TreeDN: Tree-based CDNs for Live Streaming to Mass Audiences

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Problem Statement: Can Brute Force Unicast (BFU) Keep Up Forever

- With live audiences exploding combined with increasing bitrates (4K/8K/AR), are we at an inflection point?
  - NFL Thurs Night FB on Amazon Prime (10-15M streaming viewers) <*>
    - "comprises roughly 25 percent of all internet traffic on Thursday nights"
  - NFL Sunday Ticket on YouTubeTV, NFL WC on Peacock (23M viewers)
  - 2023 Cricket IPL/World Cup: ~~32M~~ ~~43M~~ ~~53M~~ 59M concurrent streams
  - Live streaming is now responsible for 17% of all Internet traffic (from <1% in 2015)
- Live Streaming is not the same as On-Demand Streaming
  - Expectations for low latency means shorter playout buffers
    - < 10s to match traditional broadcast TV, much less for micro-betting
  - Join rates are vastly different
    - Smooth/predictable for on-demand, ~ step function for live events
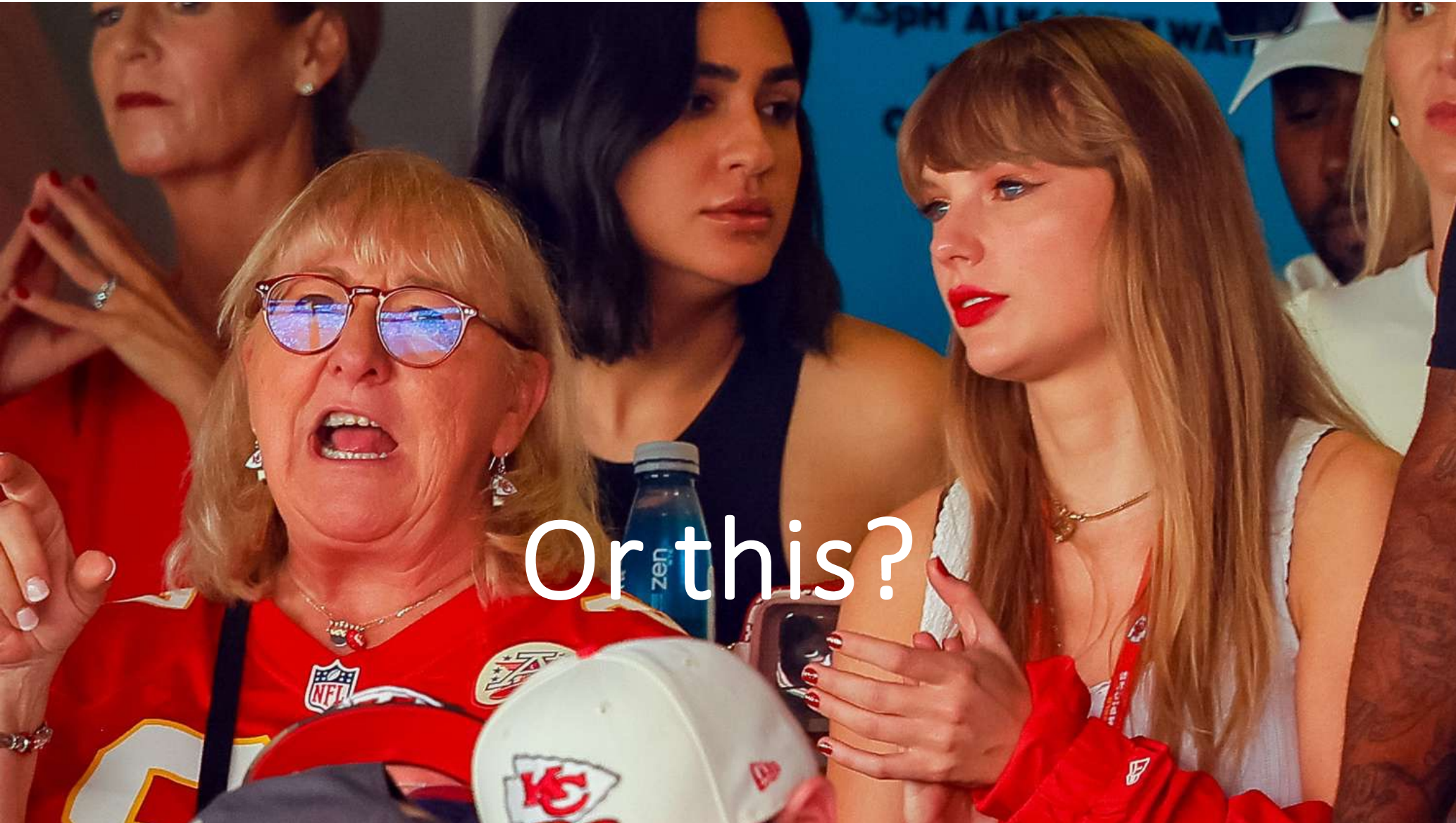
<*> TNF not available in 4K

Mass Audience Live Streaming AR

Is this possible with today's Internet???

Or this?

Network-Based Replication

- Multicast has been fairly successful in some places
  - Financials, Video Distr, VPN SPs, some enterprises
- Internet Multicast- not so much...
  - So what went wrong?

The Problems with Internet Multicast

1. "All or Nothing" Problem
   - Every L3 hop (router/fw) between source and destination must be multicast-enabled

2. "It's Too Complex" Problem
   - Perceived benefit not worth the cost of deploying and operating

3. "Chicken and Egg" Problem
   - No multicast audience because no multicast content, and vice versa

