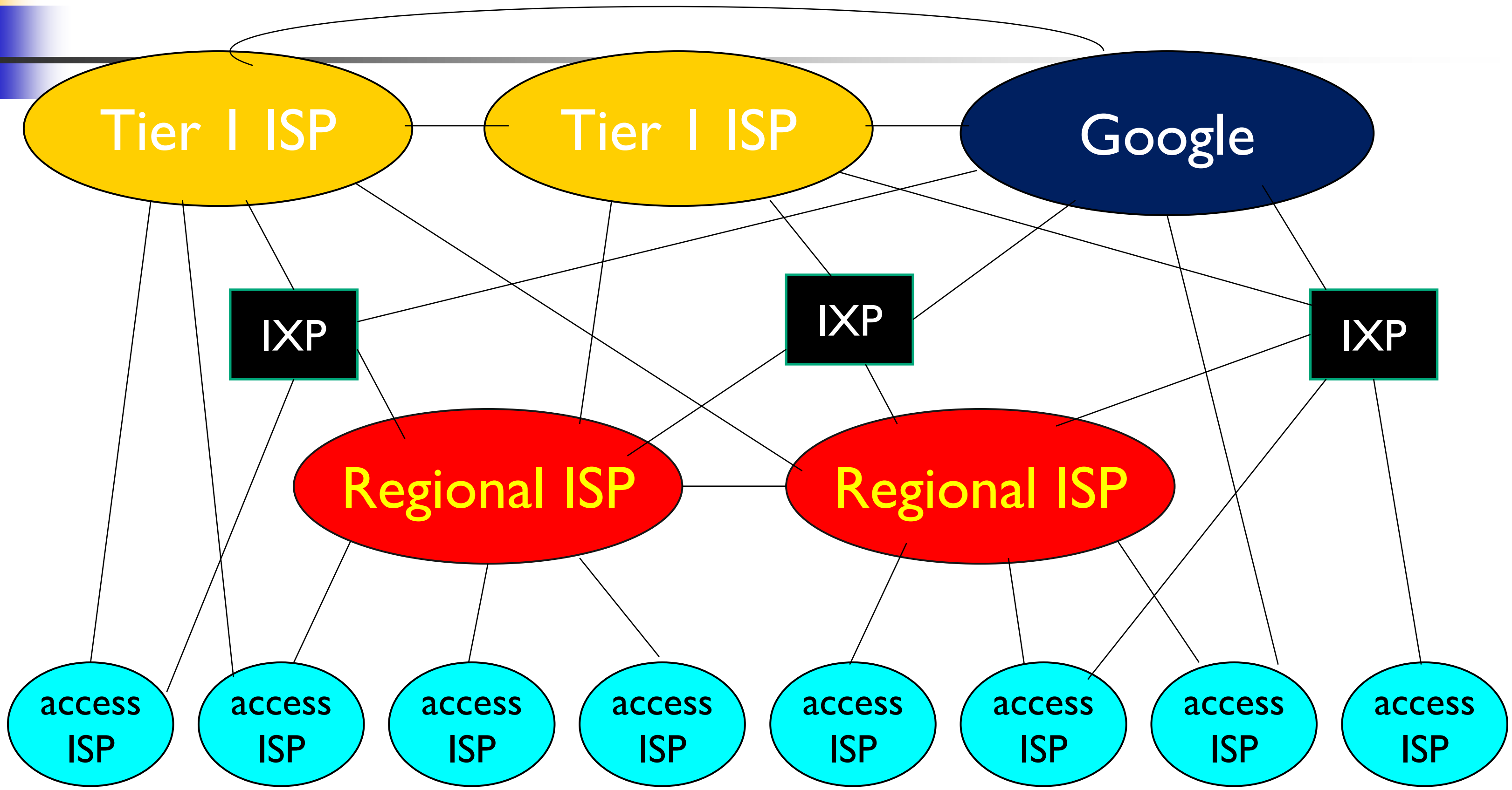


Internet Structure: Network of Networks (cont.)

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



Internet Structure: Network of Networks (cont.)



- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google)