- Good News: Network Replication technologies are now available to address these problems
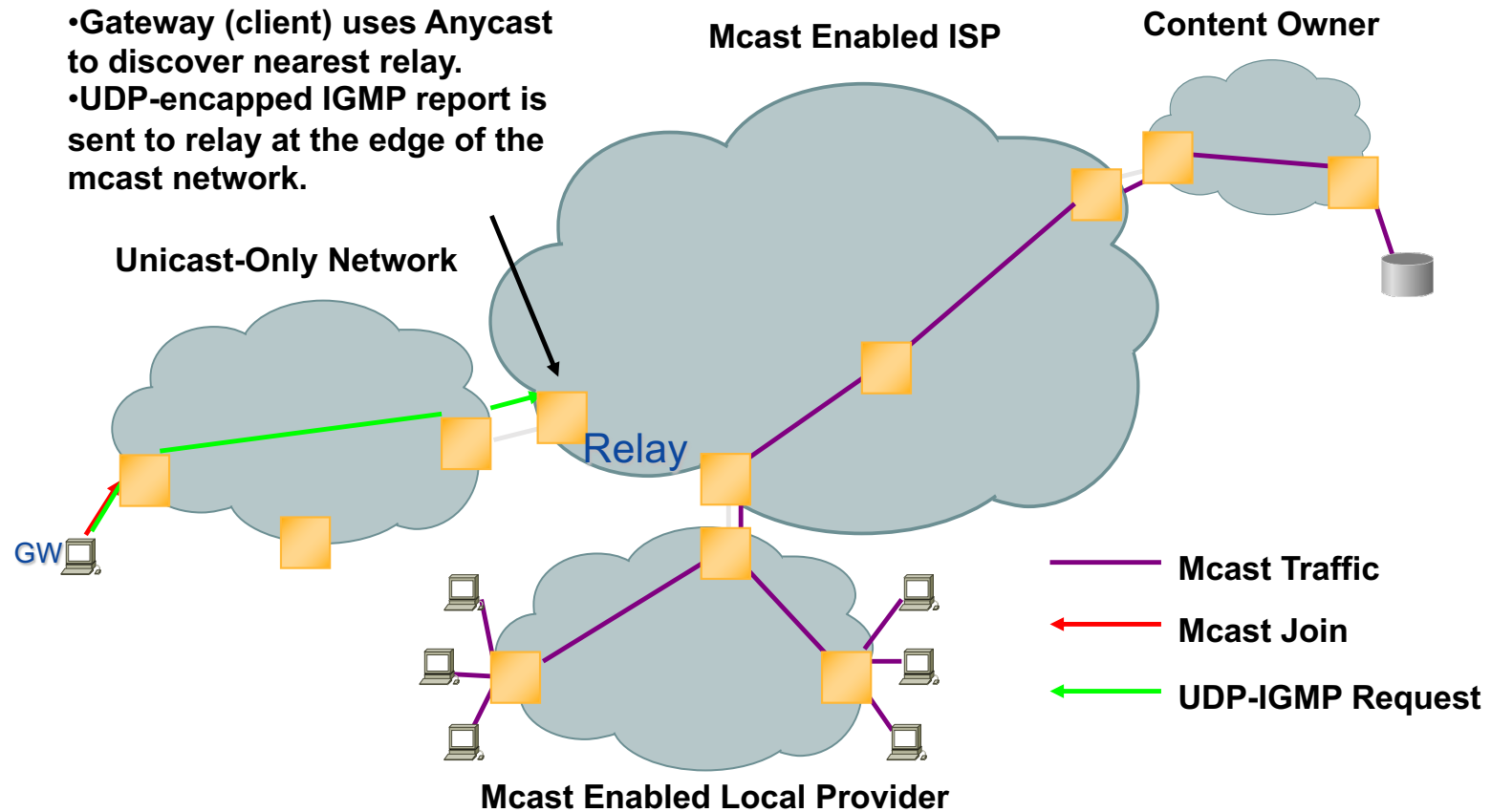
TreeDN: Tree-based CDNs

- Leverages native + overlay concepts to deliver service to end users even where parts of the network don't support multicast
  - Native (On-Net): SSM
  - Overlay: AMT (RFC7450)
- Incremental Deployment
  - Multicast-enabled parts of network enjoy benefits, unicast-only parts are tunneled over
  - Most importantly, end users receive the service (eg, no dependency on last mile provider)
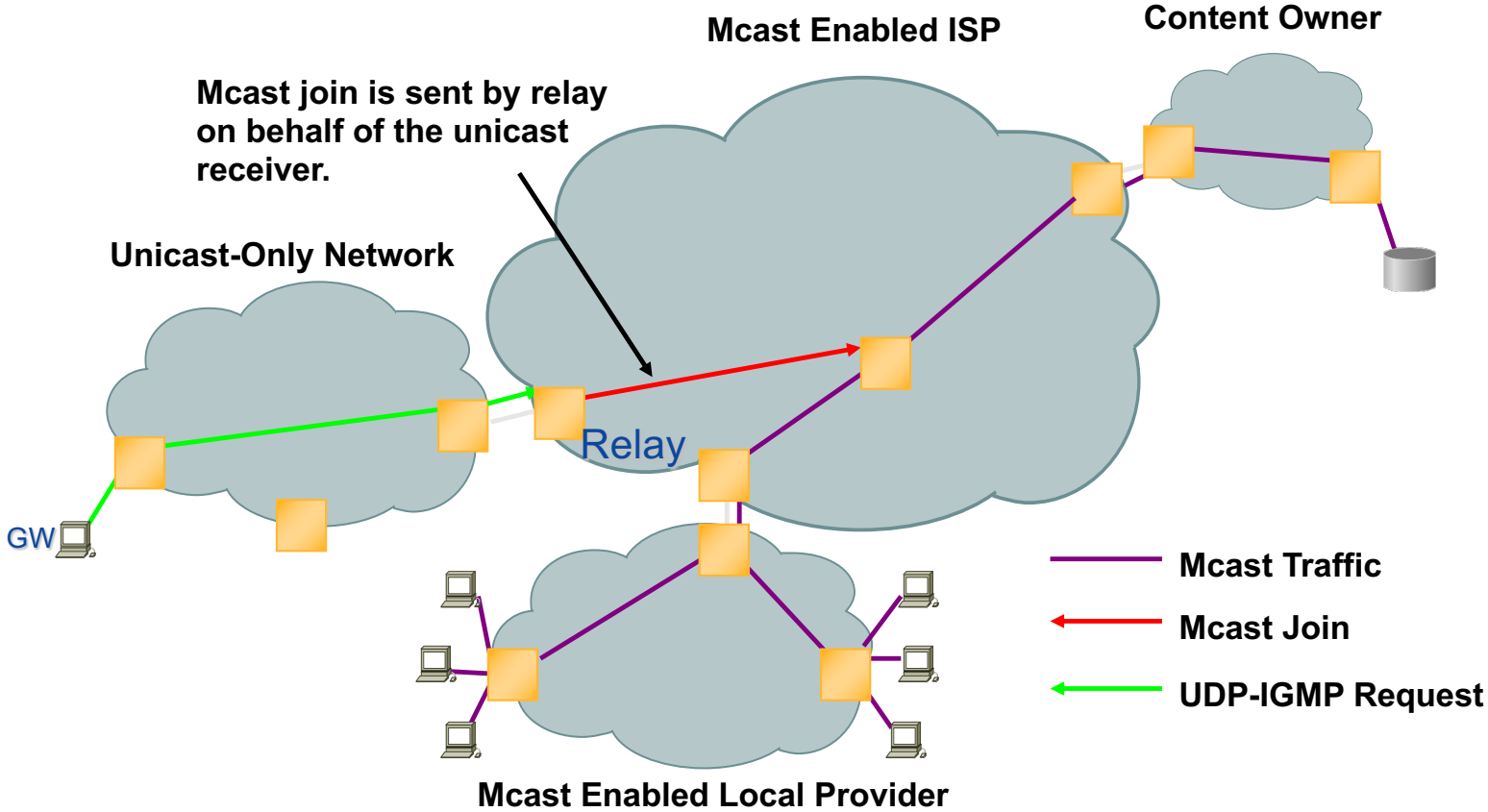
TreeDN Components

- Native (On-Net): SSM
  - SSM vastly simplifies multicast deployment, solves the "It's too complex" problem
  - Usually PIM-SSM, but could also use mLDP, GTM, BGP-MVPN, BIER, TreeSID

- Overlay: AMT (RFC7450)
  - Dynamically-built tunnels in host/app "hop over" unicast-only parts of network
  - Simplifies "last mile"- can avoid wifi and other in-home issues
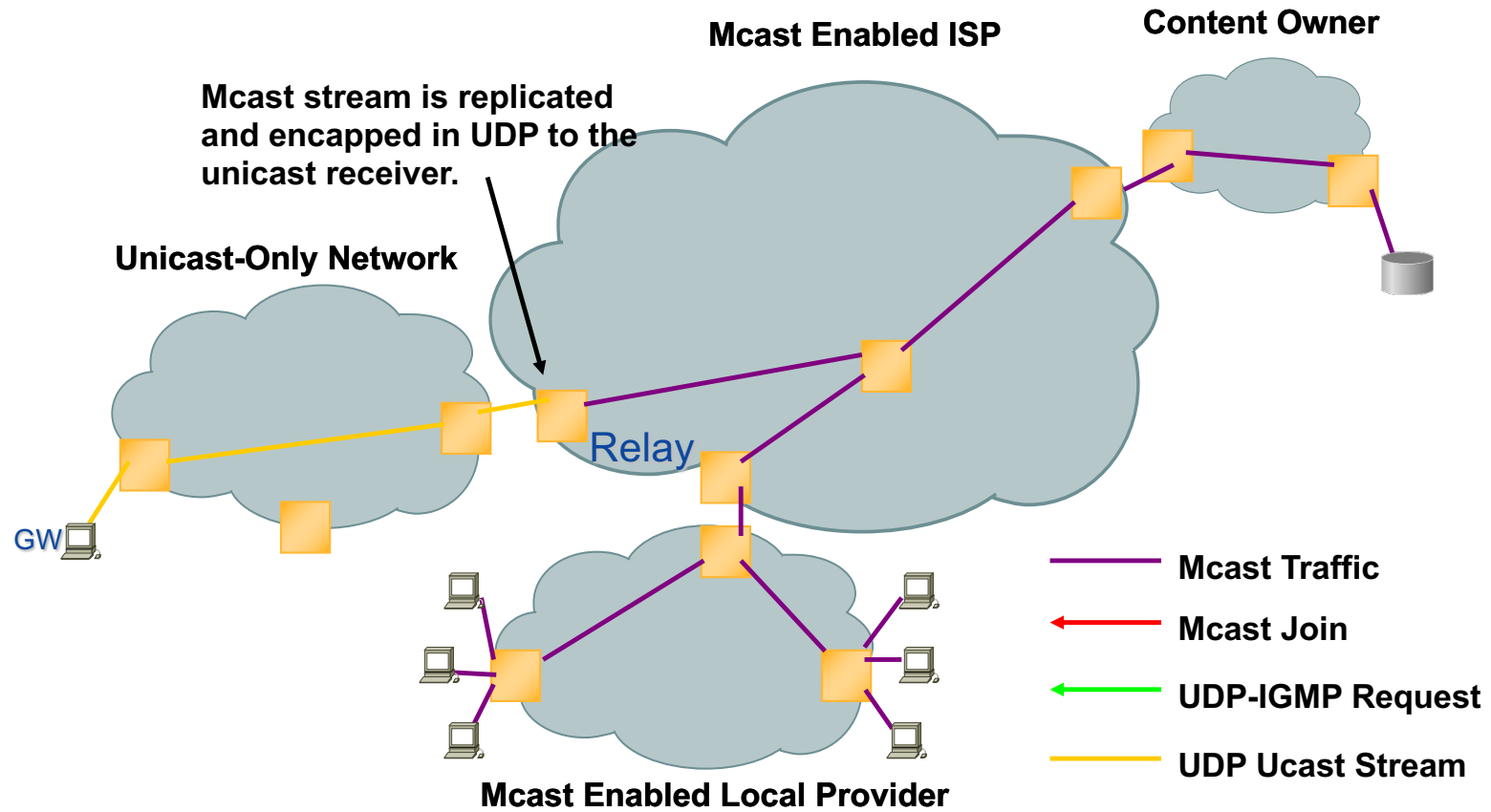 - Solves the "All or Nothing" and "Chicken & Egg" problems

AMT- How it works

•Gateway (client) uses Anycast to discover nearest relay.
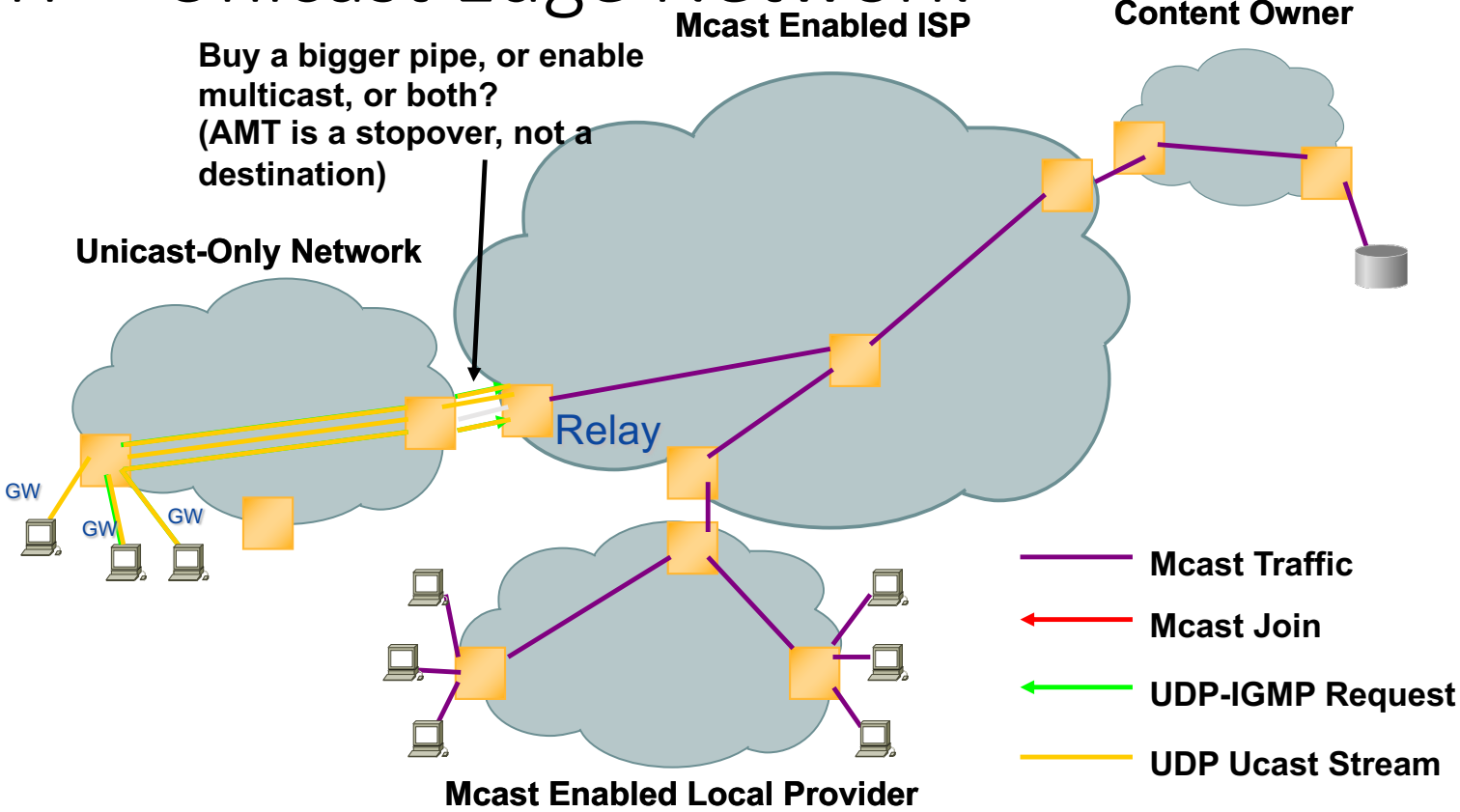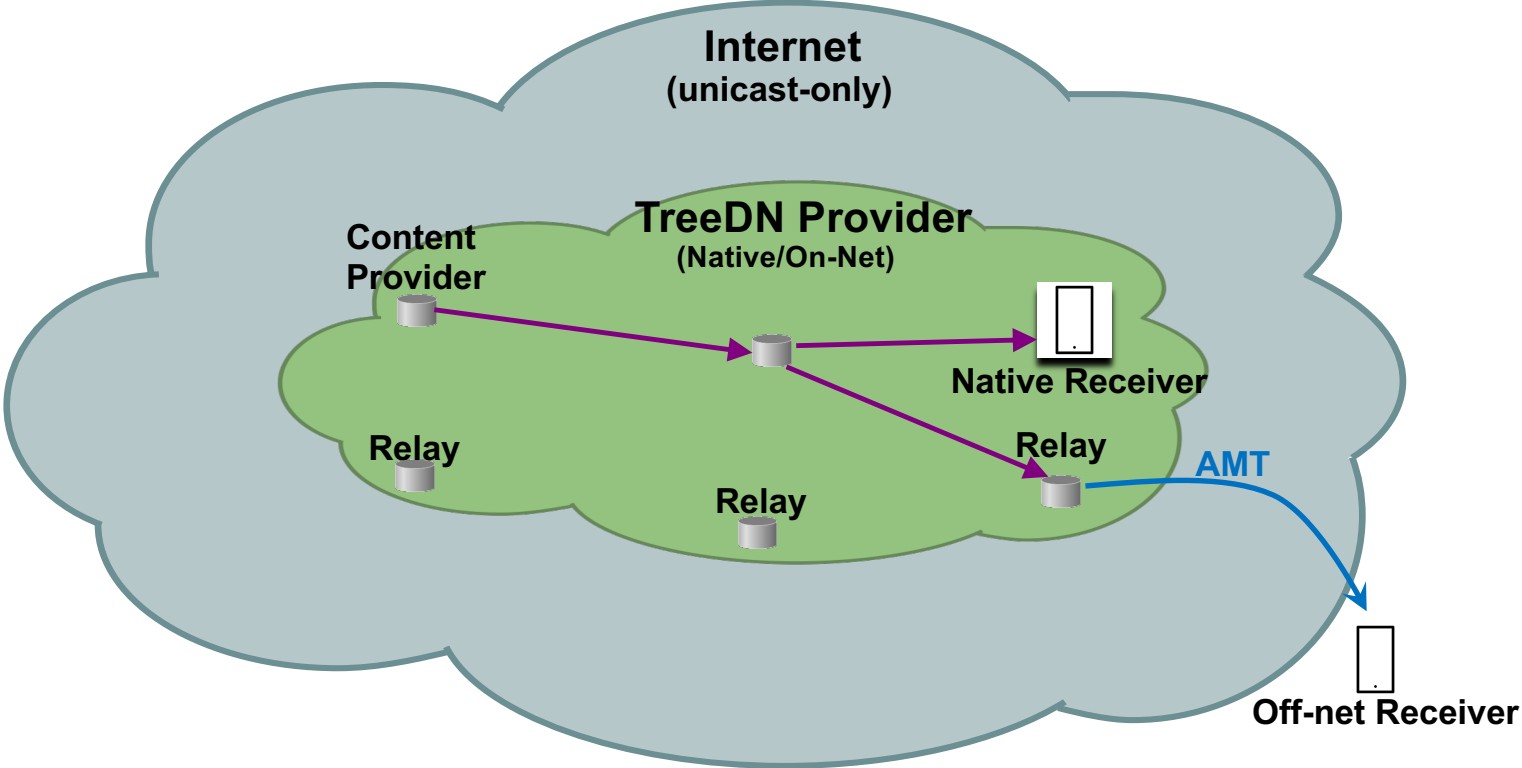•UDP-encapped IGMP report is sent to relay at the edge of the mcast network.

Mcast Enabled ISP

Content Owner

Unicast-Only Network

Relay

GW

Mcast Enabled Local Provider

Mcast Traffic

Mcast Join

UDP-IGMP Request

AMT – Unicast Edge Network

Mcast Enabled ISP

Content Owner

Mcast join is sent by relay on behalf of the unicast receiver.

Unicast-Only Network

Relay

GW

Mcast Enabled Local Provider

Mcast Traffic

Mcast Join

UDP-IGMP Request

AMT – Unicast Edge Network

Mcast Enabled ISP

Content Owner

Mcast stream is replicated and encapped in UDP to the unicast receiver.

Unicast-Only Network

Relay

GW

Mcast Enabled Local Provider

——	**Mcast Traffic**
←	**Mcast Join**
←	**UDP-IGMP Request**
——	**UDP Ucast Stream**

AMT – Unicast Edge Network

Mcast Enabled ISP

Content Owner

Buy a bigger pipe, or enable multicast, or both?
(AMT is a stopover, not a destination)

Unicast-Only Network

Relay

GW

GW   GW

Mcast Enabled Local Provider

⎯⎯⎯	**Mcast Traffic**
⟵⎯⎯	**Mcast Join**
⟵⎯⎯	**UDP-IGMP Request**
⎯⎯⎯	**UDP Ucast Stream**

TreeDN= SSM + AMT

CDN's without Multicast
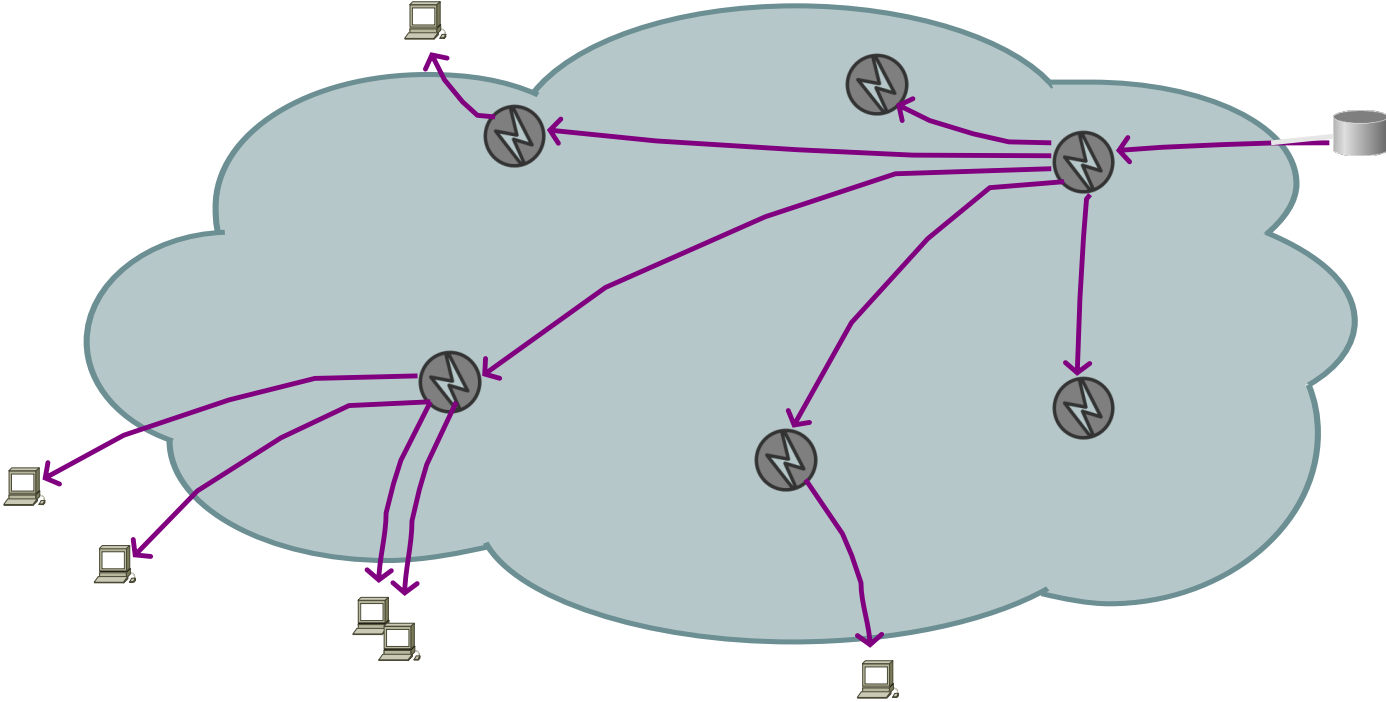
CDN's with Multicast: TreeDNs

- TreeDN: Tree-based CDN Architecture for Mass Audience Live Streaming
- If deployed on existing network infra (CDN-on-a-Chip): $0 capex
  - … and maybe $0 opex, too
 - Open, standards-based solution with mature protocols and minimal coordination with CP
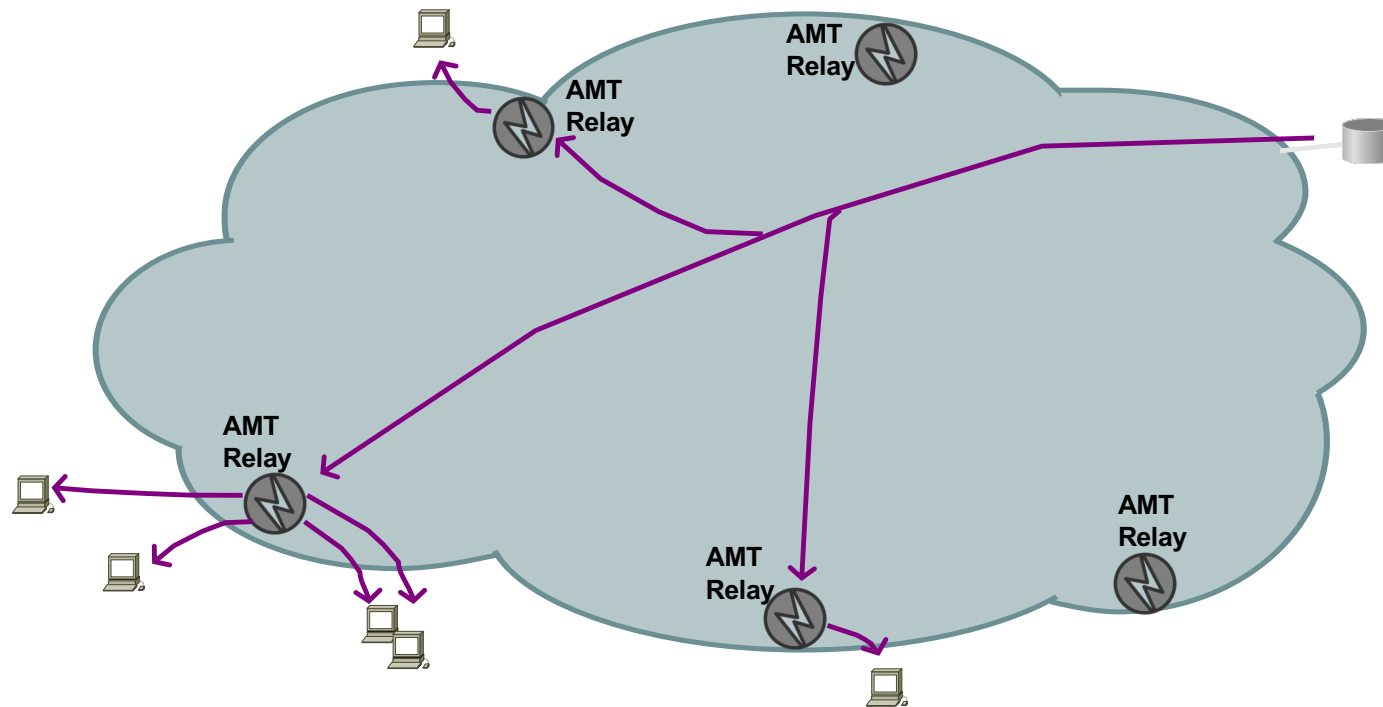
Use Cases/Applicability

- Any multi-destination content
  - Live streaming (audio/video/AR/telemetry- anything that is better live than on-demand)
    - Sports, Concerts, eLearning, Worship Services, Conferences
  - Large File SW Updates (eg, OS updates)

TreeDN Production Deployments

- EUMETCast Terrestrial over GEANT
- Internet2
- RARE Network

EUMETCast Terrestrial using TreeDN
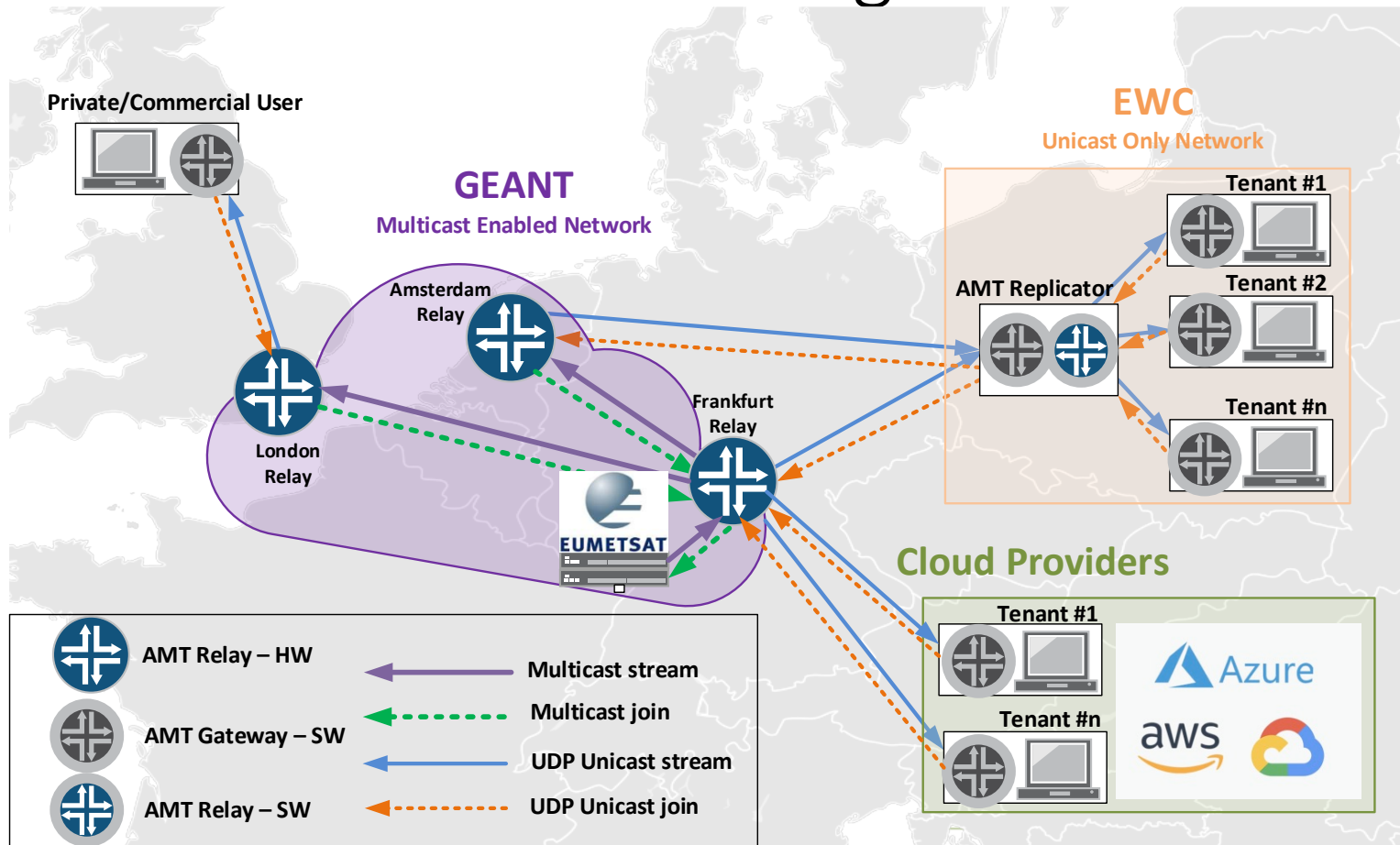
IETF 115 Talk and Slides

TreeDN over Internet2

- 4 public AMT relays deployed at several I2 members today
  - Delivers multicast streams from R&E networks to anywhere on the Internet
- Multicast Menu: TreeDN in Action

https://menu.treedn.net

- Webpage/Portal with a list of active multicast streams
  - Script periodically crawls through Looking Glasses at GEANT and I2 for multicast routes
  - Can manually add streams as well
  - Launch streams *in browser* or VLC to open
  - Supports Offnet Sourcing
  - Developed by Lauren Delwiche/Yale/TJHS
  - Demonstrated in IETF 114 and IETF 115
  - More content and relays are welcome!

RARE Network: BIER + AMT

- RARE- research net run by RENATER (NREN for France, connected to GEANT)
  - P4 Tofino switches with FreeRouter as routing stack (nb, FreeRTR ≠ FRR)
  - BIER implemented in P4 for DP, FreeRTR in CP
  - Implemented AMT in FreeRTR and added to RARE
  - vMX running BIER included in network, demonstrating successfully interop
  - IETF112 Talk and Slides
- First known deployment of BIER + AMT on the Internet

TreeDN Benefits

- More efficient network utilization
  - Delivers existing live streaming content at an order of magnitude lower cost
  - Scales to makes new content viable (eg, AR livestreaming to mass audiences, microbetting)
  - Sustainability/Green Networking
- Allows Operators to offer new Replication-as-a-Service (RaaS)
  - At potentially zero additional cost to deliver service (if existing infra support AMT)
  - Open, standards-based architecture with widely available protocols
  - Far less coordination between CP and CDN
    - No need for data storage, protection, key management- CDN just forwards packet
- Addresses fundamental problems with network replication on Internet
  - Incremental deployment, overlay networking, mcast over WIFI
- Democratizes and decentralizes content sourcing
  - Is it healthy for the Internet (and society) that a small handful of companies control nearly all content distribution?

Frequently Asked Questions on TreeDN

- What about bespoke advertising, key distribution, UX telemetry, etc?
  - Use unicast backchannels.

- What about ABR?
  - Use different groups for different bitrates. See also DVB-MABR, MAUD.

- What about packet loss/reliability?
  - Use FEC. See also DVB-MABR, MAUD.

- What about access control?
  - Use encryption. See also mQUIC and DVB-MABR/MAUD

Summary: Crossing Supply/Demand Curves for Live Streaming on the Internet

- Demand: exploding livestream audience sizes + increasing bitrates (4K/8K/AR)

- Supply: network-based replication is easier and more available than ever

- TreeDN describes a CDN model optimized to address the increasing strain of live streaming on the network, and enables new types of content delivery

References

- TreeDN in action:
  - https://menu.treedn.net/
- TreeDN Internet Draft:
  - https://datatracker.ietf.org/doc/draft-ietf-mops-treedn/

What's old is new: Live streaming is Trending

- **Brand Transparency and Authenticity:** due to spontaneous and un-editable nature, live streams are perceived as more authentic and drive greater emotional engagement than on-demand

- Viewers spend **8X longer with live video** than on-demand, **67% of live viewers are more likely to make a purchase** and **best ROI from live video compared to any other social media platform**

- The COVID Pandemic has pushed the need for solutions that enable people to gather virtually (eLearning, fitness/wellness, conferences, worship services, sporting events, drinks with friends, etc)
  - **Between January and August 2020, the number of live-streamed events hosted increased by 1468%**
  - **Live stream watch time has increased by 250%**
  - **Live Streaming E-Commerce Is The Rage In China: $180B in 2022 (from $29B in 2018)**

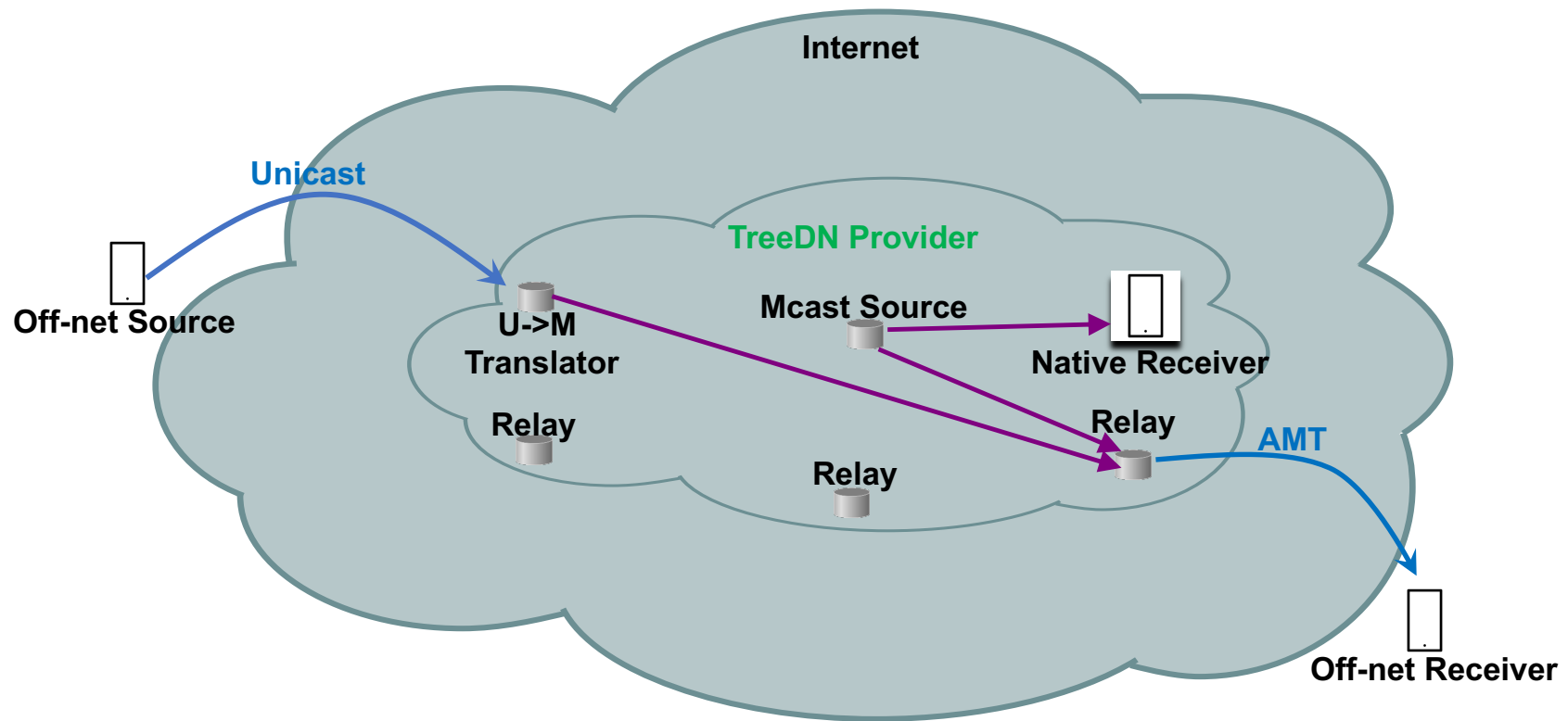# Internet Mcast and IPv6: Technological Cousins

- Any argument for/against IPv6 applies just as well to Internet Mcast
  - It's not needed: NAT, CDN
  - It is needed: v4 address exhaustion, inefficiency of duplicated video streams
- Both suffer the "all or nothing" problem
- Both require new protocols/extensions of old ones
- Both born in the 90s, struggled through adolescence, un/underemployed as young adults
- Both require faith in the unseen
  - Both do accomplish little on their own, but enable big things

Comparison: Unicast, CDN and Multicast

- Cost (audience) *for the Content Provider*

- CDNs don't eliminate the BFU problem, they just distribute it
  - EUMETSAT: multicast is an order of mag cheaper than unicast CDNs!!
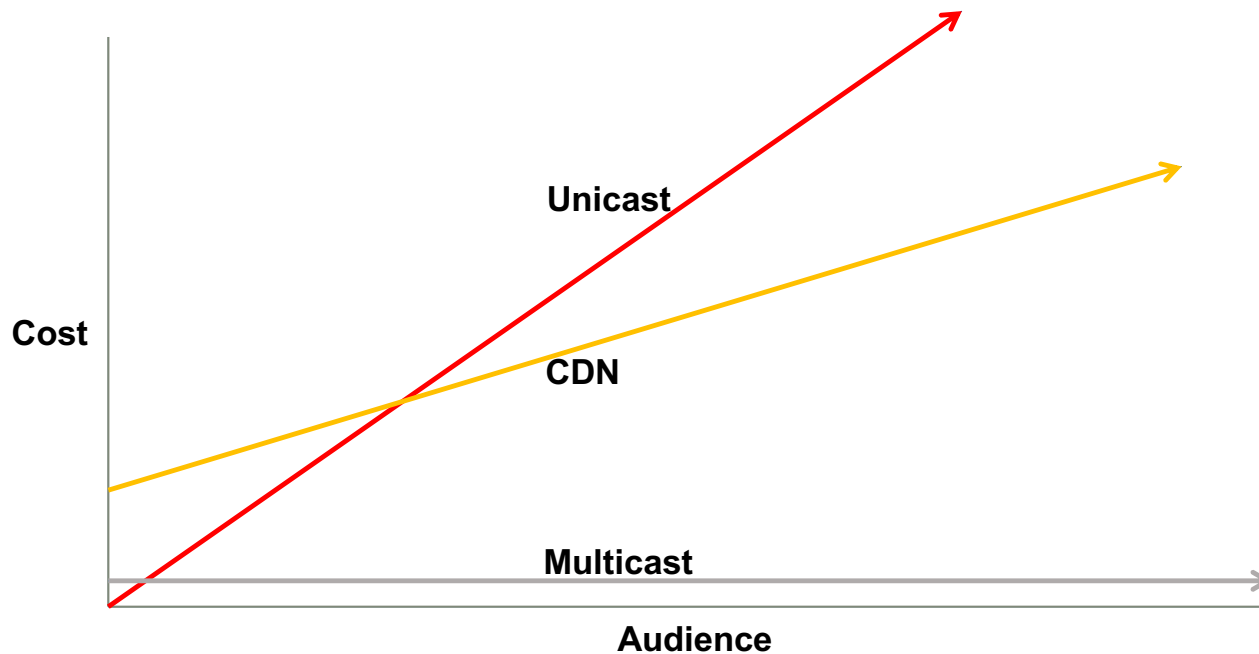
TreeDN with OffNet Sourcing

TreeDN: Tree-based CDN Architecture for Mass Audience Live Streaming